

SOLVING THE MARTIAN FLARES MYSTERY

by

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As the 20th century drew to a close, the preliminary reconnaissance of the Solar System by space probes had in many ways relegated amateur observers of the planets to the status of telescopic tourists. The instruments of the Viking and Pathfinder landers had sifted Martian soils and sniffed Martian air. Remote worlds like the moons of Uranus and Neptune, which appear as mere points of light through even the most powerful telescopes, had been mapped in detail and were now topics of debate among geologists. Yet buried in the observational records of the bygone era of earthbound planetary astronomy a few minor mysteries still lingered. Here is the story of how one yielded to the old tools and methods.

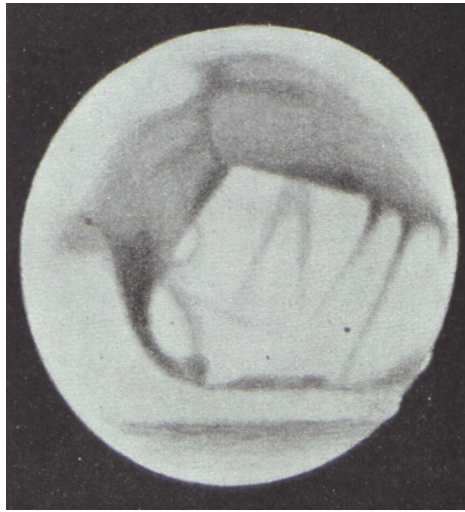
MARS CALLING!

*During the opposition of 1894, a great light was seen on the illuminated part of the disc, first at the Lick Observatory, then by Perrotin of Nice, and then by other observers. English readers heard of it first in the issue of **Nature** dated August 2nd... Peculiar markings, as yet unexplained, were seen near the site of that outbreak during the next two oppositions... As Mars approached opposition, Lavelle of Java set the wires of the astronomical exchange palpitating with the amazing intelligence of a huge outbreak of incandescent gas upon the planet... He compared it to a colossal puff of flame suddenly and violently squirted out of the planet, 'as flaming gases rushed out of a gun.'*

So wrote H.G. Wells in his 1897 science fiction masterpiece *The War of the Worlds*, setting the stage for a classic tale of an invasion by ruthless aliens. Trapped on a dying world but equipped with “intellects vast and cool and unsympathetic,” the Martians had regarded our planet “with envious eyes” and methodically prepared to venture across interplanetary space in projectiles fired from a colossal cannon. In a gloss on the supposed observations by astronomers at the Lick and Nice observatories, Wells added: “I am inclined to think that this blaze may have been the casting of the huge gun, in the vast pit sunk into their planet, from which their shots were fired against us.”

Wells was nothing if not topical, and his account was a mixture of fact and fiction. An avid reader of the British journal *Nature*, where his close friend Richard Gregory was editor, Wells had been following the debate raging about the network of “canals” on Mars reported by the celebrated Italian astronomer Giovanni Schiaparelli in 1877 and its implications for the possibility of intelligent life of some sort existing there. There really were astronomers at Lick Observatory studying Mars during the 1894 apparition, and Perrotin and Javelle (presumably the inspiration for “Lavelle of Java”) of the Nice Observatory were real figures as well. Indeed, Wells’ literary inspiration derived in part

from an article that had appeared in *Nature* in August 1892 describing observations of bright projections on the edge of the disk of Mars.



This 1890 drawing of Mars by Lick Observatory astronomer James Keeler depicts a pair of bright clouds projecting from the planet's morning limb at the lower right.

That month Mars made its closest approach to Earth in 15 years, and interest in bright flashes on the planet reached a fever pitch, especially in France. In 1891, Camille Flammarion, France's most eloquent popularizer of astronomy and outspoken advocate of the existence of extraterrestrial life, had announced the establishment of the Guzman Prize. The sum of 5,000 francs had been bequeathed to the French Academy of Sciences by a wealthy Bordeaux widow, Clara Guzman, whose departed son Pierre had been an ardent admirer of Flammarion's writings. Madame Guzman stipulated that the prize was to be awarded to "the person of whatever nation who will find the means within the next ten years of communicating with a star (planet or otherwise) and of receiving a response." She specifically excluded Mars from the competition, based on her understanding that communicating with Martians would be too easy! Flammarion did everything he could to publicize the prize, and even went so far as to suggest that "the idea is not at all absurd, and it is, perhaps, less bold than that of the telephone, or the phonograph, or the photophone, or the kinetograph."

Indeed, at a time before the possibility of wireless telegraphy or radio had been grasped, the best prospect of making contact with the inhabitants of other planets still seemed to depend in one way or another on the use of mirrors to flash messages across the intervening void. Such schemes had been toyed with by the great German mathematician Carl Friedrich Gauss and were later elaborated by the French inventor and Flammarion protege, Charles Cros. In the pages of the London *Times* for August 1892, Francis Galton, one of Britain's leading intellectuals, had weighed in with his own method of using a combination of mirrors to reflect sunlight to Mars.

Against this background, it was inevitable that the detection of bright spots on Mars by leading observers of the planet would electrify both the astronomical world and the

general public. Martian “signal lights” would continue to seize the popular imagination on several occasions during the next few years.

One of the most widely publicized observations was of a bright projection on the terminator of Mars, the boundary between day and night, seen in December 1900 by Andrew Ellicott Douglass at Lowell Observatory in Arizona. In this instance even Flammarion found it necessary to combat the notion that what had been seen had involved an attempt by Martians to communicate with Earth. Before a packed lecture hall in Paris the following month he announced to the great disappointment of his audience: “We are dealing not with signals from the Martians, but with snowy or cloudy mountaintops lit by the rising or setting sun.” The Guzman Prize remained unclaimed, though in 1905 a smaller award, funded from the interest accrued on the principal, was presented to Henri Perrotin’s niece in recognition of her late uncle’s Mars research. Eventually, the value of the prize was wiped out by rampant inflation during the First World War.

SPECULAR REFLECTIONS

The question of attempts by inhabitants of Mars to communicate with Earth by means of mirrors aside, the possibility of observing natural reflections from Martian seas was also considered. Through a telescope, Mars presents an ochre disk dappled with dusky markings and crowned by gleaming polar caps. On the basis of what was admittedly circumstantial evidence, most early astronomers had interpreted the dusky markings as bodies of water. As Percival Lowell wrote in 1906:

In the Martian disk, as in the lunar one, we seem to be looking at a cartographic presentation of some strange geography suspended in the sky; the first generic difference between the two being that the chart is done in chiaroscuro for the Moon, in color for Mars. On mundane maps, we know the dusky washes for oceans; so on the Moon it was only natural to consider their counterparts as maria; and on Mars as “seas.” Nor did the blue-green hue of the Martian ones detract from the resemblance.¹

This had also been Schiaparelli’s view of the matter. However, the sage Italian astronomer had noted that some regions on Mars had the muted intensity of halftones, and he suggested that they were probably swamps or marshes rather than proper seas. Moreover, pronounced changes in the size and intensity of many of the dark areas had been recorded over the years, suggesting that Martian seas must be shallow and their shorelines very flat. Eventually Schiaparelli found it necessary to caution against too literal an acceptance of the scheme of nomenclature he had introduced for Martian features, which included designations such as seas, rivers, canals, gulfs and lakes.

¹ Percival Lowell, *Mars and Its Canals*, New York: MacMillan, 1906. p. 112.

There was one predictable consequence that flowed from the widespread belief that there really were seas on Mars. Whenever the observing geometry is just right, any Martian sea ought to produce a brilliant reflection of the Sun. When parallel rays of light strike a smooth, planar surface like a mirror or a calm body of water, they are reflected at an angle equal to but opposite that of the incident beam; because the irregularities of a shiny surface are smaller than the wavelength of the incident radiation, the reflected rays maintain their parallelism, producing a specular reflection (from the Latin for mirror, *speculum*). However, a dull surface like rock or soil containing a large number of microscopic irregularities scatters reflected rays in all directions, producing a diffuse reflection.

As early as 1863, the British geologist John Phillips had suggested that the failure of astronomers to observe specular reflections on Mars could only mean that the planet's dark markings must be something other than seas. Schiaparelli calculated that these reflections ought to rival a third magnitude star in brilliance. Eventually the failure to observe these sun glints led to the abandonment of the maritime view of the planet. During the 1890s, the once dominant view of the dark areas as seas lost ground - or rather lost water! - and they came to be widely regarded as tracts of vegetation. As Percival Lowell summed up in *Mars and Its Canals*:

One phenomenon we might with some confidence look to see exhibited by them were they oceans, and that is the reflected image of the Sun visible as a burnished glare at a calculable point. Specular reflection of the sort was early suggested in the case of Mars, and physical ephemerides of the planet registered for many years the precise spot where the starlike image should be sought. But it was never seen. Yet not till the marine character of the Martian seas had been otherwise disproved was the futile quest for it abandoned. Indeed, it was a tacit recognition that our knowledge had advanced when this column in the ephemeris was allowed to lapse.²

Lowell's words attest to what would become the non-expectation by astronomers of seeing specular reflections on Mars. In fact, the failure of such phenomena to appear seemed to argue not only against the existence of seas on Mars, but against the existence of any significant bodies of standing water. Refining Schiaparelli's calculations, during the 1920s the Russian astronomer Vasilii Fesenkov would estimate that any open expanse of water more than 300 meters across should make its presence known in this way. And not only liquid water but ice as well, for a smooth surface of ice is no less capable of serving as a mirror. Indeed, long after the furor over the bright projections had died down and the ephemerides mentioned by Lowell had been consigned to the trash bin with other discarded theories, short-lived, brilliant flashes would be observed on Mars. They would not be projections on the terminator like those seen by Perrotin and Douglass, which were clearly high-altitude clouds, but something far more mysterious. Mars was indeed communicating, not about the presence of inhabitants but about something hardly less significant. The planet was signaling the presence of water, the one sure and absolute

² *Ibid.*

prerequisite of life, in the form of patches of frost on its surface or crystals of ice suspended in its tenuous atmosphere.

ONE WATCHER, ALONE ON A HILLTOP WITH THE DAWN...

When he took his place at the eyepiece of a borrowed telescope in the early morning of June 7, 1894, Percival Lowell was the experienced veteran of all of one week's observations of Mars. The handiwork of the renowned Pittsburgh optician John Brashear, the 18-inch refractor had been shipped to his observing site at Flagstaff in the Arizona Territory from Pennsylvania earlier that spring. Piqued by the reports of a network of "canals" on Mars, Lowell had emerged as the leader of the most hastily organized and ambitious expedition to observe Mars the world had ever seen.

In the morning sky of June 7, 1894, as dawn took hold and the rising sun began to throw long shadows, Lowell could barely contain his growing disappointment in not catching a glimpse of Schiaparelli's canals. In his observing notebook he rather austere recorded the presence of "dazzling white specks" in the south polar cap. Only later would he elaborate on the experience:

On that morning, at about a quarter of six (or, more precisely, on June 8, 1 h. 17m., G.M.T.), as I was watching the planet, I saw suddenly two points like stars flash out in the midst of the polar cap. Dazzlingly bright upon the duller white background of the snow, these stars shone for a few moments and then slowly disappeared. The seeing at the time was very good.³

Lowell did not hesitate in assigning a cause to these strange sparkles:

It is at once evident what the other-world apparitions were -- not the fabled signal-lights of Martian folk, but the glint of ice-slopes flashing for a moment earthward as the rotation of the planet turned the slope to the proper angle; just as, in sailing by some glass-windowed house near set of sun, you shall for a moment or two catch a dazzling glint of glory from its panes, which then vanishes as it came. But though no intelligence lay behind the action of these lights, they were nonetheless startling for being Nature's own flash-lights across one hundred million miles of space. It had taken them nine minutes to make the journey; nine minutes before they reached Earth they had ceased to be on Mars, and, after their travel of one hundred millions of miles, found to note them but one watcher, alone on a hill-top with the dawn.⁴

Lowell's biographer David Strauss has attributed the popular appeal of Lowell's writings about Mars and his earlier works about the Orient to his ability to relate to readers in a "dramatic and personal way." Lowell regarded science as an adventure that rivaled any of the tales spun by his favorite writer, Robert Louis Stevenson. "Lowell's books thus

³ Percival Lowell, *Mars*, London: Longmans, Green, and Company, 1896. p. 86.

⁴ *Ibid.* pp. 86-87.

appealed to an audience of men and boys who sought in literature, as in life, male heroes with whom they could identify. The romance provided the perfect vehicle to deliver these stories to the public in an attractive form.” Strauss cited the passage just quoted as some of the most exquisite prose that Lowell ever penned, and one of the most memorable examples of Lowell’s coupling of the idea of the astronomer as pioneer with dramatic revelations from other worlds.

Lowell’s vision was repeated almost half a century later. One of the most experienced and highly regarded amateur observers of the Moon and planets, Lattimer J. Wilson of Nashville, Tennessee, reported that “a series of bright flashes was seen extending across the south polar cap about one arc second north of the southern rim of the disk.” This sighting, made on May 30, 1937 through his 12-inch reflector under unusually good seeing conditions, lasted for almost an hour and a half.

*[The flashes] were entirely unexpected and when attention was attracted to them, the greater part of the period was given to concentrated study of the south polar regions... They were irregularly intermittent and were estimated to be about one magnitude brighter than the rest of the cap. A narrow string of tiny bright spots was first noted. Some of these seemed to coalesce and swell into a brilliant light which passed, generally, across the cap in the direction contrary to that of the planet’s rotation.*⁵

Like Lowell, Wilson remarked that “ice on slopes along an escarpment might flash sunlight if the angle between Earth, Sun, and Mars is just right.”⁶

Flashes amid the polar snows were rather easy to account for, but other reports would prove far more puzzling. For example, during the 1896 apparition of Mars the British amateur J.M. Offord reported that a “brilliant star-like scintillating point” stood out in Hellas, a vast tract of ochre desert centered at latitude of only 40 degrees.⁷

On the night of December 8, 1951, one of Japan’s leading planetary observers, Tsuneo Saheki of the Osaka Planetarium, was examining the tiny 5.3 arc-second disk of Mars through his 8-inch Newtonian reflector at a magnification of 400X in fairly good seeing. At 21:00 U.T. a “very small but extremely brilliant spot” suddenly appeared at the eastern end of a feature in the Martian tropics known as Tithonius Lacus, which had rotated over the morning limb but was still almost 50 degrees from the central meridian.

⁵ Quoted from a letter from Lattimer J. Wilson to Walter Haas, date unknown, currently in the Haas archive at the New Mexico State University library. Wilson’s observations are described in detail in E.P. Martz, “Planetary Report No. 24: Mars, 1937, III” *Amateur Astronomy*, 3, 8, (October, 1937), pp. 131-138.

⁶ *Ibid.*

⁷ E.M. Antoniadi, “Report of the Section for the Observation of Mars” *British Astronomical Association Memoirs*, 6, 3 (1898).

It was very white and brilliant but extremely tiny. Its diameter was quite inappreciable for my 8-inch telescope, being perhaps less than 0.5 arc-second. At first I could not believe my sight because the appearance was so completely unexpected, and I thought that it must be an illusion caused by motes in my eye. More careful examination revealed that it was not such an illusion but was a true phenomenon on Mars! I continued to observe it carefully for half an hour.

During the next five minutes it remained present and always twinkled like a fixed star Its brightness surpassed that of the north polar cap, then rather brilliant late in the northern spring of Mars. The stellar magnitude of the spot was perhaps five or six.

At 21:05 the brightness of the spot now decreased, and it gradually became a small, dull, cloud-like spot about equal in diameter to Tithonius Lacus. By 21:10 the spot was only a common white cloud near the limb. After 21:40 it very rapidly faded out until I could see no trace of the white spot.⁸



Saheki's sketches of the development of the December 8, 1951 flare at Tithonius Lacus.

The rapid fluctuations in the brightness might be attributable to turbulence in the Earth's atmosphere, but what could account for the extreme brilliance of the phenomenon? After all, a flare as bright as a fifth or sixth magnitude star would be visible with the naked eye on a moonless night if it were detached from Mars and viewed against a dark sky background.

NUKES AND KOOKS

Saheki's 1951 observation created quite a stir, eliciting a flurry of comment and speculation. Given the five-minute duration of the flare, a meteorite impact seemed rather far-fetched, but not nearly as far-fetched as some of the ideas that were bandied about. Memories of Hiroshima and Nagasaki were still fresh, particularly in Japan, and ever more powerful nuclear weapons were being tested at a feverish pace on remote atolls in the Pacific and in the desolate wastes of Soviet Central Asia. The British popularizer of astronomy Patrick Moore recalls that shortly after news of Saheki's observation reached

⁸ Tsuneo Saheki, "Some Recent Curious Phenomena on Mars" *The Strolling Astronomer*, 6, 46-9, (1952).

Europe, he received a telephone call from the science reporter of a famous London daily eager to hear his comments about “the atomic bomb that had gone off on Mars.”⁹

Although Saheki had rejected this explanation out of hand as “unreasonable,” his flare was included in a list of Martian features “most easily understood on the assumption that they are the product of intelligent beings” that appeared in the prestigious, peer-reviewed journal *Science* in 1962, the year of the Cuban missile crisis. The author, University of Colorado Professor of Plant Physiology Frank Salisbury, asked: “Was this volcanic activity, or are the Martians now engaged in debates about the long-term effects of nuclear fallout?”¹⁰

A specular reflection from brine pools or a sheet of ice was also considered, but the viewing geometry seemed all wrong - Saheki’s flare was seen far from the subsolar point. “Reflection from an ice-covered mountainside is free from this objection,” Saheki conceded, “but cannot explain the formation of a cloud just after the disappearance of the light.”¹¹

ADDITIONAL SIGHTINGS

At 13:15 U.T. on July 1, 1954, Saheki saw another flare, this time at Edom Promontorium, the bright elliptical feature tucked in the nook formed by the junction of Sabaeus Sinus and Sinus Meridiani. Far less spectacular than the 1951 flare despite the much closer proximity of Mars, this event lasted only five seconds and attained a maximum brilliance estimated at half that of the south polar cap. Although no explicit confirmation followed Saheki’s announcement of this sighting, another prominent Japanese student of Mars, Ichiro Tasaka, had recorded in his observing log that Edom Promontorium looked unusually bright that night through his 13-inch reflector.¹²



Stages in the development of the July 1, 1954 flare at Edom Promontorium.

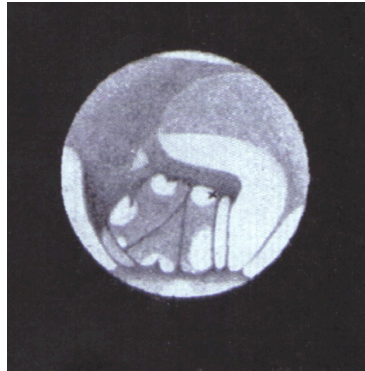
⁹ Patrick Moore, *Guide to Mars*, New York: Macmillan, 1956. p. 68.

¹⁰ Frank B. Salisbury, “Martian Biology” *Science*, 136 (1962).

¹¹ Tsuneo Saheki, “Martian Phenomena Suggesting Volcanic Activity” *Sky & Telescope*, February 1955. pp. 144-46.

¹² *Ibid.*

Another flare event at Edom Promontorium lasting 58 seconds was seen 23 days later by Clark McClelland, observing with a 13-inch refractor at the Allegheny Observatory in Pittsburgh. He reported that at 4:32 U.T. a spot abruptly appeared, then rapidly grew in brightness to equal that of a star of the first magnitude seen with the unaided eye before it faded from view.¹³



X marks the spot of the flare observed by Clark McClelland on July 24, 1954

Japanese observers reported a spate of flares during the 1958 apparition of Mars. At 15:13 U.T. on November 6, Sigeji Tanabe was observing the planet with a telescope of only 80mm aperture when he saw a spot at the southwest edge of Tithonius Lacus that grew as bright as the polar cap and faded from view after four minutes.¹⁴



Tanabe, Nov. 6, 1958

Four days later almost to the minute, Sanenobu Fukui, observing with a 10-inch reflector, recorded a “curious bright spot” northeast of nearby Solis Lacus that persisted for about five minutes.¹⁵

¹³ *Ibid.*

¹⁴ Tsuneo Saheki, “Some Important Martian Phenomena in 1958” *The Strolling Astronomer*, 16, 264-8 (1962).

¹⁵ *Ibid.*



Fukui, Nov. 10, 1958

On November 21, flares were seen by Ichiro Tasaka at two widely separated locations on Mars:

At 13:25 U.T. I found Edom was brightening, and then at 13:35 it flared up suddenly and reached its brightest stage. It was a very distinct white (rather yellowish) patch. At the same time I found that the northern top of the whitish yellow cloud covering the northern half of Hellas increased in brightness to become as bright as the Edom spot; these flares lasted for about 5 minutes and then began to fade, and by 13:40 they had returned to normal appearance. However, it is interesting that they again started to flare up soon and reached their new maximum at 13:50, as strong as at 13:35. During their brightening and fading, I was watching Mars through my 32.5cm reflector, and although sometimes the seeing conditions varied, I saw that there was no relation between these flares and the variation of seeing conditions, and I am sure that I saw actual phenomena.¹⁶



Tasaka, Nov. 21, 1958

Tasaka thought he had observed “the sudden development of white clouds as a special meteorological phenomenon of a limited area on the surface of the planet,” but Saheki was inclined to believe that he might have witnessed volcanic eruptions. However, he admitted that “the observed duration of the light may be too short, and the probable scarcity of water on Mars may raise difficulties -- terrestrial volcanoes eject large quantities of steam.”¹⁷

¹⁶ *Ibid.*

¹⁷ *Ibid.*

The University of Michigan astronomer Dean McLaughlin might have been voted the man most likely to embrace an explanation involving volcanism. An accomplished stellar spectroscopist, McLaughlin had wide-ranging interests that included geology and writing science fiction. He had recently rejected the consensus view that the Martian maria represented tracts of vegetation. Instead, he boldly proposed that they were covered with dark ashes ejected from a multitude of active volcanoes and distributed poleward by prevailing winds. Point-source emissions of ash, he argued, would account for the characteristic caret or chevron shape of features like Sinus Meridiani and the serrations along the northern boundaries of Mare Tyrrhenium and Mare Cimmerium. Yet McLaughlin took an admirably cautious approach to interpreting the flare observations:

*The bright flares were of enormous intensity compared with any volcanic glare recorded on earth. It is questionable whether even the 200-inch telescope could show the fire pit of Kilauea at the distance of Mars, even beyond the planet's terminator. It would certainly not be visible on the illuminated disk. The "fiery cloud" of Mt. Pelee (which destroyed St. Pierre in 1902) was probably two kilometers in diameter and very hot, but not brilliantly glowing. Later clouds erupted by Pelee appeared dull by daylight. The fire-fountain of Vesuvius on August 8, 1779, might have been visible from the Moon as a 5th or 6th-magnitude star. From Mars it would have appeared to be of the 16th or 17th magnitude at a very close opposition. If these Martian flares were volcanic, they would indicate that Martian volcanism is characterized by occasional great outbreaks of incandescent gas a few kilometers in diameter and with temperatures very far above those known in terrestrial volcanism.*¹⁸

These calculations certainly seemed to rule out the possibility that the fires of any Martian volcano would be visible from the Earth, compelling Saheki to modify his original suggestion. Now he attributed the flares to "the rapid development of clouds of moisture produced by the great force of active volcanoes that erupt intermittently." In 1980, the British amateur astronomer and prolific author Val Axel Firsoff, an "original thinker" notorious for his far-out theories, proposed a strange sort of nuclear-powered volcanism in which "fissile radioactive materials could become concentrated by geological processes into a natural atomic pile, which could occasionally blow up."¹⁹

¹⁸ Tsuneo Saheki, "Martian Phenomena Suggesting Volcanic Activity" *Sky & Telescope*, February 1955. pp. 144-46.

¹⁹ V.A. Firsoff, *Exploring the Planets*, New York: A.S. Barnes, 1964. p. 114, and *The Solar Planets*, London: David & Charles, 1977. p. 138. It must be admitted that Firsoff's idea wasn't utterly daft. In 1972 French scientists discovered the remains of a prehistoric atomic pile in West Africa. Some two billion years ago, natural geochemical processes had increased the concentration of uranium in the ores that occur near Oklo, Gabon, to the critical level required to sustain chain reactions and create plutonium. See J.M. Herndon, "Examining the Overlooked Implications of Natural Nuclear Reactors" *Eos*, 79 (1998), p. 451.

Small wonder that many of his countrymen were fond of saying: “There’s fact, there’s fiction, and there’s Firsoff!”

ATMOSPHERIC OPTICS

McLaughlin offered a very insightful alternative: “Perhaps it would be worthwhile to explore the possibility of a solar reflection from oriented ice crystals in the Martian atmosphere - a sort of sundog phenomenon in reverse! The slim chance that something of this sort might be involved is suggested by the fact that a whitish cloud was seen.”²⁰

Sundogs (also known as *mock suns* or *parhelia*) form when sunlight passes through a field of ice crystals like the wispy cirrus clouds that form at altitudes of 25,000 feet or more, where temperatures are always below freezing. They are usually seen when the Sun hangs low in the sky and cirrus clouds are present, often appearing as a pair of diffuse bright spots with prismatic colors located 22 degrees on opposite sides of the Sun and at the same elevation above the horizon.

Why 22 degrees? Because the tiny ice crystals high in the atmosphere are almost invariably hexagonal in shape like snowflakes, though they differ in size and proportion. Some are rod-like (“columns”), while others resemble thin slices cut from a pencil (“plates”). When a ray of sunlight passes through one of these crystals, it is refracted through an angle of 22 degrees, so that sunlight entering crystals at an angular distance from the Sun of 22 degrees is refracted directly toward an observer. But why do two spots on opposite sides of the Sun appear instead of a complete circular halo with a radius of 22 degrees? The answer to this riddle lies in the preferential orientation of the ice crystals that results from aerodynamic drag as they slowly drift downwards under the influence of gravity. Plates tend to descend like leaves, with their large basal faces parallel to the ground. Rays of sunlight that encounter plates located at the same apparent elevation as the Sun enter the sides of the hexagonal prisms and are refracted towards an observer. Above and below the Sun, however, rays enter the large flat faces of the crystals and are refracted or reflected away from an observer. When the ice crystals are randomly oriented, however, a complete halo does appear. A combination of the two effects is often seen.

A related phenomenon can be seen when the Sun is behind an observer. The subsun occurs when sunlight is reflected off a layer of millions of ice crystals that collectively act as a giant mirror. Horizontally aligned plate crystals are the usual source, and the Sun’s rays can be reflected externally from their upper basal faces or internally from their lower basal faces. The more uniformly aligned the crystals, the more brilliant and sharply defined a subsun will appear. Subsuns are often seen by the crews and passengers of commercial airliners flying above a deck of cirrus or cirrostratus clouds, a vantage point that is not too unlike looking at Mars through a telescope. Perhaps once in a great while they are seen by observers of Mars as well.

²⁰ *Ibid.*

MARTIAN METEOROLGY

In 1877, the year that Schiaparelli reported *canali* on Mars, his most accomplished rival among British observers, Nathaniel Green, called attention to the diffuse bright arc that is almost invariably seen near the morning limb of Mars. Formed during the frigid Martian night, this limb haze usually dissipates quickly under the influence of the Sun's radiation as it emerges into daylight. Visible through even a 3-inch telescope, limb haze is best seen at relatively modest magnifications through blue or violet filters.

During the 1950s, the French astronomer Audouin Dollfus determined that the polarization properties of clouds in the chilly Martian atmosphere closely resemble those of terrestrial cirrus clouds, so it would seem that sun dogs, halos, and subsuns ought to occur frequently on Mars, just as they do in the most Mars-like place on Earth, Antarctica. However, the situation is a bit more complicated.

At high latitudes, Martian clouds and hazes contain frozen carbon dioxide ("dry ice"), but in the Martian tropics water ice is the major constituent. This may be an important clue about why most Martian flares have been seen at low latitudes. Crystals of frozen carbon dioxide are about two orders of magnitude smaller than their water-ice counterparts and usually take the form of octahedrons -- two four-sided pyramids joined at their bases. Clouds of such minute particles are very efficient at producing diffuse reflections but they never present an array of aligned crystal faces to reflect or refract sunlight in a preferred direction. For that, water ice is required - and it is this fact that may lend observations of flares on Mars their particular poignancy.

Viking Orbiter data suggests that traces of water vapor are released seasonally from the uppermost two to four inches of Martian soil, particularly at low latitudes. The initial springtime increase in the atmospheric abundance of water vapor occurs at latitudes far closer to the equator than the edge of the retreating polar cap. In fact, the polar caps may contribute only one-tenth as much water vapor to the Martian atmosphere as the planet's soils.

In 1969 the Russian astronomer Victor D. Davydov of Moscow's Sternberg Astronomical Institute published a pair of articles in *Astronomicheskij Zhurnal* echoing McLaughlin's view that flare phenomena are probably caused by directed reflections of sunlight from clouds of aligned ice crystals floating in the Martian atmosphere.²¹ Davydov attributed the fleeting visibility of the flares to the effect of the planet's rotation, which would displace a reflection by 1.2 degrees during a five-minute interval. He also discovered additional sightings of flares by other experienced Mars observers, notably Nikolai Barabashov at Kharkov Observatory in 1924, helping to dispel the widespread perception that Japanese observers had a virtual monopoly on flare reports. Almost a score of

²¹ Victor D. Davydov, "New Interpretation of S. Mayeda's Flare on Mars - I" *Astronomicheskij Zhurnal*, 46, 3 (1969), pp. 623-632 and "New Interpretation of S. Mayeda's Flare on Mars - II" *Astronomicheskij Zhurnal*, 46, 5 (1969), pp. 1074-1086.

Martian flare sightings have been uncovered in the observational record, but the most celebrated cases still remain the Japanese reports.



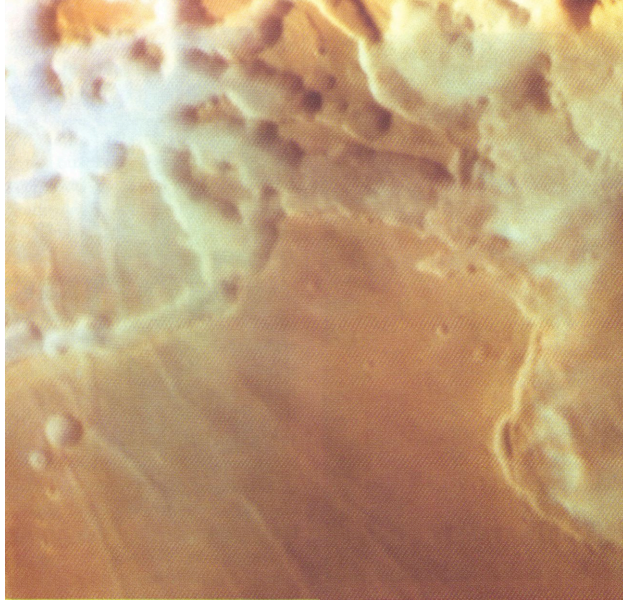
Dean McLaughlin

Victor Davydov

The Viking Lander imaging team looked for and failed to record halos and sundogs, but the landing sites on the northern plains of Chryse and Utopia would not be expected to favor such phenomena. The cameras on the Mars Pathfinder rover (which also landed in Chryse) frequently recorded bluish water-ice clouds in the early morning sky in the direction of the rising sun, but most of these clouds produced forward scattering of sunlight, indicating that their constituent ice crystals were as tiny as particles of cigarette smoke.

Nevertheless, close inspection by the Viking Orbiters of the two locales that seem prone to flare events - Edom Promontorium and Tithonius Lacus – lent credence to McLaughlin and Davydov’s explanation. On a global scale, concentrations of water vapor in the Martian atmosphere correspond closely to differences in elevation. Water vapor tends to concentrate in valleys and depressions like the floors of craters. The local topography and meteorology of both sites seem particularly favorable for generating reflections from patches of frost, surface-hugging ice fogs, or dense cloud decks.

Edom Promontorium was often depicted as a dashed line enclosing an elliptical bright patch on the maps of Mars compiled by telescopic observers. In 1969 the Mariner 6 flyby revealed that this outline corresponds to the ramparts of an eroded, flat-floored crater 460 kilometers in diameter; it now bears the name Schiaparelli. The area has long been recognized as the site of a discrete, localized cloud that varies seasonally. Often visible in integrated light, it is usually best seen through a blue-green or blue filter, though at times it is more pronounced through green or even yellow filters. When the cloud appears brighter in blue light than in green light, it resides high in the Martian atmosphere, but when it is subdued in blue light but prominent in green light, it is probably a low altitude fog of ice particles like those that have long plagued explorers and aviators in the arctic. When a sharply defined boundary is visible in yellow light, a deposit of frost may be present on the surface.



Viking Orbiter image of Noctis Labyrinthis.

THEORY AND VALIDATION

The authors used a computer program for generating planetary ephemerides called “WIMP” to determine the Mars-Earth-Sun geometry at the times of the historical flare reports. The brainchild of noted Mars observer Jeff Beish, WIMP generates precise values for the parameters that must be considered when evaluating the possibility of a specular reflection: D_s , D_e , i , and CM . D_s and D_e define the latitudes of the sub-Sun and the sub-Earth points on Mars, denoting the declination of the Sun and the declination of the Earth as seen from Mars. For example, if on a given date D_s has a value of 0 degrees and D_e is -10 degrees, an observer at the Martian equator would see the Sun directly overhead at local noon, while the Earth would culminate on the meridian 10 degrees south of the zenith. CM stands for central meridian, the imaginary line passing through a planet’s poles of rotation and bisecting its disk that defines the longitude of the sub-Earth point. Finally, phase i defines the Earth-Mars-Sun phase angle in degrees. These are the parameters that must be considered when evaluating the possibility of seeing specular reflections, which would appear halfway between the sub-Sun and sub-Earth points. Tedious calculations that took nineteenth century astronomers many hours to perform were made with a few strokes on the keyboard of a personal computer.

Two of the events occurred under textbook conditions for specular reflections. The flare at Edom Promontorium sighted by McClelland in 1954 and the flare reported near Solis Lacus by Fukui in 1958 were seen at times when the Sun was near the local zenith and separated from the apparent position of the Earth by only a few degrees of declination.²²

²² Clark McClelland, July 24, 1954 4:32 U.T. $D_e = 2.9$ degrees $D_s = -10.6$ degrees $(D_e + D_s)/2 = -3.9$ degrees = nominal Martian latitude of source of specular reflection,

Tithonius Lacus seemed to be a special case, however. The geometry of the sightings there implies that sunlight was reflected off surfaces inclined as much as 45 degrees to the horizontal.²³ Given that the area is a maze of canyons whose walls are sloped by 35 degrees or more, such a scenario is hardly difficult to envision. On the other hand, the San Diego State University astronomer Andrew Young offers an intriguing alternative: "If you need a surface inclined by more than a couple of degrees, you'd be better off trying to do this with aligned mineral grains. On Earth, it's not uncommon for minerals

assuming horizontal orientation. Phase i (planetocentric elongation of Mars with respect to Earth and Sun) = 24.9 degrees (post date of opposition). $CM = 346 \text{ degrees} - (24.9/2) = \sim 333.5 \text{ degrees} = \text{nominal Martian longitude of source of specular reflection, assuming horizontal orientation. McClelland's sketch also permits the site of the presumed reflection to be determined with a precision of at least } \pm 3 \text{ degrees of latitude and longitude. The latitude appears to be at about } -2 \text{ degrees, tolerably close to the } -6.7 \text{ degrees predicted, suggesting a north-south inclination of less than } 5 \text{ degrees, but the longitude appears to be about } 356 \text{ degrees. } 356 - 333.5 = 22.5 \text{ degrees. This corresponds to a surface inclined about } 22.5 \text{ degrees from the horizontal on an east-west axis, and in the same direction as in the case of Saheki's observation.}$

Sanenobu Fukui, November 10, 1958 15:05 U.T. Location "northeast of Solis Lacus towards Tithonius Lacus" at a latitude of approximately -15 degrees, longitude approximately 90 degrees. $De = -11.5 \text{ degrees}$ $Ds = -13.6 \text{ degrees}$ $(De + Ds)/2 = -12.6 \text{ degrees} = \text{nominal Martian latitude of the source of specular reflection, assuming horizontal orientation. Minimal north-south inclination of the source is suggested. Phase i (planetocentric elongation of Mars with respect to Earth and Sun) = } 5.5 \text{ degrees (prior to date of opposition). } CM = 90.2 \text{ degrees. } 90.2 + (5.5/2) = 92.9 \text{ degrees} = \text{nominal Martian longitude of source of specular reflection, assuming horizontal orientation. Minimal east-west inclination of the source is suggested.}$

²³ Tsuneo Saheki, December 8, 1951 21:00 U.T. Location: Tithonius Lacus, latitude -5 degrees, longitude 85 degrees. $De = 23.5 \text{ degrees}$ $Ds = 23.5 \text{ degrees}$ $(De + Ds)/2 = 23.5 \text{ degrees} = \text{nominal Martian latitude of the source of specular reflection, assuming horizontal orientation. A } 28.5\text{-degree north-south inclination of the source is suggested. Phase i (planetocentric elongation of Mars with respect to Earth and Sun) = } 33.2 \text{ degrees (prior date of opposition) } CM = 36.9 \text{ degrees. } 36.9 + (33.2/2) = 53.5 \text{ degrees} = \text{nominal Martian longitude of source of specular reflection, assuming horizontal orientation. This implies an east-west inclination of the source of about } 85 - 53.5 = 31.5 \text{ degrees.}$

Sigeji Tanabe, November 6, 1958 15:03 U.T. Location: "southwest edge of Tithonius Lacus" latitude approximately -12 degrees, longitude approximately 85 degrees. $De = -10.7 \text{ degrees}$ $Ds = -14.4 \text{ degrees}$ $(De + Ds)/2 = -12.5 \text{ degrees} = \text{nominal Martian latitude of the source of specular reflection, assuming horizontal orientation. Minimal north-south inclination of the source is suggested. Phase i (planetocentric elongation of Mars with respect to Earth and Sun) = } 9.2 \text{ degrees (prior date of opposition). } CM = 124.9 \text{ degrees. } 124.9 + (9.2/2) = 129.5 \text{ degrees} = \text{nominal Martian longitude of source of specular reflection, assuming horizontal orientation. This implies an east-west inclination of the source of about } 129.5 - 85 = 44.5 \text{ degrees.}$

like feldspars to be highly aligned in igneous rocks, and faulting sometimes exposes fairly large surfaces with nearly specular reflections.”²⁴

If Martian flares are caused by specular reflections, it should be possible to predict when they will occur, provided that the weather on Mars cooperates. A few days before Christmas of 2000, the authors realized that during the 2001 apparition of Mars the viewing geometry would be very similar to that of 1954, when flares were seen at Edom Promontorium. Our hearts raced when calculations indicated that for a few days in early June 2001 when Mars would present a generous disk diameter of 20 arc seconds, the northern half of Edom Promontorium would lie smack dab at both the sub-solar and sub-Earth points shortly before it crossed the central meridian:

June 4 \square De = 1.0 degrees Ds = 3.4 degrees \square CM transit = 5:15 U.T.
June 5 \square De = 1.2 degrees \square Ds = 3.2 degrees \square CM transit = 5:58 U.T.
June 6 \square De = 1.5 degrees \square Ds = 2.8 degrees \square CM transit = 6:28 U.T.
June 7 \square De = 1.7 degrees \square Ds = 2.5 degrees \square CM transit = 7:04 U.T.
June 8 \square De = 1.9 degrees \square Ds = 2.3 degrees \square CM transit = 8:17 U.T.
June 9 \square De = 2.1 degrees Ds = 2.1 degrees \square CM transit = 8:53 U.T.

In the May 2001 issue of *Sky & Telescope* magazine we published an article announcing our tentative prediction and urging astronomers to monitor the region carefully on the nights in question.²⁵ This promised to be the opportunity of a lifetime to capture a Martian flare on videotape, so we hastily organized an expedition to observe the planet under the most favorable conditions. Our mixed bag of amateur and professional Mars-watchers included Donald Parker and Jeff Beish, coordinators of the Association of Lunar and Planetary Observers’ Mars Section; Rick Fienberg and Gary Seronik of *Sky and Telescope* magazine; the noted astrovideographer David Moore; Timothy Parker, a jovial planetary geologist from NASA’s Jet Propulsion Laboratory; Gordon College astronomer Richard Schmude, and Tippy and Patty D’Auria of Miami’s Southern Cross Astronomical Society.

The extreme southerly declination of Mars during the 2001 apparition argued for an observing site at a low latitude to give the planet maximum elevation above the turbid, turbulent air near the horizon. At sites in the eastern and central time zones of the United States, the rotation of Mars would place Edom Promintorium near the center of the planet’s disk at the times of the predicted events. Southern Florida met both of these requirements.

The incidence of clear skies during late spring and early summer is considerably higher in the Keys than on the mainland of the Florida peninsula, where convective thunderstorms often occur late every afternoon and skies fail to clear until well into the night.

²⁴ Personal correspondence, Andrew Young to William Sheehan.

²⁵ Thomas Dobbins and William Sheehan, “The Martian Flares Mystery” *Sky & Telescope*, May 2001. pp. 115-123.

Consequently, an observing site on Cudjoe Key about 20 miles northeast of Key West was selected. It proved to be a wise choice. As luck would have it, we enjoyed clear or partly cloudy skies every night while a tropical storm churned over the western Gulf of Mexico, drenching Texas and Louisiana. The skies of northern and central Florida were generally overcast, and most of the eastern and central United States was clouded out.

Contrary to the glowing descriptions of a tropical paradise in the brochures written for prospective tourists, the Florida Keys consist largely of malodorous, mosquito-infested mangrove swamps and beaches covered with jagged shards of coral rather than sand. The oppressive heat and humidity reduced us to a state of poolside torpor by mid-afternoon, but the companionship, rum, and clear skies more than made up for any disappointment with our surroundings.

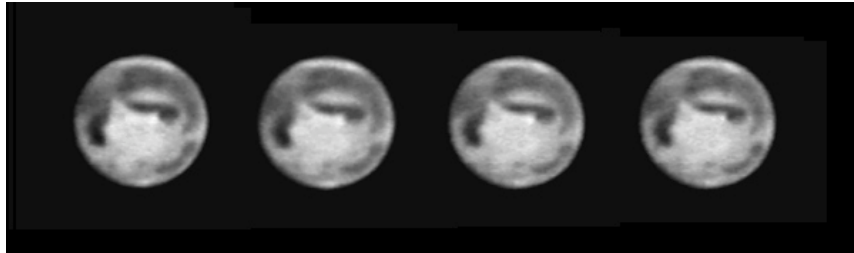
Our vigil began on the night of June 2. Sustained winds of 10 to 15 knots buffeted our telescopes mercilessly, but the laminar airflow produced remarkably steady seeing that revealed a wealth of subtle Martian detail. For thirty years it has been possible to examine images taken by orbiting spacecraft that reveal features no larger than the Los Angeles Coliseum at any point on Mars, yet crisp views of that tiny ruddy disk remain profoundly gratifying, perhaps in part because they provide a sense of being intimately connected with the generations of observers who could only wonder and speculate about what they saw.

Liberally daubed with an ineffective array of insect repellants, we stayed glued to the eyepieces of our telescopes, pausing occasionally to stretch our legs and inspect an impressive, grapefruit-sized image of Mars displayed on a television monitor fed by a video camera mounted at the focus of our largest instrument, a 12-inch Schmidt-Cassegrain.

Edom Promontorium rounded the planet's morning limb 37 minutes later on each successive night and was carefully scrutinized as it was slowly carried across the disk by the planet's rotation. Despite the favorable observing conditions, our hopes of seeing a specular reflection began to wane when we realized that the Martian atmosphere was unusually transparent and almost free of clouds.

Nothing out of the ordinary was seen for five consecutive nights. By the third night the sight of our companions faithfully keeping watch at their eyepieces made us wonder if we should found a religious cult or run for political office. Then, on the morning of June 7, an anomalous brightening of Edom Promontorium was noticed on the video monitor at 6:35 UT. Within five minutes pronounced pulsations in brightness began to occur at sporadic intervals of about 30 seconds. These recurring brightness maxima of two to three seconds duration could not be attributed to atmospheric turbulence, which was quite modest at the time. Looking for all the world like someone was intermittently blowing on a glowing ember, for the better part of the next hour they were accompanied by fleeting sparkles or glints that were detected simultaneously by the visual observers and the group clustered around the video monitor. Soon an excited chorus of "Now! Now!" and "There it is again!" replaced the muttered profanities directed at the relentless mosquitoes.

The brightest flares were far more reflective than the canopy of clouds over the polar region and the Hellas basin near the evening limb.²⁶ *Sky & Telescope* Associate Editor Gary Seronik described the spectacle as “the most exciting planetary show since Comet Shoemaker-Levy 9 slammed into Jupiter in July 1994.”²⁷ As these images extracted from the videotape attest, both the location and the appearance of the flares were uncannily similar to Saheki’s 1954 observation.



Video images corresponding to 6^h45^m42^s, 6^h46^m15^s, 6^h46^m49^s, and 6^h47^m35^s UT on June 7.

In the wee hours of the morning of June 8 we again saw flares at Edom Promontorium, this time in two discrete waves. The first consisted of a series of three to five second long pulsations that were observed visually and recorded on videotape between 07:00 and 07:20 UT. These events were similar in intensity and frequency to those of the previous night. A second series occurred between 07:53 and 08:24 UT, when the altitude of Mars was only 26 degrees above the horizon.

Although theory suggested that June 9 would be the date of the most favorable Earth-Sun-Mars geometry, no flares were seen on that date by any observers.

INTERPRETING THE OBSERVATIONS

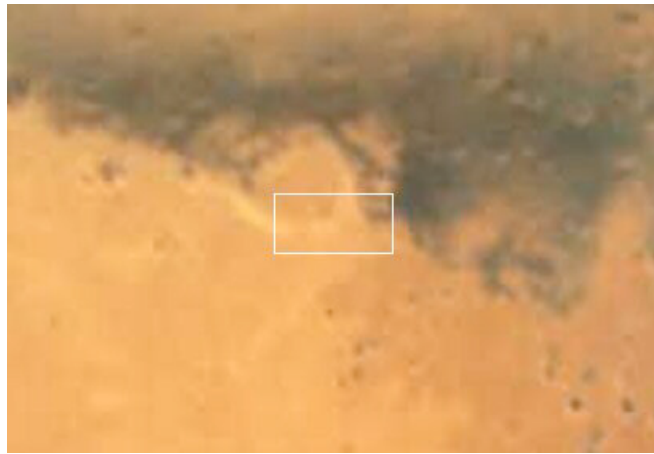
Once we returned from Florida, the real work of analyzing our data began in earnest. David Moore undertook the Herculean task of the painstaking, frame-by-frame examination of hours of videotape in order to determine the precise time, duration, location, and brightness of each flare event. He comments:

²⁶ Walter Haas, the founder and Director Emeritus of the Association of Lunar and Planetary Observers, calculated that throughout early June the luminance of one square arc second of the Martian disk ought to have been equivalent to a magnitude 4.1 star, ignoring the differences in albedo between the planet’s deserts and the maria. Taking his value as a benchmark, many of the flares recorded in Florida were certainly brighter than magnitude +2.

²⁷ Gary Seronik, “Mars Flares in Florida,” *Sky & Telescope*, September 2001, p. 112.

On June 7 I observed many of the flares visually through Don Parker's 6-inch reflector, so I have the perspectives of both a visual observer and a videographer. As a generalization, the specular reflections seemed to fall into two categories, which sometimes occurred in combination. The first category, pulsations in brightness, have been aptly described as "blowing on an glowing ember," while the second might well be called "flashes" – sudden, very brief brightenings within the general Edom Promontorium region, usually at the feature's northern end. It should be noted that these phenomena appeared in moments of both good and mediocre seeing in at least five consecutive frames in the case of the "flashes" and in hundreds of frames in the case of the "glowing ember" effect.

We also calculated the geometrical parameters that prevailed during the June 7 and 8, 2001 flares and compared them to Saheki and McClelland's 1954 sightings and Tasaka's 1958 sighting at Edom Promontorium. In all of these instances, the sources of the reflections were not appreciably inclined on a north-south axis, but were always inclined on an east-west axis by angles ranging from 19 to as much as 41 degrees. It is notable that spacecraft laser altimetry indicates an increase in elevation in the region between the Schiaparelli Basin and Meridiani Sinus consistent with the direction of the inferred inclination but not nearly as steep.



Top: A grossly over-enlarged video frame from 7 June, 2001, showing the location of one of the specular reflections. Bottom: A view of the same region, cropped from a June 26, 2001 Hubble Space Telescope image of Mars.

Following the announcement of our success in *International Astronomical Union Circular 7642*, many comments were received from the professional astronomical community. Some of the most insightful came from University of Nebraska astronomer C. Martin Gaskell, an accomplished quasar specialist who still grinds telescope mirrors and observes the planets from his backyard. To Gaskell, the fact that the reflectors were appreciably inclined on an east-west axis ruled out clouds:

I am particularly intrigued by the pulsations. These cannot be diffraction effects - they are many orders of magnitude too slow - but they fit nicely for multiple reflecting regions. With a little thought we can constrain the brightness of the flares to better than an order of magnitude. If, for example, they appear in an 8-inch telescope as a 4th magnitude star would to the naked eye (they're probably brighter than this), then for a 100% efficient idealized flat reflector on Mars, the diameter needs to be about 200 meters, consistent with what Fessenkov calculated... If the pulsations in brightness occur a timescale of around four seconds, this corresponds with motion of the Martian surface of 200 meters, consistent with the size estimates derived from the brightness. What I would envisage then are patches of ice with typical spacings of a kilometer or two.

Since the Martian reflectors are inclined to the horizontal at a fair bit, this strongly rules out clouds. It's got to be on the surface. The range of inclinations can be readily explained by a range of slopes on the surface. The rapidity of the fluctuations tells us that there are regions of the reflector with slightly different slopes. The size of region needed to explain the flashes of a few seconds is only a few times bigger than a football field. There are plenty of flat regions on this scale. I think the faces of sand dunes are an interesting possibility, although by no means the only one. These flashes are only seen when the weather is right, not every day, so they are fog/frost induced. It's not shiny rocks.

Here's my scenario for what happens: In the morning the Sun heats the ground and makes water evaporate. The Martian air is always close to saturation and, unlike the Earth's, is significantly colder than the ground. Ice crystals therefore condense in the air above the ground, forming a fog (as seen on Earth when the Sun shines on wet ground and as imaged on Mars). The ice crystals fall on the ground, creating a deposit of frost. Fog and frost must go hand in hand.

The ice crystals have a very high albedo, so they inhibit any more heating of the ground where they fall and they can stay there for quite a while. On Mars, unlike on the Earth, the surface temperature is ruled almost entirely by the amount of sunlight absorbed and by the emissivity of the surface, not by the atmosphere. (On the Earth, with a much denser atmosphere, heating by the air dominates instead).

Why do fog and frost form in valleys? Answer: because the wind is calm there and the water vapor content of the air is not reduced by turbulent mixing with drier air. The same is true on Earth. What governs when frost is seen in Schiaparelli? Answer: how windy it is. Fog and frost will only be seen on the calmest days (as on the Earth).²⁸

The Mars Global Surveyor spacecraft's Mars Orbiter Camera ("MOC") assembled daily global views of Mars from images acquired between June 5 and 7, 2001, coinciding with the Florida Keys expedition. Jet Propulsion Laboratory planetary geologist Tim Parker commented:

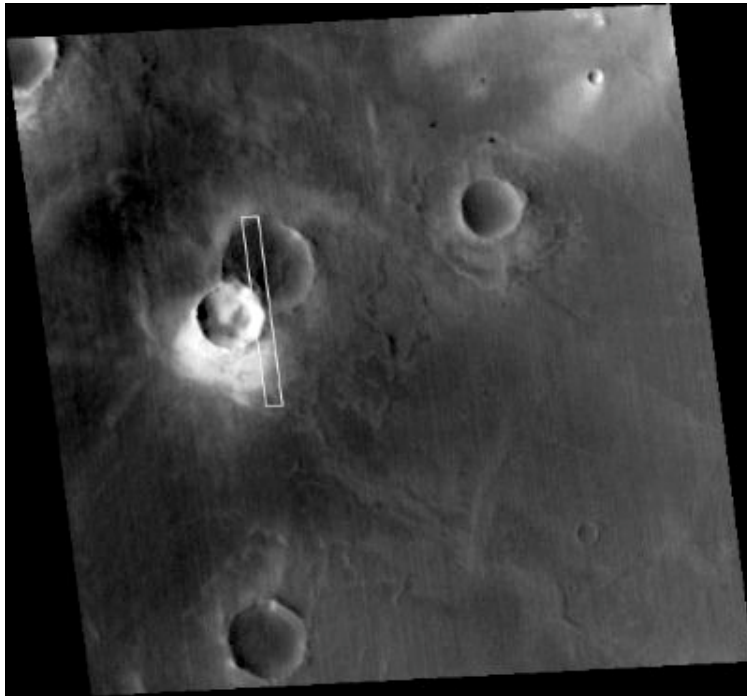
What I find most interesting about these images is the relatively cloud-free disk, particularly around the Schiaparelli-Edom Promontorium region. This suggests the intriguing possibility that the specular reflections from that area may be due to surface materials - frost, mineralogy, or texture. Keep in mind, of course, that the global views produced by the MOC camera are assembled from strips acquired from the spacecraft's 2 PM orbit, so morning and afternoon limb clouds do not show in these images.

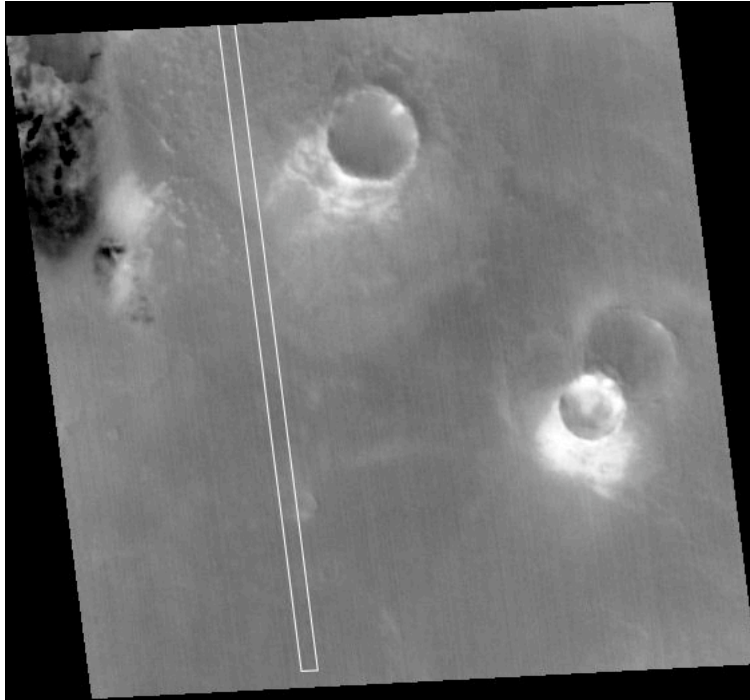
Many of the narrow-angle images of the terrain southwest of Schiaparelli show dune fields with crests oriented roughly north to south. The eastward-facing slopes could easily be on the order of 10 or 20 degrees, and might be acting as a field of reflectors.

²⁸ Personal correspondence, Martin Gaskell to Thomas Dobbins.

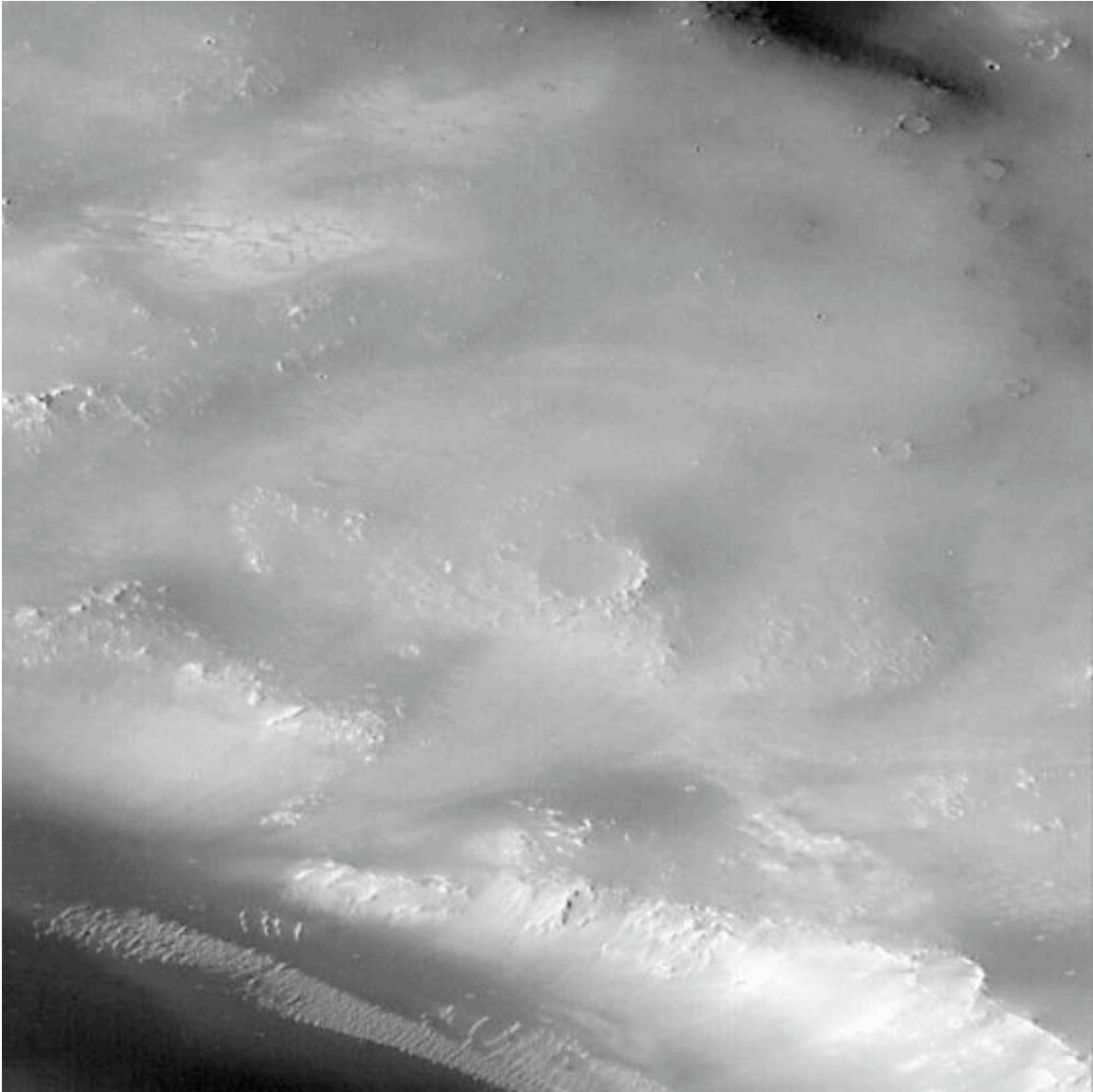
Gaskell agreed, noting that “the sand dune field of reflectors idea could certainly provide the right angle to the horizontal... Different angles would be seen in different years depending on what the wind had done. Flashes would only be seen on days when frost happened to cover the dunes.”

To support this explanation, Gaskell cited high-resolution MOC images of the Edom Promontorium and the Schiaparelli Basin taken by the Mars Global Surveyor spacecraft's Mars Orbiter Camera ("MOC") that show what appear to be patches of frost on the surface. It is notable that MOC images are acquired at 2 PM local time, so these presumed frost deposits had not sublimated away by mid-afternoon.





Another 1997 MOC image of a valley and the terrain surrounding the Schiaparelli Basin suggests that this region may be "special" despite the rather mundane appearance of its topography at low and medium resolution.



According to the Jet Propulsion Laboratory press release that accompanied the release of this image:

There are two exciting results seen in this image. First, the small dunes moving from left to right (north to south) along the canyon floor [bottom left] are apparently derived from bright deposits within Schiaparelli crater. They are brighter than most Martian dunes and may represent a unique composition. The shape of the dunes, and their relationships to one another, strongly suggest that these dunes have been active recently, although whether that means within the past year or the past century cannot be told from these images alone...

The discovery made in this image is the small depressions found in the upper left and center of image with faint dark lines crossing lighter floors. These depressions, and the pattern of lines, are similar to dry lakebeds seen throughout the deserts of the

*southwestern United States. The light material may be salts or other minerals deposited as the lake evaporated, and the dark lines may be cracks created as the material dried out. Alternative explanations for the dark lines, involving freezing and thawing of water-saturated soil, are equally intriguing.*²⁹

This network of cracks and possible water-saturated soil call to mind an inference by Masatsugu Minami, Director of the Mars Section of the Oriental Astronomical Association. Noting that flares were seen on only two nights when the positions of the Sun and the Earth were both near the zenith from the vantage point of Edom Promontorium, he suspects that both the incident and reflected beams of sunlight had to pass between the narrow walls of deep trenches or fissures:

*The observations from the Florida Keys brought out several new aspects of the phenomenon. One of the newly found characteristics is the continual series of flashes. This implies that at least longitudinally the surface of the reflector may be convex, not just simply inclined. Another important fact is that no flashes were detected on 5, 6, or 9 June. Thus the positive observations of 7 and 8 June suggest that the latitude of the reflector is located between 2.11 and 2.18 degrees North, assuming that it is locally horizontal in a north-south direction. Perhaps the reflection was not seen more frequently because the reflector is located inside a narrow trench... We can consider that the width of the trench is sufficient to allow a reflection of a beam of sunlight at vertical incidence, but too narrow to admit an inclined sunbeam. If the zigzag walls of the trench are high, the flash would not be seen except around the time when $De=Ds$.*³⁰

The Mars Odyssey space probe's gamma ray and neutron spectrometers provided an additional clue in the spring of 2002. Designed to detect traces of water on or near the Martian surface, they confirmed the long-suspected presence of vast deposits of permafrost within a meter of the surface at high latitudes on Mars. Although the regolith in the Martian tropics has become desiccated over the aeons, in the area where the flares were seen these instruments detected an anomalous enrichment in hydrogen, indicating the presence of near-surface water ice or at least hydrated minerals.³¹

FUTURE INVESTIGATION

The frost-covered slopes of dunes, the salty remnants of former brine lakes, and sheets of ice at the bottom of deep, shaded crevases all remain plausible explanations for the specular reflections recorded in 2001. After a lapse of more than a century, it may be time to revive the long-abandoned 19th century practice of calculating ephemerides for Martian specular reflections, not for features like Syrtis Major that were once mistaken

²⁹The image and accompanying caption can be viewed at:
<http://photojournal.jpl.nasa.gov/catalog/PIA01026>

³⁰ Personal correspondence, Masatsugu Minami to Thomas Dobbins

³¹ "Mars Odyssey Finds Signs of Ice at Flare Site" *Sky & Telescope*, August 2002, p. 26.

for bodies of water, but for the handful of locations that are known to harbor ice-fogs and frost deposits. During the extremely favorable perihelic apparition of Mars in 2003, the values of $\Delta\epsilon$ and $\Delta\delta$ will be virtually coincident at -19.4 degrees in late July and early August, when the apparent diameter of the planet's disk will exceed 22 seconds of arc. Northern Hellas and Iapygia, northern Thaumasia, and the axis defined by Tithonus Lacus and the 'canals' Coprates and Agathodaemon should be carefully monitored for specular reflections at this time.