2013AntAs...7...54M

The 1769 Transit of Venus Observatory in Lewes, Delaware

James E. Morrison

Member – The North American Sundial Society

Geoffrey Thurston

Member – British Astronomical Association, The British Sundial Society & The North American Sundial Society

The highest priority astronomical problem of the eighteenth century was to determine the distance from the Earth to the Sun, from which the scale of the entire solar system could be calculated. The most promising method of solving this problem was based on precise measurements of the rare event of a transit of Venus across the Sun's disc.

The American Philosophical Society of Philadelphia embarked on an extensive transit observation programme for the 1769 transit with observatories at Statehouse Square – now named Independence Square – in Philadelphia, David Rittenhouse's farm in Norriton, Pennsylvania and a temporary site in Lewes, Delaware.

The Lewes team had a very short time to establish an observatory capable of observing the transit, to determine the observatory's geographic coordinates and to document their transit observation. The methods they used to determine the observatory's coordinates are examined in detail and the probable location of the observation site is deduced.

Background

The Holy Grail of astronomy in the seventeenth to nineteenth centuries was to determine the size of the solar system and grasp the scope of interstellar space. The relative sizes of the planetary orbits were well defined as ratios at that time, but not in units of distance; miles or other measurement. If the distance from the Earth to the Sun, the so-called *Astronomical Unit* (AU), were known, then the sizes of the orbits of all the planets could be calculated and the scale of the solar system defined. Actually, the distance from the Earth to the Sun does not have to be measured. Finding the distance between any two planets, or the distance of any planet from the Sun allows the distances between all to be calculated as the relative distances from the Sun for all of the planets were known.

A *transit* is when a planet, Mercury or Venus, passes in front of the Sun's disc as seen from the Earth. In 1677, a young Edmond Halley (1656-1742), who became the second Astronomer Royal and was the discoverer of the famous Halley's Comet, conceived a method of determining the distance between Venus and the Earth by measuring the

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

duration of a transit at locations widely separated in latitude. Knowing the distance to Venus allowed the size of the AU to be calculated. He refined the details for 40 years and finally submitted it to the Royal Society in 1716.[1] Theoretically, Halley's method can be used with either Mercury or Venus, but Venus is the only practical option due to its larger size and proximity to the Earth, which offers the largest angle to be measured.

Planet	AU
Mercury	0.39
Venus	0.72
Earth	1.00
Mars	1.52
Jupiter	5.20
Saturn	9.52

The only time to make the measurements is during a transit of Venus. This rare astronomical event occurs only every 121.5 years or 105.5 years, usually followed by a second transit eight years later. Transits of Venus were observed in 1639, 1761, 1769, 1874, 1882, 2004 and June, 2012. The next transits of Venus are not until 2117 and 2125.

The key events to be observed are the instant Venus's disc touches the Sun's disc on entry (first contact), when Venus is fully inside the Sun's disc (second contact), the instant the edge of Venus touches the Sun's disc on exit (third contact) and when Venus completely exits the Sun's disc (fourth contact) (Fig. 1). Halley's method requires timing the entire transit and relies on observations taken at sites widely separated in latitude. A second method developed by Joseph-Nicolas Delisle, requires the exact time of either ingress or egress from sites widely separated in longitude.[2] The objective of both methods is to determine the difference in the position of Venus on the solar disc as seen from geographical locations as far apart as possible. The measurements for two observation sites are combined to determine the size of the Earth as seen from the Sun; the *Solar Parallax*. Calculating the AU is very simple once the solar parallax has been determined.

Both methods work, but both have problems. The requirement to time the entire transit for Halley's method restricts the observation site to a relatively small area of the globe, but needing only the time duration of the transit frees the observers from having to coordinate their local times. Delisle's method requires the time of either ingress or egress, not the entire transit. However, the accuracy of the result depends on precise knowledge of the longitudes of the observing sites, which was very imprecise in the eighteenth century.

The apparent size of the Sun as seen from Earth is about 31arc-minutes. Venus at transit, at about 1arc-minute, is small but can actually be seen with the naked eye if a dense filter is used to block the Sun's glare. The parallax angle to be measured is very small; 8.794 arc-seconds, which is about the size of a one pence coin, viewed from half a mile away. Small errors in the parallax angle give errors of hundreds of thousands of miles in the AU. It was essential that the transit observations be as accurate as possible in both the time of the event and the location of the observations.

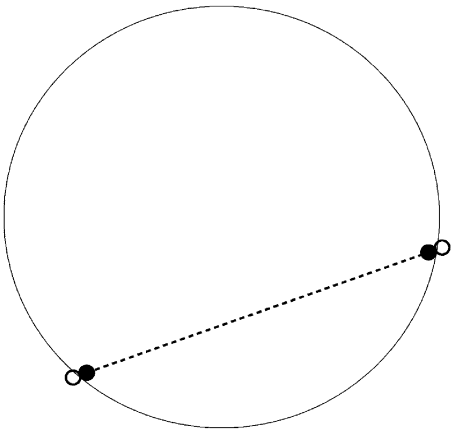


Fig. 1 Observing the Transit
By the authors

The first Venus transit observed by anyone was on November 24, 1639 (Old Style), by Jeremiah Horrocks, from Much Hoole, a village north of Liverpool, England and by William Crabtree of Lower Broughton, Salford, near Manchester observing under Horrocks's tutelage.[3] The next transit, and the first transit of Venus to be widely observed, was in 1761, and observation of the transit was a worldwide undertaking. Britain, France and other countries sent expeditions to remote locations, where some of them were quite successful but others endured terrible hardship and disappointment. The 1761 transit was barely observable from North America being visible only in Newfoundland as it ended before the sunrise further west.[4] The only reported observation from this western location was by Prof. John Winthrop (1714/15-1779) of Harvard College who journeyed to St Johns by sea.

Observing the 1769 transit became high priority, as there would not be another opportunity until 1874.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

The June 3, 1769 transit was not ideal for Eastern North America as it would end after sunset, but the predicted time of its beginning, near 2 pm, local time provided the opportunity to observe most of the transit and measure the instants when Venus first touches and is totally within the Sun's disc.[5] The Astronomer Royal, Reverend Dr. Nevil Maskelyne, distributed a 50 page manual with detailed practical instructions on how to establish an observatory and use it to observe the transit.

The driving force behind the efforts to observe the transit in North America was the American Philosophical Society in Philadelphia, which was a fully-functioning organization by 1768. Within the Society, David Rittenhouse, the most accomplished American astronomer of his time, led efforts to establish observation sites in Statehouse Square in Philadelphia and at his home in Norriton, Pennsylvania (PA), about 20 miles northwest of Philadelphia. Significant effort was exerted to define the coordinates of and equip the sites, but there was one problem: If it were cloudy at one site, it would probably also be cloudy at the other. It was decided to sponsor an observing site at a more remote, but accessible, location in an effort to provide some redundancy.[6]

The reason for selecting Lewes is not recorded, but reasonable inferences can be made. Realistically, there was little development away from Philadelphia, and Lewes was one of the very few inhabited areas within a reasonable travel time. Being located on Delaware Bay made it much easier to reach as water transportation was faster and easier than attempting to negotiate the available roads. In addition, Lewes was somewhat in the public eye at that time because a lighthouse, only the sixth in North America, went into operation there in the spring of 1769. The intent was to set up the observatory at the lighthouse, which was situated near the Atlantic coast, just south of Cape Henlopen and due east of Lewes. A secondary objective was to determine the coordinates of the new lighthouse as an aid to mariners.

A brief geographic history of Delaware

Delaware is the forty-ninth largest state in the United States of America (motto: 'Small Wonder'), and yet was the first to ratify its Constitution.

Delaware's geographic history is closely tied to Pennsylvania. When William Penn was granted a large province in North America in 1681, he was concerned that it could become land-locked if a rival or enemy closed Delaware Bay to traffic from Pennsylvania. He petitioned King Charles II for an addition to his holdings along the western shore of Delaware Bay, which was granted. Three counties were already loosely defined and all he had to do was to establish a legislative foundation and exert his control. For example, before Pennsylvania was chartered, the three counties were named New Castle, St. Jones and Deal. He immediately changed St. Jones County to Kent County and Deal County to Sussex Country. He also instituted law enforcement and legislative functions. For all practical purposes, the Delaware counties are the same now as they were in 1681.

The creation of Pennsylvania resulted in a long conflict between that province and Maryland. Maryland had been chartered in 1632, but its boundaries were not precisely defined. The key points in the grant description were that the northern border of Maryland was 'beneath' 40 degrees north latitude and east to the Delaware River, but with an important proviso; Maryland's grant did not include any land that had been previously settled.

Dutch, Swedes and Finns had already established a toe-hold along Delaware Bay with the largest settlements at New Castle (New Amstel to the Dutch) and what became Lewes. Hence, this land could not be part of Maryland. In 1681, a grant for the land within a 12 mile radius of New Castle was given to Penn. The land along Delaware Bay south of the New Castle circle to Cape Henlopen was leased to Pennsylvania. This action added three counties to the three near Philadelphia defined by Penn.

A more complicated situation was created with Maryland's northern border with Pennsylvania. The 12-mile radius from New Castle formed the southern limit of Pennsylvania, which was south of the 40 degree latitude Maryland claimed. Hence, there was a meaningful strip of land claimed by both colonies.

In addition, the western border of the three lower counties was not defined, which created even more confusion. After decades of petitions and counter-petitions by the Penn and Calvert families, the case was finally taken up by the Court of Chancery for a final, binding settlement. The case went on for another 15 years until Lord Hardwicke's resolution in 1749. The terms of the final settlement were similar, and identical in the essential stipulations, to the terms they had been arguing about for 90 years:

- The southern border of Pennsylvania's three lower colonies is defined by an East/West line, called The Transpeninsular Line, beginning 139 perches east of a stone marker at Fenwick Island and proceeding west to Chesapeake Bay. The south-west corner of Sussex County is located half the

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

length of the line from either end; the Mid-Point. The *Transpeninsular Line* was surveyed in 1750-51 by two surveyors from Pennsylvania and two from Maryland. It was resurveyed and the marker locations confirmed and reset as necessary in 1974.

- The northern border is defined by a circle of 12 mile radius with its centre at the New Castle Courthouse.
- The western border is defined by a line from the Mid-Point to the point where the line is tangent to the circle described above; the *Tangent Line*. The Tangent line is at an angle of 3° 35.2 arc-minutes west of north and is about 82 miles long. It was surveyed by Mason and Dixon in 1763.

There is an additional detail in the northwest corner that is not relevant to this outline. What we now call the state of Delaware was the 'Lower Three Counties' of Pennsylvania in 1769. For all practical purposes, Delaware became a separate entity in 1704, but was still officially part of Pennsylvania until statehood in 1787. Delaware was represented as a separate colony in the First Continental Congress in 1774. For simplicity, we refer to this area as 'Delaware' in this discussion.

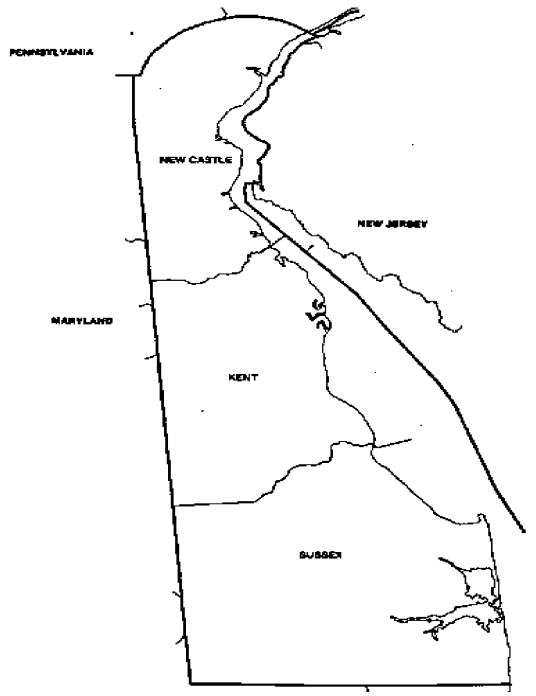


Fig. 2 The borders of the three counties of Delaware
By the authors.

The Mission

The overall mission was to establish a temporary observatory in Lewes capable of observing the transit accurately and to observe the transit and document all relevant details of the site and the observations. Knowing the exact geographical coordinates of the observation site was critical. The methods used to derive the AU depend on multiple observations of the transit elements from widely separated locations and the times are meaningful only if the coordinates of the observing sites are accurate. In particular, for the 1769 transit the observing site's longitude must be accurately known.

The Team

The men who would set up the observatory and observe the transit were chosen for their technical skills, independence, reliability and meticulous attention to detail.

Owen Biddle (1737- 10th March, 1799) was the clear leader of the expedition. He had worked as a clock and watch maker, but later became a successful import/export merchant. He was widely respected and was elected the first curator of the American Philosophical Society. He was known as a man who, if given a job to do, he did it quickly, quietly and without fanfare. Biddle was a Quaker, described by his daughter Anne as '…a man of quick feelings and nervous temperament'.[7]

Joel Bailey (1732 – 24th October 24, 1797), from Chester County, PA was, perhaps, one of the best surveyors in America. He could be counted on to make, modify, improve or repair any piece of surveying instrument and he was fully capable of taking on any surveying job, no matter the scale. He worked with Charles Mason (1728-1786) and Jeremiah Dixon (1733-1779) on the survey of the West Line defining Pennsylvania's southern border and commonly called *The Mason-Dixon Line*.[8] He also made the precision levels used to measure the length of a degree of latitude and worked personally on the measurements with Mason and Dixon. Bailey was Mason and Dixon's 'right-hand-man' and worked on every aspect of this critical survey.[9]

Little is known about Richard Thomas other than he was a competent surveyor who was engaged from time to time to do precision surveys for the Philosophical Society or the government. He was not an official team member, but paid his own way on this expedition, just to participate.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

The Place

The team arrived in Lewes on Friday, 26th May, 1769. The sailing distance from Philadelphia, down the Delaware River and through Delaware Bay is a little over 100 miles, depending on the exact course taken. If they left Philadelphia at first light, around 4:30 am local time, and averaged about 8 mph, they would have arrived in the late afternoon. Sunset on 26th May was at about 7:30 pm, which left them some time to evaluate their situation. It is possible they made the trip over two days. There is no hint that any of the transit team had ever been to Lewes before, although Bailey was familiar with the area as the Mason/Dixon team had stayed in Dover and Bailey had travelled all of western Delaware.

The original intention was to assemble their observatory near the newly-activated Cape Henlopen lighthouse. The lighthouse was located on the aptly named Great Dune, which was less than ¼ mile inland from the Atlantic and somewhat elevated over the nearby terrain. Their first order of business was to inspect the site. The lighthouse was about three miles from the centre of Lewes, using the road that was cut to provide access during construction. They grasped the reality of Middle Atlantic coastal weather immediately; constant wind and blowing sand. Clearly, this was not a place to set up delicate instruments requiring a steady mount.

Later that same day, they made arrangements to rent a house about ¼ miles southwest of Lewes on South Street, now known as Savannah Road.[10] Biddle described the house as in a 'retired state', but made no comment about it otherwise except that the door faced south. We can infer that the house was unoccupied, but adequate for their needs. The property provided an unobstructed view of the sky to the south, which was the most important factor.

Fig. 3 Cape Henlopen Lighthouse
By courtesy of the Lewes Historical Society

Weather became an issue the next day, with clouds and frequent rain. Based on their descriptions over the next few days, we can infer that their weather was the result of a low pressure system which also affected the Philadelphia and Norriton sites.[11]

The Observatory

The report of the transit observations was very simple; the geographic coordinates of the observing site and the times of first and second contact. The temporary observatory had to be capable of allowing precise measurements of the beginning of the transit and recording the times to the second.

Times were to be reported as *apparent time.*[12] That is, the time defined by the hour angle of the true sun. Setting a clock to show apparent (local) time requires the clock to be set exactly to noon when the Sun crosses the local meridian, or is due south. This, in turn, requires a lengthy process of precise observations of the Sun and selected stars to establish the rate of the clock. The method advocated by the Astronomer Royal for this purpose involves timing when the Sun or star passes through a specific but arbitrary altitude above the horizon both before and after crossing the meridian using an equal altitude instrument with two horizontal crosshairs and a means to lock the telescope in place. The meridian is midway between the two equal altitude crossings and thus, the mid-time of the observations defines the time of meridian transit of the celestial body.

They set up their instruments the next day, 27th May, and began the process of setting their clock to the exact local time by observing the Sun during the day and bright stars at night with their equal altitude instrument. The other critical element was the exact geographic coordinates of the observing site, which required performing a demanding survey. This topic is treated in detail below.

Their Equipment

They did not list all of the equipment they brought with them to Lewes, but we know it included three telescopes and mounts, a telescopic theodolite and an equal-altitude instrument. The telescope used by Biddle was a 3-inch Gregorian reflector made in London, possibly by James Short and purchased by Thomas Penn as a gift to the Philadelphia Library Company. The telescope's maker is not documented, but the instrument was sent to Short in London for repair, indicating that he probably made it.[13] Biddle made an equatorial mount for it and modified the rack work which enabled him to track the Sun easily. Bailey used

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

an achromatic refracting telescope of longer focal length, made by the Dollonds. This instrument did not have a mount and they improvised a ball-and-socket attached to a post as recommended by the Astronomer Royal. A clock to time the transit was required and theirs was very probably a full-size clock with a metre long pendulum beating seconds. The clock was attached to a sturdy post just outside the house. They made or brought smoked glass solar filters.

Fig. 4 Surveying theodolite by Benjamin Cole and chain with a set of drawing instruments
By courtesy Jeffrey Lock, Colonial Instruments

They had basic surveying gear, including the theodolite mentioned above, at least one 66-foot iron surveying chain and necessary posts, hammers, axes and other items that constituted a surveyor's kit in those days, plus their personal effects.

The Survey

One of the crucial elements of the transit measurements was exact knowledge of the latitude and longitude of the place where the observations were made. There was not enough time for them to determine their location astronomically, so they had to measure the site's geographical coordinates relative to an existing point of known latitude and longitude, which could be supplied by the Transpeninsular Line.

The Transpeninsular Line was defined by stone markers and mileposts and was intended to follow the parallel of latitude west from the easternmost marker at Fenwick Island, across the peninsula to Chesapeake Bay. The legal start of the line is not marked as it is off shore, 139 perches east of the Fenwick Island marker. A perch is a distance measure of 16.5 feet, one-quarter chain, also called a rod. The line was marked by stone markers at the 5, 10, 20 and 25 mile points and also at the Mid- Point, 34 miles and 309 perches from the start of the line. The original

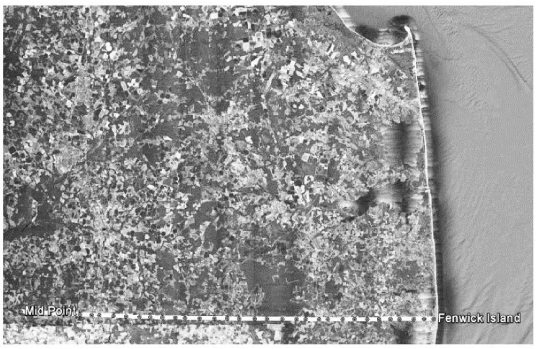


Fig. 5 The Transpeninsular Line
By the authors generated using Google Earth.

surveyors were instructed to set posts each mile, but there is no evidence this was actually done. The markers are cut from native stone with the Calvert family arms carved on the south side and the Penn arms on the north side. The dots on the line in Fig. 5 accurately represent the current markers. The boundary was resurveyed by the National Geodetic Survey in 1974, and all monuments that were lost or had been moved were replaced and mileposts were installed about each mile.[14]

The most important point on the Transpeninsular Line is the Mid-Point Marker, defining the centre of the Delmarva Peninsula and the southwest corner of Delaware. The latitude of this marker was painstakingly measured by Mason and Dixon in 1767 as 38° 27′ 34″ N using astronomical observations.

Fig. 6 Fenwick Island Marker
Photograph taken by the author J E Morrison.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

Bailey and Biddle assumed all of the markers on the line were on this precise latitude.[15] Their intent was to measure the distance from the observatory to a point on the Transpeninsular Line to determine the observatory's geographic coordinates. The modern latitude of the Mid-Point marker using the NAD83 (91) model for the shape of the Earth is 38° 27′ 36″.29213.

Owen Biddle wrote,

> The four following days continued cloudy, with frequent rains. But that we might not be idle in the meantime, and have it in our power to ascertain our latitude and longitude, in case we should be disappointed of celestial observations for that purpose; Joel Bailey and Richard Thomas, went to take the courses and distances from our observatory, to the provincial west line, which was run from Fenwick's Island to the *middle point* of the peninsula; so that our observatory might thereby be connected to Messrs. Mason and Dixon's meridian line.[16]

This statement seems a bit disingenuous. They had brought all of the equipment needed to perform the survey and clearly intended to use it. David Rittenhouse strongly implies they planned the survey from the beginning.[17] On the other hand, the surveying equipment may have been brought as a precaution against bad weather (which happened), with the intention of using it only as a backup. However, they could have just as easily done nothing and waited for good weather to make the necessary astronomical observations to pinpoint their location. Even then, it would have taken weeks and required sophisticated instruments to perform all of the astronomical observations required.

Biddle's statement that Bailey and Thomas did the survey very likely understates the magnitude of the operation. Their mission was to determine the distance of the observatory north and east of a point on the Transpeninsular Line, which required an open traverse of over 20 miles, much of it through undeveloped land, and they had less than four days to complete it and get back to Lewes.

An open traverse is a line-of-sight surveying technique using a series of connected line segments to measure the distance between two points. The distance between the start and end points is calculated from the field data using simple trigonometry. The sequence of steps is outlined as follows:

1. The starting point for each line segment is marked by a stake. The measuring instrument, a telescopic theodolite in this case, is mounted on a tripod and placed exactly over the stake using a plumb-bob for precise positioning. The instrument is levelled and usually pointed directly north or south using a compass built into the instrument.
2. A direction is chosen and a man is sent in that direction with a rod. He takes the rod to a point that is in the approximate direction desired and the man at the instrument and the man with the rod communicate with hand signals until a good place is found. The angle is recorded. The 66-foot long chain is dragged in the required direction taking care that the chain is flat over its entire length. The instrument man directs his chain men to the exact line and a stake is driven to mark the end of the chain and the number of chains is recorded.
3. This is repeated until the chain reaches the rod and any partial chains are recorded or the end point of the segment is moved until it is an even number of chains.
4. The instrument is packed and taken to the rod position and the process repeated.

This was done 120 times for a total of 2148 chains before the traverse was complete.

Clearly, two men could not do this alone. Biddle had been advanced £20 for expenses, which was a considerable amount of money for the time. They probably hired a wagon and driver to carry the equipment and extra gear needed for camping out on the way. They would also have hired two or three burley young men to drag the chain, drive stakes and cut limbs and trees that were in the way. There were surely some hangers-on attracted by the novelty of the undertaking who probably helped when needed. Experienced chain-men were available in Delaware from the Mason and Dixon survey, but there is no mention they were used. The crew was at least eight or nine men for the full traverse, with others involved to help cross creeks and the Indian River. There were probably other men on horseback who could scout the best route. Mason and Dixon's crew was generally 35-40 men and included two wagons, eight horses, cooks, stewards, tent keepers, chain men and labour-ers. Their main instrument was transported in a wagon, on a featherbed.[18]

Biddle did note that they stuck to established roads as much as possible, as it would have taken too long and been too expensive to try to clear a direct route through the woods. Colonial roads were quite different from modern roads. They were generally quite wide, up to 200 feet, as a safety measure and to accommodate the driving of livestock. Unlike modern roads, there was often no defined roadbed.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

It is clear that Bailey was aware of the location of the marker stones on the Transpeninsular Line and that he headed for the settlement now known as Selbyville, near the 10 mile marker stone. His traverse terminates at a point which he describes as being on the Transpeninsular Line at a distance of 9 miles 86 perches from the stone in Fenwick Island. We can infer he determined this by measuring 234 perches east from the 10 mile marker to his intersection point near the current milepost 9.

Fig. 7 Mason and Dixon setting out their line
By courtesy of the Mason and Dixon Line Preservation Partnership.

By calculating the accumulated distances travelled in southerly and westerly directions and applying them to his termination point, Bailey was able to establish how far the observatory was located east and north of the Mid-Point.

Fig. 8 shows Bailey's route derived from the raw traverse data. It is not perfectly valid to plot Bailey's route on Google Earth as published because there are differences in the mapped coordinates of the route points between the spherical model used by Bailey and the ellipsoidal model used by Google Earth. That said, there is still value in seeing the shape of the route and deductions can be made that lead to better understanding of the actual route taken.

Mason and Dixon did not need the longitude of the Mid-Point to complete their work and this critical element was unknown. In May, 1770, nearly a year after the transit, The American Philosophical Society commissioned Biddle and Bailey to conduct a further survey to establish the Mid-Point's longitude. The added survey was from the New Castle Court House to the observatory in State House Square, Philadelphia, to determine the longitude of the courthouse. The New Castle Court House was already connected to the Mid-Point through the Tangent Line, and the latitude and longitude of the State House

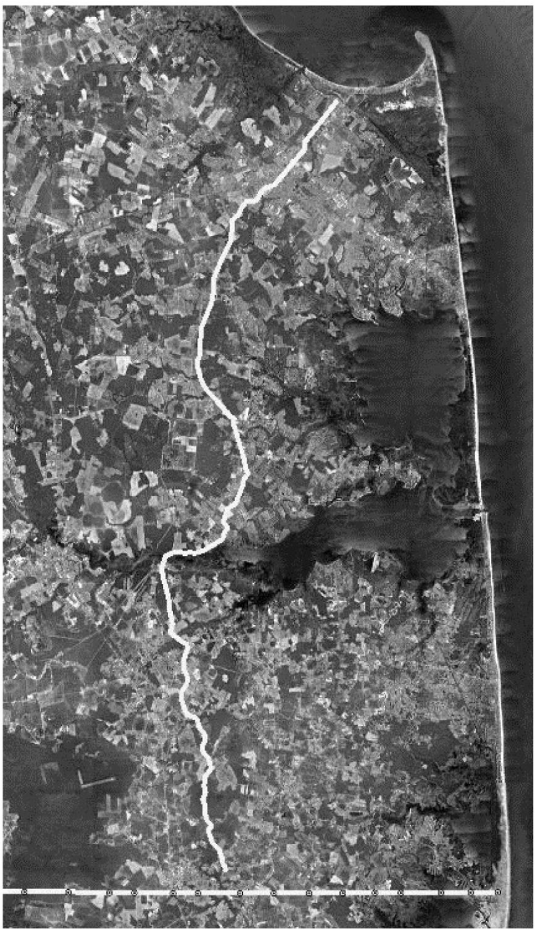


Fig. 8 Bailey's Route
By the authors generated using Google Earth.

Observatory had been determined with a survey from Rittenhouse's observatory conducted shortly after the transit. Thus, the final piece of the puzzle, the longitude of the Mid-Point, was supplied by this additional traverse.

Once this traverse was completed, Biddle and Bailey were able to declare that the Lewes observatory was located at 38° 46′ 38″.3 North and 75° 8′ 30″ West.[19]

These values would place the observatory near the intersection of Pilottown Road and Shipcarpenter's Street in current day Lewes, using modern mapping methods. Although this position was adequate for measurements of the transit of Venus, it is unlikely, for a number of reasons, that this is the precise location of the observatory. For example, Biddle mentioned that the observatory was on South Street (now Savannah Road) and about ¼ mile from the town. Their derived coordinates do not meet either of these criteria. So where was the Lewes observatory?

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

Site Latitude

When Bailey's traverse ended he was not at the latitude he assumed. Mason and Dixon's astronomical latitude of the Mid-Point was 38° 27′ 34″ N, and Bailey's assumed latitude for the entire line. Note the route shown in Fig. 8 ends at this latitude, short of the Transpeninsular Line. However, the Transpeninsular Line is not a true parallel of latitude and the latitude of both milepost 9 and marker 10 is actually 38° 27′ 04″.4 N which is 29″.6 (2995 feet.) less than the latitude assumed for the Mid-Point and the entire line. The difference in the reference latitude changes the site latitude to 38° 46′ 8″.3 N. This adjustment places the observatory position much closer to South St., as described by Biddle.

Site Longitude

The derived longitude was based on the results of four separate surveys (Fig. 9):

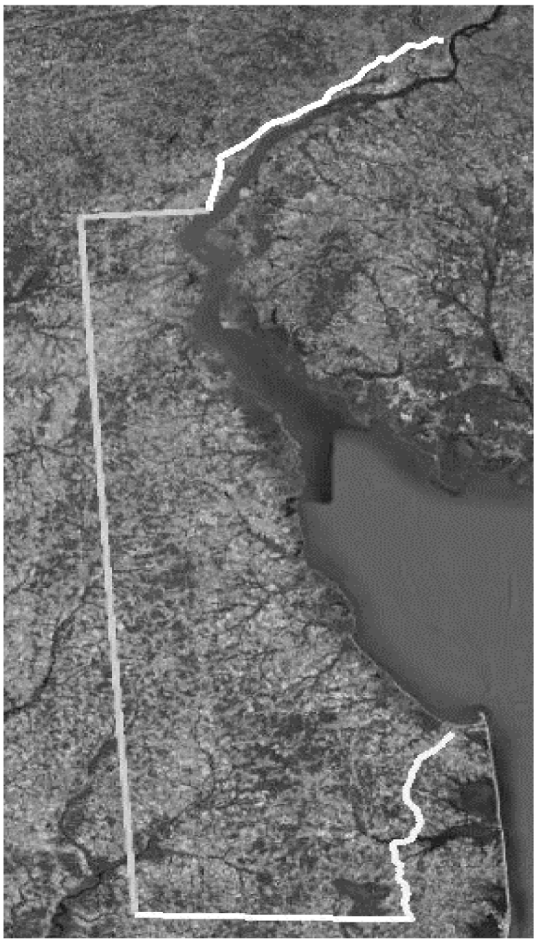


Fig. 9 Connected Traverses

By the authors generated using Google Earth.

1. The Mason and Dixon survey of Delaware's western border is a line, called the Tangent Line, from the mid-point of the Transpeninsular Line to the point where the line is tangent to a circle of 12 mile radius centred at the New Castle Courthouse. This survey establishes the difference in longitude of the Mid-Point to the New Castle Courthouse.[20]
2. The coordinates of the observatory in Philadelphia were determined by a carefully conducted traverse from David Rittenhouse's farm in Norriton to the Statehouse in July, 1769.[21] Rittenhouse had made observations over several months to measure his exact location and his results were trusted. Thus, the Statehouse observatory coordinates would include any error in Rittenhouse's measurements.
3. The survey from the New Castle Courthouse to Philadelphia was used to determine the court-house's longitude, which was then used to derive the longitude of the mid-point.

Joel Bailey's traverse measured the distance of the Lewes observatory meridian east of the mid-point.

Any errors in any of these surveys will be reflected in the final value of the longitude of the Lewes observatory.

The assumed position for the State House observatory in Philadelphia was 75° 8′ 45″ W, from the Rittenhouse survey. There are no extant remains of the State House observatory and its exact location is still not precisely known. We do know the longitude of the Philadelphia observatory was within a second or two of 75° 9′ 0″ W in modern coordinates. An analysis of the published field data using modern coordinates for the key points places the Lewes observatory at 75° 8′ 42″.7 W, which is quite close to Savannah Road.

Potential Errors

The best observatory coordinates that can be derived from the source data are: 38° 46′ 8″.3 N, 75° 8′ 42″.7 W. There are a number of factors that could have influenced the accuracy of the recorded traverse sets leading to placing the observatory incorrectly.

Bailey was a skilled surveyor who was well practiced in the painstaking methods employed by Mason and Dixon, and he could be relied upon to work to the highest accuracy within the time, weather and instrument constraints to which he was subject. However, even he would not have claimed that his results were free of all errors and it is worth considering the origin of the most likely sources of such errors:

- The magnetic declination used by Bailey might not be accurate. It is very hard to read a small compass to the accuracy needed. The variation measured by

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

Bailey in Lewes was 3° 55′.[22] Bailey also did the survey from the New Castle Court-house in Delaware to Independence Hall in Philadelphia, presumably with the same theodolite, and reports the magnetic declination as 3° 15′ W.[23] This value actually fits the data better. Changing compass needles also affects accuracy.

- All bearings are reported to 5 minutes of arc, indicating his theodolite had a vernier scale with 5 arc-min. resolution. It is unlikely reliable readings were possible to this level of precision with his equipment and differences would accumulate over the entire survey.
- Almost all distances are recorded in full perches. It is, of course, possible that the surveyors tried to execute their instrument sets in full perches, but this would be very hard to do accurately without changing the observed bearings. The skill and experience of the chain men would have been a factor in this regard.
- Bailey's model of the earth was a spherical one in which the degree of latitude was 68.896 miles long rather than the more accurate ellipsoid in current use in which a degree of latitude in Delaware is 68.977 miles. The differences are not great, but they do affect the accuracy of the overall results.
- It is also possible, even likely, that some of the published field data has typographical errors or incorrect values were printed due to setting type from handwritten source material. Several lines in the data are obviously incorrect, such as transposing digits (45 instead of 54, for example), or incorrectly declaring a direction (W instead of E).
- We cannot rule out computational errors. Bailey probably reduced his data using tables of logarithms, probably to seven places. It is very easy to make mistakes when performing such tedious calculations and the table may have had slight errors.
- It must be noted that it was raining for most of the time during the survey. It is hard to keep an accurate field journal in good weather and it is plausible that some of the recorded values were smudged and rendered difficult to read. The poor weather could have been a factor in many aspects of performing the traverse.

Route Analysis

The coordinates derived above would appear to support a likely location for the Lewes observatory. However, it is prudent to validate the result as there are so many possible errors in the raw field data.

Fig. 10 Start of Traverse from Bailey's Data
By the authors generated using Google Earth.

There is a striking visual clue when the route defined from the raw data is plotted on a Google Earth map (Fig. 10). The first leg of the route is exactly parallel to Savannah Road (South Street), but displaced to the north and west, indicating the starting point of the displayed route should be shifted to match the roads. We are able to identify and adjust for some of the errors by comparing the shape of the traverse with the clearly corresponding shape of roads and traces of former roads.

Fig. 11 Route Bias Adjustments
By the authors generated using Google Earth.

For example, the labelled section of the route shown in Fig. 11 is drawn from Bailey's data. The solid route follows the roads in this area. The two segments can be made to overlap nearly perfectly without changing Bailey's data by applying bias adjustments that apply to the entire traverse. We found through trial-and-error that, if all of Bailey's distance measurements are

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

increased by 1.5% and each course were increased by 1° 18′, the resulting route matches the roads in this area very closely. These adjustments are justified by the inherent difficulty of making precise measurements with their instruments and considering the weather.

We do not need to match the whole traverse to locate the observatory. We need only establish the position of the first leg to identify the starting point, and this is made easier because we know that the first course was straight down Savannah Road. The adjusted traverse provides an excellent match to the first nine miles and, thereby, allows us to identify Bailey's starting point with confidence

No detailed maps of the 1769 road system in Sussex County exist, but it was found that maps from D. G. Beer's Atlas of 1868 match the modern roads very closely. Fig. 12 shows how closely the adjusted route follows the roads at the start of the traverse. Figs. 13 and 14 show the route taken in southern Sussex County.

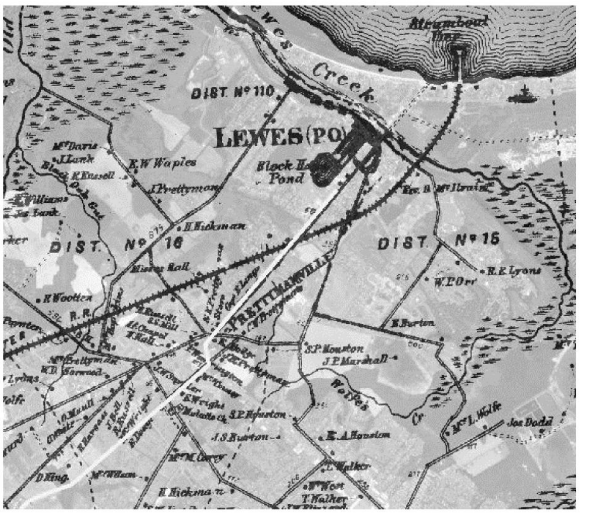
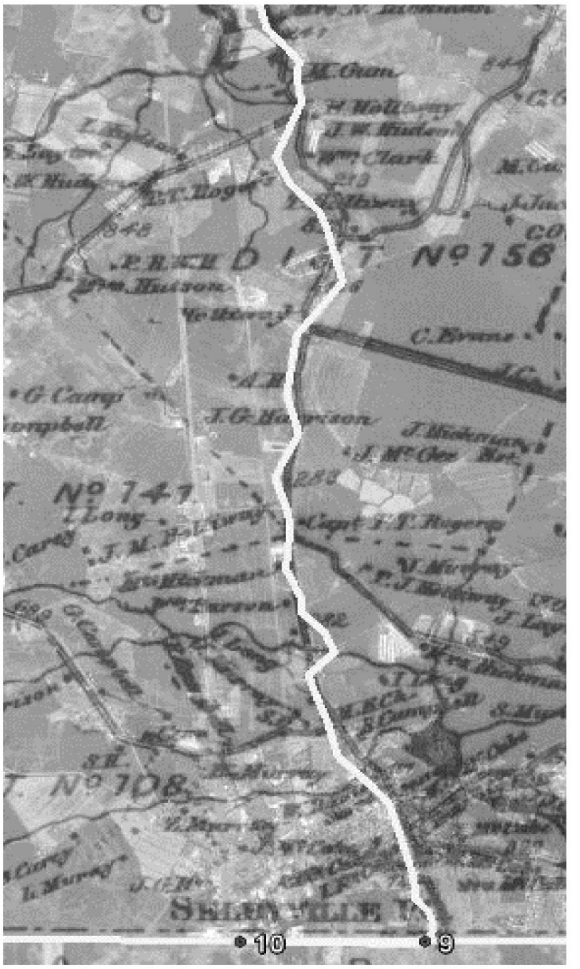


Fig. 12 Beginning of Route
By the authors generated using Google Earth and *D.G. Beers Atlas* of 1868 supplied by the Delaware Department of Transportation, Mapping Division.

Figs. 13 & 14 Route near Dagsboro and ending in Selbyville
By the authors generated using Google Earth and *Beers Atlas of 1868* supplied by the Delaware Department of Transportation, Mapping Division.



© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

The Location of the Temporary Observatory

The conclusion on the most likely location of the temporary observatory is based on Bailey's traverse data recreated in WGS84 coordinates and corrected by comparison with the road patterns visible on Google Earth. These corrections comprise small adjustments to the whole traverse to eliminate apparent biases in course and distance and one adjustment of 6° to one leg to match an obvious line feature. The adjusted route provides a significantly better match to the road patterns and suggests a very credible route for the traverse.

Fig. 15 Observatory Site
By the authors generated using Google Earth.

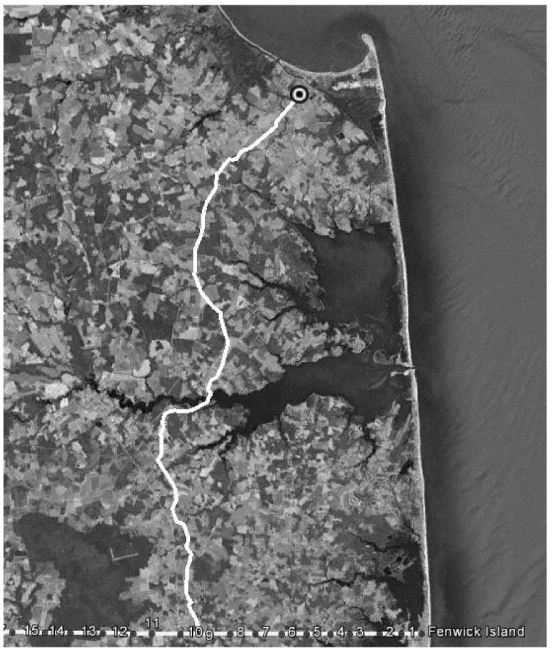


Fig. 16 Complete Traverse
By the authors generated using Google Earth.

We conclude the most probable location for the Lewes Transit Observatory of 1769, is near **38° 46′ 12″.3 North** and **75° 8′ 38″.1 West**. The site was within the boundaries of what is now Bethel Methodist Cemetery, which is on land originally intended for use as a Quaker cemetery, but was apparently never used for that purpose. It is about 0.2 miles southwest of 4th Street and is on South Street (Savannah Road), thus meeting all of the qualitative criteria mentioned by Biddle. Coincidently, this site is the highest point in Lewes.

The most probable site location is shown in Fig.15. The circle is about 1 arc-second in radius (≅ 100 feet), for scale. We are confident the Lewes Venus Transit Expedition observatory was within the circle. The complete traverse as reconstructed is shown in Fig. 16.

Astronomical observations at Lewes Observatory

The requirements of the astronomical activity at Lewes were threefold. Firstly, optical instruments were required which made the precise timing of the contacts discernible to the observers. Secondly, timepieces set to apparent (local) time were needed to record the timing of the contacts. Finally, instruments capable of determining latitude and longitude were desirable to validate any ground surveys used to locate the observatory.

The transit of Venus across the sun is visible to the human eye provided a filter is used to reduce the light intensity from the sun's disc. However, the planetary disc has an apparent size of less than one arc-minute at inferior conjunction and thus the timing of exterior and interior contacts is difficult to achieve with precision. The task becomes more practicable if a telescope is used to provide an enlarged image of the planet and that part of the sun's limb around the point of contact. A filter was still required and was generally created by smoking clear glass over a candle flame. The filter was then interposed between the eyepiece and the observer.[24]

Biddle made his observation of the transit using a reflecting telescope with a magnification of 150 times, which was of Gregorian type with a focal length of two feet.[25] He claimed that it was in 'exceeding good order at the time and defined the limb of the Sun, and spots on its disc, very nicely'. He had mounted it on a

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

Fig. 17 Gregorian Reflector made by James Short of London, 1755
SSPL Image No. 10324543
By courtesy of the Science Museum, London.

polar axis and had contrived a fine adjustment in right ascension to keep the planet within the field of view.

Bailey used a refracting telescope of about four and a half feet length which had been manufactured in London by the Dollonds using their recently patented achromatic doublet as the objective. This doublet lens used elements made from crown and flint glass and

Fig. 18 Dollond achromatic telescope fitted on an equatorial mounting and used by Dr Lind to observe the 1769 transit of Venus in Scotland
SSPL Image No. 10196616
By courtesy of the Science Museum, London

was designed to minimise the chromatic aberration inherent in a refracting telescope. Chromatic aberration results in each colour being brought to focus at a slightly different distance from the objective lens and in particular generates a coloured fringe around the limbs of sun and planets. Such a fringe would obviously impede the determination of the moment of contact and would be clearly undesirable in transit observations. It is clear that Biddle regarded this instrument as inferior to his reflecting telescope and so we might infer that the chromatic aberration was still troublesome despite Dollond's innovative objective lens. Bailey was also disadvantaged because this telescope was mounted using a ball and socket joint with no recorded means of compensating smoothly for the rotation of the earth.[26] Biddle recorded that he set

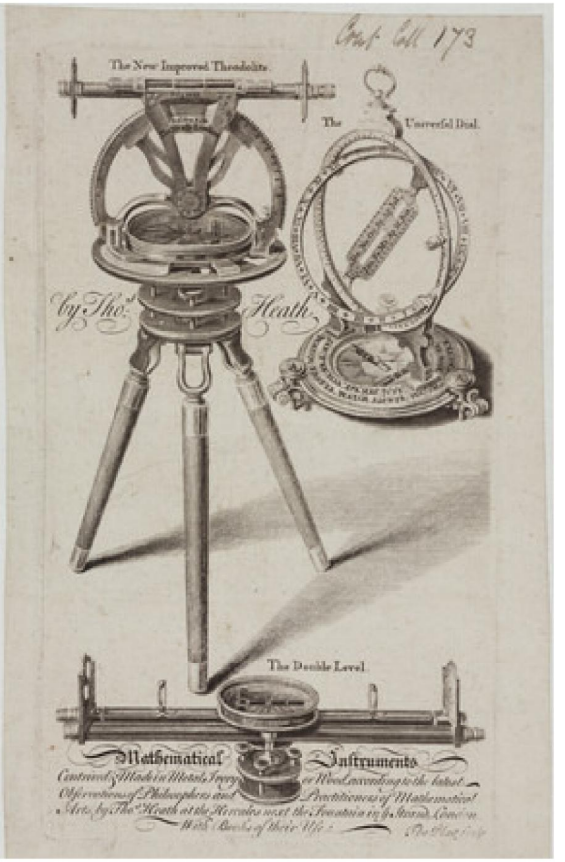


Fig. 19 Theodolite and Surveying Level by Thomas Heath, London, eighteenth century
SSPL Image No. 10422653
By courtesy of the Science Museum, London

the clock using a theodolite to record equal altitudes of the Sun and stars. He described this theodolite as follows;

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

> It was a theodolite, with telescopic sights, in which there were cross hairs; it had a spirit level to adjust the plane of the instrument horizontally; and also one applied to the telescope parallel with its axis, and at right angles to the other spirit level. By means of these two levels and adjusting screws, we found we could adjust it very nearly, the instrument being a very good one of its kind.[27]

The basic requirements for an equal-altitude instrument are to have a telescope which can be adjusted and then fixed in altitude and which can then be rotated about a vertical axis to observe a body as it passes through that fixed altitude on each side of the meridian.

The Astronomer Royal published instructions and advice to those observing the transit in The Nautical Almanac and Astronomical Ephemeris for the Year 1769 and he gave particularly detailed instructions therein for the equal altitude method.[28] The Nautical Almanac was first published by Nevil Maskelyne for the year 1767 and contained daily data on solar and lunar positions. It can be assumed from the regular flow of correspondence between the Astronomer Royal and the American Philosophical Society that Biddle would have had access to the 1769 edition of the almanac and the relevant ephemeris data before embarking for Lewes, even if he were not carrying a copy with him.

The method of use for obtaining equal altitudes may be summarised as follows:

1. Mount the instrument on a substantial wooden pier firmly fixed in the ground.
2. Level the instrument by means of the spirit levels and adjusting screws.
3. Select a suitable body for observation to the east of the meridian and note the altitude and the time by clock when the body crosses each horizontal wire in the telescope eyepiece.
4. Repeat the observation with the telescope set to the same altitude when the body crosses the corresponding wire in the opposite direction to the west of the meridian and note the time by the clock.
5. The mean of these times for a star gives the time by the clock when the star transits the meridian and, provided that the right ascension of the star is known, the apparent sidereal time can be determined.
6. The same procedure also works for the sun but in this case a correction has to be applied to account for the changing declination of the sun between observations. The correction can be calculated by means of a table appended to the Nautical Almanac so that the apparent solar time can be determined.

A theodolite is also equipped with a graduated, horizontal azimuth circle which can be used to determine the instrumental azimuth of the body at the fixed altitude east and west of the meridian. The true meridian then lies midway between these azimuths. The meridian may be more accurately determined by calculating the local time of transit for a given body and then clamping the azimuth circle at the time of transit with the vertical wire of the telescope bisecting the body. A meridian mark may then be made on the ground by swinging the telescope down to the horizon and marking a distant point which falls beneath the vertical wire.

Biddle's observations were hampered by prolonged bad weather but he was able to make sufficient observations to enable him to rate his timepiece and set it to local apparent time. He recorded that he set up his observatory on 1769 May 27 and set his clock by taking equal altitudes of the sun and then of some fixed stars in the evening. Unfortunately, the next four days were cloudy so observations were not possible. On June 02 the weather cleared and more equal altitudes of the sun were taken. On June 03, the day of the transit, the weather was fine with calm air and not a cloud in view, so further equal altitudes of the sun were taken before and after the time of the transit. It appears that Biddle had ample observational data to enable him to determine accurate apparent times for the external and internal contacts from his timepiece.[29]

According to Bailey, his survey compass was calibrated with reference to their meridian line which indicates that Biddle had also made observations as described above to establish a meridian mark on the ground.[30]

We do not know the exact nature of Biddle's astronomical instruments but his own account indicated that he was prepared to determine both latitude and longitude by celestial observation. The zenith distance of the sun or a star of known declination in transit would have provided a measure of the latitude of his observatory but it is unlikely that his theodolite would have been able to measure zenith distance with better than one arc-minute accuracy and the derived latitude would therefore have been defined only to within one nautical mile.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

The Nautical Almanac for 1769 included predictions for the eclipses of Jupiter's innermost moon, Io so that the local timings of these events could be compared to observations made at Greenwich. The difference in local time of the observations would then correspond to the observatory's difference in longitude from Greenwich. However, the table seems to indicate that during Biddle's time in Lewes there were no eclipse events simultaneously visible from Lewes and Greenwich. Thus, it is not surprising that he was unable to establish his longitude by astronomical observation.

Results from the observations

The transit observation itself, on June 3, went perfectly. The weather was crystal clear, without a cloud in the sky, and the transit team documented the required times.

The results of the observation reported by Biddle in apparent time were:

Owen Biddle's external contact:	2 hr.11 min.53 sec.
Owen Biddle's internal contact:	2 hr.29 min.53 sec.
Joel Bailey's external contact:	Lost by accident
Joel Bailey's internal contact:	2 hr.29 min.53 sec.[31]

This information, together with the precise location of the observatory, would contribute to a determination of the size of the solar system and provided the justification for the expedition.

Simon Newcomb was rather complimentary about the Lewes observations. Biddle had taught two boys to chant the seconds so the person logging the events would hear the notice of the event and the spoken second at the same time.[32] By contrast, Rittenhouse had not made adequate provisions for exact time recording for all three observers and Newcomb did not use Rittenhouse's observations as the times were suspect, although he did use the other two. Newcomb's decision is understandable as Rittenhouse fainted at the instant the transit started, probably due to being over-excited about the event to which he had devoted so much.

The solar parallax derived by Dr William Smith using Biddle's external contact and those recorded at several European observatories was 8″.862.[33]

Observational times were submitted by 171 professional and amateur astronomers. The published values of the solar parallax were derived from combining many reports and no single site dominated the analysis. Later astronomers considered only observations that met some technical criteria relating to how the observations defined the instant of ingress and egress, and the specific observations were not always listed. Encke combined many observations in 1824, probably including the Lewes results, to arrive at a value of 8″.571 ± 0.037″ for the solar parallax, which resulted in a value of 95,370,000 miles for the AU, a value that was used for many years. The uncertainty in this parallax value amounted to about half a million miles in the AU.

Great effort to refine the values was mounted for the 1874 and 1882 transits, including the use of photography, but the results were still not satisfactory and measuring the solar parallax in this way was abandoned. It proved too difficult to get sufficiently precise ingress and egress times for Venus on the Sun's disc. The modern value for the Constant of Parallax is 8″.794143, which gives a value of 92,955,807 miles (149,597,871 km) for the mean Astronomical Unit.[34] There were, however, many side benefits of the transit expeditions around the world and the exact coordinates of many remote locations were measured, along with detailed observations of eclipses, transits of Mercury and measurement of magnetic declination and gravity. In the case of Lewes, the survey also established the coordinates of the Cape Henlopen lighthouse. The modern value for the AU was found by radar ranging of Venus and Mercury and by telemetry measurements from interplanetary spacecraft.

Epilogue

Owen Biddle was prominent in the American Philosophical Society. He was elected curator (1770), secretary (1773) and councillor (1782), and delivered the annual oration in 1781.[35] He was a Quaker, but was active in a non-combatant role in the Revolutionary War, serving primarily as Deputy Commissioner of Forage, under his brother, Clement and with Thomas Paine, author of *Common Sense*, as his clerk. In this role, he was responsible for finding, buying and distributing food, animal feed and raw materials, a thankless and frustrating job considering colonial finances. After the war, he was disowned by the Quakers, along with about a hundred others, for his participation in the war. He was instrumental in the formation of a new 'Free Quaker' community. The war and its aftermath were not kind to Biddle. Three ships in which he had invested were captured during the war and he was forced to dissolve most of his property to avoid bankruptcy. He was not active in the American

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

Philosophical Society after 1782. He worked as an apothecary merchant in Philadelphia.[36] His later years were spent in the Community of Friends, where he was active in establishing a boarding school in Chester County. He had seven children.

Joel Bailey continued work as a surveyor. His role in the transit apparently impressed the membership and he was elected to the American Philosophical Society in 1770.

Although the objective of the expedition was to collect the required data for the Venus transit, the long term impact was much greater. The observers established the geographical coordinates of several important places with good accuracy. The study and discipline required to equip and use the transit observatories and to collect and process the transit data was the first venture of the colonies into world-class astronomy and their experiences were invaluable in building a foundation for American science.

Conclusion

This paper has described the extraordinary efforts made to observe and accurately time the transit of Venus in 1769 from a temporary observatory in Lewes and to determine the geographical location of that observatory. The data relating to the location of the observatory has been analysed and a probable precise location has been determined.

Acknowledgments

The authors wish to thank:

Mike DiPaolo, Executive Director of the Lewes Historical Society, George Kent, of the Delaware Department of Transportation, Mapping Division, William ('Sandy') Schenck of the Delaware Geologic Survey. This project could not have been accomplished without their generosity.

References & Notes

1. Halleio, Edm., 'Methodus Singularis Qua Solis Parallaxis Sive Distantia a Terra, ope Veneris intra Solem Conspiciendoe, Tuto Determinari Poterit', *Philosophical Transactions of the Royal Society*, 29 (1714-16), 454-464.
2. Ball, Robert, *A treatise on Spherical Astronomy* (Cambridge, 1908), 312-322.
3. Chapman, Allan, 'Jeremiah Horrocks, The Transit of Venus, and the 'New Astronomy' in Early Seventeenth-Century England', *Quarterly Journal of the Royal Astronomical Society*, 31 (1990), p. 333.
4. Winthrop, John, 'Observation of the Transit of Venus, June 6, 1761, at St. John's, Newfound-Land: By John Winthrop, Professor of Mathematicks and Philosophy at Cambridge, New England' *Philosophical Transactions of the Royal Society*, 54 (1764), 279–283
5. Rittenhouse, David, 'Calculations and Projections of the Transit of Venus', *Transactions of the American Philosophical Society*, 1 (1771, revised 1789), p. 4.
6. Danson, Edwin, *Drawing the Line*, (Wiley, 2001), p. 194.
7. Biddle, Henry D., 'Owen Biddle', *The Pennsylvania Magazine of History and Biography*, 16 (1892), p. 300.
8. Mason, Charles, 'Mason & Dixon's Line', *Original Journal of the Commissioners* (1763), 331-332.
9. Danson (2001), p. 85.
10. Biddle, Owen. 'An account of the Transit of Venus over the Sun's Disk as observed near Cape Henlopen', *Transactions of the American Philosophical Society*, 1 (1771, revised 1789), p. 84.; Biddle, Owen, 'Observations of the Transit of Venus over the Sun, June 3, 1769; made by Mr. Owen Biddle and Mr. Joel Bayley, at Lewestown, in Pennsylvania. Communicated by Benjamin Franklin, LL.D., F.R.S.' *Philosophical Transactions of the Royal Society*, 59 (1769), p. 414.
11. Biddle (1769), p. 415.
12. Maskelyne, Nevil, 'Instructions relative to the observation of the ensuing transit of the planet Venus Over the Sun's disk On the 3rd of June 1769', *The Nautical Almanac And Astronomical Ephemeris, for the Year 1769.*
13. Wolf, Edwin, *At the instance of Benjamin Franklin: a brief history of the Library Company of Philadelphia, 1731-1976*, (Library Co. of Philadelphia, 1976).
14. Meade, Buford K., *Report on Surveys of Delaware/Maryland Boundaries* (U.S. Department of Commerce, National Ocean Survey, 1982), 7-8.
15. Biddle (1771, revised 1789), p. 85.
16. Biddle (1771, revised 1789), p. 84.
17. Smith, William, 'An account of the Transit of Venus over the Sun's Disk as observed at Norriton', *Transactions of the American Philosophical Society*, 1 (1771, revised 1789), p. 11.
18. Mason, Charles, *Mason & Dixon's Line Original Journal of the Commissioners 1763*, p. 70.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System

2013AntAs...7...54M

19. Biddle (1771, revised 1789), 88-91.
20. Mason, C. & Dixon, J., 'Observations for Determining the Length of a Degree of Latitude in the Provinces of Maryland and Pennsylvania, in North America', *Philosophical Transactions of the Royal Society*, 58 (1768).
21. Smith, William, 'Account of the terrestrial measurement of the difference of longitude and latitude, between the observatories of Norriton and Philadelphia', *Transactions of the American Philosophical Society*, 1 (1771, revised 1789), 114-120.
22. Biddle (1771, revised 1789), p. 86.
23. Biddle (1771, revised 1789), p. 87.
24. Maskelyne, Nevil, Instructions relative to the observation of the ensuing transit of the planet Venus Over the Sun's disk On the 3rd of June 1769, *The Nautical Almanac And Astronomical Ephemeris, for the Year 1769.*
25. Smith (1771, revised 1789) p. 11.
26. Biddle (1771, revised 1789), 89-90.
27. Biddle (1769), p. 415.
28. Maskelyne (1769).
29. Biddle (1771, revised 1789), p. 84.
30. Biddle (1771, revised 1789), p. 86.
31. Biddle (1771, revised 1789), p. 90.
32. Newcomb, Simon, 'Discussion of observations of the transits of Venus 1761 and 1769', *Astronomical Papers prepared for the use of the American Ephemeris and Nautical Almanac, Bureau of the Navy* (1890), p. 387.
33. Smith, William. The Sun's Parallax deduced from a comparison of the NORRITON and some other American observations of the transit of Venus, 1769; with the GREENWICH and other European observations of the same., *Transactions of the American Philosophical Society*, (Volume I, 1771 revised 1789) Page 176.
34. At the 28th General Assembly of the International Astronomical Union, Beijing, 2012, it was resolved that the astronomical unit be redefined as 149597870700m exactly and the symbol 'au' be adopted. (IAU Division 1, resolution B2)
35. Biddle (1892), *passim*.
36. Bell, Whitfield Jenks, *Patriot-Improvers: Biographical sketches of members of The American Philosophical Society, Volume One, 1743-1768*, (American Philosophical Society, Philadelphia, 1997), p. 302.

The Authors

James E. Morrison is retired from a 40 year career in computers, including 30 years with IBM. He is the author of *The Astrolabe*, a complete treatise on the history, design and uses of all types of astrolabes and related instruments. He has a bachelor's degree in Physics from Oklahoma State University and a Masters Degree in Systems Engineering from Southern Methodist University. He lives in the United States at Rehoboth Beach, Delaware.

Geoffrey Thurston served as a General Duties Officer in the Royal Air Force for 26 years. He then managed a research and development programme for high-altitude, long-endurance unmanned aircraft. He is now retired and devotes most clear nights to the observation of asteroids. He has an MA in mathematics from Oxford University.

© Science History Publications Ltd • Provided by the NASA Astrophysics Data System