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The North American Eclipse of 1869

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A coast-to-coast eclipse on 7 August 1869 gave US astronomers a chance to make their mark on 19th-century astronomy.

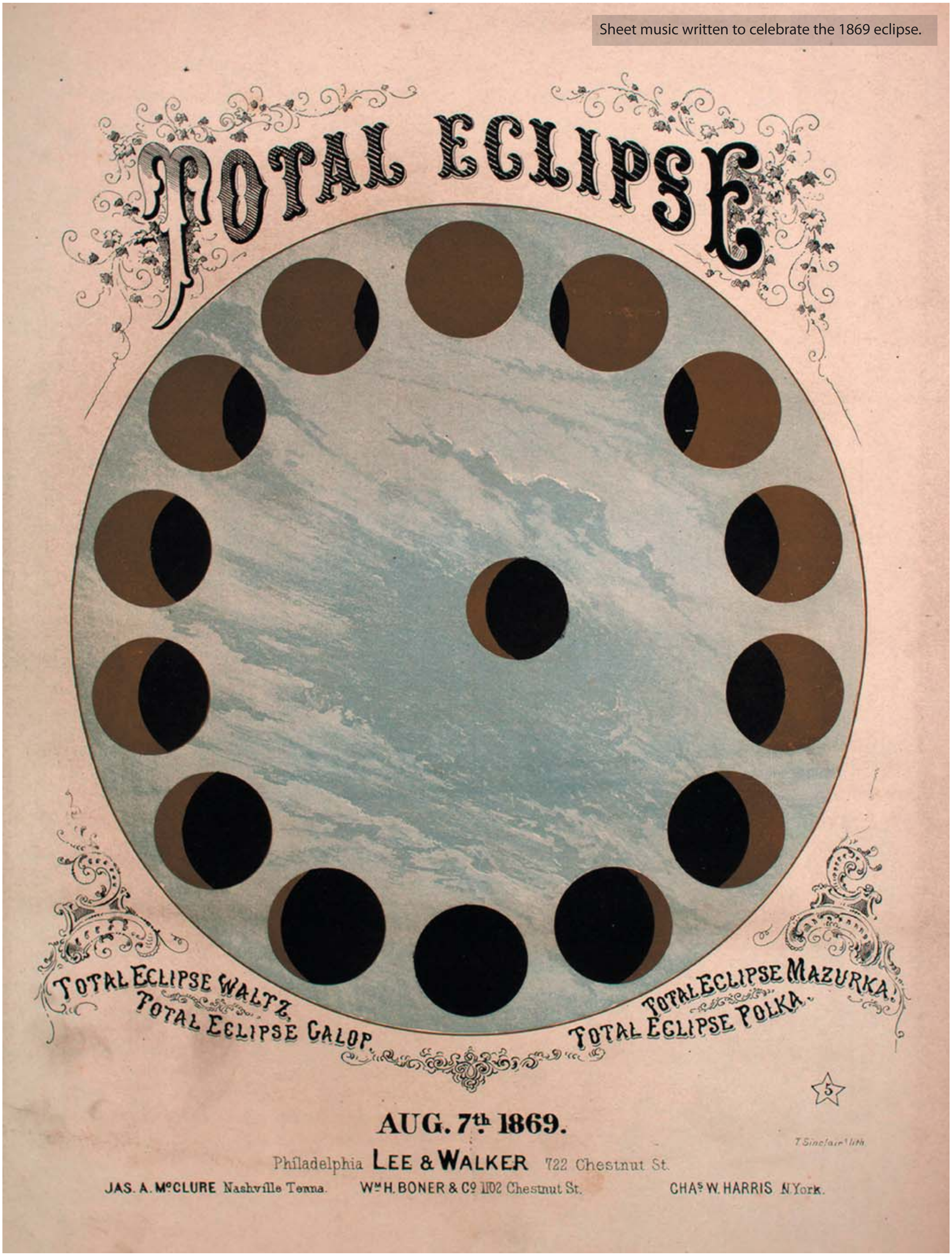
On 7 August 1869, hundreds of scientists awaited mere minutes of solar darkness along an eclipse path that stretched from Alaska to North Carolina. With a good chance of clear summer skies in the central US came a prime opportunity for North American scientists to combine eclipse science with new technology to answer some of astronomy's most pressing questions.

Work in the 1820s gave astronomers mathematical tools to compute eclipse paths in ample time to mount viewing expeditions. Throughout the mid 19th century, such eclipse expeditions enabled astronomers to refine theories of solar and lunar motion to generate tables that would improve navigational accuracy. They also raised new questions about undiscovered celestial bodies, the nature of the solar corona, and the precision of observational techniques.

US astronomers saw the 1869 eclipse as a chance for scientific redemption. They had been sorely disappointed when clouds obscured the eclipse over North America in 1860, and they hoped to use the lessons from that experience for better outcomes the second time around.

Astronomers would also benefit from the expansion of communication with and transportation to the western states. By 1869 messages sent on speedy new telegraph networks

GADO IMAGES/ALAMY STOCK PHOTO.



Sheet music written to celebrate the 1869 eclipse.

facilitated preparations, and freshly built railroads meant bulky instruments and teams of observers could easily reach the zone of totality. There, they aimed to refine tables of lunar motion, explore photography as a measurement tool, and investigate the composition of the chromosphere. US scientists' efforts to prepare for and observe the 1869 eclipse highlight the ambitions of a scientific community just beginning to take its place on the world stage.

Astronomical mysteries to solve

A total solar eclipse observed over Europe on 8 July 1842 generated some enticing questions for astronomers. Reports described brilliant red flames protruding from the lunar disk. What were those rosy prominences? Did they belong to the Sun or the Moon?

The brevity of totality complicated the analysis, but technology brought hope. In 1840 New York University chemistry professor John Draper had made a one-inch-diameter daguerreotype image of the Moon and displayed it in New York City to great acclaim. By 1845 French physicists Armand Fizeau and Jean Foucault had built a camera shutter capable of just 1/60th of a second exposure and used it to photograph the Sun. The race was on to photograph the solar corona.

Meanwhile, astronomers using Newtonian mechanics had predicted the existence of a celestial body large enough to explain the orbital perturbations of Uranus. After the 1846 observation of Neptune confirmed those predictions, new speculation arose about an as yet undiscovered planet that might explain the unaccounted-for drift in Mercury's perihelion. Hopes ran high that the hypothetical body, often called Vulcan, could be spotted near the Sun during an eclipse.

The pride of superior-precision lunar tables was also on the line. Solar eclipse observations on 28 July 1851 verified the US Nautical Almanac Office's claim that its tables for the Moon's position were significantly more accurate than those of its British counterpart. In Washington, DC, predictions in the British almanac were observed to be off by 78 seconds at the start of the eclipse and 62 seconds at the end. The US almanac only missed by 13 seconds and 1.5 seconds.[1] Could the US do even better?

Midcentury astronomers also used eclipse expeditions as practice for observing an even rarer predictable phenomenon: the transit of Venus, when Venus's path crosses between the Sun and Earth. Transits of Venus occur in pairs eight years apart, with pairs separated by more than a century. It has only been observed seven times, first in 1639 and most recently in 2004 and 2012. The transit of Venus won't happen again until 2117. One of the rarest recurring predictable astronomical events, it requires that observers be in a specific location on the globe.

For 19th-century scientists, observing and timing the transit phases would provide data essential for determining the distance between the Sun and Earth. Ultimately, the scientists hoped to tackle one of the great open questions of the time: How big was the solar system? US astronomers were already planning major expeditions to observe upcoming transits of Venus in 1874 and 1882. The two total solar eclipses of the 1860s were a chance for Americans to test observational techniques for even higher-stakes astronomy.

The disappointment of 1860

The total solar eclipse of 18 July 1860, which would arc across the Washington Territory, over the tip of Labrador, and to the Red Sea, seemed like an ideal opportunity to explore those key astronomical questions. The remoteness of totality did not discourage US Navy lieutenant James Gilliss, who boarded a steamer in New York with a few boxes of second-rate equipment and arrived three weeks later in San Francisco. There he joined his son, who was stationed with the US Coast Survey, for a two-week trek to camp just west of the Cascade mountains.

A young navy computer, Simon Newcomb, undertook a far more arduous 47-day journey to the Saskatchewan River. Despite difficult travel through clouds of mosquitoes on a mud-stuck stagecoach and the occasional night in a canoe, he and three colleagues somehow had fireworks to celebrate the Fourth of July.[2] A Coast Survey steamer took 11 other men on a "somewhat dangerous" trip through ice fields, mountain snow, and coastal mist to the northern extremity of Aulezavik Island.[3]

In the end, not much came from those extraordinary efforts. Gilliss got a clear view of the corona, but he didn't have a camera. He reported rosy prominences that "greatly resembled" those he'd seen during an 1858 eclipse in Peru, and he was now certain they were part of the Sun. But the sunrise eclipse was so spectacular that he "was irresistibly drawn to its contempla-

FIGURE 1. THE KEW PHOTOHELIOGRAPH, an instrument that combined a telescope with a camera for eclipse observation and photography, designed by Warren De la Rue. (Courtesy of the Science Museum Group Collection, CC BY 4.0.)

tion" and neglected scientific observations.[4] Newcomb's colleague, entymologist Samuel Scudder, described their party's experience as "three thousand miles of constant travel . . . to reach by heroic endeavor the outer edge of the belt of totality; to sit in a marsh, and view the eclipse through the clouds!"[5] The group in Labrador fared little better. At totality, "nine-tenths of the sky was covered with clouds" and only one astronomer saw a glimpse of the corona.[6] Equally disappointing, clouds thwarted the search for the intra-Mercurial planet.

An ocean away, European scientists accomplished much more with the same eclipse. Aided by the British Admiralty and a newly built railroad in Northern Spain, Royal Society fellow Warren De la Rue transported observational equipment and an entire darkroom to the zone of totality. De la Rue made the controversial choice to use collodion photography (see figure 1), which was more sensitive to light, capable of capturing finer detail, and far less reliable than daguerreotype. His gamble paid off. On 12 September 1860, the *New York Times* gushed that "the rosy flames" shooting out from the eclipsed Sun had been "not only observed, but measured and photographed!" De la Rue's photo of the corona combined with observations like Gilliss's showed that the flames were features of the Sun and not the Moon.

Again in 1868 European astronomers made eclipse news. The Royal Astronomical Society sent John Herschel to Jamkhandi, India, to observe an eclipse on 18 August 1868; he used a telescope outfitted with a prism to study the chemical composition of the solar corona. French astronomer Pierre Janssen undertook a similar spectrographic project. For both, the spectrum of the chromosphere showed an unfamiliar yellow line near the sodium-D lines. It turned out to be helium, an element not isolated on Earth until 1895.[7]

That discovery raised new questions about the chemistry of the corona. US astronomers hoped to find answers during the upcoming solar eclipse of 7 August 1869. The empty experience of the 1860 eclipse informed preparations for the 1869 expeditions. With so much potential for scientific glory, the good fortune of an accessible eclipse path in the US was an opportunity not to be missed for US science.

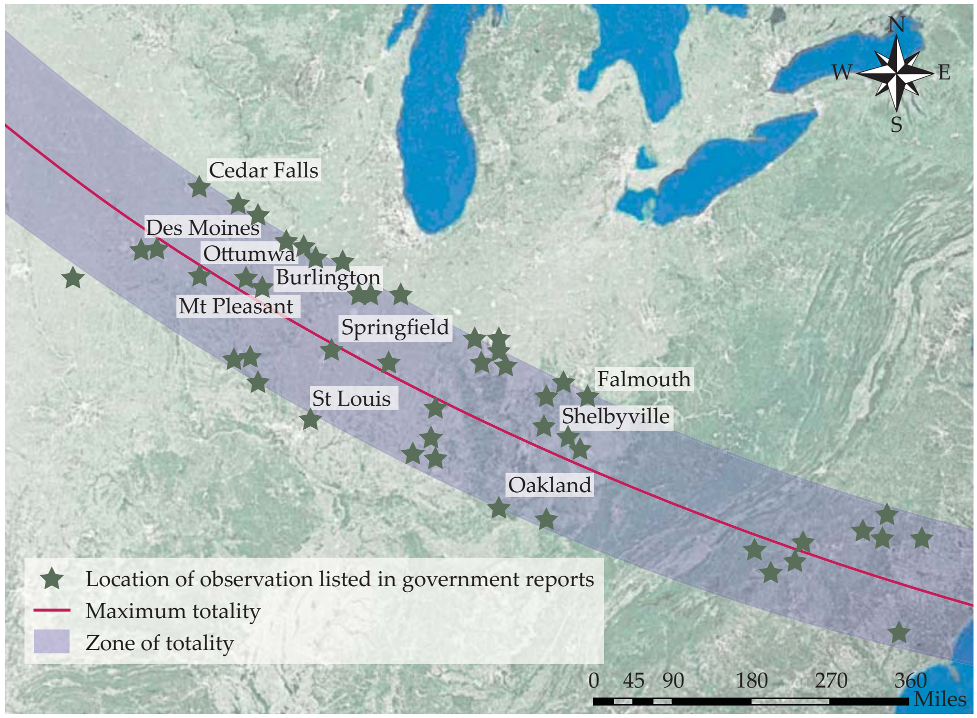


FIGURE 2. A MAP OF 1869 ECLIPSE OBSERVATION SITES and the zone of totality.

Preparations for 1869

Late in 1868 Congress appropriated $5000 for a special expedition directed by James Coffin, a professor of mathematics at the US Naval Academy and the superintendent of the US Nautical Almanac Office. Coffin selected Burlington, Iowa, as his point of observation because both spectators and scientists could easily reach it by train from Chicago (see the map in figure 2). In anticipation, the Burlington City Council formed a committee for the support of eclipse visitors; police were provided to guard the observatory at night and control crowds on eclipse day.

In May, Coffin asked Henry Morton, University of Pennsylvania chemistry professor and secretary of the Franklin Institute, to organize a party of photographers to join the expedition. Shipments to Iowa left Washington, DC, in late June so temporary observatories could be built. Preparations proceeded for official scientific tasks: observe the corona, conduct spectral analysis, search for intra-Mercurial planetoids, and photograph phases of the eclipse, especially totality.

Meanwhile, the Burlington Collegiate Institute offered its telescope to astronomer Maria Mitchell and a cohort of 11 current and former Vassar College students who had made eclipse calculations in Mitchell's classes. Among them was Coffin's daughter Martha.

The Coast Survey planned to station personnel and equipment all along the path of totality. Coast Survey explorer George Davidson had surveyed Alaska before its final purchase in 1868 and specifically mapped the Chilkat River in anticipation of observing the eclipse there. Asaph Hall, a US Naval Observatory professor of mathematics, was sent to the Bering Strait. Cincinnati Observatory director Cleveland Abbe led a wagon train to the northwestern end of the eclipse path in the Dakota Territory.

Farther east, Coast Survey staff began finding the geographical positions of their observing locations in April. Violent thunderstorms slowed survey work and made camping in the prairies miserable. The president of Western Union Telegraph Company helped by arranging an extensive telegraph relay and donating free use of the wires for the determination of longitude.[8]

From the US Naval Corps, Newcomb, William Harkness, and J. R. Eastman, along with assistant surgeon general Edward

FIGURE 3. A PHOTOGRAPH OF TOTALITY obtained at Burlington, Iowa. (From ref. 8.)

Curtis, would observe in Des Moines, Iowa, the westernmost site of totality that was accessible by railroad. Not knowing what to expect so far west, Curtis, Eastman, and Harkness arrived in Des Moines a month before the eclipse. Harkness found a builder to construct an observatory with a darkroom at the chosen hilltop site overlooking the river at the outskirts of town. Starting 10 July, Eastman and his wife meticulously recorded hourly meteorological observations.

In the weeks leading up to the eclipse, Curtis and his assistants rehearsed an elaborate choreography of exposing and developing a range of photographic plates in various weather conditions. They would have only about three minutes to attempt to capture a coronal image with a multistep photographic process. To practice, they self-imposed narrow time constraints for taking a photograph to replicate the immediacy of the anticipated eclipse event.

Academic astronomers also planned to take advantage of the eclipse. Joseph Winlock, director of the Harvard Observatory, made arrangements for several stations in his home state of Kentucky. Harvard University mathematics professor and Coast Survey superintendent Benjamin Peirce would oversee observations in Springfield, Illinois. Scientific parties were also assembled for Tennessee, Kentucky, and Virginia to distribute observers and reduce the risk of being completely clouded out.

Photography for research

Despite successes like De la Rue's, the status of photography as a research tool remained uncertain in the mid 19th century.[9] US scientists saw the 1869 eclipse as an opportunity to explore its utility during a high-stakes astronomical event. In particular, they hoped photography could produce images that would be measured after the event to determine precise times of the principal eclipse phases. They hoped similar photographs of the transit of Venus in 1874 could be used to determine the exact time at which Venus crossed in front of the Sun, information that could enable them to calculate a precise value for solar parallax.

Morton recruited 20 Philadelphia-area volunteer photographers to join Coffin's party. For months, they practiced astrophotography in a purpose-built temporary structure on private grounds in West Philadelphia. They used two equatorially mounted telescopes, one with a 6-inch aperture and 9-foot focal length borrowed from Philadelphia High School and the other with a 6.42-inch aperture and 8.5-foot focal length lent by Pennsylvania College at Gettysburg. Both instruments were outfitted with chronographs to record the time each photo was taken. From the University of Pennsylvania, Coffin's group had a third equatorial telescope, with 4-inch aperture and no clockwork. The volunteers experimented with developer fluids, photographed the Moon to set time exposures, made mechanical adjustments, and refined techniques in hopes of precise work during the eclipse event.

Exactly a week before eclipse day, the photographers loaded more than five furniture cartloads of equipment into a custom car furnished by the Pennsylvania Central Railroad Company. Railroad companies also donated free transportation for the entire Philadelphia photographers' expedition, a generosity that stretched Coffin's government appropriation by $1500.

Picturing totality

Alfred Mayer, an astronomy professor at Lehigh University, joined Coffin in Burlington around noon on Wednesday, 4 August. Torrential rains on Friday night meant a sleepless night of nerves and instrument adjustments for Mayer, but the clouds cleared by 10:00am. Everything was ready by 3:00pm, about one hour before first contact, when the Moon starts to pass in front of the solar disk. By taking a rapid sequence of exposures around the calculated time of first contact, they got a photo of first contact and, as a pleased Morton put it in a Naval Observatory report, "a very good result."[10] The Burlington team also took six pictures of totality (see figure 3).

In Mount Pleasant, Iowa, 28 miles farther west in the zone of totality, a second party set up the University of Pennsylvania telescope under the guidance of Morton and MIT professor Edward Pickering. That group used a globe lens with a 12-inch

FIGURE 4. AN ECLIPSE OBSERVATION SITE AT OTTUMWA, IOWA. This building was constructed to enable eclipse observation and photography. (Digital positive from the original collodion silver negative in the George Eastman Museum collection. © George Eastman House.)

focal length to capture the most extensive photo of the 1869 corona. Their 41 total photos also included one with an improbably slight indentation between the shadow of the Moon and the bright edge of the Sun—given contemporary predictions and technology, it would be nearly impossible to photograph first contact exactly. From that valuable image, said Morton, calculations would produce the time of actual first contact "more precisely than would be possible with any eye observation."[10]

Dickinson College professor Charles Himes and his party took the Pennsylvania College telescope 75 miles west of Burlington to the Ottumwa, Iowa, observation site (see figure 4). The group did not fare as well as the Burlington and Mount Pleasant teams. Severe thunderstorms ruined the observatory roof. They had also forgotten their chronometer in Burlington, and, worse, the telescope clockwork suffered serious damage in transit. Instrument maker Joseph Zentmayer avoided catastrophe by rebuilding the chronograph in record time. In the end, with clear skies Saturday afternoon, they obtained 34 negatives—including four pictures of totality.

The Philadelphia photographers were not the only ones who successfully photographed the 1869 eclipse. In Shelbyville, Kentucky, Winlock's alma mater and prior employer Shelby College provided accommodations for more than a dozen observers. The college lent its state-of-the-art telescope to Winlock. His main goals were to capture a good photograph of the corona and to establish a systematic approach to determining via photograph the relative positions of celestial bodies. To achieve the latter, he kept the camera in the same position throughout the eclipse, with the aim of comparing partial and total views to determine accurate position angles between the Sun, Moon, and Earth. Those hopes were largely dashed, but his goal of photographing the corona was better realized. Winlock was pleased with his seven photos of totality.

Peirce's party in Springfield included a trio of photographers and their assistant along with an entourage of Coast Survey assistants, Harvard faculty, and students. With them, Boston photographer James Wallace Black took 178 photos at nine-second intervals. On their plates, the Sun's image was about two-thirds of an inch in diameter. In Des Moines, navy observers' elaborate practice routine paid off. Curtis made a total of 115 photographs, including two remarkable images of totality.

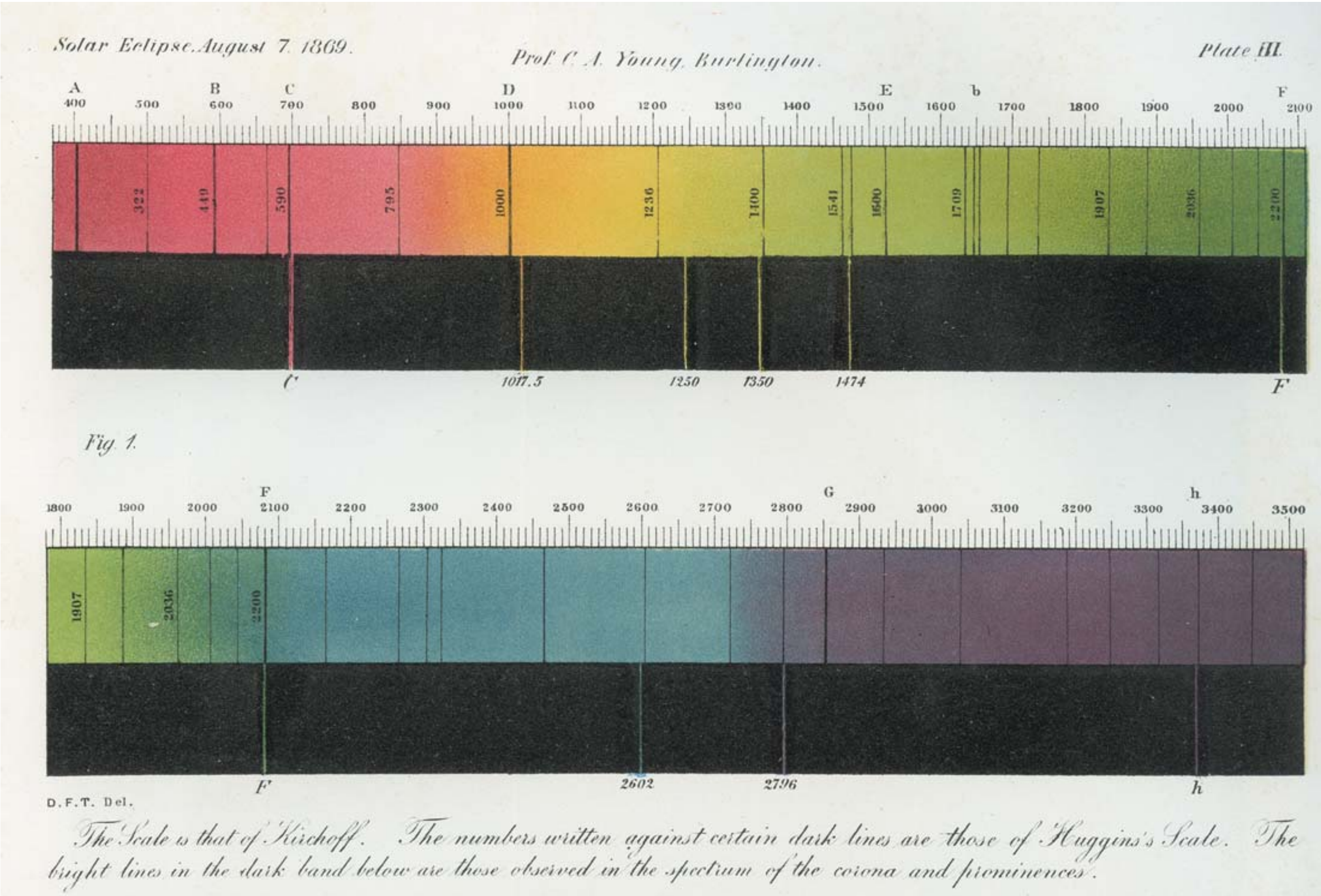


FIGURE 5. CHARLES AUGUSTUS YOUNG'S SPECTRUM of the corona. (From ref. 8.)

Spectroscopy and the 1869 eclipse

Since spectroscopic results from the 1868 eclipse had yielded insight into the content of the corona, US scientists hoped the 1869 eclipse observations would produce more information about the chemical composition of the Sun. Spectroscopes were less common instruments than telescopes and chronometers, however, and not every observing party had one. Davidson, for example, had initially hoped for spectroscopic readings in Alaska, but he was told in May that no one had volunteered for the daunting journey to deliver an instrument there.

The most productive spectroscopic results came from Charles Augustus Young, an astronomy professor at Dartmouth College who was with Coffin's party in Burlington. Young used various Dartmouth instruments to rig up a spectroscope with five prisms. The instrument, Young wrote, had been arranged "in a manner somewhat different from anything heretofore used, but which proved efficient."[11] Young observed initial contact through his spectroscope and concluded that the approach would be ideal for timing the transit of Venus. During totality, he observed a green line, K1474, that appeared from the coronal light beyond the prominences; he concluded it belonged to the spectrum of the corona (see figure 5).

Harkness obtained similar results in Des Moines. He used a single-prism spectroscope originally designed for use in laboratory chemistry, but significantly altered and attached to his personal 3-inch telescope for eclipse observations. Like Young, Harkness also observed a coronal spectrum containing a bright green line.

Collecting better eclipse data

In November 1868, Peirce wrote to Davidson that the highest Coast Survey priority during the eclipse was to "secure the greatest precision in observing the phases, times, &c. with reference to data for the longitude."[12] To that end, Davidson took 17 chronometers north from San Francisco. He left 9 of them in Sitka, Alaska, and traveled the last 250 miles over dangerous rivers in an open canoe. His use of multiple timepieces illustrates his interest in minimizing error.

Similar concerns about error led the Coast Survey to distribute observers across the zone of totality. Observations from multiple stations at different sites could be averaged to yield a more accurate value for the Moon's distance from Earth. Coast Survey observers in Des Moines were sent out to determine the north and south limits of totality. A group of at least eight headed toward St Louis, Missouri. They stationed themselves at one-mile intervals near the calculated limit, and each observer timed totality. Five other observers headed toward Cedar Falls, Iowa, and spread out to three different points in an effort to locate the northern boundary of the eclipse path.

Observers were likewise dispatched at intervals near the limits of totality in Kentucky. Arthur Searle, from the Harvard Observatory, had marked stations to measure the breadth of the Moon's shadow. Searle himself was stationed at Falmouth, Kentucky, just inside the line of totality. A mechanical malfunction voided his timing, but others in his party noted that the duration of totality was 45 seconds. On a hill just north of Falmouth, two observers recorded 41.5 seconds. Another pair nearer the northern limit timed 12 seconds of totality, and two farther out missed it entirely. Near the southern boundary of totality in Oakland, Kentucky, Samuel Langley, director of the Allegheny Observatory outside Pittsburgh, Pennsylvania, clocked just two seconds of totality.

Newcomb's 1869 eclipse work also focused on precision. He observed from Des Moines in conditions that must have seemed luxurious compared with his backwoods ordeal of 1860. He arrived in Iowa at the end of July and staged his search for intra-Mercurial planetoids from the statehouse yard. Not seeing any new planets during totality, he switched focus to comparing observed times of contact with those predicted by existing tables to check theories of solar and lunar motion. He found discrepancies of several tenths of a second.

The afterglow

Newspapers from San Francisco to New Hampshire and even overseas carried news of the total solar eclipse across North America. Millions witnessed a partial eclipse as far east as Boston and as far west as California. Thousands traveled to experience totality, which Newcomb described as "glorious beyond description."[13] Newspapers also circulated glowing descriptions of both the flaming corona and the eerie features preceding totality.

And what of the scientific venture? The search for an intra-Mercurial planet came up empty, and reams of painstakingly recorded meteorological data did not prove illuminating. Still, the parties exceeded contemporary expectations in the number and precision of eclipse observations collected. Spectroscopic work by Harkness and Young resulted in the discovery of a new coronal line, K1474. For a time, observers believed it was from a new element that they named coronium; it would be another 70 years before the K1474 line was correctly attributed to highly ionized iron at over 1 million kelvins.

Remarkable photographs of the eclipse also established hope for photography as a useful astronomical tool. Micrometric analysis of the glass-plate negatives generated improvements to photographic measurement before the transit of Venus.

After his 1869 experience, Mayer saw potential for photography to produce "solar parallax comporting with the most exact astronomical measures of this century."[14] The efforts and output of the 1869 expeditions gave the 19th-century American audience something to celebrate. It also gave scientific practitioners valuable experience with equipment and techniques for major event science.

In 1874 patriotic arguments swayed Congress to grant a staggering $177 000 for the Transit of Venus Commission. This funded eight expeditions to locations that included the Kerguelen Islands in the Southern Indian Ocean; Hobart, Tasmania; Peking, China; and Vladivostok, Russia.[15] Alas, eight sets of new equipment and many observers with eclipse experience were no match for a day of bad weather and the black-drop effect—when a dark linkage between the end of Venus's silhouette and the sky develops for a few seconds before Venus is clearly inside the Sun's disk. The black drop made it impossible to time the contacts precisely.[16]

By 1882 Newcomb had abandoned hope that photography could help calculate the distance from Earth to the Sun, but Harkness persisted. He obtained more appropriations—$10 000 to improve instruments and $75 000 for the expeditions—for the 1882 Transit of Venus. In the end, he produced a landmark result. By early 1889 Harkness had measured and analyzed 1475 photographs to arrive at a final result of 92 455 000 ± 123 400 miles. In 1894 he refined that result to 92 797 000 ± 59 000 miles.[17] In 2012, the International Astronomical Union adopted a value of 149 597 870 700 meters (92 955 807 miles) for the astronomical unit, a measure of the average distance to the Sun.

The second half of the 19th century was arguably the golden age of eclipse expeditions. Then, as now, observational astronomers made herculean efforts to organize and implement major projects to gain insight on the biggest scientific questions of the day. The success of extensive planning and major expenditures depended on accurate theories and well-posed questions and also on the vagaries of weather and technology. And observers had to deliver despite the thrall of mesmerizing events. For the US, the 1869 eclipse expeditions merged new transportation technologies with the marvel of celestial observation. They capitalized on the technologies of astrophotography and deployed legions of government and civilian scientific practitioners who would build on that experience in future high-stakes astronomical events. The great success and attendant publicity boosted US astronomy and laid a foundation for the ventures to come.

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