Replicating the discovery of Venus's atmosphere

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The 2012 transit of Venus gave us a chance to reproduce Mikhail Lomonosov's 1761 observation and demonstrate the excellent quality of 18th-century telescopes.

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Great experiments not only reveal profound features of our world, they also impress us with the beauty of their design. By reproducing seminal experiments in the history of physics, one can gain a better understanding of the course of our discipline and clarify the specific features that contributed to the original achievements. Replication may be suitable as a classroom exercise, as in the case of Hans Christian Oersted's and Michael Faraday's experiments showing the connection between electricity and magnetism. Or it could be difficult and expensive; no student laboratory will restage the recent discovery of the Higgs-like boson in the foreseeable future!

Experimentally rerunning Mikhail Lomonosov's 1761 discovery of the Venusian atmosphere may not be of Higgs-boson difficulty, but it poses unique challenges. Not the least of those is that the observation relies on the planet's transit across the Sun's disk, an extremely rare event seen by astronomers only in 1639, 1761, 1769, 1874, 1882, 2004, and 2012. Last year's early-June transit afforded a last-in-a-lifetime opportunity to replicate Lomonosov's accomplishment; the next transit isn't until 2117. An additional spur was provided by several scientists who questioned whether anyone in the 18th century could have detected Venus's atmosphere with the apparatus then available and who called for a reexamination of the circumstances of discovery. The November 2012 issue of PHYSICS TODAY includes a letter (page 11) expressing skepticism about Lomonosov's discovery along with a brief rebuttal from one of us (Shiltsev).

Mr. Dollond's opus

The 18th-century discovery was incidental to the first truly international scientific effort to determine the yardstick of the solar system—the mean Earth–Sun distance, or astronomical unit. The campaigns of 1761 and 1769 involved some 300 astronomers observing the transit of Venus from more than a hundred stations. But only a dozen observers noted, during ingress or egress, a luminous arc or bright aureole around the portion of Venus's disk off the Sun. Most observers reported that bright arc as a nuisance; only a few jumped to the correct conclusion that they were seeing sunlight refracted through Venus's atmosphere.

Lomonosov (1711–65) saw the luminous arc when observing the 1761 transit at Saint Petersburg, Russia, and he published the most detailed scientific report attributing the aureole to the presence of an atmosphere around the planet. Figure 1a shows one of his sketches from that report. (For more on the great Russian polymath, see the article by Shiltsev in PHYSICS TODAY, February 2012, page 40.) He supplied just enough detail about his apparatus and methods that we decided to attempt to replicate his observations with historically appropriate refractors during the 2012 transit.

Unfortunately, Lomonosov's original telescope—"a 4½-foot-long telescope with two lenses," according to his report—was destroyed during World War II, a victim of the heavy bombardment that leveled Pulkovo Observatory in the suburbs of St. Petersburg. However, Yuri Petrunin, a scholarly collector of historical telescopes and president of the Telescope Engineering Co in Golden, Colorado, discovered a prewar publication indicating that Lomonosov's instrument was almost certainly a double-lens, achromatic (focusing all colors to the same point) telescope produced by the renowned English optician John Dollond. Lomonosov did not specify the aperture of his telescope, but Dollond's astronomical refractors circa 1760 had objective lenses with diameters ranging from 50 to 70 mm. Petrunin thus supplied our colleague Alexandre Koukarine, who was stationed near the Lick Observatory in California, with the telescope shown in figure 2: a 140-cm-long, late-18th-century Dollond achromat with a 67-mm objective and a magnifying power of 37. Shiltsev, observing from Illinois, procured a late-18th-century, 72-cm-long Dollond achromat with a 40-mm objective, magnifying by 23.

In his 1761 report, Lomonosov specified a weak solar filter of "not-so-heavily smoked glass" and noted that he regularly rested his eyes. Accordingly, Shiltsev manufactured a filter following 18th-century methods: He flame-smoked a piece of window glass so that it would reduce the solar intensity to 1/1700th of its unfiltered value—enough so that solar viewing was barely tolerable—and carefully broke it so that it fit into a cell in front of the ocular. To allow for a comparison of 18th- and 21st-century materials, Koukarine employed a modern

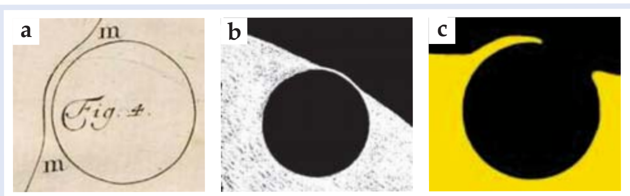

Figure 1. A bulge about Venus arises during the ingress and egress of a transit as sunlight refracts through the Venusian atmosphere. The drawings here are from **(a)** Mikhail Lomonosov's discovery report of 1761 and modern replications by **(b)** Alexandre Koukarine and **(c)** Vladimir Shiltsev.

film filter with a 1/6000 attenuation, stronger than Shiltsev's but much weaker than now-popular 1/100 000 attenuation filters. Both observers limited themselves to 10- to 20-second observing periods per eye, followed by about 20 seconds during which both eyes rested.

To further improve their visual sensitivity, Koukarine and Shiltsev used light shields. And, following 18th-century precedents, they lay on the ground while using tripod-supported telescopes; that allowed them to maintain a relaxed viewing position. Both observers reported excellent image quality—for example, both saw fine details around sunspots.

The envelope, please

On 5 June 2012, Koukarine and Shiltsev clearly saw the aureole indicating Venus's atmosphere—a full or partial arc around the planet—as illustrated in figures 1b and 1c. Unfortunately, another of us (Nesterenko) in Russia and Petrunin in Colorado encountered significant air turbulence and cloud cover and did not observe the aureole with their respective 31- and 57-mm-diameter antique achromats. Their bad luck replicated that of more than a few 18th-century observers.

Figure 2. The 140-cm-long Dollond telescope used by Alexandre Koukarine during the 2012 transit of Venus, with close-ups of the lens housing and eyepiece.

The reason for the sporadic success in the detection of Lomonosov's arc, now and in the past, is that the observation is a complicated process involving the Sun, with its 30-arcminute diameter; Venus, whose diameter is 1/30th that of the Sun; telescope optics; attenuating filters; and the complex human eye. The arc is the refracted image of the Sun that forms at the upper layers of the planet's atmosphere when Venus is near the Sun's edge; its thickness is no more than 1/10 arcsecond. At the beginning of ingress, the arc's intrinsic brightness is a small fraction (0.1–3%) of the Sun's brightness, but as the ingress nears completion the brightness increases to 10–100% of solar luminosity.

The arc is invisible to the unaided human eye. When observed through a telescope, the brightness of the arc is determined by how much its width is spread due to diffraction, an effect inversely proportional to the aperture diameter, and to atmospheric turbulence, which is independent of telescope parameters. For example, for a telescope with good quality optics and under reasonably good atmospheric conditions, the brightness of the arc viewed through the telescope is about 1/40th of its intrinsic value. As with any extended object, the brightness of the arc and Sun should not depend on the optical system's magnification.

Observations in Saskatchewan by one of our teams (Rosenfeld's) supported the above analysis. Rosenfeld and company used high-quality, modern doublet refractors equipped with changeable aperture stops and confirmed that aperture diameter plays the critical instrumental role in the detection of the aureole. They found that the minimum diameter required for a reliable detection of the arc with a standard 1/100 000 filter was about 50 mm. The telescope magnification, they determined, was a less important variable.

When light entering a telescope is attenuated with, for example, a piece of smoked glass, the absolute brightness of the sunlight and arc are reduced by the same factor. Because of the nonlinear response of the eye, the optimal filter to be selected depends on the observational goal. To see the arc around Venus, the weakest filter that allows for comfortable and safe viewing should be used. A stronger filter would be better suited for studying the Sun over a long period, but it would reduce the arc's perceived brightness so much that the arc would be invisible against the background. The use of attenuating filters makes ambient backside illumination at the eyepiece a relatively larger nuisance; it is important, therefore, to reduce stray light.

Unlike Lomonosov, most observers in the 18th century directed their attention exclusively to timing the contacts of Venus with the solar disk. The longer observation periods needed to achieve that goal demanded stronger filters than that used by Lomonosov for detection of the arc. Not all of the instruments of the time could match the quality of the Dollond achromats, which we have found to be significantly superior to lower-end modern instruments. And atmospheric conditions did not always cooperate.

Our experimental studies during the 2012 transit of Venus showed once again that a great discovery involves deep insight into physics on the part of the discoverer, the right instruments and techniques, and a bit of luck. From what we learned through restaging his Enlightenment experience, Lomonosov seems to have been the only one to discover the Venusian atmosphere not by accident but by designing an experimental protocol that made it possible.

The online version of this Quick Study includes additional resources and illustrations.

Additional resources

▶ D. W. Kurtz, ed., *Transits of Venus: New Views of the Solar System and Galaxy*, Cambridge U. Press, New York (2005).

▶ A. Koukarine et al., "Experimental reconstruction of Lomonosov's discovery of Venus's atmosphere with antique refractors during the 2012 transit of Venus," http://arxiv.org/abs/1208.5286.

▶ A. García Muñoz, F. P. Mills, "The June 2012 transit of Venus—framework for interpretation of observations," *Astron. Astrophys.* **547**, A22 (2012).

▶ R. Rosenfeld et al., "The Venus aureole effect: Minimum aperture for visual detection," *J. R. Astron. Soc. Can.* **107**, 29 (2013). ■