19th-Century Eclipse Expeditions and the Forging of Mathematical Communities

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A total solar eclipse brings a transcendent wonder. This rare celestial event happens when seasons and orbits align for the Moon to pass between the Earth and the Sun, temporarily obscuring its full wattage and leaving visible the spectacular solar corona. The phenomenon comes with chilly wind and an eerie hush and – just for a few minutes – it's safe to remove your eclipse glasses and gape at the spellbinding sight. It's an incredible experience, one I absolutely recommend if you have an opportunity.

I first experienced eclipse totality in August of 2017. I had no idea at the time either that eclipse expeditions would be almost as relevant to my own work and experience of the professional community as they were for 19th-century mathematical practitioners. There's a particular connective power to the shared experience, perhaps as effective now (and in the future) as it was in the 19th century. Still, the story today begins with a decided lack of community. We'll start in 1840, in the United States, in Cambridge, MA, where Benjamin Peirce was a professor of Mathematics at Harvard. It was a time when technical scientific or mathematical training in the US was rare, and the educated elite remained sceptical about science as a profession. There was no well-formed identity for an American scientist, much less an American *mathematician.* Peirce, nonetheless, had big ambitions to develop and showcase American mathematical talent. His effort to start the first research-level mathematical publication in the United States failed within a year. With only about 360 mathematical practitioners in the country – most of whom had been trained in law or theology – there simply wasn't a community substantial enough to sustain it. had nonetheless published a manifesto about astronomical work as *the* avenue for American science to establish itself internationally.

A big chance came in 1846. That year, the observation of a new planet Neptune, and the international priority controversy surrounding it provided a key opportunity for Peirce to stake a claim for American mathematical practitioners on the global stage. It's a drama of astronomical rivalry, full of controversy between Britain and France (with a late entry from the United States).

In 1781, Caroline Herschel and her brother John Herschel observed a new planet Uranus, which soon deviated from its calculated orbit. As the planet appeared to go further and further off track, astronomers puzzled over explanations. Both John Couch Adams (who had recently graduated from Cambridge as Senior Wrangler and Smith Prize winner) and Urbain Le Verrier (an established French astronomer who had done extensive study of the motion of Mercury) independently predicted the existence of a never-before-seen planet to explain the apparent disruption to the orbit of Uranus. They used Newton's gravitational theory and Kepler's laws of planetary motion to predict the mass and position of this hypothetical body. When the new planet was spotted from an observatory in Berlin, scientific administrators in France and England felt robbed of planetary glory. The squabble meant Peirce and the Americans quickly calculated the orbit of Neptune to salvage some share of the success.

Still, the biggest winner was probably Newton's theory of gravitation: By mathematics alone, a new planet had been predicted to exist and then discovered! This raised tantalizing questions about what *other* big questions mathematics might be able to solve. For one, there was an unexplained wobble that had been observed in the orbit of Mercury – something called the precession of the perihelion of Mercury. Le Verrier had thought a lot about the motion of Mercury and proposed the Neptune trick might work again. Could another new planet solve this second mystery? Excitement ran high, and this phantom planet took on the name of Vulcan.

One challenge with *seeing* Vulcan, though, would be its proximity to the Sun's brightness. Astronomers knew it'd be easiest to observe the vicinity of the Sun during the precious few minutes of a total solar eclipse. This became one of the outstanding scientific questions pursued by eclipse expeditions in the second half of the 19th century: Is there a currently unknown planet between Mercury and the Sun?

A total solar eclipse also provided an opportunity to test models of the (notoriously tricky) motion of the moon. Lunar theory related to navigational accuracy, so was connected to national concerns of military, trade, and commerce. In 1849, the US Naval Appropriations Act authorized an official American almanac to avoid dependence on foreign sources for astronomical data. Solar eclipse observations on 28 July 1851 brought triumphant vindication: the US Nautical Almanac Office's new tables of the Moon's position were significantly more accurate than those of its British counterpart (The Brits do not seem to have cared). That same year brought a huge milestone for the developing technology of photography. The first photograph of the Moon had been displayed in New York City in 1840. To photograph the Sun would require a faster shutter and one was developed in 1845. This paved the way for Berkowski to produce the first photograph of the solar corona during eclipse totality in Königsberg in July of 1851. With this success came a new debate: Could photography become a reliable astronomical tool?

The second half of the 19th century – the so-called golden age of solar eclipse expeditions – brought many opportunities to find out. A new mathematical approach to calculating the path of eclipse totality meant astronomers had plenty of time to plan and organize eclipse expeditions to reach the zone of totality. Mid-century astronomers were especially keen to use eclipse expeditions as a practice to observe an even rarer predictable occurrence: the transit of Venus. Venus passes between the Sun and the Earth twice, eight years apart, about every 125 years. From Earth, it's possible to observe Venus transit the Sun. This has only been observed seven times, first in 1639 and most recently in 2004 and 2012. It won't happen again until 2117. For 19th-century scientists, timing the phases of Venus during its transits in 1874 and 1882 would provide essential data for determining the distance between the Sun and Earth. They hoped to answer one of the great open questions of the time: How big is the solar system? The run of accessible eclipses gave invaluable practice with observational tools and techniques for even higher-stakes astronomy.

US Navy Lieutenant James Gilliss took a few boxes of second-rate equipment and travelled for three weeks on a steamer from New York to San Francisco. His son was stationed there with the US Coast Survey and together they travelled two weeks more to camp near the Cascade mountains. Gilliss had a clear view, but no camera. He also found the sunrise eclipse was so spectacular that he "was irresistibly drawn to its contemplation" and neglected scientific observations. (A very relatable sentiment, for anyone who's experienced eclipse totality). That was the best outcome from the three American parties. The second, a small party who travelled for 47 days to the Saskatchewan River braved clouds of mosquitoes, a broken stagecoach, and overnights in a leaky canoe. After all that, on eclipse day, they sat in a marsh while clouds obscured the corona. And then made the long trudge home again. The third group of American eclipse hopefuls in 1860 was a team of 11, who navigated a Coast Survey steamship through ice fields, mountain snow, and coastal mist to the northern extremity of Aulezavik Island. There, cloud cover met totality and only one person – someone left on the boat, with no equipment – caught a glimpse of the corona.

An ocean away, Royal Society fellow Warren De la Rue had the help of the British Admiralty and a new railroad in Northern Spain. He transported this purpose-built Kew Photoheliograph and an entire dark room to the zone of totality. He gambled on collodion photography, a risky new technique that had the potential to capture much finer detail than the existing standard. It worked. De la Rue's sensational photo of the Sun's "rosy flames" made headlines around the world. This British success only compounded US disappointment in 1860. They resolved to take full advantage when eclipse totality again returned to North America in 1869. Planning started in 1867 when the transfer of Alaska coincided with Benjamin Peirce becoming Superintendent of the US Coast Survey.

The path of totality in 1869 would cover a great belt of inhabited country, much of it accessible by newly built railroads, and supplied with telegraph lines. The railroads facilitated the transport of bulky observational equipment and dark rooms for developing photographs, while the telegraph lines meant surveyors could determine longitude for observers. In charge of governmental mapping and exploration, Peirce promptly sent surveyors to Alaska to locate a path to reach the inland path of totality. Chilkat Tlingit Chief Kohklux drew this map of ancestral trade routes that were invaluable for USCS personnel to observe the eclipse. It's the oldest known map of southwest Yukon. Drawn in pencil, it shows trade routes and landmarks stretching hundreds of kilometres inland from the village of Klukwan, Alaska, traversing the traditional territory of several First

Nations.

While the Americans were busy planning for 1869, another path of totality crossed the Indian subcontinent on 17 August 1868 and European astronomers again made news. The Royal Astronomical Society had sent John Herschel to Jamkhandi, India, with this single prism spectroscope to study the chemical composition of the solar corona. French astronomer Pierre Janssen made similar observations. For both, the spectrum of the chromosphere showed an unfamiliar line near sodium-D. They had detected helium (named after Helios, for the Sun), an element first isolated on Earth in 1895. This discovery raised new questions about the chemical composition of the solar corona and put new items on the US Eclipse to-do list. Charles Augustus Young, who had become a Dartmouth professor of Natural Philosophy and Astronomy in 1866 after his Civil War service, "immediately took up solar spectroscopy, initiating a research trajectory that would make him by century's end one of America's most significant astronomers." Young developed a new style of spectroscope, in hopes of more effectively identifying elements in the corona.

As Peirce oversaw US preparations for eclipse observation in 1869, he viewed it as "nothing less than a duty owing to civilization that everything in our power and within our means should be done to make the observations as complete as possible." Available means included a $ 5,000 Congressional appropriation (via the Secretary of the Navy), travel and custom rail cars in excess of $2,000 donated by the railroads.[1] The total 1869-70 CS appropriation of $487,000 covered equipment and survey personnel in the region of totality. About 35% of the 1869-70 CS report focused on eclipse. Other participating governmental agencies included the US Naval Observatory, the Hydrographic Office, the Surgeon General's Office, the Army Medical Museum, and the Naval Academy. There were also observing parties organized and outfitted by individual observatories and colleges. The photo of the temporary observatory built in Burlington, Iowa (an easy train journey from Chicago, IL, and the destination for thousands of eclipse watchers) shows a posed scientific party. The group included Maria Mitchell, a professor at Vassar College, and some of her female students, whose scientific visit created a sensation in the local newspapers.

Charles Young also observed in Burlington, with this spectroscope he designed and built himself. It successfully captured the green coronal line, *K1474* was first thought to be another new element initially called Coronium, but in the early 20th century was determined to be highly ionized iron. Nearby in Des Moines, Iowa (the furthest west in the band of totality that was accessible by railroad), Simon Newcomb recorded his eclipse-day disappointment in his diary. Here, he writes how he was sad not to find an intra-mercurial planet (as you would be).

But, overall, the 1869 eclipse observations were viewed as a tremendous success – The effort produced photographs and observational data as well as exciting tremendous popular interest. Newspapers from San Francisco to New Hampshire described the flaming corona and the eeriness of impending totality. Thousands witnessed at least a partial eclipse as far east as Boston and as far west as California. This level of interest led to increased governmental funding "to supply astronomers for scientific expeditions."

One other – perhaps surprising – outcome of this eclipse expedition is the beginning of what is currently one of the highest-ranked journals in mathematics. *The Annals* had the unlikeliest of starts – in Des Moines, Iowa, under the editorship of Joel Hendricks. Hendricks was self-taught in mathematics and astronomy and had made money as a railroad surveyor. He was essentially retired, and living with his family in Des Moines, then viewed as the "border of civilization." Not a likely candidate to start and sustain a mathematical research journal, but he knew the mayor, and the mayor there threw a party for the visiting eclipse scientists. There, Hendricks met and mingled with East Coast scientists he likely never would have met otherwise. So when, a few years later, his idea of a mathematical journal is realised, he draws on a wide network of correspondents in Boston, Italy, the UK, etc, and it becomes unprecedentedly successful, running for 10 years before being taken over by the University of Virginia, then to Harvard, then to Princeton, where it's now edited jointly with the Institute for Advanced Study. This, perhaps unexpected, outcome for an eclipse expedition exemplifies the potential of scientific meetings to foster surprising collaborations and new ideas. A bit less surprising is that enthusiasm about the 1869 eclipse generated momentum for planning expeditions to observe eclipse totality in Spain in 1870.

Peirce planned to go himself – it would be his only international trip – and viewed the constitution of the Sun as "one of the chief scientific problems of our time." He thought the 1870 eclipse "afforded an opportunity for removing the last obscurity from the subject of the corona." It didn't exactly accomplish THAT, but the eclipse

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[1] In 1869, $5000 now has a current economy cost of just over $17,000,000 and $2000 in 1869 has a current economy cost of about $6,800,000. Measuringworth.com

in 1870 did generate widespread excitement.

A map of the camp of the US observation party gives a sense of the size of their expedition party – there's a transit observatory, a photographer's tent, a spectroscope tent, and telescopes outside, too. One observer in the group was Zina Fay Peirce, known as an American feminist and founder of the "cooperative housekeeping movement." Zina had married Charles Sanders Peirce, who worked with his father at the Coast Survey, which is how she found herself on a ship crossing the Atlantic to observe an eclipse in Italy.

During the weeks at sea, Zina pinned a photo of the moon to the canopy of her bed so she could look up at it and practice drawing a reasonable likeness in under 2 minutes. About her eclipse experience, Zina said "The time is too brief, the novelty too complete, and the agitation too great, I am convinced, for a person observing an eclipse for the first time, to see truly more than one point in it." Still, her preparation paid off. Zina produced this sketch that captures three dark lines, "all I brought away with me, all that I can vouch for in what I did see, are my three dark rays." Her father-in-law declared the 1870 observations to be "the triumphant vindication of the American observations of the year before, the novelty of which had made them somewhat suspected in Europe, as well as the establishment of the superior accuracy of the American predictions."

At a time when sciences were not yet well-established in the US, solar eclipse expeditions generated public interest and support. Connections forged beneath – and about – the sun's shadow, sustained networks of communication, facilitated periodical publication, and set precedent for government funding in support of mathematical activity in the 19th- and early 20th-century United States. This provided the growing scientific community with a platform to advance mathematics and astronomy in the US. The highly publicized 1878 eclipse across North America involved a (mistaken) sighting of the planet Vulcan. Spoiler: It's not there.

Newton's gravitational theory, powerful enough to predict Neptune, could only explain half of the observed shift in Mercury's solar orbit. As the closest planet to the Sun, Mercury occupies a region of the solar system where Einstein's theory suggested the Sun's mass would disturb spacetime. Eclipse observations in 1919 and 1922 confirmed Einstein's predictions and ushered in an era of General Relativity in what is probably the most famous result of an eclipse expedition.

Many other eclipse expeditions also provide great material for historical research. This work has developed a community of researchers captivated by 19th-century eclipse expeditions, including a number of early-career scholars whose projects at St Andrew's have developed into publications and funded graduate research positions. They join a global community of scholars from the South Pacific, the Indian subcontinent, China and South Asia, Europe and the African regions who will gather next year at an ICMS-funded workshop. This ambitious meeting will bring together a cross-cultural, interdisciplinary cohort of scholars with the vision of generating a coherent sense of shared ownership of the mathematical tradition of eclipse reckoning.

As in the 19th Century, present-day astronomers also see solar darkness as a valuable, time-limited opportunity for observation. Now, as then, high-stakes astronomical expeditions depend not only on well-posed scientific questions and adequate funding but also on the vagaries of changeable weather and delicate instruments. They also involve networks of scientists working alongside civilian observers. You, too, can share the collective experience of eclipse observation with several accessible paths of totality in 2024, 2026, 2027, and 2028. Mark your calendars now for an opportunity to forge your own connections in the shadow of the sun!

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