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LOMONOSOV, THE DISCOVERY OF VENUS'S ATMOSPHERE, AND EIGHTEENTH CENTURY TRANSITS OF VENUS

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Abstract: The discovery of Venus's atmosphere has been widely attributed to the Russian academician M.V. Lomonosov from his observations of the 1761 transit of Venus from St. Petersburg. Other observers at the time also made observations that have been ascribed to the effects of the atmosphere of Venus. Though Venus does have an atmosphere one hundred times denser than the Earth's and refracts sunlight so as to produce an 'aureole' around the planet's disk when it is ingressing and egressing the solar limb, many eighteenth century observers also upheld the doctrine of cosmic pluralism: believing that the planets were inhabited, they had a preconceived bias for believing that the other planets must have atmospheres. A careful re-examination of several of the most important accounts of eighteenth century observers and comparisons with the observations of the nineteenth century and 2004 transits shows that Lomonosov inferred the existence of Venus's atmosphere from observations related to the 'black drop', which has nothing to do with the atmosphere of Venus. Several observers of the eighteenth-century transits, including Chappe d'Auteroche, Bergman, and Wargentin in 1761 and Wales, Dymond, and Rittenhouse in 1769, may have made *bona fide* observations of the aureole produced by the atmosphere of Venus. Therefore, it appears that several observers—but not Lomonosov—should receive credit for first detecting the aureole due to refraction of sunlight by the atmosphere of Venus during a transit. This crucial observation occurred almost three decades before Johann Schroeter independently demonstrated the existence of the atmosphere of Venus from his analysis of extensions of the semicircle of light of the planet near inferior conjunction, which are produced by back-scattering of light by aerosol-sized particles.

Key words: 1761 and 1769 transits of Venus, atmosphere of Venus, 'black drop', Lomonosov, Chappe d'Auteroche, Bergman, Wargentin, Wales, Dymond, Rittenhouse, Schroeter

1 INTRODUCTION

The surface of Venus is hidden from our visual view by the planet's extensive atmosphere, almost one hundred times denser than Earth's. Though the atmosphere was eventually penetrated during the twentieth century by Earth-based radars and subsequently by Soviet spacecraft that landed on the surface itself, how was this atmosphere first discovered?

The discovery has been almost universally attributed to the Russian polymath Mikhail Vasil'evich Lomonosov (Menshutkin, 1952), who observed the 1761 transit of Venus from St. Petersburg, and extensively reported his results at the time, including his conclusion that Venus had an atmosphere "… similar to, or possibly even greater, than the Earth's." (Lomonosov, 1761a; our English translation).

2 THE ATMOSPHERE OF VENUS AND THE BLACK-DROP EFFECT

Our own interest in optical and solar effects in relation to observations of transits of Venus and Mercury (Pasachoff, Schneider, and Golub, 2005) dates to work by Schaefer (2000; 2001), who reported that most published reports of an effect known as the 'black drop', even current ones, incorrectly attribute it to Venus's atmosphere. The Cytherean atmosphere, in fact, though very dense, is not deep enough to cause this effect, which was drastic enough to interfere with the accurate timing of the second and third contacts. Schneider, Pasachoff and Golub (2004) provided definitive evidence, as had long been suspected (Sheehan and Westfall, 2004), that the black drop effect is caused by a combination of the point-spread function of the telescope smearing any image, in combination with the solar limb darkening, which is especially marked in the arcsecond or so nearest the limb that shows the black drop.

From a historical context, the black drop is important because of its role in spoiling the precise timings of contact points on which Edmond Halley's grand project to estimate the Earth-to-Sun distance (or 'astronomical unit') using the transits of Venus critically depended (see Halley, 1716). Halley's method called for precise determinations of the duration of the transits of Venus. This was to be achieved by measuring precisely—to approximately one second of time—the second-contact and third-contact times from locations separated widely in latitude on the Earth's surface. Because transits of Venus are rare,[1] the opportunities to apply this method were extremely limited. This, needless to say, greatly increased their poignancy and significance.

Halley himself died in 1742, well before the transits of 1761 and 1769, which were to be the last until 1874 and 1882. Other astronomers, however, followed up his lead, and in the eighteenth century transits came to be regarded as the most important astronomical events of the era, the energizing core of years of planning, calculations, and heroic travel to remote locations by most of the important astronomers of that time. Indeed, these transits became "… the first example of big-science, extensive international cooperation, and government/science liaisons; all of which are now the hallmarks of modern research." (Schaefer, 2001: 325).

Figure 1: Lomonosov, from the frontispiece of his republished book of selected writings (after Lomonosov, 1961a).

The French astronomer the abbé Chappe d'Auteroche, who had observed the 1761 transit from Tobol'sk, Siberia, remarked prophetically to a friend over dinner in Paris before his departure for Baja California to observe the 1769 transit that "… certainty of death on the day after the observation would not be sufficient motive to keep him from setting out." (Chappe, 1982: 87). Indeed, though many other observers of the transits no doubt shared his obsession, Chappe was, as far as we are aware, the only one willing to endure martyrdom for the cause of science. Unwilling to give up his choice of a site for his observations merely because of a raging epidemic (probably of typhus), he (and most of his party) died in Baja within weeks of the transit.

In the result, the observations of the contacts were frustrated by several unexpected optical effects. There was an indistinctness, blurring, or ligament of darkness formed between Venus and the edge of the Sun when the two were in near-contact, i.e., at just the most critical times, thus rendering timings discrepant by a minute or more even for observers standing side by side (Hughes, 2001; Sheehan and Westfall, 2004). These optical effects severely compromised attempts to apply the Halley method for determining the solar parallax. Some observers (like many modern authors) attributed this 'black drop' to the interposition of a substantial atmosphere surrounding Venus. In addition, more rarely, observers reported a luminous ring around Venus when it was still partly off the disk of the Sun. Here we consider the phenomena observed during the contacts at the eighteenth-century transits of Venus and their significance—beginning with the celebrated observations of the Russian Academician Mikhail Vasil'evich Lomonosov (Figures 1 and 2) at St. Petersburg.

Figure 2: Lomonosov's statue in front of the Old Library of Moscow State University (photograph by Jay M. Pasachoff).

The stories are told in more detail in such books as those by Anderson (2012), Lomb (2011), Westfall and Sheehan (2013) and Wulf (2012).

3 LOMONOSOV'S OBSERVATIONS OF THE 1761 TRANSIT

Lomonosov (1711–1765) is one of the best remembered of the many observers of the 1761 transit. Born on an island in the Dvina River, near Arkhangelsk in the northern part of European Russia, he was initially destined for the life of a fisherman. However, possessed of native intelligence and insatiable curiosity, at the age of 19 he left his native village (on foot) for Moscow, and eventually taught himself enough to become a student at the St. Petersburg Academy. After a stint in Germany, where he studied at the University of Marburg, he returned to Russia, and won an appointment to the Academy in 1741, though without receiving any specific assignment. Much of his career was spent battling with incompetent and narrow-minded colleagues, who had him arrested and imprisoned for a time, but he eventually succeeded in establishing himself. His work was championed by Empress Elizabeth—who was won over by his poetry—and by the Swiss mathematician Leonhard Euler. Lomonosov became a professor at the Academy and was put in charge of a laboratory, where he did prodigious amounts of work in physical chemistry. Embracing many of the ideas of the Enlightenment sweeping Europe at the time, he was a stalwart enemy of superstition and critic of the Orthodox Church, and a reformer of popular education in Russia, activities that, needless to say, continued to make him suspect in the eyes of the clergy (Menshutkin, 1952; Shiltsev, 2012).

Lomonosov's scientific interests were broad, and not surprisingly, he attentively followed the plans being devised throughout Europe to observe the transit of Venus on 6 June 1761 (N.S.) or 26 May 1761 (O.S). In Russia, the lead in calculating Venus's path across the Sun had been taken by F.U.T. Epinus (1724–1802), a German natural philosopher and the Director of the St. Petersburg Observatory. However, Lomonosov discovered errors in Epinus' calculations, and proceeded to correct them. This did not endear him to Epinus. Eventually, Lomonosov decided to carry out observations of the transit from his own observatory at his home while his colleagues Andrey D. Krasilnikov (a one-time student of the French astronomer J.N. Delisle) and Nikolay G. Kurganov based themselves at the St. Petersburg Observatory (on the top of the Academy building). These seasoned astronomers were assigned to the primary project of carefully observing the contact times in order to apply Halley's method in determining the length of the astronomical unit, while Lomonosov focussed on the physical phenomena that occurred during the transit. For these observations he used a non-achromatic refractor with a focal length of 4.5 feet that consisted of little more than two lenses (objective and eyepiece) capped with a smoky glass that Marov (2005: 213) somewhat unkindly referred to as "… a sort of spyglass ...." This tended to produce distorted images of objects that were not perfectly centered. The poor quality of this instrument must be borne in mind when interpreting the significance of Lomonosov's observations of the transit, while yet another factor affecting the observations would have been the seeing. The transit began shortly after sunrise at St. Petersburg, and the seeing was initially good; however, it deteriorated as the transit progressed.

Lomonosov (1761a; 1761b) was among the first observers of the transit to publish his results. An account in Russian was published by the St. Petersburg Academy of Sciences within a month of the transit (see Lomonosov, 1961a). Another account was written at the same time in German, undoubtedly by Lomonosov himself, who had learned German at Marburg (see Lomonosov, 1961b).[2] However, neither of these publications appears to have had much influence at the time, and few astronomical historians have consulted them since. Among the exceptions are Meadows (1966)[3] and Marov (2005).[4]

Thus, for instance, in his magisterial work on the transits of Venus, Harry Woolf (1959) doubted that Lomonosov's paper was even published during his lifetime, and could not find a copy. The usually reliable Willy Ley (1963: 207) similarly claimed that "… this paper, like many others by Lomonosov was not printed during his lifetime …" and suggested that it did not appear even in Russia until the end of the nineteenth century. Ley (ibid.) further maintains that only in 1910 did it become known outside Russia, when Boris N. Menshutkin, later Lomonosov's biographer, published excerpts in German. It is likely that Ley has been relied on by many later authors, who followed him in believing that Lomonosov had seen a 'luminous ring' around the planet, which he thought indicated the presence of an atmosphere that was possibly greater than that of the Earth. Another influential source has been the Russian astronomer Sharanov (1960).

Unfortunately, eighteenth-century accounts of transit observations are often vague and unreliable, which is certainly excusable, since none of these observers had ever seen a transit of Venus before. Many of the phenomena observed during the transit were unexpected, and collectively raised havoc with the precise timings of the contacts. Descriptions by eighteenth-century transit observers commonly talk of an 'atmosphere' around the planet that was seen during ingress and egress but also, in some cases, remained visible as the planet crossed the Sun. They mention a "feeble light," a "reddish hue," "a luminous band," and even, most vividly, a "narrow waterish penumbra" around the planet (see Meadows, 1966). More often than not the term 'atmosphere' was used to describe these phenomena, by observers who were predisposed on religious or philosophical grounds (see below) to believe that all the planets were inhabited and therefore must, like Earth, possess atmospheres needed to support life. In addition, these various effects shade imperceptibly into those involving the black ligament or black drop, which was by far the most striking and ruinous phenomenon observed at the transits. It has only recently become clear that these effects are produced by the smearing of the isophotic contours of the planet's disk by a combination of solar, instrumental and terrestrial-atmospheric effects. Not only was this faint light or dusky 'atmosphere' seen around Venus, but the black ligament and black drop also were ascribed by many eighteenth-century observers to an actual atmosphere around Venus—something for which, again, they can be excused, particularly as Schaefer noted that even many twentieth-century authors fell into the same error (Schaefer, 2001). Significantly, similar effects were seen during transits of Mercury (which of course is known to be airless) by observers using similar instruments under the same conditions, while a small black drop was noted even by well-equipped observers of the 1999 transit of Mercury (see Pasachoff, Schneider and Golub, 2005).

It would be tedious, and achieve no useful purpose, to consider case by case all of the reports by eighteenth century observers of the various luminous effects, penumbrae, feeble lights or other phenomena seen during the transits and attempt to account for each one. Instead, we consider in detail the case of Lomonosov as representative of all of these. We have consulted both of Lomonosov's original publications, which were written in Russian (1761a) and German (for which we use the 1961 version: Lomonosov, 1961b). The German account (which will be discussed further below) is an excerpt from the Russian, and omits the discussion of the transit observations altogether.[5] The Russian text is therefore of fundamental importance, and the original German almost as much so. We here present the entire account pertaining to Lomonosov's observations and his scientific discussion in a fresh translation from the Russian, based on that made at our request by Olga Tsapina, Norris Foundation Curator of American Historical Manuscripts at the Huntington Library. We have made a few slight changes to make the text more accessible; for instance, where Lomonosov refers to himself in the third person, as "the observer," we have modified the text to first person, and clarified a few ambiguous terms by introducing those that conform to current astronomical idiom. Note that our Figure 1 shows the frontispiece of his book while our Figure 3 encompasses the various figures as given and numbered by Lomonosov himself and referenced in the text below:

> Having waited for Venus to enter the Sun for some forty minutes beyond the time listed in the ephemerides, I finally saw that the edge of the sun at the place of the expected entry became indistinct as if blurred, although before it had been clear and evenly colored [he refers to B in Figure 3.1]. Seeing no darkness and thinking that it was my tired eyes that caused this blurring, I stood back briefly from the telescope. After a few seconds I took up my place again and saw that, where the solar limb had previously been only somewhat disturbed, there was a definite spot or segment; it was very slight, but there could be no doubt that it belonged to the encroaching Venus. Afterwards I watched with keen attention for the ingress of the trailing limb of Venus, which, it seemed, had not yet taken place, for there seemed to be a small segment not yet entered upon the

Sun. However, there suddenly appeared between the trailing limb of Venus and the following [solar] limb a hair-thin luminous sliver. The time that separated the two appearances was not more than a second.[6]

During Venus's egress from the Sun, when its preceding limb was beginning to encroach upon the solar limb, and was (as far as my eye could judge) about a tenth of the diameter of Venus away, then a small blister [see A in Figure 3.1] appeared on the edge of the Sun, which became more and more evident as Venus approached the moment of its complete egress [see Figure 3.3]. LS designates the solar limb, mm, the bulging outline of the Sun in front of Venus [see Figure 3.4]. The blister suddenly broke, and Venus appeared without its limb [see Figure 3.5], nn shows the small, but very clear, sector which was clearly defined.

The complete egress of Venus, or its last contact with the limb of the Sun, occurred with a certain amount of uncertainty, and was accompanied as before with a blurring of the solar edge.

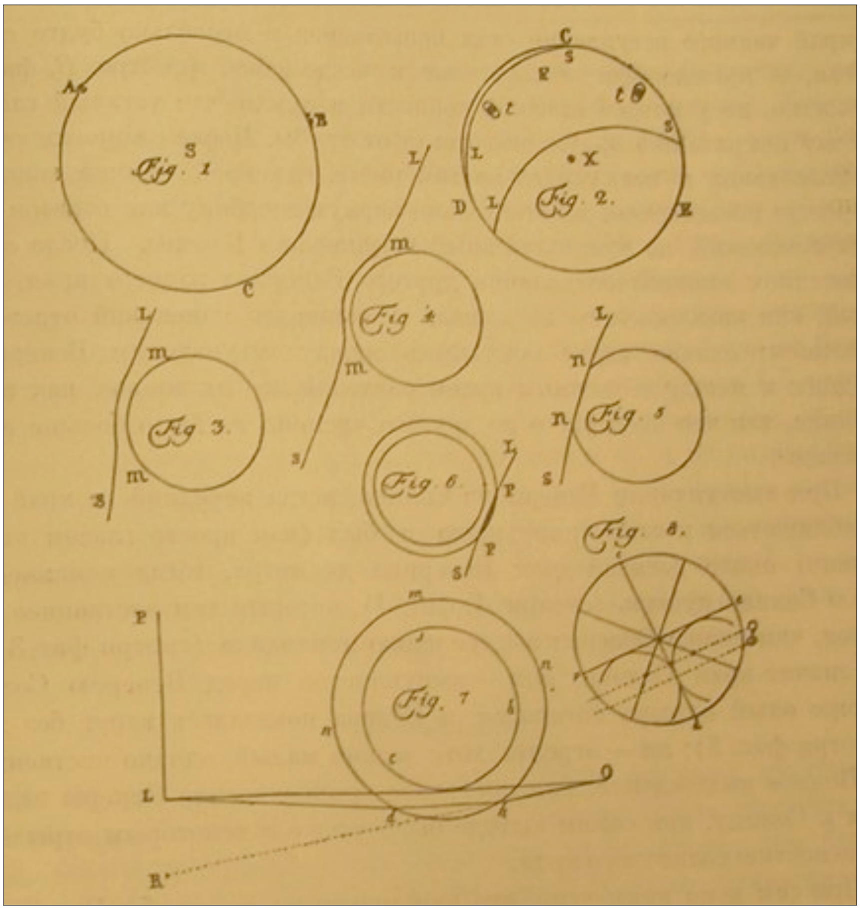


Figure 3: Lomonosov's figures, described in the text.

While this was happening, it was clearly noticed that as soon as Venus moved away from the centre of the telescope and approached the edge of the field of view, a fringe of colours would appear due to refraction of the light rays, and the limb of Venus appeared smeared the further it was from the centre of the telescope tube [Figure 3.2]. Because of this, throughout the transit the telescope was positioned in such a way that Venus was always in the center of the field, where its limb appeared crisp and clear without any colour.

From these observations I concluded that the planet Venus is surrounded by an extensive atmosphere of air, similar to (if not even greater than) that which surrounds our own globe. The reasons for this conclusion are, in the first place, the blurring of the previously well-defined solar limb B, just before the actual ingress of Venus, which was caused, so it would seem, by the encroachment of Venus's atmosphere upon the solar limb. This effect is made evident [see Figure 3.6], where LS is the edge of the Sun and PP the portion of the atmosphere of Venus. At the egress of Venus, contact of the preceding limb produced a blister. This effect, it would seem, can only be due to refraction of solar rays by the atmosphere surrounding Venus. Thus LP is the end of a chord of the visible surface of the Sun [see Figure 3.7]; sch is the main body of Venus, mnn is its atmosphere; LO is the ray from the surface of the Sun that would extend to the eye of the observer in the case where Venus had no atmosphere. However, in the presence of an atmosphere, the ray Ld from the limb of the Sun is refracted toward the perpendicular at d and reaches h, thus arriving at the observer's eye in point O. Now the optics of the situation tells us that the latter is the ray along which the eye actually looks: thus the limb of the Sun, L, after refraction, appears to lie at R, along the straight line OR, or beyond the actual position of the limb L. The excess distance LR represents the blister at the solar limb which bulges out ahead of the pre-ceding limb of Venus at egress.

Thus ends the excerpt taken from Lomonosov's text.

A superficial reading of this —and, in particular, the reference in the first paragraph to what is here translated as "a hair-thin luminous sliver", but which others have referred to as a "luminous ring" (Ley, 1963), or even a "very narrow aureole" (Meadows, 1966)—conjures up visions of the delicate feathery line of light seen along the trailing limb of Venus when the planet had not yet completely entered the limb of the Sun (or the preceding limb of Venus when it had not completely exited) seen by observers of the nineteenth-century transits and by ourselves in 2004. The latter is indeed, properly speaking, an aureole, produced by the refraction of sunlight in the Venusian atmosphere, but since the total apparent angular height of Venus's air is only about 0.02 arc seconds, it is, despite its brilliance, a delicate feature, and would presumably have been beyond the range of most eighteenth century observers with the small instruments available to them.

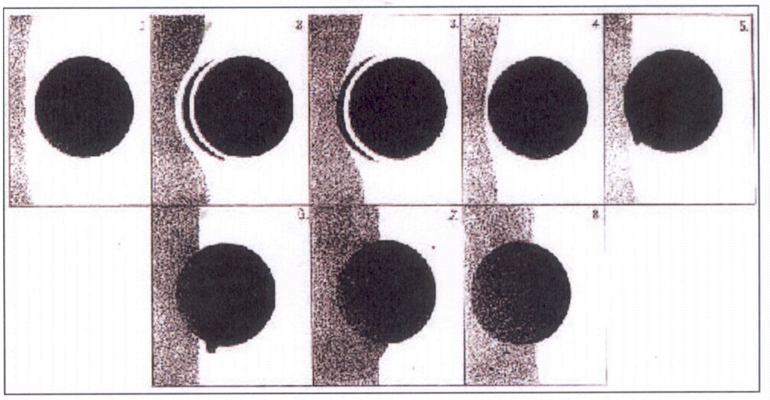
Though some observers used early Dollond achromatic refractors (though Dollond himself used a non-achromat! (Meadows, 1966)) and others used small reflectors, even the best of these instruments were primitive by modern standards, and suffered from varying degrees of achromatic and other aberrations. Lomonosov, in particular, makes clear that his own instrument was of marginal quality. It clearly suffered from chromatic aberration—and possibly other optical distortions—since, as noted above, the image deteriorated markedly whenever Venus neared the edge of the field of view. Though many of the other observers of the eighteenth-century transits described luminous rings and reddish or purplish haloes around the disk of Venus, including some that remained visible throughout the duration of the transit across the Sun, these suggest the effects of eye fatigue or chromatic aberration or both. So some of these 'luminous rings' were edge effects on the dark disk of Venus. If there were an 'arc' off the limb, between first and second contacts or between second and third contacts, then the atmosphere may indeed have been sighted. But at no time did Lomonosov report any phenomena that resembled the phenomena seen during the transits of 2004 and 2012, with an arc above Venus's external limb. We know now that such an arc may be visible for 20 minutes, far from what Lonomosov described.

In any case, a careful reading of Lomonosov's text reveals that the "hair-thin luminous sliver" refers to nothing more than the flash of sunlight between the trailing limb of Venus and the limb of the Sun marking the end of second contact. It corresponds to the breathtaking appearance of the 'diamond ring' at a total solar eclipse. Without going into all the details here, we maintain that multiple other observers' reports of luminous hairs or threads—which have also been uncritically accepted as sightings of the aureole—prove to have been of this same phenomenon. One must remember that observers were especially on the *qui vive* for this moment. After all, the main purpose of observers of the eighteenth-century transits was to determine the precise moments of the second or third contact. When the bright flash or thread appeared at ingress, it meant that second contact had passed; it corresponded with the moment the black ligament broke or the black drop dissolved. The problem they encountered was, of course, that the black ligament or drop spoiled the whole methodology by rendering determination of this critical moment imprecise.

Regarding Lomonosov's discussion of the blister at second contact: it is clear in light of recent work that his arcs mm and nn are artifacts, presumably related to the double cause of the black drop as described by Schneider, Pasachoff, and Golub (2004) and Pasachoff, Schneider, and Golub (2005). Nineteenth century observations of suggestively similar effects, made with much better telescopes, were made in 1874 by the British astronomer Bigg-Wither (1875; 1879; 1883) and many others who reported on their observations in the *Monthly Notices of the Royal Astronomical Society*, where they were indexed under "Sun, Parallax of, from observations of ...," and in 1882 by the skillful Belgian observer E. Stuyvaert (1884). See our Figure 4.

Bigg-Wither (1883: 98) describes, from his observations in India, "At the Egress most unexpected phenomena presented themselves ... As *Venus* approached the edge of the Sun's disk, she appeared to push before her a ring of light concentric with her disk ..." It was seen for almost a half hour, and generally matches the satellite observations of Venus's atmosphere that we made in 2004. He wrote "I am unable to form an idea of the cause of the formation of this crescent: it certainly did not appear at the Ingress, nor was there anything of the sort at the Transit of *Mercury* in 1868, the Egress of which I observed in England with the same telescope." (Bigg-Wither, 1883: 99).

Since Lomonosov's observational data were flawed, his detailed geometrical treatment also proves to have been spurious. Schaefer, though noting that the idea that the black drop results from the refraction of sunlight in the Venusian atmosphere is false—and indicating that it may have been proposed by Lomonosov—goes on to say that Lomonosov "… saw other effects during the 1761 transit which he correctly used to deduce the existence of air around our sister planet." (Schaefer, 2001: 327). We have now shown definitively that this is not the case. Lomonosov arrived at the correct conclusion but on the basis of a fallacious argument. Perhaps it will help to introduce an additional factor that explains the readiness of intelligent and cautious observers to make what seems, in retrospect, to have been such a speculative leap. This factor is the general acceptance of plurality-of-worlds beliefs by many eighteenth-century observers, a topic explored in depth by such historians of astronomy as Steven Dick (1982), Michael Crowe (1986), Helge Kragh (2008) and Møller Pedersen and Kragh (2008). Many astronomers and writers of the Enlightenment—including such well-known figures as Christiaan Huygens and Bernard de Fontenelle, both of whom wrote books on the subject, and afterwards William Herschel and Johann Schroeter—were convinced that the purpose of the planets was to support inhabitants, and thus took the presence of atmospheres for granted.



The black drop effect during egress, observed by E. Stuyvaert at San Antonio. (Picture courtesy o
John G. Wolbach Library, Harvard-Smithsonian Center for Astrophysics)

Figure 4: This observation was by E. Stuyvaert,[7] member of a Belgian team led by Jean Charles Houzeau to San Antonio, Texas, in 1882 (after Stuyvaert, 1884: Plate 1).

That Lomonosov—whose support of Enlightenment thought frequently brought him into conflict with his contemporaries—was of the same school is demonstrated by what he writes after his discussion of the observations of the transit of Venus and geometrical treatment demonstrating the supposed refraction by the planet's atmosphere. In fact, as Joseph Gangestad, who translated the work for us, has pointed out, Lomonosov's article in German (which, as Duerbeck points out, includes "Aus" = "Taken from" in its title)

> … is only an excerpt of Lomonosov's report, and discusses none of his scientific findings. It appears that this excerpt comes somewhere near the end of the whole thing, after the scientific description of his observations has already been made. In these pages, he talks exclusively about the religious implications of other planets having atmospheres, the possibility of extraterrestrial life, quoting the Bible and saints, and giving a history lesson on astronomy and the heliocentric vs. geocentric views of the Solar System. This excerpt is almost an exegesis, explaining how atmosphere-bearing bodies with other living creatures and a heliocentric universe can be reconciled by properly-educated Christians (as he has some rather nasty things to say about uneducated 'common people').

Duerbeck (pers. comm., 2011) points out that this is the only passage lacking in the more academically-oriented German edition of 1761, and proves that the 1961 editors worked from the basis of the Russian

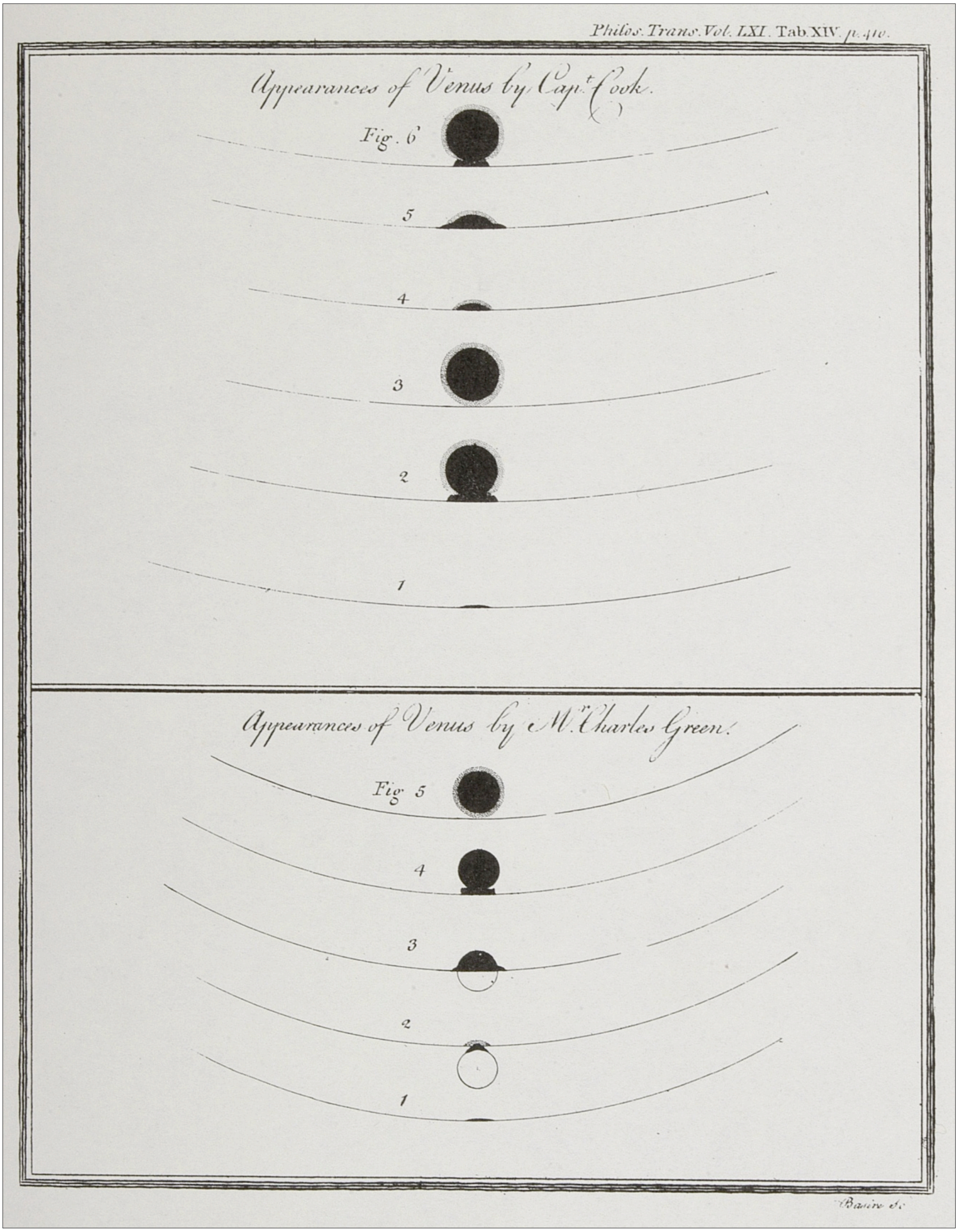


Figure 5: Drawings published in *Philosophical Transactions of the Royal Society* by Green and Cook (1771) of the 1769 transit of Venus that they observed in Tahiti (courtesy: Royal Society of London).

edition. The point is that Lomonosov observed the transit of Venus with a strong predisposition bordering on certainty that the planet was surrounded by an extensive atmosphere. So—when he saw blurring of the Sun's limb and other curious effects—he naturally deduced from these phenomena what he had already been predisposed to believe. In that respect, his supposed discovery of the atmosphere of Venus was not unlike, say, the well-known case of Percival Lowell's discovery of a system of artificial canals on the planet Mars.

4 VENUS'S ATMOSPHERE ACTUALLY OBSERVED

Among other observers of the eighteenth century transits, the best known were Lieutenant James Cook and the astronomer Charles Green, who observed the 1769 transit from Tahiti (Orchiston, 2005); the abbé Chappe d'Auteroche, who observed the 1761 transit from Tobol'sk, Siberia, and the 1769 transit from Baja California; and David Rittenhouse, who observed the 1769 transit from Norriton, near Philadelphia.

Because Cook's Royal Society-sponsored expedition to Tahiti marked the first phase of what would eventually turn into three dramatic voyages of geographical exploration and discovery, he is by far the most celebrated observer of the eighteenth century transits. Cook and Green successfully observed the transit in a cloudless sky in intolerable heat. Cook refers to an "atmosphere" of Venus, a term which may mislead the incautious. The drawings of these observers (Green and Cook, 1771) show a greyish penumbra around the black disk of Venus silhouetted against the Sun, which is clearly an optical effect (Figure 5). Cook's journal entry for transit day, 3 June 1769, reads:

> This day prov'd as favourable to our purpose as we could wish, not a Clowd was to be seen the whole day and the Air was perfectly clear, so that we had every advantage we could desire in Observing the whole of the passage of the Planet Venus over the Suns disk: we very distinctly saw an Atmosphere or dusky shade round the body of the planet which very much disturbed the times of the Contacts particularly the two internal ones. (Beaglehole, 1968: 97-98).

This description is clearly of instrumental effects and the black drop effect, not of a true atmosphere of Venus.

Among the other observers of the 1761 transit, several have been credited (by Link, 1949; 1959; 1969) with having seen the aureole produced by refraction of sunlight in the Venusian atmosphere. The strongest candidates are: P.-G. Wargentin (1761) in Stockholm, Thorbern Bergman (1761) in Upsala and Chappe (1761) in Siberia. In addition Maraldi at the Paris Observatory and Grandjean de Fouchy in La Muette at the Cabinet du Physique may have done so (see Link, 1969). The observations are not entirely satisfactory, for though the phenomena recorded bear some likeness to the aureole, it is also possible that what was observed was merely an optical halo (e.g., see Bergman's drawings in Figure 6).

Chappe's (1762) observations at Tobol'sk merit detailed discussion. On the morning of the transit, Chappe awoke from a sleepless night (he had gone to bed with the skies hopelessly overcast), and found the Sun heartbreakingly hidden by clouds. Fortunately, as soon as the Sun rose at Tobol'sk, the clouds began to dissipate; his first glimpse of the planet on the Sun showed that first contact had already occurred—the disk of Venus was entered halfway onto the Sun's limb. Then Chappe noted a "… singular phenomenon … [a] luminous ring …" (*anneau lumineux*), crescenttic in form and reaching about two-thirds of the way around the semi-circle of the opaque planetary disk. The ring remained visible as Venus glided farther over onto the Sun. Chappe surmised that the ring must be due to refraction of sunlight in an actual atmosphere around the planet, and he worked out by subtracting the diameter of the Sun as seen at Venus from the measured diameter of the planet, a corrected value for the planet's diameter of 58½ seconds of arc (the modern value for the time of the 1761 transit is 58″ .18; note that his calculation did not depend on whether the ring was real or not).

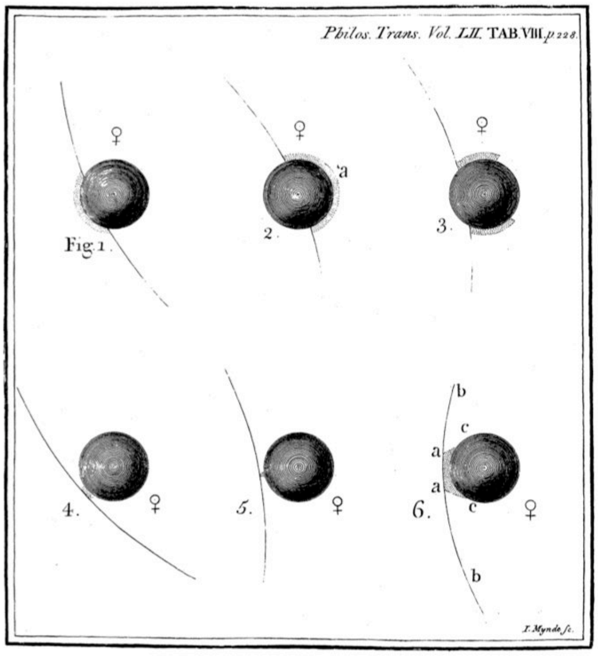


Figure 6: Drawings by Bergman (1761) from the *Philosophical Transactions of the Royal Society* of the entrance and egress of Venus into the solar disk at the 1761 transit. The upper drawings are somewhat ambiguous, and may indicate the aureole, though more likely they record an optical halo. The lower series are unambiguous: they definitely exhibit nothing more than an artifact (courtesy: Royal Society of London).

During the 1769 transit, Chappe, now in Baja California, looked for but failed to see the aureole (see Cassinin de Thury, 1772). Neither did anyone else, as far as we can tell, with the possible exceptions of the pioneering American astronomer David Rittenhouse at Norriton, near Philadelphia, and Joseph Dymond and William Wales at Prince of Wales Fort (now Churchill) on Hudson Bay.

Rittenhouse, a clockmaker and orrery-maker by profession (Hindle, 1964), as a member of the American Philosophical Society's Committee to observe "… that rare Phaenomenon, the transit of Venus over the Sun's disc …", made careful preparations in advance of the great event, including a series of timings of the eclipses of Jupiter's satellites, to determine the longitude of his observatory at Norriton (Rittenhouse, 1769).

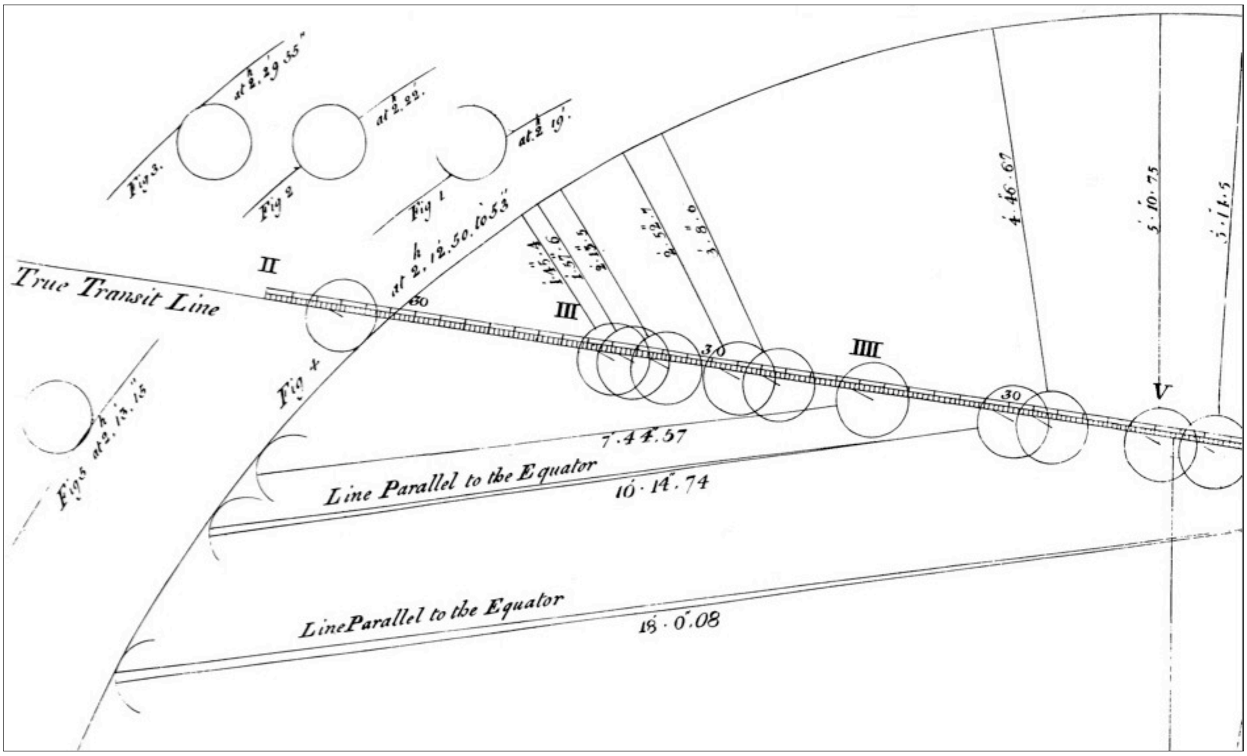


Figure 7: David Rittenhouse's multiple-image drawing of the 1769 transit of Venus (after Rittenhouse, 1769: Plate III).

On the day of the transit, he and his colleagues—William Smith, John Lukens, and John Sellers—were favored with a beautifully clear sky. Their instruments included a Gregorian reflector of two-foot focal length shipped from London, of which Charles Mason and Jeremiah Dixon, who had observed the 1761 transit from Cape Town and were later to become famous for surveying the Mason-Dixon Line, declared "… they never used a better …", also a 42-foot refractor whose lenses had been shipped from London to Harvard College but did not arrive in time for the transit. These instruments were employed by Smith and Lukens, respectively. Rittenhouse observed with his own refractor, with an object-glass of 3-inch aperture and 36-foot focal length, magnifying 144×, to the eyepiece of which he fitted "… with a little bees-wax …" a piece of deeply smoked glass. After describing his earliest intimation of first contact, Rittenhouse's account (1769) proceeds as follows (see Figure 7):

> When the Planet had advanced about one third of its diameter on the Sun, as I was steadily viewing its progress, my sight was suddenly attracted by a beam of light, which broke through on that side of Venus yet off the Sun. Its figure was that of a broad-based pyramid; situated at about 40 or 45 degrees on the limb of Venus, from a line passing through her center and the Sun's, and to the left hand of that line as seen through my Telescope, which inverted. About the same time, the Sun's light began to spread round Venus on each side from the points where their limbs intersected each other.
>
> As Venus advanced, the point of the Pyramid still grew lower, and its circular Base wider, until it met the light which crept round from the points of intersection of the two limbs; so that when half the planet appeared on the Sun, the other half yet off the Sun was entirely surrounded by a semicircular light, best defined on the side next to the body of Venus, which constantly grew brighter, till the time of the internal contact.
>
> Imagination cannot form any thing more beautifully serene and quiet, than was the air during the whole time; nor did I ever see the Sun's limb more perfectly defined, or more free from any tremulous motion; to which his great altitude undoubtedly contributed much.

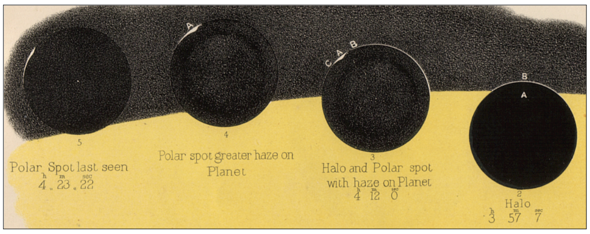


Figure 8: Observations from Sydney, Australia, of the transit of 1874, by New South Wales Government Astronomer Henry Chamberlain Russell, showing the arc of Venus's atmosphere visible outside the limb (after Russell, 1892: Plate XXV).

Of all the eighteenth-century observers, Rittenhouse has perhaps the strongest claim of having made out Venus's atmosphere appearing as an actual arc, owing to refraction of sunlight. Similar effects to those he describes are in the drawings by the Australian astronomer Henry Chamberlain Russell made at Sydney Observatory during the 1874 transit (Russell, 1892; Orchiston, 2004; cf. Pasachoff, Schneider and Widemann, 2011). Some of Russell's drawings are shown in Figure 8. Rittenhouse's descriptions also bear comparison with the best images ever made of the transit, the ones from NASA's TRACE spacecraft during the 2004 transit (Pasachoff, Schneider and Widemann, 2011; see Figures 9 and 10).[8]

5 CONCLUSIONS

So, if we cannot accord credit for discovering the atmosphere of Venus to Lomonosov, who does deserve the credit? Possibly Chappe. He reported an arc of sunlight produced by refraction in the atmosphere of Venus, and concluded that it was an effect of the atmosphere of Venus on the Sun's limb. He may or may not have been correct. He did not attempt to explain, by geometrical analysis of the kind that Lomonosov presented, how the aureole might be produced by refraction of sunlight in the atmosphere of Venus. Also, Bergman and Wargentin may deserve some credit, though their observations are not quite convincing to us. Wales and Dymond may have seen the aureole and recognized its significance. However, the strongest claim of any of the eighteenth century transit observers to have seen the aureole and recognized its significance was Rittenhouse, whose descriptions are detailed enough to be compared with modern observations, including those made from spacecraft.

The first comprehensive demonstration of Venus's atmosphere to draw on observations other than those at a transit was provided a generation later by Johann Schroeter, who skillfully analyzed the extension of the semicircle of light around the dark side of Venus near inferior conjunction, noted in a crucial series of observations made in 1790 (Baum, 2007; 2010). Earlier references, provided by Duerbeck, include Schroeter (1796), American astrophysicist Henry Norris Russell (1899),[9] and Link (1949, 1959), with more quotations in Meadows (1966: 126). Schroeter methodically eliminated other possible explanations for the phenomenon he observed, in contrast to eighteenth-century transit observers. As Schroeter himself continued to believe that airless Mercury had an atmosphere from a bright halo it exhibited at the transit of 1799, it would seem that transit phenomena were too complex, multifarious, and variable in causation to be entirely reliable grounds for deduction.

The discovery of the atmosphere of Venus was one of the great achievements in planetary astronomy. In our view, at least several observers of the transit deserve credit for having intimations of its existence based on reasoning from the various phenomena they recorded; however, in our opinion, Schroeter deserves the most credit, as the first to offer a definitive demonstration.

6 NOTES

1. Only six transits of Venus have been observed since the invention of the telescope, beginning with that of 1639, which was observed by only two people: Jeremiah Horrocks and William Crabtree (see Chapman, 2005).
2. Duerbeck (pers. comm., 2011) notes that this reference says

> Taken from [= Aus] Erscheinung ..., i.e., it is only an extract of the 1761 paper. It is obviously not based on the German original, it seems that it was translated back from Russian, so it is quite worthless. The 1761[?] paper, with an old-fashioned flavor, but of course much more precise, is very rare; I could trace a single copy in the library of the Martin-Luther-Universität Halle-Wittenberg, which provided a copy. The title page reads: 'Erscheinung der Venus vor der Sonne, beobachtet bey der Kayserlichen Academie der Wissenschafften in St. Petersburg den 26. May 1761. Aus dem Rußischen übersezt.' It describes the observations by Krassilnikow [sic] and Kurganow, and continues '... hat auch der Collegien = Rath und Professor Lomonossow in seinem Hause hauptsächlich Physicalischer Bemerkungen wegen diese Himmels = Begebenheit observiret ... Indem derselbe auf den Eintritt der Venus in die Sonne bey vierzig Minuten länger, als er nach den Ephemeriden hätte erfolgen sollen ...' [i.e., the beginning of our text]. After Lomonosov's observations (which include the set of eight figures bound at the end), follows a 'Zugabe', which is a variant of the text printed in the German Lomonosov edition of 1961(b).

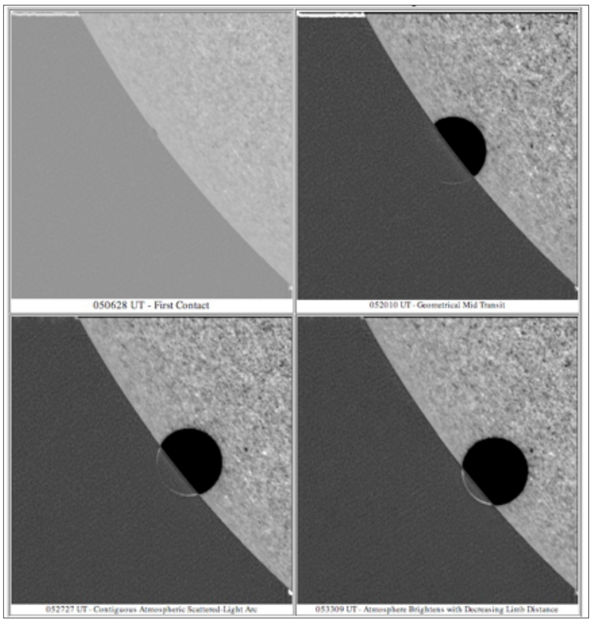


Figure 9: The arc outside the solar limb before second contact, seen in a series of images from NASA's Transition Region and Coronal Explorer (TRACE), reveals Venus's atmosphere seen in refracted sunlight. (The part of the image outside the solar limb, the diagonal, slightly curving line from upper left to lower right, has been artificially enhanced.) (After Pasachoff, Schneider, and Widemann, 2011; courtesy: Lockheed Martin Solar and Astrophysics Laboratory and NASA).

3. H. Duerbeck (pers. comm., 2011) informs us that Meadows correctly quotes F.U.T. Eginus, though he does not quote the 1761 Russian and German papers with their titles, only the (Russian) collected works, making it unclear whether he has seen the German edition; however, he quotes printing runs and publication dates—which must have been taken from other sources.
4. Duerbeck (pers. comm., 2011) also informs us that Marov uses F.U.T. Eginus working from Russian sources, but he also quotes the German title of Lomonosov's 1761 paper exactly as it is written on the title page—so he must have seen it; only the year of publication is guessed since the original has no date.
5. Duerbeck informs us (pers. comm., 2011) that the 1761 text is almost complete, especially concerning

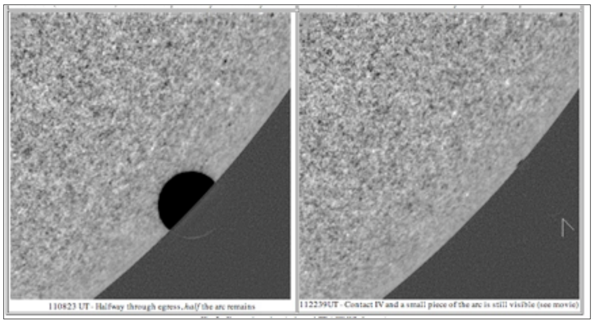


Figure 10: The atmosphere of Venus, at egress from TRACE (left), and (right) the last bit of Venus's silhouette on the solar disk (after Pasachoff, Schneider, and Widemann, 2011; courtesy: Lockheed Martin Solar and Astrophysics Laboratory and NASA).

the observations; only some trivia on Copernicanism in the second half are not translated. In the German 1961 text, on page 428/20, there is a poem with an introductory sentence: "Schade ... kroch?!" This sentence is missing in the 1761 German text.

6. Since so much of our argument depends on this paragraph, we provide the original German text and comments from Duerbeck (pers. comm., 2011):

   > Auf einmahl aber entstund zwischen dem hintern Rand der Venus und dem Sonnen = Rande ein ganz helles Licht, wie ein Haar breit, welches die Venus vom Rande der Sonnen absonderte, so daß beydes in Zeit von nicht mehr als einer Secunde geschahe. So the 'solar' is also here; 'sliver' is expressed as 'Licht' = light. The verb 'absondern' is not totally clear; in modern usage, I would translate it as 'to emit' or 'to discharge', but it can also mean 'to segregate, to detach'.

   Duerbeck (ibid.) took the text from Lomonosov (1960) where passages from Lomonosov's original paper are quoted. The relevant sentence in Duerbeck's transliteration, with the word for 'solar' italicized by us, is:

   > Posle s prileshaniem smotrel vstupleniye drugogo Venerina zadnego kraya, kotoryi, kak kazalos', eshtche ne doshel, i ostavalaya malen'kiy otrezok za Solnzen; odnako vlrug pokazalos' mezhdu vstupayushtchim Venernym zadnim i mezhdu *solnetchnym* krayem razdelyayushtcheye ikh tonkoye, kak volos, siyanie, tak tachto ot pervogo do drugogo wremeni ne bylo bol'she odnoy sekundy.

7. Stuyvaert was a good observer, who had recorded radial streaks in the B ring of Saturn, thus anticipating the 'spokes' we now know to exist. The image shown here is reproduced in Sterken and Duerbeck, 2004 (Figure 13).
8. See, also, the animations available online through a link in the Pasachoff, Schneider, and Widemann (2011) *Astronomical Journal* paper. The publisher has guaranteed that this animation will be available for 100 years (not quite long enough for the next pair of transits, in 2117 and 2125). This animation is also available through the website of Pasachoff at http://www.transitofvenus.info. Inspections of these animations show that the Cytherean atmosphere was visible for at least 10 minutes at ingress and a similar time at egress, which agrees with Rittenhouse's observations.
9. H.N. Russell (1899) concludes:

   > (1) The observed prolongation of her cusps shows that the sunlit and visible areas on Venus extend about 1°10′ farther than they would on an opaque sphere without atmosphere. (2) This has usually been explained as the result of the refraction of a clear atmosphere, more than twice as extensive as our own; but a consequence of this theory is that, when Venus appears as a luminous ring, a very conspicuous refracted image of the Sun ought to appear on that part of the ring farthest from the Sun; and this image has never been seen, even when a refraction of only 12′ would have produced it ... while a much smaller amount of refraction will explain the transit phenomena satisfactorily.

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