A (Not So) Brief History of the Transits of Venus

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"This great marvel which we have just witnessed, fellow savants (it almost takes my breath away), is nothing less than the transit of Venus!"

— *Some Learned Tales for Good Old Boys and Girls,*
Mark Twain, 1875

How is it possible to measure distances in the solar system? Today, astronomers simply bounce a radar signal off the planet Venus and calculate the distance between Earth and the Sun using Kepler's laws. But in the 18th century, astronomers had to be much more clever in their measurements. Like surveyors out to measure their surroundings, astronomers set sail around the world with a surveyor's method to measure the solar system.

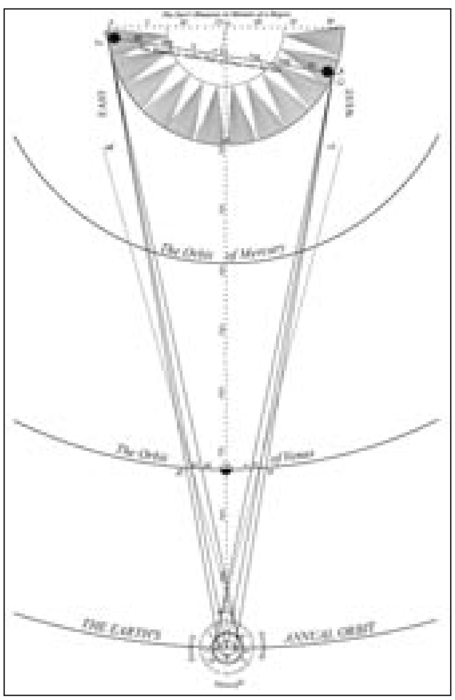

Figure 1a. — A rendition of the Transit of Venus by James Ferguson, 1778. Reprinted with permission from *The Transit of Venus: the Quest to Find the True Distance of the Sun* by David Sellers (Magavelda Press 2001).

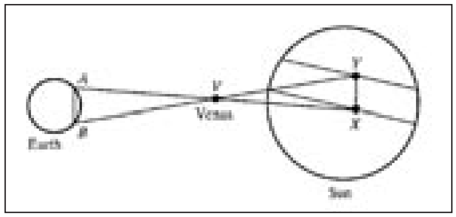

Figure 1b. — Observers at different latitudes on Earth will measure different parallel tracks of Venus across the Sun. From precise timings of the duration of the transit, the angle that the two terrestrial stations subtend at Venus can be determined, and hence both the distance to Venus and the scale of the solar system (from known orbital parameters).

The surveyor's method is called triangulation or parallax. By sighting an object from two widely separated positions and measuring how its image appears to shift against the background, the unknown distance to the object can be determined through basic geometry (see Figure 1a and 1b). It's the same as holding your thumb at arm's length: by measuring how its angular position changes first with one eye, then the other, and knowing the distance between your eyes, you can calculate the length of your arm.

However, the method can't be applied to measure the Sun's parallax directly because in the daytime, the Sun blocks out all the background stars — there's nothing to compare the Sun's position with. Could the disk of the Sun itself be used as a background? In 1629, Kepler predicted that Venus would pass directly across the face of the Sun two years hence, in 1631, and that it would just miss in 1639. Because of the tilt of Venus' orbit compared to Earth's orbit, this is a rare event — it occurs in pairs separated by eight years, with more than a century between the pairs (see Table 1 and Figure 2). After the 17th-century pair, the next wouldn't be until 1761 and 1769. Observers in this century will see transits next year, in June 2004, and 2012. No one alive has seen a transit of Venus.

Table 1

Past and Future Transits of Venus
December 7, 1631
December, 4, 1639
June 6, 1761
June 3-4, 1769
December 9, 1874
December 6, 1882
June 8, 2004
June 6-7, 2012

Figure 2. — Past and future transit paths (Proctor 1874).

The 1631 transit occurred when it was nighttime in Europe so there are no recorded observations. In the spring of 1639, the promising young scientist, Jeremiah Horrocks, discovered that Kepler was wrong: Venus *would* transit across the Sun that year, and in only a few weeks time (Fernie 2002). Horrocks and another Englishman, William Crabtree, were the only two people to observe the transit. They lived 30 miles apart but had never met — they communicated by letter. Both were so excited to see the small black dot of Venus dwarfed by the bright disk of the Sun that they failed to make any useful timings.

Horrocks details Crabtree's experience: "But a little before the time of sunset…the Sun breaking out for the first time from the clouds, he eagerly betook himself to his observation, and happily saw the most agreeable of all sights, *Venus* just entered upon the *Sun*. He was so ravished with this most pleasing contemplation, that he stood viewing it leisurely, as it were; and from an excess of joy, could scarce prevail upon himself to trust his own senses."[1] Indeed, the surprise must have been great, for Kepler had thought the Sun was much closer and that Venus would cover one quarter of its disk. Both Horrocks and Crabtree suddenly got an image of the immensity of the solar system. Horrocks dutifully filed a report anyway and indicated that the event could be useful for determining solar distance.

During the subsequent decades astronomy got organized. National societies formed that held regular meetings and published papers and transactions. The most important of these were the Royal Society of London and the French Academy in Paris.

Edmund Halley, an esteemed member of the Royal Society, published a paper in 1716 outlining how the upcoming transits could be used to find the Earth-Sun distance. Knowing he would probably be dead by the time of the next transits, he issued a call-to-arms to astronomers worldwide, "Therefore, again and again, I recommend it to the curious strenuously to apply themselves to this observation."[2] Halley further pointed out the desirability of making observations from multiple widely separated stations, both to improve the observations and to guard against the problem of one station being clouded out.

Under the auspices of the professional scientific societies, it was now possible to heed Halley's call and mount major expeditions. Expeditions were sent to many of the world's far-flung places: Northern Canada and Siberia, South Africa and the South Pacific, Baja, Mexico, and the Indian Ocean.

During an age when travel was decidedly less comfortable, if not downright dangerous, the scale of the expeditions was truly impressive. More than 100 astronomers participated. For those traveling by sea, the normal problems of navigational errors, monsoons, and scurvy were exacerbated by the Seven Years' War, fought between France and Britain in every hemisphere in the early 1760s. For some it was the adventure of their lives. For the less fortunate, it cost their lives.

The 18th-Century British Expeditions: Mason and Dixon's Trip to South Africa

Before gaining lasting fame for surveying the eastern United States in 1763, the British team of Charles Mason and Jeremiah Dixon set sail for Bencoolen (modern Bengkulu), Sumatra in December 1760. They gained firsthand knowledge of the hazardous state of affairs, for within hours of leaving port they were attacked by a French frigate. With 11 dead and 37 wounded, they limped back to port and promptly wrote to the Royal Society threatening to quit. Not only was the Royal Society unsympathetic, they went so far as to warn the rattled astronomers that their refusal to continue could not "…fail to bring an indelible Scandal upon their Character, and probably end in their utter Ruin."[3] For good measure, the Society added the threat of court prosecution "with the utmost severity of the Law."[4]

Mason and Dixon reluctantly capitulated and set sail again two months later when the ship was repaired, this time having at least secured an escort. As it took three months to round the tip of Africa, they decided to stop and set up their observatory at Cape Town, South Africa. The fact that Bencoolen had been captured by the French may have contributed to their decision.

On transit day, June 6, the sky was perfectly clear and Mason and Dixon obtained valuable readings. This was fortunate for the British because their other Southern Hemisphere observer, Neville Maskelyne, the Astronomer Royal, who was sent to the island of Saint Helena — located between the middle of the South Atlantic and the middle of nowhere — was completely clouded out. (Perhaps that's why Maskelyne's liquor expenses topped out at £141, nearly half his total expenditure of £292.)

Mason and Dixon stayed on at Cape Town for a while to measure Earth's gravity and the longitude and latitude of Cape Town. The precision of their geodetic work didn't go unnoticed, for two years later they were summoned to the American colonies to survey the disputed Pennsylvania-Maryland border — casting a line that bears their name to this day.

Other 18th-Century Expeditions

Transit fever reached the American colonies too. The Governor of the Province of Massachusetts gave a stirring appeal to the House of Representatives on behalf of John Winthrop, professor of mathematics and natural philosophy at Harvard, that this was a "[P]henomenon which has been observed but once before since the

[1] J. Donald Fernie, *The Whisper and the Vision: The Voyages of the Astronomers*, p. 10.

[2] `www.dsellers.demon.co.uk/venus/ven_ch8.htm`

[3] Fernie 1976, p. 16.

[4] Ibid.

Creation of the world."[5] Winthrop was duly equipped with observational instruments and assistants and sailed to St. John's, Newfoundland in the Province-sloop "Massachusetts" (see the recent *JRASC* article by Smith, 2003). Despite an unabating plague of "venomous" insects, the team enjoyed clear weather and made useful timings of the end of the transit (the beginning of the transit occurred before sunrise in North America).

Intrigue and adventure came in various forms during the transit expeditions. Maximilian Hell, an Austrian Jesuit and member of the French Academy, was renowned in Europe as a writer, educator, and astronomy popularizer. In 1755, he was named court astronomer by Archduchess of Austria Maria Theresa and commissioned to set up an observatory in Vienna. From there he made good observations of the 1761 transit.

For the 1769 transit, Hell was invited by King Charles VII of Denmark and Norway to lead an expedition to the island station Vardö, located near Lapland north of the Arctic Circle. On transit day, Hell and his assistants were so pleased to see the clouds part just before the transit began that they loudly celebrated afterwards by firing their ship's cannon nine times and singing a *Te Deum* in gratitude. Hell then stayed on for eight months to collect additional scientific data for a proposed encyclopedia on arctic regions.

Back in Paris, French Academy members grew impatient with Hell's delay in reporting his data and some suspected him of waiting to hear other reports so that he could adjust his data accordingly. Though greatly esteemed as scholars, academic opinion had recently turned against Jesuits because they were thought to have too much political power. The insinuations ceased for a while when Hell finally published his full observations in 1772, three years after the transit. This was a year before the Jesuit Society as a whole was suppressed and many Jesuits were expelled from their respective countries. Hell maintained his position in Vienna, but despite collecting available data and publishing the best value of the solar parallax for his time, the last two decades of Hell's life were seriously affected by the initial suspicions over his data.

The matter didn't end with Hell's death. In 1823, when Johann Encke made a comprehensive evaluation of both the 1761 and 1769 transits, discussed further below, he rejected Hell's data. Ten years later, Carl Littrow took the opportunity as director of the Vienna observatory (Hell's old position) to examine a rediscovered fragment of Hell's original data sheets. Littrow claimed at last to have found evidence that Hell erased some figures and corrected them in a slightly different coloured ink. On the strength of this purported evidence, Hell's reputation was destroyed.

It wasn't until 1883 that American astronomer Simon Newcomb, who figures prominently in the 19th-century transits, discredited Littrow's evidence and exonerated Hell. Newcomb found that Hell's changes were due to using a defective pen at the time of the observations, and further, that Littrow had been colourblind.

The 18th-Century French Expeditions: Pingré's Voyage to Roderigue

The French Academy launched several expeditions for the 1761 transit. Alexander-Gui Pingré, a prolific 50-year-old astronomer and theologian, ventured out from Paris in November 1760 to the French island of Roderigue, east of Madagascar, in the Indian Ocean. Amongst his half-ton of baggage was a letter addressed to the British Admiralty directing them not to interfere with his important expedition. At a time when first contact between warring ships was typically made by cannon fire, it's hard to see what good such a letter would do, but perhaps it provided moral support.

Pingré got off to a slow start. Arriving at port with his considerable load, the shipping agents refused to let him take so much baggage, whether it was essential astronomical equipment or not. The problem was finally rectified by the intervention of the French Academy. He was further delayed in the south seas when his ship met a hobbled French ship whose captain demanded that they escort him back to Isle de France (today known as Mauritius), a slowdown that cost Pingré six or seven weeks.

Arriving at Roderigue only a week before the transit, Pingré and his assistant worked 'round-the-clock to get their instruments in working order after the long sea voyage, using turtle oil — from the local delicacy — as a lubricant. With little time to spare, they built a crude shelter to act as an observatory. "I think there never was a more inconvenient one."[6]

No matter: on transit day it was cloudy. Undaunted, Pingré held out hope that the weather would clear. His patience paid off and he was able to obtain observations and timings for the end of the transit.

With the transit over, Pingré's much-prized letter seemed to act as a magnet for British ships because three weeks later one sailed into the harbour, sacked and looted the small settlement and took away Pingré's ship as spoils of war. Pingré was stranded until another French ship came along three months later — but not before two more British ships arrived to wreak more havoc. Finally, on his way home again, Pingré had yet another run-in with British ships that this time captured his ship and escorted him into port in Lisbon.

No doubt happy to see land again, Pingré stuck to it and finished his journey by carriage. Despite the rough ride, at least he was rid of the British. Crossing the Pyrennees into France, he noted with some exasperation in his journal that he'd been away 1 year, 3 months, 18 days, 19 hours, and 53 minutes.

Back in Paris, Pingré resumed his work at the Academy[7]. One of his main interests was the problem of determining

[5] Donald Fernie, *American Scientist*, Sept-Oct 1997.

[6] Angue Armitage, *The Pilgrimage of Pingré: An Astronomer-Monk of Eighteenth-Century France*, p. 51.

[7] Pingré was a free associate of the Academy. Scientists in Orders were barred from ordinary membership.

the longitude of a ship at sea. In 1767, he made a two-month voyage with the famed comet-hunter, Charles Messier, to test a new marine chronometer. Subsequently, he tested another chronometer on a much longer voyage to Santo Domingo in what is now the Dominican Republic. From there he observed the 1769 transit of Venus at a picturesque coastal mountain site. With this data, he was able to calculate one of the better values for the solar parallax from that period.

The 18th-Century French Expeditions: Chappe's Journeys to Siberia and Mexico

For widescreen cinematic drama, few expeditions can match that of Jean Baptiste Chappe d'Autoroche who undertook a 4000-mile trek to Tobolsk, Siberia, in the dead of winter. A gifted Jesuit with a great enthusiasm for astronomy, Chappe gained a reputation as a skilled scientist beginning at the age of 25 when he observed a transit of Mercury at the Paris Observatory with another French astronomer, J.B. le Gentil (whose considerable adventures are detailed further below). Tobolsk was chosen because from there the transit would have the shortest duration (Van Helden 1995). Chappe's plan was to travel east from Paris to Vienna, then northeast through Warsaw to St. Petersburg and finally across the vast Russian steppes.

Chappe might have dreamed of today's superhighways and automobiles with shock absorbers because during the eight-day journey by carriage to Strasbourg, near the German border, all of his thermometers and barometers were shattered and the carriages were damaged. While the carriages were being replaced, Chappe industriously made himself a new set of instruments.

To avoid a repeat of that ordeal, when he got to Ulm, Germany, he switched modes of transport and took a boat down to Vienna. There he met and discussed transit problems with the astronomer Hell who was making his own preparations to observe it there. Upon reaching Warsaw, he again switched modes of transport, this time to horse-drawn sleds and made good time to St. Petersburg, arriving by mid-February.

But his Russian colleagues feared he wasn't coming and had sent their own observers on ahead. Aware of the scientific urgency of the expedition, and the onrushing spring, they quickly outfitted Chappe with an interpreter, guides, new giant sleds drawn by five horses abreast, plus supplies and provisions for his stay at the remote outpost. In early March, Chappe was off again. A vivid imagining is given by Donald Fernie: "One can picture them racing for the Urals through the silence of the frozen countryside, great clouds of snow rising from the horses' flying hooves."[8] Had *Dr. Zhivago* been about an astronomer, this would have been a pivotal scene.

It was a month of steady winter travel, often overnight, with sleep gained *en route*. Chappe wrote that it was anything but a smooth ride: "had very little rest, on account of the frequent shocks and overthrows I met with."[9] Other problems included his guides' daily complaints about the rapid pace — Chappe often bribed them along with brandy. Through sheer determination, Chappe beat the thaw — and the prospect of being mired forevermore in the Siberian mud. They rumbled into Tobolsk on April 10, 1761.

Chappe got to work immediately and set up his observatory on a mountain out of town. He must have been pleased to get settled and started on his scientific program. Soon he determined the longitude and latitude of his observatory, crucial data for the transit observations.

However, trouble now came from the spring thaw. This year it was unusually early and severe, and the two local rivers flooded the town. The superstitious townspeople acted accordingly: they blamed the foreign astronomer for messing with the Sun. To quell the rising mob, the local Governor posted guards for both Chappe and his observatory.

The day before the transit, Chappe had everything ready and he took a moment to reflect on the situation: "The sky was clear, the Sun sunk below the horizon, free from all vapors; the mild glimmering of twilight, and the perfect stillness of the Universe, completed my satisfaction and added to the serenity of my mind."[10]

But the perfect weather didn't last. By 10 p.m., the sky was completely clouded over. Naturally, Chappe feared his heroic expedition — and his honour in participating in this rare event — was now in jeopardy and he grew increasingly despondent. He wrote: "In these dreadful agitations I passed the whole night; I went out and came in again every instant, and could not continue a moment in the same position."[11]

In the morning, Chappe's hopes were revived as the clouds began to disperse. The gradual improvement in the sky seemed to affect his very being: "a pleasing satisfaction diffused itself through all my frame, and inspired me with a new kind of life…everything seemed to rejoice at the return of a fine day…and as my hopes became more sanguine, the joy of my mind was still more complete."[12] The governor and the archbishop came to visit, but the rest of the townspeople shut themselves up in their houses or in the churches.

Chappe's luck with the weather continued to improve and at last he was ready: "I stood fixed with my eye to the telescope, wandering over the immense space between us and the Sun a thousand times in a minute…. The moment of the observation was now at hand; I was seized with an universal shivering, and was

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[8] Donald Fernie, *The Whisper and the Vision: The Voyages of the Astronomers*, p. 34.

[9] Jean-Baptiste Chappe d'Autoroche, *A Journey to Siberia,* p. 46.

[10] Ibid., p. 80.

[11] Ibid., p. 82.

[12] Ibid., p. 82.

obliged to collect all my thoughts in order not to miss it."[13] From there, things seemed to go well, and Chappe made good observations.

Chappe dispatched his data back to Paris days later via mounted courier and stayed on another couple of months to make additional observations of the region. He took a leisurely trip back to France, and a glimpse into his character is seen from his visit to Echaterinenburg, where he stopped to make some observations. Evidently smitten with one of the local women, he hired a band and threw a party, hoping to gain her attention. Unfortunately, he doesn't report on the outcome of the event. Chappe also spent some time in St. Petersburg and finally arrived back in Paris in November 1762.

By the time of the next transit in 1769, Chappe wanted to go somewhere different — likely somewhere tropical. He decided on Baja, Mexico. After nearly three months at sea crossing the Atlantic, a lengthy hike across the breadth of Mexico (in which Chappe and his colleagues travelled by litter), and a three week voyage across the Gulf of California in which they were becalmed and saw their food, water, and time run perilously short, Chappe's team at last arrived at a small village on the tip of Baja on May 19. As the village was suffering from an epidemic of yellow fever, they took a considerable risk when they decided to stay there. Chappe thought they wouldn't have time to find a new location and went ahead with the preparations. It was a costly decision.

Chappe recorded the following in his journal: "Myself and all my train took up our abode in a very large barn. I had half the roof taken off towards the south, and put up an awning, that could be spread out or contracted at will. All my instruments were fixed just as they were to stand to observe the transit of Venus. The weather favored me to my utmost wish. I had full time to make accurate and repeated observations for the setting of my clock. At last came the third of June, and I had the opportunity of making the most compleat [sic] observations."[14]

This was his last journal entry. In the days after the transit, he cared for his colleagues who had caught the deadly disease until he too fell ill. Despite fits of pain and fever, Chappe rallied himself to view a lunar eclipse on June 18, as an independent longitude determination. The epidemic that claimed three-fourths of the village also claimed Chappe on August 1. Only one member survived to bring the data back to Paris.

Chappe's team gathered some of the best data of all and his words from the earlier 1761 transit have a lingering poignancy, "Pleasures of the like nature may sometimes be experienced; but at this instant, I truly enjoyed that of my observation, and was delighted with the hopes of its being still useful to posterity, when I had quitted this life."

The 18th-Century French Expeditions: Le Gentil's Epic Voyages

If Chappe's previous sled journey across frozen Siberia was a scene from a cinematic epic, then the voyage of Guillaume Le Gentil (full name: Guillaume-Joseph-Hyacinthe-Jean Baptiste le Gentil de la Galasière) to the Indian Ocean was a comedy of errors and a bounty of bad luck. As Helen Sawyer Hogg wrote once in this *Journal,* it "is probably the longest lasting astronomical expedition in history. In fact, it is quite possible that, except for interplanetary travel, there will never be astronomical expeditions to equal in duration and severity those made for that particular pair of transits."[15]

Le Gentil, a young member of the French Academy, set out from Paris on March 26, 1760, for Pondicherry, on the east coast of India, a full 14 months in advance of the transit. He intended to sail around the southern tip of Africa — the Cape of Good Hope — to Isle de France where he would catch another boat for India. Little did he know how familiar he was to become with Isle de France. He arrived there in July 1760, after a four-month voyage, and learned that because war had flared up between the French and British at Pondicherry, no boats were travelling there. So he waited. Six months later, he was still waiting. Just as he was about to give up and join Pingré in Roderigue, a few hundred miles to the east, a French frigate arrived on February 19, 1761 bound for the coast of India. Local officials assured Le Gentil that despite the monsoon winds, the ship would easily make it to the coast of India within two months — plenty of time to make preparations for the transit. Le Gentil decided to chance it.

Initially, they made good progress but soon the favourable winds abandoned them and they were blown away off course. Le Gentil wrote in his journal, "[W]e wandered around for five weeks in the seas of Africa, along the coast of Ajan, in the Arabian seas."[16] In other words, they wandered everywhere except towards their destination.

Finally, on May 24, they came within sight of Mahé, on the west coast of India, directly across from Pondicherry. Here they received news from another ship that Pondicherry was now in English hands. To Le Gentil's "great regret," the captain decided to return to Isle de France. Consequently, when transit day (June 6) arrived, Le Gentil was aboard a rolling ship in the middle of the Indian Ocean, unable to make any reliable observations. He dutifully observed the transit and measured his longitude and latitude but knew full well that his data was useless.

Rather than make the long journey back to France, Le Gentil was determined

[13] Jean-Baptiste Chappe d'Autoroche, *A Journey to Siberia*, p. 83.

[14] Doyce B. Nunis, *The 1769 Transits of Venus*, 1982.

[15] Helen Sawyer Hogg, *Out of Old Books: Le Gentil and the Transits of Venus, 1761 and 1769,* Journal of the Royal Astronomical Society of Canada, volume 45, p. 37, 1951.

[16] In Sawyer Hogg 1951, p. 41 and Fernie 1976, p. 42.

to make some useful scientific observations of the region. He writes, "I resolved then not to leave the Indian Ocean until this time [after the next transit in 1769], to make all the observations I could on geography, natural history, physics, astronomy, navigation, winds, and tides."[17] Indeed, 18th-century scientists were much more broadly trained than those of today. After a few years of this work, he began to think about the next transit. According to his calculations, the best place to observe the transit would be in Manila, Philippines.

He dashed off a letter to the French Academy informing them of his intentions and caught the next boat for Manila. His satisfaction at moving on was evident in his journal: "I finally left the Isle de France May 1, 1766, quite resolved to say good-bye forever to that island."[18] He was soon to learn, however, that sometimes personal resolve just isn't enough.

Le Gentil arrived in Manila in August 1766 and began getting settled. Though the climate appeared promising, Le Gentil soon had doubts because the Spanish governor was not kindly disposed towards the French and, on top of that, he ran the place like a tyrant. Le Gentil's doubts became genuine worries when letters of introduction from the French Academy arrived in July 1767; the governor rejected them as forgeries, saying that 14 months was too short a time to receive a reply to his letter.

An additional letter noted that Pingré, now safely returned to Paris — and perhaps wishing further seagoing adventures for his colleague — thought that Pondicherry would be a better site for observing the transit than Manila. By this time, Pondicherry was back in French hands, so, rather than expose himself further "to the caprice of him who governed,"[19] Le Gentil decided to have another attempt at viewing the transit in India. After all, he wrote, he was now a veteran traveller: "Sea voyages no longer cost me anything, I had become so familiar with this element."[20]

He embarked on a Portuguese vessel and was soon on his way to India again. *En route*, he mediated an argument between the ship's pilot and captain and took over the helm himself. Nevertheless, he described it as the finest of voyages and reached Pondicherry in a mere 32 days.

Le Gentil arrived at Pondicherry on March 27, 1768. The Governor welcomed him with a feast that very night; it seemed he'd made the right decision. The next day, the Governor invited him to choose a spot for his observatory; he chose a partially ruined palace (thanks to the British), that, aside from being well situated, still had a large gunpowder magazine in its basement.

Over the months, Le Gentil occupied himself by studying Indian astronomy and local customs. From Pondicherry, the transit was to be visible first thing in the morning on June 4. As the clear mornings of May passed, Le Gentil was nearly beside himself with impatience. The night before the transit was perfectly clear and Le Gentil observed the satellites of Jupiter with the Governor, using a telescope sent by the now-friendly British at Madras.

But his good fortune couldn't last. He awoke at 2 a.m. and "saw with the greatest astonishment that the sky was covered everywhere, especially in the north and north-east, where it was brightening; besides there was a profound calm. From that moment on I felt doomed, I threw myself on the bed, without being able to close my eyes."[21]

From there, his journal contains a long passage that would be familiar to anyone trying to observe a particular astronomical event. He veers back and forth between "hope and fear" that the winds would change and clear the clouds from the sky. Instead, the weather got worse. A freak squall blew in, piling the clouds together and completely obscuring the Sun when it rose. When the transit was over, the winds calmed and the sky cleared — the Sun shone brilliantly for the rest of the day.

Le Gentil was so stupefied at his misfortune that it seems only fair to quote him at length.

"That is the fate that often awaits astronomers. I had gone more than ten thousand leagues [30,000 miles]; it seemed that I had crossed such a great expanse of seas, exiling myself from my native land, only to be the spectator of a fatal cloud which came to place itself before the Sun at the precise moment of my observation, to carry off from me the fruits of my pains and of my fatigues....

"I was unable to recover from my astonishment, I had difficulty in realizing that the transit of Venus was finally over.... At length I was more than two weeks in a singular dejection and almost did not have the courage to take up my pen to continue my journal; and several times it fell from my hands, when the moment came to report to France the fate of my operations...."[22]

To make matters worse, he soon learned that the skies had been clear in Manila that day!

Now, Le Gentil wanted nothing more than to return to Paris. In the world of Le Gentil, this was easier said than done. His departure from Pondicherry was delayed by a recurring fever and dysentery that prevented him from travelling. He finally left Pondicherry, still ill, in March 1770, making it only as far as his former home-away-from-home, Isle de France, where he decided he was too ill to continue. Here, his spirits were further dampened by the death of an astronomer named Veron, whom he'd met in India. Incidentally,

[17] In Sawyer Hogg 1951, p. 42.

[18] In Sawyer Hogg 1951, p. 43 and Fernie 1976, p. 43.

[19] In Sawyer Hogg 1951, p. 90.

[20] Ibid.

[21] In Sawyer Hogg 1951, p. 131 and Fernie 1976, p. 48.

[22] In Sawyer Hogg 1951, p. 132 and Fernie 1976, p. 49.

Veron had suffered the same misfortune as Le Gentil for the 1761 transit — finding himself stuck at sea. Le Gentil described his death as "from a fever which he had acquired by his great zeal to observe throughout the night on land when he was at the Moluccas."[23]

By July, Le Gentil thought he was finally fit for travel and more than ready to leave Isle de France for good. But it wasn't until November that a ship was ready to take him. Two weeks into the voyage, the ship met a hurricane that took down parts of its main masts. Unable to continue, the ship hobbled back to Isle de France. As if returning to the island wasn't bad enough, here Le Gentil received news that his heirs were spreading rumours of his death and that the only thing holding up their taking possession of his estate was a death certificate.

With renewed determination, he left Isle de France on March 31, 1771 on a Spanish frigate. Around the Cape of Good Hope, the ship met "tempests upon tempests" but Le Gentil wrote that "My sole worry in the midst of all these storms was the fear of being forced to see again the Isle de France."[24]

But the Spanish sailors were more than capable and the ship arrived in Cadiz, Spain on August 1, 1771. Le Gentil finished his journey on land, like Pingré before him, and crossed the Pyrennees on October 8. It was an absence of eleven years, six months, and thirteen days.

Le Gentil's return was not entirely happy. He immediately had a lengthy court battle to regain part of his estate that had been lost due to a careless manager, and he'd lost his seat at the French Academy — on whose behalf he'd taken his journeys in the first place.

On the positive side, he gained some satisfaction from "hearing people recognize me and attest loudly that I was really alive."[25] He married, had a daughter, and took up a quiet life writing his memoirs. Having met many untimely tempests in his life, he mercifully died in 1792, months before the great storm of the French Revolution descended upon Paris.

Everyone seemed to fare better in the 1769 transits than poor Le Gentil. Mason and Dixon, who got off to such a rotten start in 1761 for the Royal Society, stayed closer to home for the 1769 event. They split up, with Mason venturing to Ireland and Dixon to northern Europe and viewed it without incident. The Royal Society sent out other expeditions, including that of William Wales to Hudson's Bay, and the most famous of all, that of Captain Cook and the *Endeavour,* both described below.

The 18th-Century British Expeditions: William Wales' Expedition to Hudson's Bay

Having heard about all the adventures in 1761, William Wales, who had recently computed lunar navigation tables for Neville Maskelyne's *Nautical Almanac* volunteered to observe the 1769 transit for the Royal Society as long as the destination was warm and not too far out of the way. Naturally, he got the opposite. He was sent to Fort Churchill, on the Hudson's Bay, known even then as the Polar Bear capital of the world.

As the shipping routes to the Hudson's Bay would be frozen solid until early summer, it was necessary for Wales and his assistant, Joseph Dymond, to sail in late-spring 1768 and winter over in Churchill. An agreement with the Hudson's Bay Company was reached to drop the astronomers off and pick them up a year later. The journey across the North Atlantic was unremarkable until they got to the Hudson Straits where the fog was exceedingly thick. When it lifted, Wales spent much time counting ice floes: one day 32, another 58.

Upon arrival in Churchill, August 10, 1768, Wales writes about the "intolerably troublesome" hordes of "moschettos" and sand-flies: "There are continually millions of them about one's face and eyes, so that it is impossible either to speak, breathe, or look, without having one's mouth, nose, or eyes full of them."[26]

For the first month, Wales and Dymond busied themselves with building their observatory and making it secure for the winter. Once that was done, Wales ceased keeping a journal "except of the weather...which is, in reality, the only thing we have to keep a journal of here in the winter season,"[27] giving an indication of how little they had to occupy themselves.

Wales gives additional details in some "short memorandums," where he writes of proudly donning his "winter rigging," decking himself out head to toe in furs furnished by the Hudson's Bay Company[28] and of sleepless nights due to the loud cracking of the cabin boards under the stress of the frost. Though the aurorae were unimpressive that year, the nights were cold enough to ice over a half-pint of brandy left in the open air in five minutes. By February, the bedboards dripped with icicles. Even so, when the clouds of "moschettos" returned in the summer, Wales began to think that winter was "the more agreeable part of the year."[29]

After more than a year of preparation and waiting, transit day, June 3, dawned partly cloudy. At noon, the transit began and the two astronomers differed in their initial contact times of Venus on the disk of the Sun by 11 seconds, a result that was a great disappointment to Wales. They stayed in Churchill another three months before sailing back to England, with the great comet of 1769 (discovered

[23] In Sawyer Hogg 1951, p. 133 and Fernie 1976, p. 50.

[24] In Sawyer Hogg 1951, p. 174.

[25] In Sawyer Hogg 1951, p. 177 and Fernie 1976, p. 53.

[26] Helen Sawyer Hogg, *JRASC*, volume 42, p. 158; and Fernie 1976, p. 20.

[27] In Sawyer Hogg 1952, p. 159.

[28] Unfortunately, these were all confiscated by customs officials on his return to England.

[29] In Sawyer Hogg 1952, p. 192 and Fernie 1976, p. 24.

by Messier) visible in the night sky. Robbed of favourable winds in the English Channel, they made the final leg of the trip to London via stagecoach.

Back home, Wales was so distressed by his transit observations that he refused to submit them to the Royal Society because they were inaccurate. However, the Society would not be denied. In March 1770, Wales presented his results to the members of the Society and read a 50-page manuscript of his journal excerpts detailing the various botanical, climatic, and scientific information he obtained. Happily, he was applauded for his efforts and now on his way to warmer climes: Captain Cook recruited him to act as navigator for Cook's second and third voyages around the world. Wales then finished his career as a mathematics teacher in London and taught the likes of Samuel Taylor Coleridge and Charles Lamb (Fernie 2002). In his essay, *Recollections of Christ's Hospital,* Lamb describes his schoolmaster, "There was in William Wales a perpetual fund of humour, a constant glee about him, which heightened by an inveterate provincialism of north-county dialect, absolutely took away the sting of his severities."[30] Despite all the "moschetto" stings, Wales seems to have enjoyed his tenure as a world traveller and it is tempting to wonder how much of Coleridge's *Rime of the Ancient Mariner* was inspired by Wales' stories.

The 18th-Century British Expeditions: Lieutenant Cook's Voyage to Tahiti

For the Royal Society, the 1769 transit of Venus coincided perfectly with their plans to explore the South Pacific. Alexander Dalrymple, among others, was certain that it hid another continent, *Terra Australis Incognita,* the unknown southern land. The idea of such a place had lurked in geographers' minds since Ptolemy had put it on his map in his *Geography*. But an exploratory expedition, with the aim of claiming newly discovered lands for Britain, would surely raise the suspicions of the other European powers. The transit was the perfect ruse.

The Royal Society proudly proclaimed that the transit would benefit navigation, knowing full well that the size of the Solar System had nothing whatsoever to do with getting ships around the Earth. However, as navigation went before shipping, trade and profits, such boosterism was the only way to secure funding from the government for the expedition. Then, the Royal Society wrote a spirited, patriotic letter to their patron, King George III, about the importance of the observations. The King was good enough to chip in with the requested £4000 (equivalent to about £300,000 today).

The Royal Navy agreed to loan a ship for the expedition but refused to have it be commanded by a mere civilian. For his part, Dalrymple refused to be a mere passenger and thus withdrew from the entire expedition. Desperate to find a commander for their ship, the Navy cast about until a man who had at least two things going for him was nominated. He had charted the Gulf of St. Lawrence and had submitted observations to the Royal Society of a solar eclipse seen from Newfoundland (to better determine its longitude). The man was James Cook.

Here the Navy hit an embarrassing snag because Cook was not a commissioned officer. Did they have no one of higher ranks, with some astronomical abilities, who could lead the expedition into uncharted waters? Apparently not. So, Cook was promoted to lieutenant — not to captain, that only came later — and given command of the *HMS Endeavour.*

The official astronomer was Charles Green, an assistant at Greenwich (and brother-in-law of William Wales) adept at finding longitude at sea solely based on observations of the Moon and stars. He sailed with Neville Maskelyne in 1763-4 to Barbados to test John Harrison's fourth marine chronometer — the device that finally solved the problem of determining longitude at sea. Interestingly, by the time the *Endeavour* sailed in August 1768, similar chronometers were still very expensive and the ship went without.

The *Endeavour* carried another scientist, Joseph Banks, a young aristocrat who was devoting his life to science, particularly botany. Banks, a formidable personality, travelled with an entourage of assistants, including two illustrators for his botanical samples. He later became President of the Royal Society and dominated science in late 18th-century England.

At sea, Green was dismayed to find out none of the naval officers knew the lunar observations method for determining longitude. For four years, the Royal Greenwich Observatory had been publishing the *Nautical Almanac*. What was the point of publishing it, he grumbled, when naval officers didn't know how to make appropriate observations. However, when shown, Cook quickly mastered the method. Evidently, Cook's reputation for knowing the precise whereabouts of his ship was due in part to Green who enthusiastically took lunar observations at any opportunity.

The *Endeavour* sailed west down the length of the Atlantic in nearly four months, took four attempts to cross the tumultuous Strait Le Mare at the tip of Tierra del Fuego and passed Cape Horn on January 25, 1769.

As part of the purpose of the expedition was to find *Terra Australis*, Cook now sailed in a northwest direction, contrary to the winds and currents. The days passed on and no unknown continents were sighted. In his journal, Banks took a jab at armchair philosophers like Dalrymple: "It is however some pleasure to be able to disprove that which does not exist but in the opinions of theoretical writers, of which sort most who have wrote [sic] anything about the seas without having themselves been in them. They have generally supposed that every foot of sea which they believed no ship had passed over to be land, though they had little or nothing to support that opinion but vague reports."[31]

[30] Charles Lamb, *Recollections of Christ's Hospital*.

[31] J.C. Beaglehole, *The Endeavour Journal of Joseph Banks,* p. 240.

After three months on open water the mountains of Tahiti were sighted and the *Endeavour* landed at Matavia Bay on April 13, 1769. Before going ashore, Cook issued a set of rules to his men in order to promote the best relations with the island's inhabitants. Foremost on the list was cultivating a friendship with the locals, while other rules regulated trade and responsibility. The last rule prohibited the exchange of "Iron, or anything that is made of Iron…for anything but provisions."[32]

This last rule was necessary to literally keep the ship together. The Tahitians were a metal-less culture and thus held metal objects, such as nails, scientific instruments, and tools, in extraordinarily high regard. According to sailors on the *Dolphin,* which had landed in Britain just before the *Endeavour* sailed, Tahitian women were beautiful and uninhibited. They would trade sexual favours for a simple iron nail — the very things that held wooden ships together. For men at sea months on end, such a price was so beguiling that they nearly pulled the ship apart to procure the costs of love. Cook wasn't about to jeopardize the rest of his expedition over these dalliances and thus took the necessary steps to protect his ship.

Soon after arrival, Cook and Green observed the moons of Jupiter to establish the longitude of Tahiti. Then, they set about building their observatory, which they located at the northernmost end of the bay. As the transit was the ostensible *raison d'être* for the expedition, Cook didn't want to take any chances with instruments going missing, or worse, an uprising, and thus had a fort built around the observatory.

However, on May 2, a month before the transit, when the instruments were brought into the finished observatory, the sturdy case for the astronomical quadrant was opened and found to be empty. Where was it? Because it had only been brought ashore on the previous day and placed in Cook's tent, no one could figure out how it could have gone missing. Normally diplomatic, Cook became livid because the instrument was crucial to the transit observations. He immediately sealed the bay so that no one could escape by canoe.

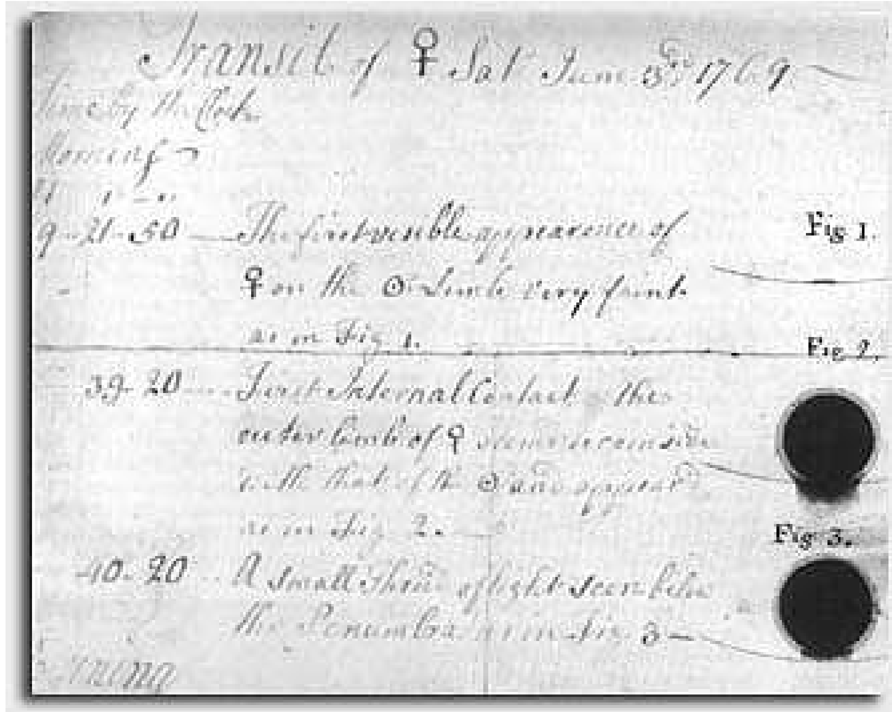

Figure 3. — Excerpt from Cook's journal showing the "black drop" effect. Copyright James Cook University.

Meanwhile, Green and Banks, who had already developed some rapport with the Tahitians, made some discrete inquiries and were soon hot on the trail. They recovered one piece of it and this time it was Banks who became livid because the thief had clearly taken apart the quadrant and the likelihood of damage, or of not recovering all the pieces, was great. In front of a gathered, chattering crowd, he took out his two pistols to show his firepower. The demonstration had the desired results and the quadrant was returned piece by piece. Green confirmed that only minor pieces were now missing, and that it could be made operable again. Upon return, the two scientists found in the confusion of suspicion and search parties, a chief had been taken into custody. Cook immediately released the man and days later made amends by presenting him with an axe.

As the transit day drew near, Green and Cook made final preparations while keeping an eye on the weather. They'd had a mix of sunny and cloudy days and were understandably concerned. Cook dispatched a small party to a nearby island to improve their chances of success.

Luckily, on June 3, the Sun broke through the dawn haze and, according to Cook, "[the] day proved as favourable to our purpose as we could wish. Not a cloud was to be seen the whole day…."[33]

When the transit began, the team made an important discovery: "We very distinctly saw an Atmosphere or Dusky shade round the body of the planet, which very much disturbed the times of the contact, particularly the two internal ones."[34] Side by side and using telescopes

[32] Peter Aughton, *Endeavour,* p. 65.

[33] W.J.L. Wharton, *Captain Cook's Journal,* p. 76.

[34] Ibid. In fact, the atmosphere of Venus was first discovered by the Russian astronomer Lomonosov during the 1761 transit, though his priority wasn't established until 150 years later when one of his papers was translated into German.

of the same power, Cook and Green "differed from one another in observing the times of the contact much more than could be expected."[35]

This became known as the "black drop effect" (see Figure 3) and despite all the 1761 observations, neither Cook nor Green seems to have expected it. Due to Venus' atmosphere, contact with the Sun's disk was not distinct — it appeared like an oil drop that wouldn't fully detach from its source — making it difficult to obtain precise timings. Consequently, they knew their results were suspect. After such a long voyage, Cook was inevitably disappointed in the outcome of its primary purpose.

There was further intrigue that day. During the observations, the ship's storeroom was broken into and a large quantity of nails was stolen. Evidently, the transit provided enough distraction for other sorts of pursuits. Cook turned a blind eye to the fraternization between his crew and the local women for the sake of morale but he couldn't ignore thievery. When one sailor was caught with some nails on him that day, he suffered two dozen lashes as punishment.

Now it was time to complete the expedition. After three months on Tahiti, the *Endeavour* raised anchor and set sail on July 13, 1769. Though Cook nearly lost two men to desertion (and took extreme measures to have them returned), he gained one, a local chief and priest named Tupia. The wealthy Banks agreed to take responsibility for him in England, reasoning, in his most aristocratic way, that he could keep him as a curiosity in the same way his neighbours kept lions and tigers. Tupia proved useful as an ambassador while the *Endeavour* explored nearby islands.

At sea again, the *Endeavour* was now to continue its search for the unknown continent — there were even sealed secret instructions from the Admiralty, which Cook now opened. From Tahiti, he was to sail south to 40° latitude and then westward until he either hit the unknown continent or New Zealand.

Like William Wales and Joseph Dymond on their journey home, they observed the great comet of 1769; Cook claimed its tail was an astonishing 42°! Tupia saw it as a harbinger of war and feared his people would be invaded by those of a nearby island.

After days and weeks on the open seas, a stir of excitement was caused when land was sighted. Could it be the unknown continent? No, it was New Zealand. The *Endeavour* had removed the unknown continent from another large chunk of uncharted ocean.

On November 9, Green and Cook observed a transit of Mercury from New Zealand and used it to calculate their longitude. The *Endeavour* spent four months charting New Zealand then Cook ventured west to the coast of Australia where he had not one but two harrowing run-ins with the Great Barrier Reef. The ship limped all the way to the nearest large port, Batavia (modern Jakarta, Indonesia) for repairs.

By insisting on fresh food and water for his crew whenever possible, Cook had done more than any commander before him to keep his crew healthy and to keep scurvy at bay. However, he couldn't combat the diseases contracted at Batavia: malaria and dysentery. Seven crew members died during the month-long stay and another 23 died in the voyage across the Indian Ocean to Cape Town, South Africa, where the ship landed on March 14, 1771. Included in the unfortunate death toll was Charles Green, who had been battling health problems over the many months at sea.

On April 29, Cook recorded the longitude in his log with the comment, "[have] now Circumnavigated the Globe in a West direction."[36] Two months later, on July 13, 1771, three years after beginning its voyage, the *Endeavour* returned to England. Upon return, Banks began his own grand tour of the salons of London, telling all and sundry of his numerous botanical discoveries. Consequently, newspaper reports wrote about the voyage as Banks' own expedition, barely mentioning Cook and his many navigational triumphs.

Table 2

A Range of Solar Parallax Values and the Corresponding Earth-Sun Distance

Solar Parallax (arcsec)	Earth-Sun distance (km)	Earth-Sun distance (miles)
8.3	158,500,000	98,500,000
8.4	156,600,000	97,300,000
8.5	154,800,000	96,200,000
8.6	153,000,000	95,000,000
8.7	151,200,000	94,000,000
8.8	149,500,000	92,900,000
8.9	147,800,000	91,800,000
9.0	146,200,000	90,800,000
9.1	144,500,000	89,800,000
9.2	143,000,000	88,800,000
9.3	141,500,000	87,900,000

Tallying Up I

The 18th-century transit expeditions were truly an impressive effort. More than 120 observers from 62 separate stations around the world observed the 1761 transit, while the 1769 transit was recorded by 138 observers from 63 stations (Woolf 1953). Once the data from the transits was published, it was analyzed time and again by astronomers as they tried to find the best value. For the 1761 expeditions, the range of the solar parallax was 8.3″ to 10.6″ (Dick *et al.* 1998; and see Tables 2 and 3), considerably larger than expected. The range was marginally reduced for the 1769 transits, in which values ran from 8.43″ to 8.80″. The French astronomer Lalande combined data from the two transits to obtain a range of 8.55″ to 8.63″, corresponding to a distance of 153 ± 1 million kilometres (Pogge 2003). Halley had thought the method would produce a precision of 1 part in 500, so this error, a factor of three larger than expected, was cause for disappointment.

Many papers were published with mean values determined from different pairs of stations. But it wasn't until the mathematician Karl Friedrich Gauss came

[35] W.J.L. Wharton, *Captain Cook's Journal,*

[36] Ibid.

Table 3
Some Transit of Venus Observations

Observer	Date	Parallax Error (arcsec)	Mean Earth-Sun Distance Error (km)	Mean Earth-Sun Distance Error (miles)
Lalande 1769 transit	1771	8.55 to 8.63	153,900,000 to 152,400,000	95,600,000 to 94,700,000
Pingré 1769 transit	1772	8.80	149,500,000	92,885,000
Encke 1761 and 1769 transits	1824	8.5776	153,400,000	95,250,000
Harkness 1882 transit, American photos	1891	8.842 (0.0118)	148,788,000 (199,600)	92,455,000 (123,400)
Newcomb 1761 and 1769 transits	1891	8.79 (0.051)	149,700,000 (868,000)	93,000,000 (540,000)
Stone 1882 transit, British and Canadian results		8.832	148,957,000	92,560,000
Newcomb, system of constants	1895	8.800 (0.0038)	149,500,000	92,898,000
Modern IAU system of constants	1976	8.794148 (0.000007)	149,597,870.691 (0.030)	92,955,859

Adapted from Dick *et al.* (1998). Except for the final value, errors are "probable errors," which are 74% of the "mean error" or "standard error" used today.

up with the method of least squares early in the 19th century that the heaps of data could be reliably analyzed (Fernie 1976). In 1824, Encke used this method to obtain a value of 8.5776″ for the two transits (Dick *et al.* 1998), equivalent to 153.4 million kilometres. This value stood for a quarter century when new lunar motion measurements indicated that it was too large. The solar parallax would have to be measured again.

The 1874 and 1882 Transits

Mid-century, Astronomer Royal G.B. Airy called the measurement of the Earth-Sun distance "the noblest problem in astronomy"[37] and immediately set out a plan for observing the next transit of Venus in 1874. Soon, transit fever caught on around the world and it became a matter of national pride to participate in the observations. According to Agnes Clerke, in her book *A Popular History of Astronomy in the Nineteenth Century,* "Every country which had a reputation to keep or to gain for scientific zeal was forward to cooperate in the great cosmopolitan enterprise of the transit." Consequently, Russia led the way with twenty-six expeditions, Britain twelve, the United States eight, France and Germany six each, Italy three, and Holland one (Dick *et al.* 1998). New this time around was an opportunity to use the nascent technique of photography.

In 1874, Father S.J. Perry led a British team of observers to Kerguelen Island, a damp, chilly, windswept, and altogether uninviting island that lies in the southern Indian Ocean, closer to Antarctica than to either South Africa or Australia. Discovered by the French explorer Yves de Kerguelen-Trémarec in 1772, it often goes by a nickname given it by Captain Cook, who stopped there on his third voyage around the world: Desolation Island. Until a scientific base was set up there in 1950, this remote, inhospitable island was home only to seals and penguins.

Perry was director of Stonyhurst Observatory, near Manchester, and gained respect from his contemporaries for his sunspot studies and his geodetic and magnetic work (Ashbrook 1966). His expedition left England in May 1874 in two ships, the V*olage* and the *Supply,* seven months before the December 9 transit.

The team gathered in Cape Town where the naval lieutenants, according to instructions by Airy, made a series of practice observations. In addition to visual timings, they were to make photographic observations, so the four assistants had their hands full with learning wet-plate and dry-plate photography. They rehearsed for two months before venturing on to Kerguelen Island on October 8, 1874.

In his journal, Perry recorded his first bleak impressions of the island: snow "as far as the eye could see." Because spring was still lingering in the Southern Hemisphere they had "pleasant prospects of rambles in snow-shoes over rugged hills and half-frozen marshes and bogs."[38]

Upon landing at Morbihan Bay, the party unloaded 600 crates of equipment and erected huts for living in and shelters for the instruments. Weather was a big concern — the average cloudiness was 75% in December — so Perry sent two teams to secondary sites around the bay to improve their chances of success. Lieutenant Cyril Corbet led one team and

[37] Steven J. Dick *et al.* 1998, p. 226.

[38] Joseph Ashbrook 1966, p. 341.

Lieutenant Goodridge another.

Like Chappe, Le Gentil, and Wales before him, Corbet kept a journal giving us a vivid and colourful glimpse of the drama of the event. After making longitude and latitude measurements of their station, Corbet recorded the conditions: "We got a few observations in the evening, but it was terrible work in the high winds — lamps flickering and blowing out, couldn't hear the ticks of the clock or anything."[39]

At a mere 24 years of age, Corbet was already a Fellow of the Royal Astronomical Society and keenly aware of the importance of the expedition. On December 6 he wrote: "Trying to keep calm and collected for the day after tomorrow."[40] In fact, it seems his youthful zeal nearly got the better of him because the night before the transit he recorded the following:

"Weather still bad and the barometer very low and still falling, but I shall keep hoping, hoping, hoping for tomorrow. Oh! to think it is so close — I feel funnier today than I have ever felt in my life, and I suppose really tomorrow morning will be about the most unpleasant time of my life up to 11 o'clock, when one will know one's fate...."[41]

It was a classic case of "butterflies in the stomach." Understandably, he was far too anxious to sleep that night and was up at 4:30 a.m. He waited until 6 o'clock before rousing his assistants and "got their fat heads shaken out of them" even though he described the weather as "dubious, very."

First contact was due at 6:30 a.m. and Corbet was not disappointed: "Oh! the happy moment, when from 6:00 am to 6:30 I had been watching intently the bottom of the Sun for an impression, and I saw it — really and truly the happiest moment of my life."[42] It was exactly the opposite of the "unpleasant time" that he had feared.

Corbet then kept a detailed observer's report. He and his assistant differed by as much as 15 seconds for their first contact (of Venus to the Sun's disk) timings due to the nefarious black drop effect. Soon, heavy clouds moved in and though Corbet caught a glimpse of Venus leaving the Sun's disk, he wasn't able to time it.

When the event was over, the team treated themselves to a breakfast of Oxford sausages and a bottle of champagne. Meanwhile, Perry's team had both a photographic and visual program. At their station, a single cloud obscured first contact but the sky cleared and they got good timings and photos of the end of the transit. Goodridge's team had similar, partial success.

After the transit, the teams re-gathered at the primary station and compared notes, though this took a few days due to stormy weather. There was more work to do yet — Airy had given instructions to make more than a hundred additional lunar observations to fine-tune the longitude determination. However, the weather turned for the worse and it took three months to collect the necessary observations — forcing the expedition to go on half rations (Ashbrook 1966). On February 27, 1875, the expedition set sail back to England. Upon leaving the island, Corbet recorded his wistful thoughts:

"We watched the dreary desolate island for ever so long till all the low land had sunk into the sea and we could see the snow mountains only.... We were clear of the land by night, and all with light hearts and full of happiness at getting away from Kerguelen at last after five months of it, which sometimes seems an age, and at other times as nothing but a mad whirling gap in one's existence."[43]

Unfortunately, both Corbet and Perry ultimately gave their lives to their work. A year after the transit, Corbet succumbed to a fever off the coast of Africa, cutting short a promising career. Like Hell before him, Perry gained a reputation as a lecturer. He continued to make expeditions: he observed the 1882 transit in Madagascar and later died at sea in 1889, after completing solar eclipse observations in French Guiana (Gerard 1911; Kilburn 2002).

The American effort was spearheaded by Simon Newcomb, who recommended the establishment of a government commission in 1870 and was an early proponent of recording the transit photographically. Newcomb's biggest concern was to accurately establish the photographic plate scale in order to minimize conversion errors (measurements on the photographic plate were linear while the parallax measurements were angular). Because Venus was to look like a small, circular sunspot, Newcomb recommended adopting a solar observation method perfected by Joseph Winlock at Harvard Observatory (Janiczek & Houchins 1974; Dick *et al.* 1998). The final design was a horizontal telescope with a 40-foot focal length in which the Sun's light was directed to the photographic plate by a tilted, slowly moving mirror (known as a heliostat).

Much of the instrument making became the task of Alvan Clark and his firm in Massachusetts. Clark had his hands full outfitting eight U.S. expeditions with identical equipment, including the five-inch refractors for the visual observations, the five-inch 40-foot photoheliograph lenses, and the heliostat mirrors for the photographic program as well as chronographs for accurate time measurement (Dick *et al.* 1998). This was on top of the 26-inch refractor he was already commissioned to build for the Naval Observatory.

Beginning in May 1873, the teams gathered on the grounds of the Naval Observatory for a series of practice observations with an artificial sun and Venus mounted on a building. Even Henry Draper, one of the pioneers of

[39] Maunder and Moore 2000, p. 66.

[40] Ibid.

[41] Ibid.

[42] Ibid., p. 68.

[43] Ibid., p. 69.

astrophotography, lent a hand for a few weeks.

In June 1874, the *USS Swatara* left New York Harbour on a "milk run" to the Southern Hemisphere destinations. A total of five parties were dropped off: Kerguelen Island, Tasmania (two parties), New Zealand, and Chatham Island (880 km east of New Zealand). The three Northern Hemisphere parties travelled to Nagasaki, Japan; Vladivostok, Siberia, and Beijing, China. If anything, the American expeditions were routine, with few mishaps. Though travel had become much more predictable, the weather had not and on transit day the Southern Hemisphere stations were cursed with poor weather much of the time. Like the British parties on Kerguelen Island, the American party stationed there viewed only a portion of the transit.

Things were slightly better in the Northern Hemisphere. Unlike Chappe in Siberia, who battled the spring thaw, Asaph Hall's party in Vladivostok was stuck fighting the Siberian winter. Gale winds continually threatened to blow the roof of their observatory off and lubricants for the sidereal clock and heliostat froze. The temperature difference between the inside of the photography house and outside was 30 degrees Celsius, plaguing the photography program with unsteady air.

In Beijing, James Watson caused a stir among Chinese officials during his preparations when he discovered an asteroid. He diplomatically asked Prince Kung, regent of the empire, to name the new minor planet. Today, the 139th asteroid, "China's auspicious star" or, *Shui Hua Hsing*, is known by its contracted form, Juewa (Ashbrook 1974).

Newcomb was optimistic about the results and thought the solar parallax could be determined with a probable error between 0.02″ and 0.03″ (Dick *et al.* 1998). Here he was sorely disappointed. Not only that, he was soon to be frustrated in his attempts to complete the data analysis — a task that had fallen to him as secretary of the commission.

Due to confusion about appropriation of funds earmarked for this work, Newcomb was shortchanged $3000 and had to discharge his computers in 1876. The next year, new money was held up in a legal dispute and Newcomb had to lay off his computers a second time. In 1879, an additional fiscal dispute caused a now predictable reaction: Newcomb let his computers go a third and final time. For Newcomb, this was the last straw and he turned the work over to William Harkness.

William Harkness had developed important equipment for the 1874 transit and led an expedition to observe it from Tasmania. Getting the transit data analyzed and published became part of his life's work. Meanwhile, the 1882 transit was fast approaching. With no data published by the Americans from their long-focus photographic method, European astronomers began to suspect whether it was superior, even though the British had already admitted that their short-focus photography method was a failure. And, because the range of values obtained from the visual contacts method for the 1874 transit was again intolerably wide (thanks in part to the black drop effect), astronomers approached the 1882 transit with considerably less enthusiasm than for the previous ones.

Other methods for determining the solar parallax contributed to the disillusionment in the transit method, but with the next one not occurring for another 122 years, at the 11th hour, a "now or never" attitude prevailed and many countries hastily prepared expeditions. For the Americans, partly through the efforts of Harkness, Congress finally approved funding for expeditions four months before the transit.

It so happened that this transit was partially visible from North America, so there were many official and unofficial stations in Canada and the United States. If professional interest was lacking, public interest was at an all-time high. The *New York Times* reported that "A telescope was mounted on Broad Street, near the Stock Exchange, and the owner of this, too, had all the business he could attend to."[44] Elsewhere in the city, some enterprising amateur astronomers set up telescopes and made good money — the going rate was 10 cents a look! (DeVorkin 1982)

Though Newcomb doubted the usefulness of the transit observations in light of more recent methods, he led an expedition to Wellington, South Africa. He set up in a garden of a seminary and encouraged students and teachers alike to partake in the observations. The teachers were women and some claimed to have made better observations than the professional astronomers. Newcomb graciously wrote that "it was partly the result of good fortune and partly due to the quickening of the faculties which comes with intense interest,"[45] though the women preferred to interpret their success "as a tribute to the greater powers of their own sex."[46] Nevertheless, Newcomb gave them full credit for their observations in his report.

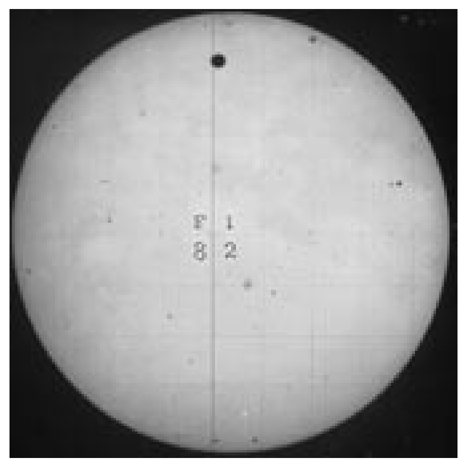

Figure 4. — Photo from the 1882 transit. Courtesy of the U.S. Naval Observatory Library

[44] DeVorkin 1982.

[45] W.P. Koorts, *The 1882 Transit of Venus: Observations from Wellington, South Africa,* www.saao.ac.za/~wpk/tov1882/tovwell.html

[46] Ibid.

For his part, Harkness observed the transit from Washington, D.C. where he had the good fortune to view all four contacts. Three other American parties had similar success so that in terms of weather, the 1882 transit was much better observed, yielding better data and more photographs than the 1874 transit. One of the 11 surviving photographic plates from the 1882 transit is shown in Figure 4. In total, Harkness collected 1380 measurable photographs from the various American stations for the 1882 transit, compared to only 221 measurable photographs for the 1874 transit.

The wealth of data swamped Harkness. He directed the measurement of the photographs, the time and latitude determination of each station and the various subsidiary calculations that today are done instantaneously by computer programs. In 1888, six years after the 1882 transit, he finally published the results in the *Astronomical Journal*. He calculated the solar parallax to be 8.847 ± 0.012″ (Harkness 1888), a value that corresponded to a distance of 148,675,000 km (92,385,000 miles), with a probable error of 201,000 km (125,000 miles). He later revised this to 8.842 ± 0.0118″ (Harkness 1891), corresponding to 148,788,000 km (92,455,000 miles), with a probable error of 199,600 km (123,400 miles).

Harkness must have been pleased to come up with a result when Newcomb couldn't and then equally annoyed to see Newcomb summarize results from a variety of methods and give his results low weight. It was Newcomb's new value for the solar parallax from a variety of methods, 8.800″, that was widely adopted by astronomers. In fact, this was very close to the modern value.

In Canada, Charles Carpmael, Director of the Toronto Observatory, was in charge of coordinating the 1882 Canadian transit observations. He received a federal grant of $5000, which was mostly directed toward acquiring good medium-sized telescopes (Sawyer Hogg 1982). These instruments no doubt greatly influenced local interest in astronomy. Thirteen stations were set up from Winnipeg to Halifax and five of them enjoyed at least partial success — not bad for December in Canada. The results were communicated to E.J. Stone, of Oxford, who used them to derive a solar parallax of 8.832″, corresponding to an Earth-Sun distance of 148,957,000 kilometres (92,560,000 miles) (Fernie 1979).

Tallying Up II

Why weren't better results obtained? Precise timing of the contacts of Venus with the disk of the Sun was fraught with difficulties. Firsthand reports indicated three major problems in the timings: (i) boiling of the image, (ii) a fuzzy ring surrounding Venus (too thick to be due to its atmosphere) and (iii) the notorious black drop effect (Bray 1980). Given these difficulties, one wit remarked to Sir George Airy, "You might as well try to measure the zodiacal light."[47]

The first two effects were due to heating of the ground and parts of the telescope by the Sun's rays. Such heating produces turbulent air currents that act to change the telescope's focus. Modern solar telescopes are designed in such a way as to eliminate these problems; 18th- and 19th-century astronomers found out about the complications the hard way. The "black drop" was first properly described by Lalande in 1770 as a blurring of the image due to normal terrestrial atmospheric smearing such that a meniscus appears (Schaefer 2000). Diffraction within the telescope is also a contributing factor, explaining why the 19th-century observers who used larger aperture telescopes had less of a problem with the black drop than the 18th-century observers. A similar effect, due to the finite size of the eye's pupil, can be seen by looking at your thumb and index finger held very close together near your eye. So, part of the problem with the results was the initial, overly optimistic expectations in the method itself.

Modern methods to calibrate the Earth-Sun distance are almost embarassingly straightforward. Giant radio telescopes are used to fire a radar beam towards Venus and the signal's return is timed by atomic clocks. Combining half the round-trip time with the speed of light gives the Earth-Venus distance at that moment; this is transformed to the Earth-Sun distance via Kepler's laws. Based on these measurements, in 1976, the International Astronomical Union adopted the value of 8.794148″ ± 0.000007″ for the solar constant, though the Earth-Sun distance, or the astronomical unit, is known to even greater precision: 149,597,870.691 km ± 0.030 km. With a precision of 1 part in 5 billion — like knowing the distance between Vancouver and Toronto to within 0.7 millimetres (Fernie 2002)! — this latest result has surely exceeded Halley's wildest dreams.

Thanks to their rarity, the transits of Venus provide a sort of "passing of the baton" through the generations. No one observed the 1631 transit and only two people saw the next one, in 1639. The 1769 and 1769 transits were observed by perhaps a few hundred amateur and professional astronomers. The next pair, in 1874 and 1882, was likely seen by thousands. Now, with television and the Internet, the next transit in June 2004 could have an armchair audience of millions.

In an address to the American Association for the Advancement of Science in 1882, William Harkness gave the following poignant words:

"We are now on the eve of the second transit of a pair, after which there will be no other till the 21st century of our era has dawned upon the earth, and the June flowers are blooming in 2004. When the last transit season occurred [1761 and 1769] the intellectual world was awakening from the slumber of ages, and that wondrous scientific activity which has led to our present advanced knowledge was just beginning. What will be the state of science when the next transit season arrives, God only knows. Not even our children's children will live to take part

[47] Agnes Clerke 1902, p. 236.

in the astronomy of that day. As for ourselves, we have to do with the present...."[48]

Bibliographic Notes

Part of the reason for this essay, on the eve of the next transit pair, was to bring together some of the colourful tales and journal excerpts that are scattered widely in books, magazines, and journals. The best sources are Don Fernie's two books, which describe the 18th-century transits in warm detail. Interested members and readers with access to back issues of the *JRASC* (that is, back issues that go way back), are also encouraged to look up Helen Sawyer Hogg's *Out of Old Books* series for extensive and illuminating journal excerpts from Wales and Le Gentil.

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[48] Quoted in Dick *et al.* 1998.