Feature Story:

A Tale of Two Transits – Visual Observations of the Transits of Venus in 2004 and 2012

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Introduction

Transits of Venus are exceedingly rare events, occurring in 8-year pairs with gaps of either 105.5 or 121.5 years between the pairs. The first transits of the new century — and indeed the new millennium — occurred on June 8, 2004 and June 5, 2012. I describe my own observations from Bakebung Lodge, Pilanesburg, South Africa, in 2004, and from Lowell Observatory in Flagstaff, Arizona, in 2012. A number of interesting phenomena are reported.

The Black Drop

The last transit of Venus prior to 2004 took place in 1882, so that no one now living had ever seen a transit. Historically, transits were the occasion for expeditions on a global scale to attempt to observe the contacts of the limbs of Venus with the edge of the Sun, so as to apply Edmond Halley's 1716 method of triangulating the solar parallax and working out the all-important distance from the Earth to the Sun (Woolf, 1959; Sellers, 2001; Sheehan and Westfall, 2004). (Fig. 1.) The resulting measures at the 1761, 1769, 1874 and 1882 transits were less accurate than Halley's expectation (to within 1 part in 500). This was in large part owing to the inconvenient appearance of the so-called "black drop", a glutinous strip that seemed to tether the limb of the Sun to that of Venus, and "snapping" or dissipating only after Venus was well advanced upon the Sun. What had appeared to be an elegant and straightforward solution of what Halley called the "noble problem" was thus spoiled by this unexpected and rather sinister-appearing phenomenon.

Even as late as 2001, as was pointed out at an American Astronomical Society meeting by Louisiana State University astronomer Bradley Schaefer, many authors continued incorrectly to assert that the black drop was an effect produced by the atmosphere of Venus (Schaefer, 2001). At the 2004 transit, most interest centered on attempts, with modern instruments (and GPS) to apply Halley's method and see how well it could do under optimal conditions. Of course there was also great interest in seeing whether the black drop would make an appearance. It did, though with some qualifications. In contrast to the striking blobs and dark ligatures seen by 18th century observers, most observers of the 19th century transits and the 2004 transit, if they saw anything at all, saw rather muted effects. Joseph Ashbrook summed up the 19th century experience (Ashbrook, 1984) thusly: "Although the black drop features in many reports from 1761 and 1769, it was less often seen at the next two transits... The better equipment used in 1874 and 1882 sometimes showed instead a dusky, hazy appearance between Venus and the Sun's limb, causing an uncertainty of several seconds in timing contacts II and III." This was also the case in 2004.

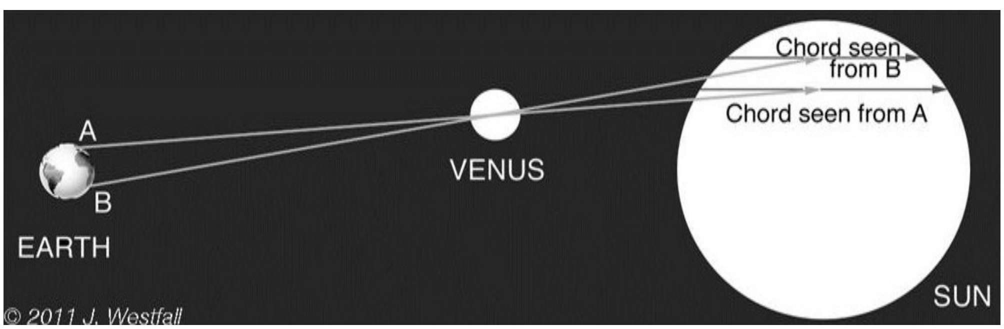

Fig. 1. Halley's method for determining the Earth-Sun distance by observing the transit of Venus across the face of the Sun. Chords across the Sun from two stations, A and B, widely separated by latitudes within the zone from which the entire transit is visible, traverse chords of different lengths (and thus different durations) when crossing the Sun's disk. The distance to the Sun can be worked out using simple trigonometry if the distance between the stations A and B is known. Source: Sheehan and Westfall, *The Transits of Venus*, p. 130.

The 21st century transits have settled once and for all the actual causes of the black drop. It has nothing to do with the atmosphere of Venus; instead, it is an effect due to blurring of images by imperfect optics and enhanced by poor atmospheric seeing caused by turbulence in the Earth's atmosphere and — in the case of satellite results obtained in conditions of no seeing effects from the Earth's atmosphere — the contribution of the Sun's rapidly varying limb darkening playing an important role (Schneider, Pasachoff, and Golub, 2004). Nowadays, the blurring of images is frequently described in terms of the "point spread function (PSF)" of telescopes, "contrast resolution" as described by the "modulation transfer function (MTF)," or "phase transfer function (PTF)." However, the basic principle involved — it used to be referred to as "irradiation" — has been known for a very long time. Irradiation is the tendency of light from a bright area seen in juxtaposition to a dark area to

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bleed into the dark area. As pointed out by the 18th century French astronomer Jerome Lalande to explain the black drop seen at the 1761 and 1769 transits, irradiation caused the apparent disk of Venus on the Sun to appear smaller than the real disk. At the same time, the apparent limb of the Sun appears larger than the actual solar limb. (Fig. 2.) The black drop occurs when the *real* disk of Venus comes into contact with the *apparent* limb of the Sun. Within this zone, there is no point at which the light can get in, thus the area appears dark (Forbes, 1874).

The correctness of this explanation is now attested by numerous observations of the transits of 2004 and 2012 (see, for instance, Duval et al., 2005, and Duval et al., in press). Because the effect described is more pronounced in small and optically inferior instruments and in bad seeing, the 18th century reports of the black drop tended to be much more dramatic than the subtle and sometimes effectively nonexistent effects reported by 19th and 21st century observers. As an aside, it is now evident that the actual 2nd and 3rd contacts whose precise timings were sought as the key to the methods of triangulating the solar

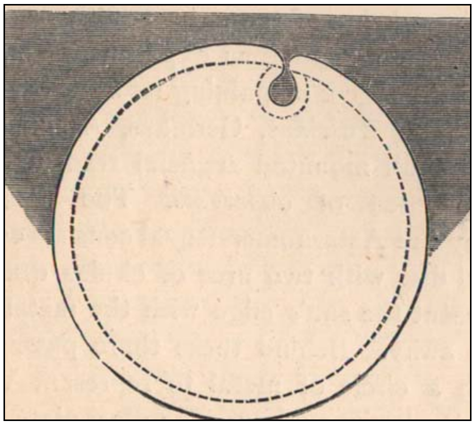

Fig. 2. Explanation of the origin of the black drop effect. A bright area seen in juxtaposition to a dark area will appear to bleed into the dark area. In the case of Venus in transit, this causes the apparent disk of Venus on the Sun to appear smaller than the real disk, while the apparent limb of the Sun appears larger than the real limb. The black drop occurs when the real disk of Venus comes into contact with the apparent limb of the Sun. In this region, there is no point at which the light can get in, so the area appears dark. Source: George Forbes, The Transit of Venus (London: MacMillan, 1874), p. 51.

Fig. 3. South African amateur Trevor Gould demonstrates his set-up for observing the transit of Venus to French galactic astronomer Françoise Combes at Pilanesburg National Park, June 8, 2004. Photograph by William Sheehan.

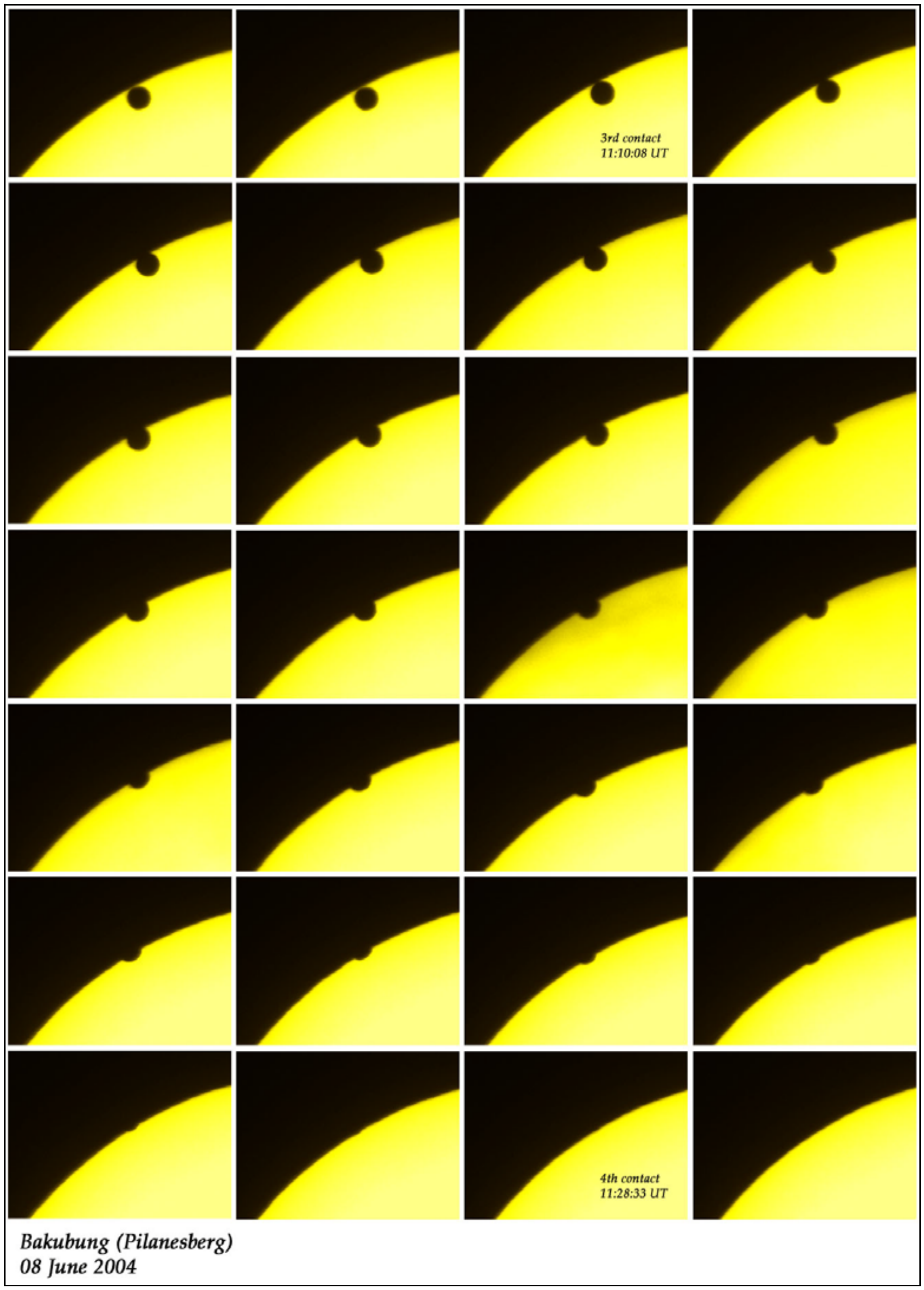

Fig. 4. A series of CCD images by Bert van Winsen showing conacts III and IV at the June 8, 2004 transit of Venus; courtesy Daniel Fischer.

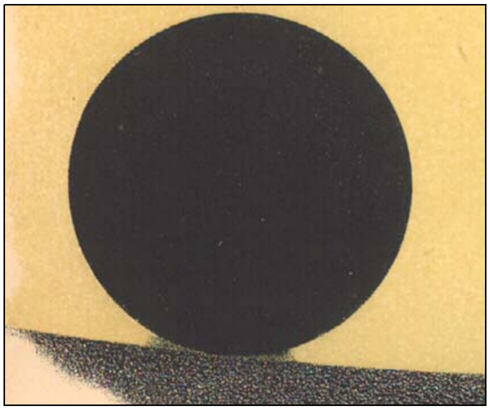

Fig. 5. The black drop (or shading) at Contact III during the transit of Venus, December 9, 1874, as observed by H.C. Russell with the 11½-inch refractor of the Government Observatory in Sydney, New South Wales. Note the instrument was stopped down to 5 inches. From Sydney Observatory, *Observations of the Transit of Venus*, 1892.

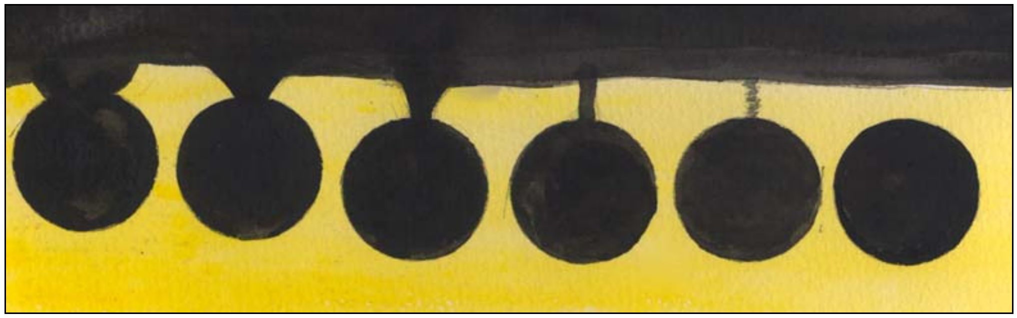

Fig. 6. Black drop sequence by William Sheehan at Lowell Observatory at the June 5, 2012 transit, observed visually with a C-11 equipped with a 3-inch filter aperture.

parallax correspond to the moment when black drop disappears at Contact II and reappears at Contact III. Observer in the 18th and 19th century could not have known this: using telescopes that were of poor optical quality by modern standards — sometimes in appalling conditions (Captain Cook in Tahiti in 119 degree F. heat!) — they saw a confusing train of phenomena that stretched over a considerable period of time and were confounded in their measurements. We can only commiserate with their perplexity, though in their defense, as pointed out to me by David Sellers (personal communication, August 20, 2012), at least some of them (Pingré in 1761, Cook and Green in 1769) did take care to time the *end* of the black drop effect at ingress and the *beginning* of it at egress (in addition to the apparent internal contacts), so that their timings were much more accurate than has generally been supposed.

My own observations of the black drop in 2004 and 2012 are consistent with this analysis. In 2004, I observed the transit at Bakebung Game Lodge in Pilanesburg National Park in South Africa with South African amateurs Trevor Gould (who kindly supplied a homebuilt 8-inch Newtonian) and Val Fraser. (Fig. 3)

(As the transit was observed in connection with an international conference on galactic bars, there were lots of astronomers as well as a healthy contingent of South African school children and their teachers nearby. Real estate for setting up instruments was at a premium because we all wanted the most unobstructed view, so everyone set up just shy of an electric fence beyond which was the open veld where, wildebeests and other potentially dangerous animals roamed at large; Daniel Fischer, the noted German astronomy writer, and his associate Dr. Susanne Hüttemeister set up next to us.

We missed Contact I and Contact II because of clouds, but Contact III and Contact IV occurred in very steady daytime conditions. Though the Sun was high in the sky, the seeing was estimated to be 1-2 seconds of arc. With the large aperture and in the steady seeing, the black drop was noted but it was extremely subtle and would have been easy to miss. (Fig. 4.) There was little more visible than a dusky shading between the limb of Venus and that of the Sun, which appeared for only a few seconds just before the limb of Venus merged with the surrounding darkness of space, and it looked exactly as depicted in the splendid drawing by Henry Chamberlain Russell in New South Wales in 1874 (Fig. 5). Here, as in the case of high-resolution ground-based and spacecraft imaging of the transit (Schneider, Pasachoff, Golub, 2004), solar limb darkening — the falling off of light at the Sun's edge — probably contributes significantly to the effect.

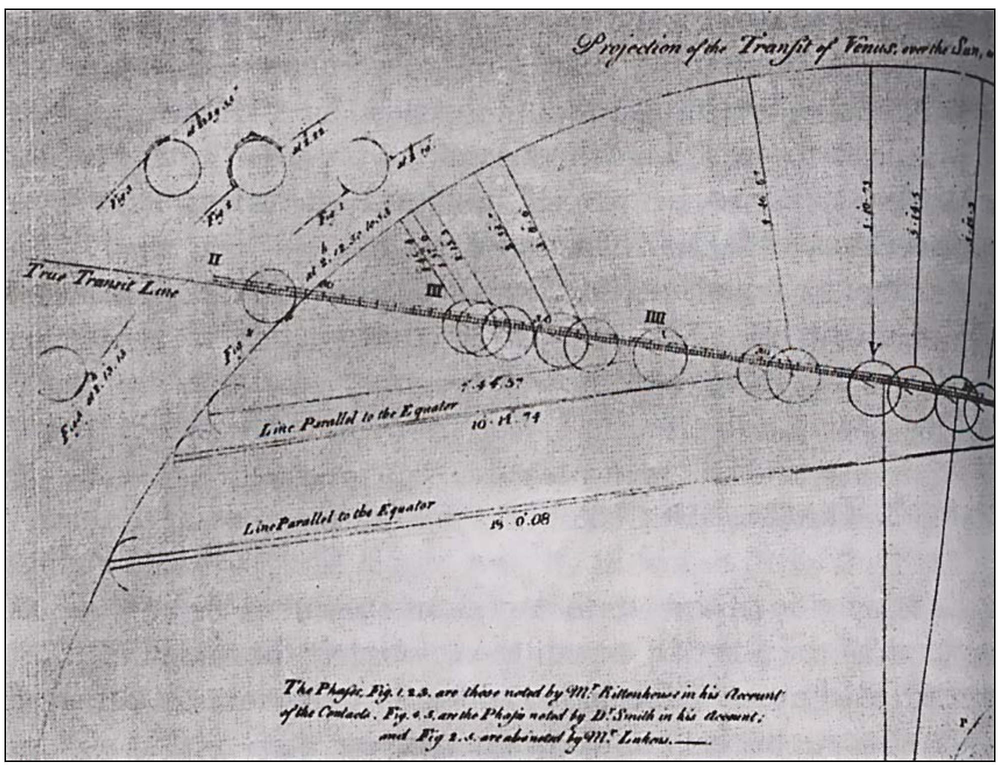

Fig. 7. David Rittenhouse's sketches showing the aureole at the 1769 transit of Venus. From Brooke Hindle, David Rittenhouse. Princeton, New Jersey: Princeton University Press, 1964.

Having had this rather typical experience in 2004, I was rather surprised that at the 2012 transit, I observed a rather classical black drop from Lowell Observatory in Flagstaff, Arizona, which would have done any 18th century observer proud. The instrument used was a C-11 (Celestron 11-inch, Schmidt-Cassegrain) equipped with a 3-inch, off-axis filter aperture and belonging to Flagstaff amateur astronomer Bill Burke. It was set up, perhaps somewhat injudiciously, in a parking area covered with oyster shells near the residence of Lowell Observatory trustee William Lowell Putnam III, just north of the Pluto telescope dome. The oyster shells reflected a great deal of solar radiation, which did not help the ground-level seeing. On the other hand, the conditions proved to be ideal for the production of an impressively sinister black drop, for as I had told a member of the audience at a public lecture I gave at Sun City, South Africa, on the eve of the 2004 transit and who had asked how best to observe the black drop, what was needed was a smallish telescope — preferably with appalling optics — set up on a broiling asphalt surface (or oyster bed!). These conditions, I predicted, would give rise to a very splendid black drop indeed.

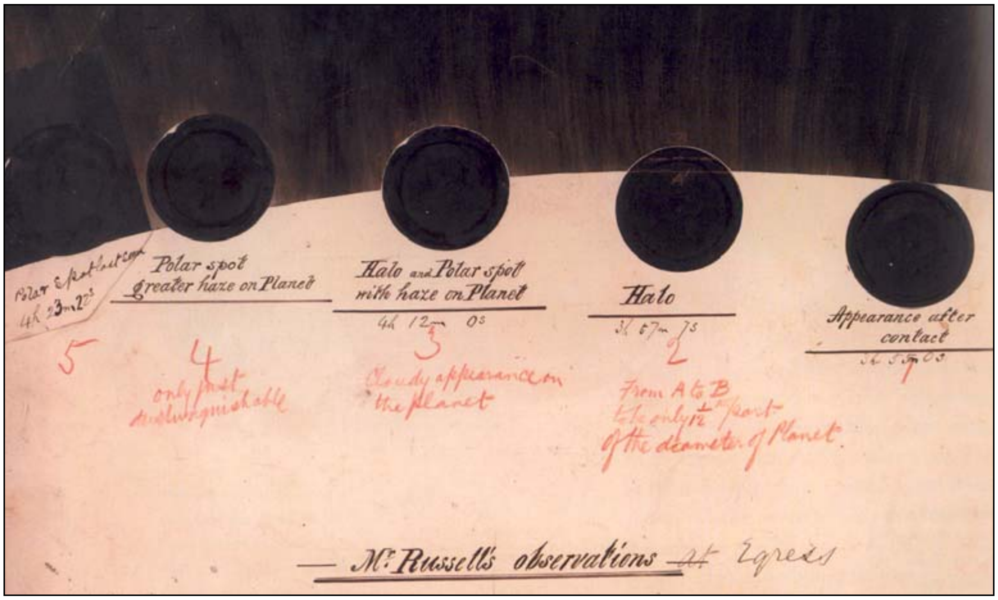

Fig. 8. The polar spot and aureole as recorded by H.C. Russell, director of the Sydney Observatory, in 1874. Courtesy Nick Loam.

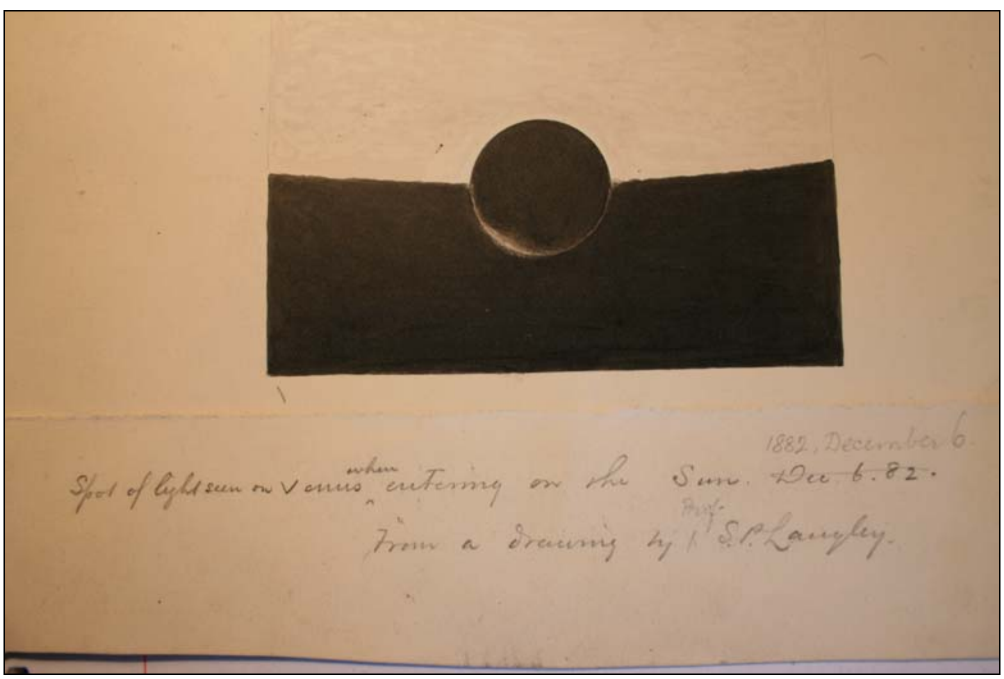

Fig. 9. S.P. Langley's impression of the aureole, as observed with the 13-inch refractor of the Allegheny Observatory at the 1882 transit. Courtesy Peter Hingley, Royal Astronomical Society Library.

I attribute the small effective aperture and poor seeing (resolution cannot have been much better than 4 or 5 seconds of arc, and at times probably deteriorated to 6 or 7 seconds of arc) to the production of the black drop seen at Lowell. At first, Venus appeared like a small black globe to which was attached a virtual thunderhead of blackness. As Venus continued its progress onto the Sun, the black drop became pyramid-shaped, then turned into the classic ligament and finally, after some two minutes, dissolved. (Fig. 6.)

The Aureole

At the 2004 transit, much of the focus was on the attempt to time the contacts in order to repeat earlier observers' attempts to measure the solar parallax. There was also a great deal of curiosity about the black drop. Of greater scientific importance, however, were observations of the thin, bright arc ("aureole") observed at past transits at ingress and egress when a portion of the planet's disk still lies outside the solar photosphere. Because the aureole's brightness is at best 10 to 100 times fainter than the solar photosphere nearby, and the total angular height of Venus's atmosphere is only about 0.02 seconds of arc, it can only be seen in contrast to a black background, and vanishes in close proximity to the photosphere. Few observers of the 18th century transits made credible observations of the aureole; the "bump" seen by the Russian Academician M.V. Lomonosov at Contact III during the 1761 transit may — or may not — record the aureole. (See Pasachoff and Sheehan, 2012, and Koukarine, Nesterenko, Petrunin and Shiltsev, 2012 for discussions.) However, the sketches of David Rittenhouse, who observed the 1769 transit at Norriton, near Philadelphia, Pennsylvania, are entirely convincing. (Fig. 7.) However, by the next pair of transits, instruments and observing techniques had improved, so

Fig. 10. Klaus Brasch looks on as Paolo Tanga assembles the coronagraphs in the apartment of the Slipher building at Lowell Observatory. Photograph by William Sheehan.

Fig. 11. The coronagraphs in place on the bed of oyster shells. Photograph by Jan Milsapp.

that as the black drop went out, the aureole came and was very well-seen by many serious observers of the transits (e.g., by Henry Chamberlain Russell with the 11½-inch refractor, stopped down to an aperture of 5 inches, of the Government Observatory at Sydney, New South Wales in 1874, and by Samuel Pierpont Langley with the 13-inch refractor at Allegheny Observatory in 1882 (Russell, 1892; Langley, 1883). (Figs. 8 and 9.)

These historical visual observations of the arc have long been correctly interpreted as being produced by refraction of sunlight by the outer layers of a dense atmosphere of Venus, with rays passing closer to the planet's center being more deviated than those passing farther out.

The next phase of studies of the aureole began at the June 8, 2004, transit, when it first became possible to perform photometry using electronic imaging devices to allow quantitative analysis of the phenomenon (Pasachoff, Schneider, and Widemann, 2011; Tanga, Widemann, Sicardy, et al., 2012). The 2004 results, in turn, led to extensive planning and implementation of the Venus Twilight Experiment, an ambitious global effort to make coronagraph (cytherograph?) observations of the aureole during the transit of June 5-6, 2012, as part of the Transit of Venus coordinated campaign. The goal of this project, headed by Thomas Widemann of the Paris Observatory and Paolo Tanga of the Cote d'Azure Observatory in Nice, was to carry out a detailed investigation of the dynamics and composition of the mesosphere of Venus as seen by Earth-based observers and to obtain precious information about how the atmosphere of a non-habitable world observed as an exoplanet would differ from that of a habitable planet like Earth (Tanga, 2012).

The Mesosphere of Venus

Venus's mesosphere extends from the top of the upper cloud layer (approx. 60 km) to the upper thermosphere (approx. 120 km). Prior to the 2012 transit, spacecraft monitoring of thermal profiles and winds in the mesosphere had already revealed important time variability, driven by processes largely unknown.

Since the aureole is produced by the refraction of solar rays, and the solar rays passing closer to the planet's center are more deviated by refraction than those passing farther out, the image of a given solar surface element is flattened perpendicularly to Venus's limb by this differential deviation. It can be shown that the deviation due to refraction and the luminosity of the aureole are related to the local density scale height and the altitude of the refraction layer. Since the aureole brightness is the quantity that can be measured during the transit, an appropriate model allows determination of both parameters. This model was first applied to data collected during the 2004 event (Tanga et al., 2012). In general, different portions of the arc can yield different values of these parameters, thus providing a useful insight into the physical variations of the Venus atmosphere as a function of latitude.

The Venus Twilight Experiment

The 2004 observations of the aureole, beyond confirming the presence of the aureole as it had been reported in historical records of similar events, were seminal in providing essential information about details of the phenomenon. They also hinted that the variability of the aureole as seen over the 5 transits since the 18th century could be related to the variability recently discovered in the mesosphere of the planet.

In 2004, no specific observing campaign was prepared in advance and the observations were not optimized for analyzing the signal of the aureole. In particular, the observations did not allow a reliable multi-wavelength spectrum of the aureole to constrain the role of Rayleigh or Mie scattering (a number of recent models showed that, depending on details of the scattering, the resulting signal could have a widely different wavelength dependency; see Ehrenreich et al., 2011).

The Venus Twilight Experiment was organized to provide better results during the 2012 transit by taking into account the measured brightness of the aureole and the need for multi-band observations

Fig. 12. Percival Lowell's 6-inch Clark refractor about to be used for its first-ever transit of Venus, with the Pluto Dome in the background. Photograph by William Sheehan.

as suggested by the modeling. The instrumentation was inspired by observations made with an amateur coronograph, using a 9-inch refractor, designed by A. and S. Rondi, and successfully deployed at the 2004 transit (Pasachoff, Schneider, and Widemann, 2011, and Tanga, Widemann et al., 2012). A number of identical coronagraphs with different filters were deployed at sites around the world. When I visited Paolo Tanga in Nice, France, in February 2012, we discussed a number of options for our observing site, including Hawaii, Mt. Wilson, and Lowell Observatory. Jay Pasachoff, Glenn Schneider and a number of their colleagues were already planning to set up one coronagraph at Haleakala, Hawaii, so that left Mt. Wilson, which was generally thought to have the best daytime seeing, versus Lowell Observatory. (Both sites were only able to see ingress, because, unfortunately, the Sun set before Venus exited the Sun.) It was not an easy decision, but Paolo and I finally settled on Lowell, partly for logistical reasons — I was going to be there already and had friends with equipment that would be suitable for our purpose — but also partly for sentimental reasons, given Lowell's historical importance in the study of the planets (it proved to be a good decision; though we did not have outstanding seeing at Lowell, conditions at Mt. Wilson would prove even worse on the day of the transit).

A complete list of the sites, with observers and filters used (B = blue, V = visual, the area of the eye's maximum visual sensitivity which is in the green, R=red, I=infrared), are as follows:

- Mees Solar Observatory, Haleakala, Hawaii
  J. Pasachoff, B. Babcock, Muzhou Lu, B (450 nm)

- Mobile Station, Hokkaido, Japan
  N. Thouvenin, M. Imai, T. Fukuhara, V (535 nm)

- Moondara Observatory, Mont Isa, Queensland, Australia
  F. Braga-Ribas, L. Fulham, (760 nm)

Fig. 13. Paolo Tanga (left) and William Sheehan relax for a moment shortly before first contact. Photograph by Klaus Brasch.

- Tien Shan Observatory, Kazakhastan,
  F. Colas, F. Vachier, B
- Lowell Observatory, Flagstaff, Arizona
  W. Sheehan, V (visual)
- Lowell Observatory, Flagstaff, Arizona
  P. Tanga, V (CCD)
- Taiohae, Nuku Hiva, Marquesas Islands
  C. Veillet, R (607 nm)
- Udaipur Observatory, India
  P. Machado, A. Ambastha, R

As evident from the above, Lowell was the only Venus Twilight Experiment site where two coronagraphs would be employed. Paolo would use one with a 535 nm filter to obtain CCD images, and I would use another with the same filter to make visual observations.

The Expedition Gets Underway

While Paolo was testing and preparing the coronagraphs in Nice, I flew from Minnesota to Arizona to prepare the groundwork there. There were a number of vivid touches that added to the drama. Lowell Observatory which was founded by Percival Lowell in 1894 for the study of the Solar System and which boasts a high altitude of over 7,000 feet, was in many ways the perfect place in which to carry out an investigation of the atmosphere of Venus — ironically, a transit had never been witnessed from Lowell (the 2004 transit was not visible from the southwestern or western United States, while the previous transit, in 1882, occurred the year Flagstaff was founded). Also, despite climate-change deniers, it was a summer of searing heat; much of the United States lay under a heat advisory, all-time records were routinely being broken during the month of June and when I left for Arizona to observe the atmosphere of Earth's sister-planet which has become synonymous with the runaway Greenhouse Effect, much of the western U.S. was burning. In fact, flying in to Phoenix a few days before the annular eclipse which I was headed into Utah to observe with friends two weeks before the transit, I saw plumes of smoke from the Crown King Fire. The smoke gave the sky a translucent milky quality as far north as Flagstaff. An even larger fire broke out in New Mexico before the eclipse, and made for some surreal images of the annular ring of the Sun burning through billowing smoke.

Visual Observations of the Aureole at Lowell Observatory

Paolo arrived with the coronagraphs on Saturday and the transit was the following Tuesday. With Klaus Brasch, another member of our team, we assembled them in the Slipher apartment in the Administration Building, which had been built in 1916 on Mars Hill. (Fig. 10.) (It was in this apartment, by the way, that Clyde Tombaugh was living in February 1930, when he discovered Pluto using the blink comparator in a room below, so we certainly had a great ambience). We were very anxious about the weather. Though there were clouds in the forecast for Monday, they were supposed to clear out by Tuesday; but the winds on Mars Hill can be very high — even gale-like — at this time of the year, and high winds were predicted for transit-day. We considered a back-up option of observing from Williams. However, we had all the logistical supports, including Klaus's AstroPhysics 400, which supported Paolo's coronagraph, and Bill Burke's Losmandy G-11 that would support the one I was to use, electricity and other amenities (including a tremendous and growing amount of interest) on Mars Hill. The evening before the transit, we set up all the instruments on the oyster-shells near Bill Putnam's residence, near the Pluto dome where they would be far from the crowds. (Fig. 11.) (In fact, the crowds materialized; paid admissions to Mars Hill on the transit day was 1,000, the most that had ever attended a daytime event, which rather surprised us; clearly we did not lack public interest!) That night the mounts remained under tarps and the coronagraphs spent a final night with me in the Slipher apartment before their day of destiny.

On the morning of the transit (which did not occur until close to 3 p.m. local time), we had the coronagraphs in place, and also set up the beautiful 6-inch Clark refractor that Percival Lowell had taken with him to Japan and sent west with A.E. Douglass for the site-surveys that led to Mars Hill's being chosen for the site of the observatory. The instrument, though it dated back to the 1890s, had never been used to observe a transit of Venus. (Fig. 12.)

The sky was blessedly clear; there were not even the usual orographics over the San Francisco Peaks. The transparency was reasonably good despite a slight pallor lingering from the wildfires which were still raging in New Mexico; however, we could not claim that they were "coronal," as solar physicists refer to skies so clear and pure that the sky looks the same color blue, with no scattering, when you block out the Sun with your thumb held at the end of your outstretched arm. The winds, as expected, were high, but there was nothing to be done about that; our spirits were high, too. (Fig. 13.)

We fiddled with the telescopes all morning, and Klaus, Bill Burke, and I took turns monitoring the field and adjusting the occulting disk on the coronagraph for the first glimpse of the aureole from a full hour before first contact. Paolo at the other side of the oyster bed, with a table to support his video monitor and pieces of apparatus, tweaked his equipment. We all were worried that we might not have the telescopes oriented the right way; Paolo, in fact, discovered that he had the telescope oriented 180 degrees in the wrong direction, but in plenty of time to make the correction.

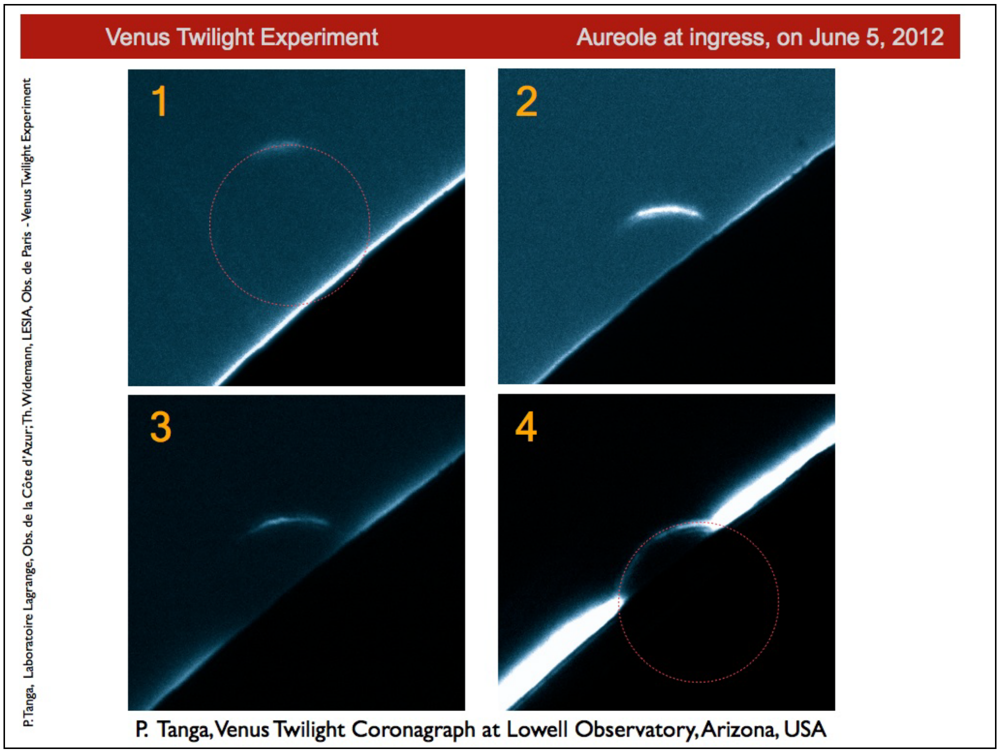

Fig. 14. The aureole as imaged by Paolo Tanga at Lowell Observatory. Photographs by Paolo Tanga.

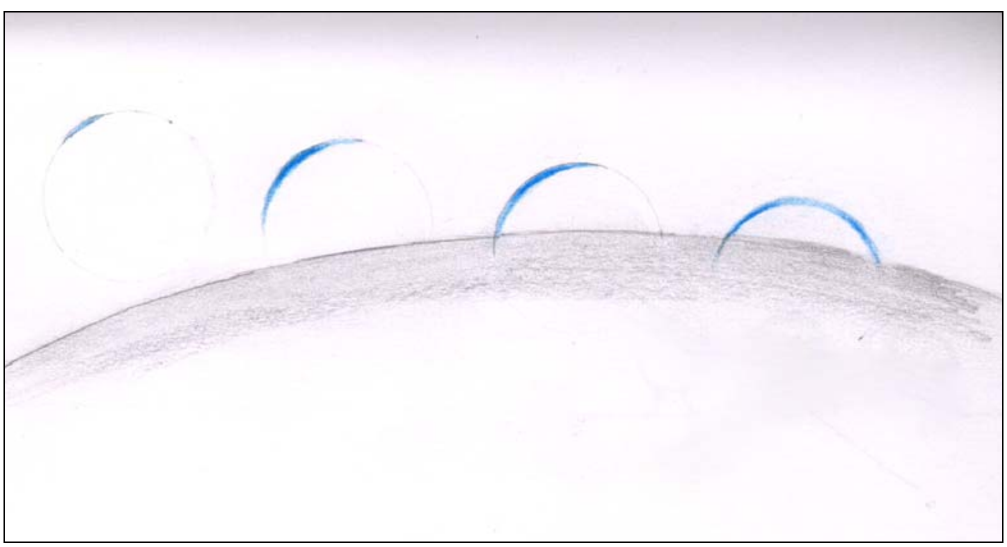

Fig. 15. The aureole as sketched by William Sheehan at Lowell Observatory.

Contact I was due at 15:05:58.4 Arizona time (MST), when the Sun's altitude was 52.9 degrees. The aureole first made its appearance on Paolo's video screen about 3 minutes before Contact I. (Fig. 14.) Klaus, Bill and I did not at first see it, but Paolo ran over and pointed it out. Overeager, I took my place at the eyepiece — and bumped the telescope, knocking the planet out of view. (This was a near-catastrophe, obviously; losing Venus just at the critical moment things were getting interesting, and I momentarily pondered adding my tale to those of frustrated transit of Venus observers of the past, such as the ill-fated LeGentil!)

Fortunately, Klaus remained calm, and — reciting repeatedly to himself the mantra, "Klaus, don't panic" — managed to recapture Venus and set the coronagraph's central obstruction over the Sun. He had nerves of steel, and his feat will in my mind rank with that of Neil Armstrong clearing a field of boulders and setting the Eagle down by manual controls in the Sea of Tranquillity just as he was about to run out of fuel.

There were no more mishaps. I now noted with astonishment the small polar spot, shining brilliantly in the blackness space just over a minute of arc from the solar limb. As I continued to observe, it began to turn slightly peaked or crescentic, and gradually widened into a bright, asymmetric arc, in the manner shown in the drawings. (Fig. 15.)

The arc continued to remain visible and even brilliant—growing ever brighter and more asymmetric — right up to Contact II, which occurred at 15:23.26.4, when it seemed to swirl around and mix together with the black drop forming at the limb of the Sun and then disappeared. The aureole's maximum magnitude had to be at least -6. After Contact II, I switched from the coronagraph to the off-axis 3-inch aperture on the Mylar filter on Bill

Burke's C-11, and observed, fascinated, the well-developed thunderhead of a black drop as it elongated and faded and finally dissipated like a black cloud on a summer day. I could no longer make out the aureole, but there was a faint bright ring (due to contrast, or perhaps this corresponded to the outline of the real image of Venus into which light from the photosphere was bleeding to produce the apparently smaller image). This aureole is well-known from previous transits and remained visible for the duration. It was very evident in Percival Lowell's old refractor.

Venus then continued to carry on its majestic march across the Sun — Sousa's "Transit of Venus March" played in my head. Now we took away the orange cones that had thwarted the encroachment curious bystanders, so that Lowell staff and the general public could finally look through the assembled instruments. All in all, it was a euphoric afternoon, and one we will never experience again. The Sun, with Venus still stuck to it like a determined beetle, descended into the ponderosa pines to the west of the Slipher building. I sat alone and in the gloaming in the upstairs porch for awhile and contemplated all that we had done, until at last my revery was interrupted by a request to trot down to the Steele Visitors' Center on the Lowell campus and sign a copy of my book (with John Westfall) *Transits of Venus;* the dedication was to the granddaughter of the woman who presented it to me, born that very day. I wished both grandmother and granddaughter the best, and hoped the granddaughter would live to see the next transit, in 105 ½ years.

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