The Victorian Space Program

by Trudy E. Bell

THE VICTORIAN ERA WAS A HEYDAY of adventure science. Botanists, geologists, naturalists, geographers, anthropologists, and other scientific explorers fanned out into African deserts, Amazonian jungles, and Arctic ice packs, risking disease, disability, and death itself—all for samples of plants, rocks, insects, spoken syllables, or even for one solitary measurement (e.g., the ultimate source of the Nile). Their isolated years in the wilds were financed not only by private philanthropists, but also by governments hungry for the international prestige of having their countrymen be the *first* to find The Grand Answer (The Grand Question, of course, depending on the scientific field).

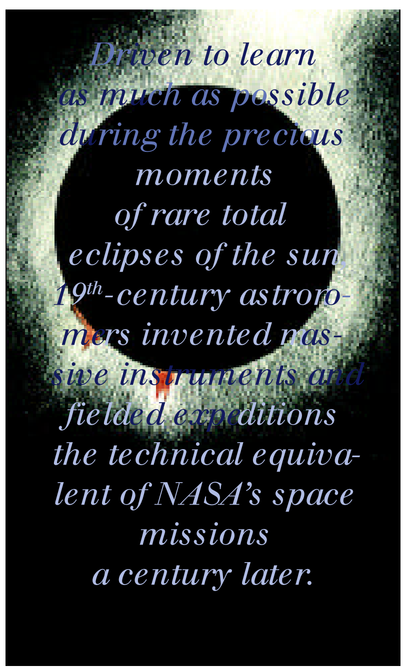
Prominent among 19th-century scientific adventurers was a crowd now surprisingly forgotten: solar astronomers.[1]

Their quest? To be in the right spot at the right instant when the moon passed exactly in front of the sun, completely blocking its blinding disk in a total solar eclipse. Only those rare precious minutes of midnight at midday allowed observations that were then impossible to obtain any other way.

When an expedition costing untold dollars, months, and sweat is focused on observing a unique event shorter than 450 seconds with no second chance, what are the highest priorities?

To use 21st-century terminology: maximizing the data rate and reliability.

Therein lie fascinating little-known tales. Total-solar-eclipse expeditions in the last half of the 19th century were the most advanced field expeditions of any science, technically equivalent to NASA's planetary flybys or manned lunar landings a century later.



WHY TOTALITY?

The international race for totality started in a classic incident of scientific serendipity.

Total solar eclipses are comparatively rare. Although the sun is partially eclipsed at least twice every year—an event visible from an area thousands of miles wide and long—an eclipse may not be total anywhere on the earth. Even if it were, it could be seen as total only from within a narrow path swept from west to east by the tip of the darkest central cone of the moon's shadow (the umbra). Although also thousands of miles long, the path of totality is always less than 170 miles wide and is usually much narrower: visualize a string draped in an arc over a classroom globe. Finally, from any one spot on the earth totality never lasts longer than seven-and-a-half minutes, and typically lasts only two or three.

Upshot: *good* total eclipses of the sun—defined as ones with more than a minute of totality over accessible land with decent weather prospects when the sun is relatively high in the sky—occur only a few dozen times per century. And in keeping with Murphy's law, they are usually inconveniently distant (the next total solar eclipse visible from the continental United States is 2017; the last one was 1979).

The eclipse that riveted the attention of the world's astronomers on the sun was that of July 7, 1842, when totality was predicted to sweep across the south of densely populated continental Europe.

It's essential to recall that early 19th century astronomy was less about the cosmos than it was about using the heavens as a reference frame for the earth. Astronomers tracked the positions and motions of the sun and moon to check the mathematics of lunar orbital theory for determining longitudes on both land and sea.

Astronomers realized that the route of the path of totality for the July 7, 1842, eclipse offered an unparalleled opportunity to correct longitudes of many European locales hundreds of miles apart and thereby to link isolated regional maps into a coherent whole. So that summer, the most distinguished observers of Europe carried portable telescopes and clocks to southern France and northern Italy, after having devoted months in training themselves how to time the four *contacts:* the precise instants the moon's leading and trailing edges would obscure and uncover the sun's disk.

Well, serendipity has been defined as digging for fishing worms and striking gold. What astronomers actually

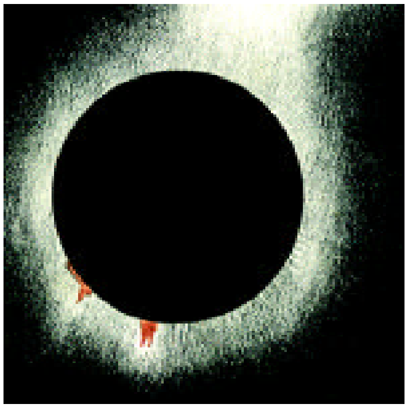


Fig. 1.
The wholly unexpected appearance of brilliant scarlet flame-like prominences ("red protuberances") and of the gossamer silvery corona to so many trained observers in southern Europe during the total eclipse of the sun of July 7, 1842 astounded astronomers. Those phenomena—coupled with Samuel Heinrich Schwabe's announcement a year later of a periodicity of sun spots—launched the Victorian "space program" of worldwide eclipse expeditions, fully comparable in technical complexity to NASA's moon landings and planetary flybys more than a century later.

Source: Plate labeled "Biela in Padua," frontispiece to O. M. Mitchel's *Sidereal Messenger,* vol. 1, no. 3, September 1846 (opposite p. 17).

saw that clear summer day left them stunned, as illustrated by the report of British astronomer Francis Baily, a founder of the Royal Astronomical Society, watching from a room in Pavia, Italy:

> *I was astounded by a tremendous burst of applause from the streets below, and at the* same moment *was electrified by the sight of…the dark body of the moon…*suddenly *surrounded by a* corona, *or kind of bright glory…. But the most remarkable circumstance attending this phenomenon was the appearance of* three large protuberances *apparently emanating from the circumference of the moon…[all] of the same roseate cast of colour and very distinct from the brilliant vivid white light that formed the corona.*[2] [Baily's emphasis]

In scientific journals, observers published exquisite hand-colored drawings [Fig. 1] and clamored with questions: *What* were those magnificent and wholly unexpected marvels? Were they real or some kind of optical illusion? If real, were they part of the sun or the moon? What caused them? And why were they visible only when the sun was totally eclipsed?

As news sped around the world, astronomers geared up to chase the moon's shadow wherever it might lead—no matter how short the totality or how arduous the journey.

LAUNCHING AN EXPEDITION

The average 19th-century eclipse expedition was a *very* big deal, with striking parallels to the monumental logistics of sending astronauts to the moon today.

One to four *years* in advance, astronomers began laboriously hand-calculating latitudes and longitudes, poring over contradictory maps of little-known territories, and gathering information about weather odds. There were administrative matters of requesting appropriations from national governments to help finance the expedition and to secure free passage on chartered trains or naval vessels.

Meanwhile, astronomers borrowed special telescopes or cameras from other observatories or invented observational instruments specifically for the expedition. Although every expedition had its complement of tripod-mounted portable telescopes and meteorological stations, the expedition's centerpiece was usually some mammoth custom-built apparatus (more on this later). Since such precious equipment could not be left exposed night and day to the elements—which could include anything from hail to blowing sand—there were temporary observatories needed to house the instruments [Fig. 2], often involving concrete piers and foundations and (after about 1860) photographic darkrooms.

Just as launching payloads to the moon or planets is neither easy nor cheap, shipping crates of delicate apparatus to Timbuktu required elaborate planning. To minimize weight, some clever astronomers designed the wooden packing crates themselves to serve as the bodies of the instruments at their destination. To economize on return freight charges, astronomers commonly abandoned all but the optics and precision mounting gears at the observing site after the eclipse, just as the Apollo astronauts abandoned landers and rovers on the moon. Although some tried to improvise with lo-

Fig. 2.
Temporary observatories for total solar eclipse expeditions, such as this wooden building erected in Des Moines, IA, for the eclipse of August 7, 1869, were often quite elaborate. This building, used by U.S. Army Assistant Surgeon Brevet Major Edward Curtis, an officer skilled in photography, and his assistants, measured 16 x 32 feet, the long dimension oriented nearly north-south. A southern room 16 x 25 feet under the retractable roof sheltered several astronomical telescopes (note the observers and instruments); the northern quarter (invisible behind the partition and under the wooden roof) was a 7 x 16-foot ventilated photographic darkroom complete with indoor plumbing for processing wet collodion plates. During the eclipse, Curtis and his three assistants were among the first to photograph the sun's faint outer corona. Source: Plate I from "Report of Dr. Edward Curtis, U.S.A.," Appendix II. *Reports on the Observations of the Total Eclipse of the Sun, August 7, 1869,* U.S. Naval Observatory.

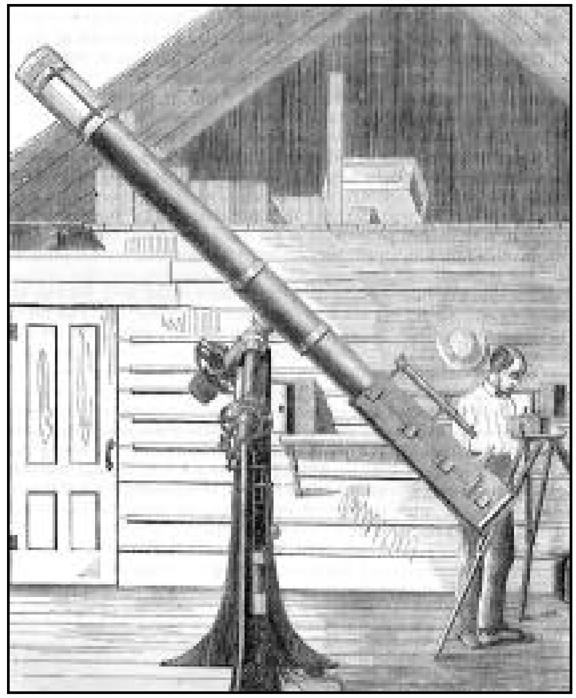
cal materials as much as possible—such as using bags of native sand and gravel as counterweights—others took no chances, carrying their own bricks, cement, and pre-cut numbered lumber.

Then there was the whole question of life support for one to seven *months*. Many times, observers were venturing into lands that were not only remote, but also so barren they could scarcely feed an indigenous population (which also might be ravaged by plague or fever). As astronauts a century later, Victorian astronomers hauled all the food they anticipated needing. They packed large canvas tents as temporary living quarters for themselves, their observing assistants, and—on particularly long expeditions, even their wives and children—plus kitchen help and other support personnel. Although most eclipse expeditions ranged from a solitary astronomer to a community of several dozen observers and assistants, plus unnumbered local volunteers recruited after arrival, the single largest 19th century expedition (led by British astronomer Sir Norman Lockyer to Viziadrug, India, for the eclipse of January 11, 1898) totaled *150* individuals.

Getting to the destination port or train station, although covering most of the mileage, was often the least of the effort. For example, the 35-day, 7,500-mile ocean voyage of Edward Singleton Holden's Lick Observatory expedition from California to Caroline Island for the eclipse of May 6, 1883 was delightfully uneventful. But owing to a shallow, rugged coral reef encircling the entire island, the naval sailing ship *Hartford* could find no safe anchorage closer than half a mile from shore. Thus, the heavy crates with their delicate instrumentation had to be heaved onto the backs of the ship's men, who splashed 2,700 feet through knee-deep surf over glass-sharp coral to the beach.[3]

Despite the best-laid plans, local weather patterns sometimes forced an unanticipated change in site. Lt. James M. Gilliss of the U.S. Coast Survey, in a somewhat impromptu and modest two-man expedition to Payta, Peru, for the single minute of totality during the dawn eclipse of September 7, 1858, arrived several weeks early. When eight days in Payta yielded only one sunrise clear to the eastward, Gilliss and his sole companion realized they had to move inland into the Andes to escape morning coastal fog. Hiring two muleteers and eight mules, they set out westward. Over the next week, they slogged nearly 200 miles across:

> *a desert of sand, which is so drifted by the strong daily winds that the mule paths are obliterated almost as soon as made, and the traveller [sic] finds his way by the tall stakes that have been planted and the skeletons of animals that have died on the road from heat and thirst.*[4]



Source: Page 126 from "Report of Dr. Edward Curtis, U.S.A.," Appendix II. *Reports on the Observations of the Total Eclipse of the Sun, August 7, 1869,* U.S. Naval Observatory.

Fig. 3.
A close-up in the interior of the Des Moines temporary observatory shows the equipment that captured more than 100 wet collodion photographs of the sun's outer corona for the first time in 1869.
The telescope, the main refractor of the U.S. Naval Academy made by Alvan Clark & Sons in 1857, had a lens of 7.75 inches in diameter and a focal length of 9.5 feet (f/14.7). Mounted at the eye end was a camera box for holding the dripping photographic plates onto which was projected the sun's image. The observer (presumably Edward Curtis in the picture) is in the act of timing an exposure with a chronometer (strapped to the tripod). On the wall behind the telescope and chronometer are the small doors of the dumbwaiters that communicated with the darkroom, through which the observer received and passed wet photographic plates for exposure and developing.

CAPTURING PICTURES ON THE FLY

As a spacecraft's close-up images of an alien world is the crucial reward for the cost and effort in launching a mission to fly by a distant planet, photographs of the eclipsed sun were the *only* tangible product of a 19th-century eclipse expedition halfway around the world. And just as a spacecraft flying by a planet has *only one chance* to grab data, on an eclipse expedition 19th-century expeditionary astronomers had *only one chance* before the moon inexorably continued past the sun.

Although the camera was turned skyward as soon as it was invented around 1840, photography did not immediately supplant eyeball astronomy. The poisonous copper-mercury daguerrotype process was far too slow, insensitive, and temperamental to be scientifically useful (the first daguerrotype of the moon in 1852 required an exposure of *half an hour* to record an image an inch across). By 1860, the daguerrotype had been made sensi-

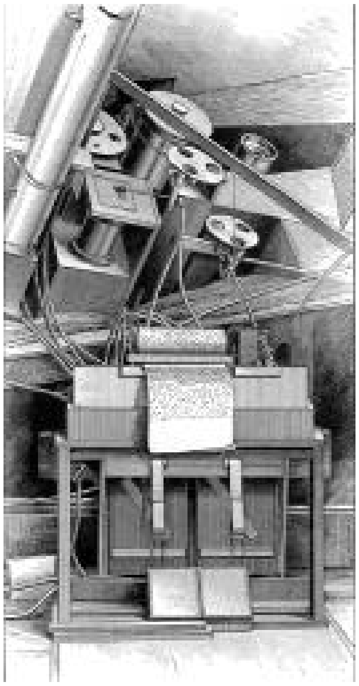


Fig. 4
Pneumatic commutator and battery of instruments was invented by Amherst College Observatory director David Peck Todd and mounted at Cape Ledo, Africa, for the total solar eclipse of December 22, 1889. In all, 23 telescopes (principally photographic) were attached to a massive clock-driven polar axis and pointed parallel to each other toward the sun. Exhaust air currents through pneumatic tubes, connected with each telescope and photographic plate-holder, were controlled by a slowly moving perforated sheet of paper similar to the music sheets used in automatic organs or player pianos, exposing more than 300 photographic plates.

Source: Page 361 from *Stars and Telescopes* by David P. Todd (Boston: Little, Brown & Co., 1899).

tive enough to photograph the "red protuberances" during the total solar eclipse of July 18—the moon's motion across them evident in a sequence of images that proved the prominences (as they are now called) were part of the sun.

The fainter silvery corona, however, eluded astronomical photographers until the eclipse of August 7, 1869. The breakthrough was the development of a significantly more sensitive photographic process: wet collodion.

Collodion was a colorless, semi-viscous fluid produced by dissolving guncotton in a mixture of alcohol and ether; when impregnated with silver salts, it was rendered susceptible to light. When spread upon glass, the fluid formed a transparent membrane. Although much faster than the daguerrotype, the wet collodion process required that each plate had to be made just before use, had to remain wet during the entire exposure, and had to be developed immediately afterward—all of which required a physical facility complete with ventilation and running water. In desert or jungle conditions, eclipse expeditions' temporary darkrooms invented for wet-plate photography were impressive improvisations, especially since indoor plumbing then was rare, even in the wealthiest homes. For example, the darkroom by U.S. Army surgeon Edward Curtis in Des Moines, IA, for the 1869 eclipse consisted of:

> *seven negative baths, standing in a long trough filled with water to keep them cool, a sink composed of a common wash-tub with an India rubber waste-pipe attached, a barrel of water standing on a platform outside the building with a pipe closed by a stopcock projecting through the wall, a large fixing-bath composed of a wooden trough with grooved sides like a negative rack, capable of holding one hundred and fifty plates and filled with a very weak solution of hyposulphite of soda.*[5]

How many astronomers does it take to capture a wet-collodion photograph of the eclipsed sun? Four, in the case of Curtis' expedition: one to coat each glass plate and put it into the bath; a second to take it out, wipe its back, place it into a holder, and pass it from the darkroom to Curtis in the observatory by a light-tight dumbwaiter; Curtis himself to position the dripping plate holder in the camera at the end of the telescope, draw the slide, time the exposure, and put the exposed plate into a second dumbwaiter and send it back to the darkroom; and a fourth to develop, wash, and fix each exposed plate [Fig. 3].

Tainted local water was a perpetual headache for eclipse chasers who developed their plates in camp, sometimes leaving fine silt or indelible black spots on precious negatives. Moreover, in the tropics, the same heat and humidity that molded clothes and shoes overnight caused photographic chemicals—although sealed by the manufacturer—to absorb so much moisture that what was originally a fine powder caked into a solid mass, which could only be broken up by first breaking the glass bottle.

After the invention of dry plates in the 1870s (a direct forerunner of modern film), the reliability of the photographic process itself was a risk. For example, during the eclipse of July 29, 1878, *none* of the scores of exposed photographic plates independently taken by Joseph A. Rogers and Simon Newcomb and sent to the U.S. Naval Observatory for development two weeks later had any image at all.

MAXIMIZING THE YIELD

Even after emulsion speed had improved to the point where useful images could be captured in exposures as short as a second, astronomers still sought ways of maximizing the scientific yield during totality. The usual technique was carrying a dozen or more portable or semi-portable telescopes, and then drafting local volunteers to operate a camera for each telescope with strict discipline.

But during the eclipse of August 19, 1887, in Japan, inventive Amherst College Observatory director David Peck Todd was struck by a novel idea: why couldn't a whole battery of telescopes be pneumatically controlled by some automatic mechanism instead? For the eclipse of December 22, 1889, he tested his idea in West Africa [Fig. 4]. The pneumatic apparatus proving bulky, however, David Todd resolved to use electricity instead when planning another expedition to Japan for the eclipse of August 9, 1896. Then began shaping up perhaps the weirdest apparatus ever to point at the sun: the Amherst machine [Fig. 5].

The electric Amherst machine consisted of 20 telescopes borrowed from every institution and individual with whom

Todd had connections. Endless chains of plate-holders of different sizes were rigged to pass behind each of the telescopes at varying speeds. The exposure time for each plate was controlled by another Todd invention, an electric commutator that consisted of "a slowly revolving copper cylinder full of pins, each of which represented a certain movement of one particular instrument at a given fraction of a second."[6] As the cylinder rotated, each pin touched an appropriate metal tooth, closing a circuit that set in motion a particular instrument at a prearranged instant.

To compensate for the motion of the earth during the eclipse, Todd bolted all the telescopes with their cameras to a central frame, which was in turn mounted onto heavy polar axis. In West Africa, Todd had made his first pneumatic system track the sun by means of a sand clock, in which "a heavy weight resting on a tube of sand slides gently down, as the sand runs out below at a uniform rate, hour-glass fashion." But sand proved not smooth enough for controlling long exposures, so for Japan in 1896 Todd used a column of glycerine.

The result on E-day? In two minutes and 40 seconds of totality, the Amherst machine exposed *more than 400 photographs*—a phenomenal vindication of automation for productivity.

MAGNIFYING THE VIEW

Not only did solar astronomers want as many images of the eclipsed sun as possible, they wanted them *big* for close-up views of the detailed structure of the prominences and corona. Although several 19th-century astronomers had suggested using long-focus lenses specifically for viewing the sun, Harvard College Observatory director Joseph C. Winlock was the first to come up with a scheme that was practical and cheap.

As with a camera, a telescope's magnification is directly proportional to the focal ratio of its objective (main) lens or mirror—that is, the ratio of the distance needed for focusing an image to the objective's diameter (aperture). The larger the focal ratio, the greater the magnification, that is, the larger the image produced at the objective's focus. An eyepiece then magnifies that principal-focus image still farther. In the 19th century, the average focal ratio of a refracting (lens) telescope was about f/15—long enough with an eyepiece to give decent magnification of the planets, but short enough for the telescope to be housed in a reasonably compact dome and not to flex and jiggle when it was moved from one celestial object to the next.

Winlock, however, wanted to get rid of the eyepiece, as he suspected it might dim or distort the image of the gossamer corona. Now, Winlock happened to have at Harvard a four-inch lens with the remarkably long focal length of 40 *feet*—that is, a focal ratio of f/120. He knew it would be hopelessly ungainly to mount such a long, skinny telescope in mid-air to track the sun. So he elected not to move the telescope at all. Instead, he laid it horizontally on the ground—a scheme he called a "heliostat" (now called a photoheliograph).

Specifically, Winlock fixed the four-inch lens vertically on a pier outdoors, so it would focus light through a long horizontal tin and canvas tube into the observatory's darkroom. Sunlight was directed into the four-inch lens by reflecting off a movable plane mirror (uncoated and wedge-shaped to discard most of the sun's heat). In the darkroom, an astronomer would pull the slide off a photographic plate and then shout to an assistant 40 feet away at the lens; the assistant then released what was essentially a rubber-band-powered or *windowshade* shutter—a slit that snapped quickly across the lens for a split-second exposure.[7]

In 1870, Winlock first gave his novel horizontal solar telescope a go at Jerez de la Frontera, Spain, during the eclipse of

Fig. 5.
Todd's electric *Amherst machine,* shown at center in its temporary observatory building with hinged roof open, shot more than 400 photographs during two minutes and 40 seconds of totality during the August 9, 1896, eclipse in Esahi, Japan. Endless chains of photographic plates of different sizes passed through the focal plane of each of its 20 telescopes at varying rates of speed. The exposure times for all 20 instruments were controlled by a slowly revolving copper cylinder full of pins; each pin, as it passed along, touched its appropriate metal tooth, closing an electrical circuit that set in motion some particular instrument at a prearranged instant. The entire framework carrying all 20 instruments was driven by an hour-glass-like glycerine clock to follow the sun.

Source: Plate opposite page 10, *Corona and Coronet,* by Mabel Loomis Todd (Boston and New York: Houghton, Mifflin, & Co., 1899)

Source: Plate II from "The 1900 Solar Eclipse Expedition of the Astrophysical Observatory of the Smithsonian Institution," by S.P. Langley, Director, No. 1439 (Washington: Government Printing Office, 1904)

Fig. 6.
The longest focal-length photoheliograph used for photographing the inner corona during a 19th-century eclipse expedition was that used by Samuel Pierpont Langley of the Smithsonian Astrophysical Observatory during the total solar eclipse of May 28, 1900, which he observed from Wadesboro, NC. The lens, borrowed from the Harvard College Observatory, had a diameter of 12 inches and a focal length of 135 feet (f/135) projected through the horizontal white tube shown in the right two-thirds of the photograph. It projected an image of the moon 15-3/8 inches across on photographic plates measuring 30 by 30 inches, manipulated in a darkroom (black rectangle near the photo's right edge). Also using that darkroom was a shorter photoheliograph having a five-inch lens of 38 feet focus (whose tube is canted upward at the far right). A third photoheliograph (61.5 feet long) at the left belongs to a neighboring camp set up by Yerkes Observatory.

December 22. From then on, photoheliographs rapidly became standard equipment on eclipse expeditions, their black-canvas walls snaking across the ground becoming the dominant landmark of any eclipse camp.

Many astronomers had their own ideas for modifying Winlock's basic design. Some kept the telescope horizontal but fitted the plane mirror with a clock drive to track the sun automatically. Others—notably John M. Schaeberle of Lick Observatory in his many single-handed eclipse expeditions in the 1880s and 1890s—did away with the plane mirror, inventing elaborate frameworks and digging deep pits for propping his 40-foot-long tube at a high angle to point directly at the sun, and swiveling the photographic-plate holder along an arc to track the sun.[8] Still other astronomers built truly huge photoheliographs, the record-holder being one with a lens 12 inches in diameter and a tube *135 feet* long, large enough for an astronomer to *stand inside* and to expose glass photographic plates measuring *30 inches* on a side [Fig. 6].

ENGINEERING OUT OF TROUBLE

Just as astronauts and mission controllers have had to rely on their wits to save lunar and planetary missions, rough field conditions often demanded ingenuity to save an eclipse expedition—essential as there was no way for Victorian expeditionary astronomers to radio "Houston, we've got a problem."

Nowhere better is that illustrated than by Samuel Pierpont Langley's expedition to the 14,110-foot summit of Pike's Peak, CO, for the eclipse of July 29, 1878. Before he departed, he had received "a letter from General Myer, of the Signal Service, inviting me to accept the hospitalities of the station" there, where the observers would be "under a roof with shelter for the instruments."[9]

Instead, after a grueling 18-mile climb with mules lugging a ton of precious equipment to the blustery summit, footsore Langley discovered that "owing to no orders for our reception having been sent from the Signal Office at Washington… there was no room for us in the Signal Service station on the summit, but a tent would be pitched."

Easier said than done. Although the summit was a plain of several acres, it was littered with so many "sharp-edged and fractured bowlders of granite of every size" that "the mounting of instruments or even the pitching of tents, at first sight, seemed hardly possible." As there was no level ground or rock large enough for a tent floor, Langley laid firewood logs between boulders, spread on them a sack of hay for each man, and rolled up in blankets—some mornings awakening to find themselves covered with 10 inches of snow that had blown into the tents overnight.

Langley's equipment, as abandoned by his unwilling porters, was heavy and bulky. The main astronomical instruments were a horizontal heliostat telescope with an objective lens five inches in diameter and a focal length of 38 feet, plus a separate five-inch refracting telescope that strained the definition of *portable* by weighing in at nearly 1,000 pounds disassembled into five cases.

Worst of all, at the moment of his arrival, "the rain poured freely…upon the boxes which lay in the wet," threatening to rust the instruments right in their cases. In desperation, Langley assembled the *portable* refractor and mounted it in the open air near the hut. Then, "[p]rocuring some lard from the kitchen, I covered every part of the steel-work with it, and wrapped the instrument in a piece of canvas."

Setting up the heliostat among the boulders required even greater ingenuity. Luckily, Langley's principal expedition partner was his brother John W. Langley, a chemistry professor at the University of Michigan, who had previously taught physics and built astronomical instruments. But John's principal asset, Samuel noted prophetically, was that he "was a better coadjutor than any other I knew for an expedition to a point where we were to be cut off from all external aid and left to our own resources." In other words, John was a good man to have in a tight spot.

And he proved his worth. To support the heliostat's ungainly 41-foot-long tube, John improvised four piers from sticks and stones. For each pier, he spiked lengths of firewood between the boulders and tied their ends to form a hollow square cage, which he filled with rocks. Across the top he laid short planks—a structure that "rendered the whole admirably firm." Cleverly, he also thought to mount the optics separately from the support structure for the canvas tube "so that the vibrations from this long structure, which exposed a large surface to the wind, could not be communicated to the apparatus which produced the solar image."

All this improvisation demanded days of "labor of much hardship," owing not only to "scanty material" but also to exposure and altitude sickness that left the men gasping for breath and suffering "constant and severe headache, and nearly every symptom which attends seasickness."

But the rewards were well worth the hardships. With his naked eyes during the eclipse, Langley saw that the outer solar corona extended "considerably more than a solar diameter in width, and it was now visible to fully 12 diameters in length. …[i]t was evident that I was witnessing a real phenomenon heretofore undescribed." His observations were the first to document that the outer corona can extend more than five million miles away from the sun [Fig. 7].

MISSION ACCOMPLISHED

In the 77 years between 1842 and 1919—at solar eclipses whose collective time of totality scarcely summed *one hour*—expeditionary astronomers discovered the element helium in the sun, decades before it was identified on the earth. They discovered the sun's chromosphere—a scarlet intermediate layer of the solar atmosphere out of which leap the ruby flame-like prominences—a discovery that led to finding chromospheres around other stars, essential in the understanding of stellar structure and evolution. They proved the ghostly corona was the sun's rarefied outer atmosphere, and documented how its streamers dramatically changed size and shape depending on the level of solar activity (the sunspot cycle). And in 1919, expeditionary astronomers' photographs of stars near the limb of the sun, visible only during the fleet moments of totality's darkness, verified a key prediction of Einstein's general theory of relativity: that starlight would be bent by the sun's strong gravitational field.

With each succeeding eclipse expedition, astronomers' equipment grew more elaborate, bigger, and heavier, eventually topping out at more than *15 tons* of apparatus shipped from California's Lick Observatory to Australia in 1919. While some instruments were unique and cantankerous artifacts that survive only in diagrams and photographs in dusty tomes (such as the Amherst machine), others became standard astronomical tools (such as the photoheliograph).

While 19th-century technology allowed eclipse expeditions to harvest the most data per second, solar astronomers craved far more *face time* with the sun's elusive layers. By the late 19th century, British and French astronomers simultaneously invented techniques for photographing the sun's chromosphere and prominences *sans* eclipse. And by the 1930s, the French invention of the coronagraph revealed the sun's outer corona at will.

Astronomers rejoiced. No longer did they need to launch colossal, costly pilgrimages thousands of miles for a minute's fleeting rendezvous with sun and moon. Now they could study an artificially eclipsed sun every clear day.

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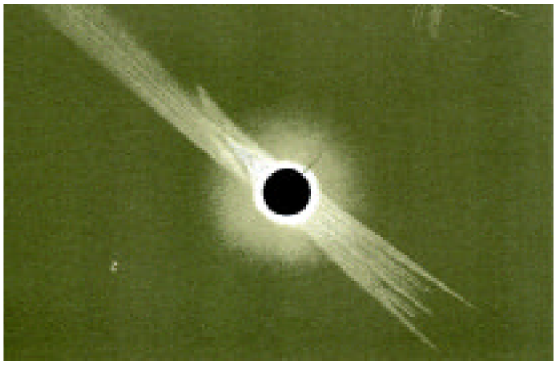

Fig. 7
This drawing by Samuel Pierpont Langley of totality during the solar eclipse of July 29, 1878, first documented the fact that the sun's outer corona can extend tens of millions of miles from the sun. From his vantage point at an elevation of 14,110 feet atop Pike's Peak in Colorado, Langley recorded that "making an angle of about 45° with the vertical," the corona extended "three to three and one-half [solar] diameters below and towards the right. …Upon the opposite side of the sun, …the light stretched further into space to the extent of six diameters." As his eyes became accustomed to the dimness of the light, he revised that estimate to "fully 12 diameters in length." Moreover, he was convinced that the 12 solar diameters *"were but a portion of its extent"* (Langley's italics).

Source: Plate 10 and pp. 207–208, "Report of Professor S. P. Langley," *Reports on the Total Solar Eclipses of July 29, 1878, and January 11, 1880.* United States Naval Observatory. Washington Observations for 1876.—Appendix III. Washington: Government Printing Office, 1880.

Freed from the tyranny of totality, the Victorian *space program* and its heroic eclipse expeditions came to an end.

To be sure, through the first half of the 20th century some observatories and the National Geographic Society continued to fund modest expeditions—largely to re-verify observational evidence of Einstein's prediction of the bending of starlight (an experiment still more easily done in the field). But technology had irrevocably diminished professional astronomers' need for total solar eclipses.

On the other hand, with the 20th century's development of commercial air travel, no longer is a total solar eclipse the sole province of a few hardy scientists. Today commercial eclipse-trip organizers charter airplane flights and luxury "cruises into darkness" as learning vacations for *amateur* astronomers and paying tourists.

But don't be fooled by the change in clientele. Although physical adventure and ingenuity are no longer prerequisites for chasing the moon's shadow, undiminished is the magnificent grandeur of a celestial rendezvous of sun and moon that in 1842 launched the **Victorian space program**.

REFERENCES

[1] For just a few examples on how general histories of scientific expeditions concentrate on biologists, botanists, geologists, and naturalists while overlooking astronomers, see Peter Raby's *Bright Paradise: Victorian Scientific Travellers* (Princeton U]cientific expeditions in Eric J. Leed's *The Mind of the Traveler: From Gilgamesh to Global Tourism* (Basic Books, 1991).

[2] Quoted in *Eclipses of the Sun* by S.A. Mitchell (New York: Columbia University Press, second edition, 1924), pp. 132–133; this classic book is still the most comprehensive history of 19th- and early 20th-century eclipse expeditions.

[3] [Edward S. Holden] "Report of the Operations of American Expedition to Observe the Total Eclipse, 1883, May 6, at Caroline Island, South Pacific Ocean," *Memoirs of the National Academy of Sciences*, vol. II. 1883. Washington: Government Printing Office. 1884, pp. 17–18.

[4] Gilliss, Lieut. J.M., "An Account of the Total Eclipse of the Sun on September 7, 1858, as Observed near Olmos, Peru." *Smithsonian Contributions to Knowledge*, January 1859, p. 3.

[5] "Report of Dr. Edward Curtis, U.S.A." *Appendix II. Reports on Observations of the Total Eclipse of the Sun, August 7, 1869.* U.S. Naval Observatory, 1870, p. 127.

[6] Todd, Mabel Loomis, *Corona and Coronet* (Boston and New York: Houghton, Mifflin and Co., 1899); relevant passages describing the Amherst machine appear on pp. 10–12 and 278–279. See also David P. Todd, *Stars and Telescopes* (Boston: Little, Brown, & Co., 1899), pp. 360–364.

[7] A history of Winlock's invention of the first practical photoheliograph appears in the *Annals of the Harvard College Observatory*, vol. VIII, Part I (Cambridge, 1876), pp. 35–41, 56ff. Its work is also briefly mentioned in Solon I. Bailey's *The History and Work of Harvard Observatory* (New York and London: McGraw-Hill Book Co., 1931), p. 53.

[8] Eddy, John A., "The Schaeberle 40-ft Eclipse Camera of Lick Observatory," *Journal for the History of Astronomy*, vol. 2, part 1, February 1971, pp. 1–22.

[9] "Report of Professor S. P. Langley," *Reports on the Total Solar Eclipses of July 29, 1878, and January 11, 1880.* United States Naval Observatory. Washington Observations for 1876.—Appendix III. Washington: Government Printing Office, 1880. For a vivid account of tenacity in the face of hardship, Langley's whole account (pp. 203–217) makes fascinating reading.