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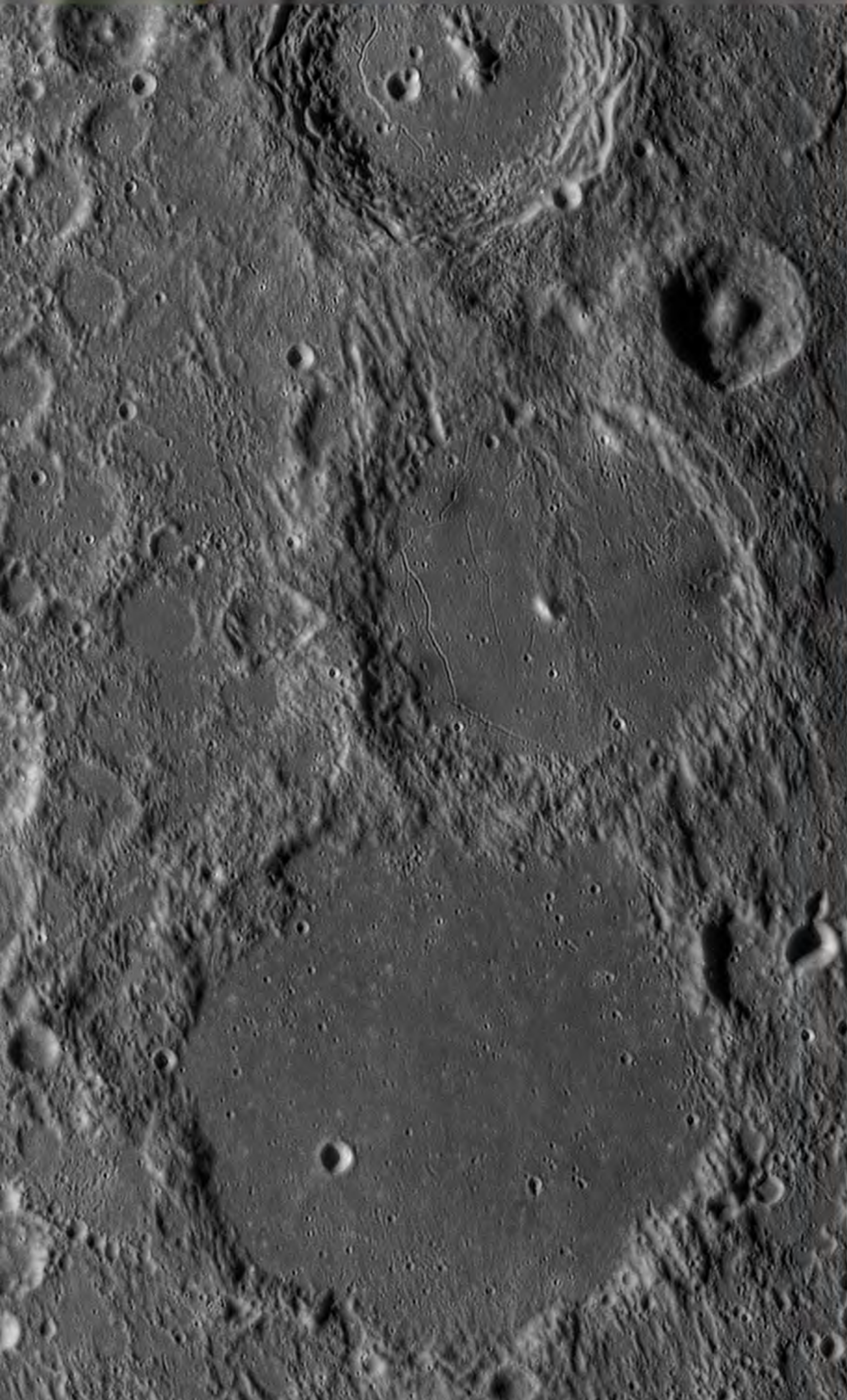

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Selenology Today

Selenology Today is devoted to the publication of contributions in the field of lunar studies. Manuscripts reporting the results of new research concerning the astronomy, geology, physics, chemistry and other scientific aspects of Earth's Moon are welcome. Selenology Today publishes papers devoted exclusively to the Moon. Reviews, historical papers and manuscripts describing observing or spacecraft instrumentation are considered.

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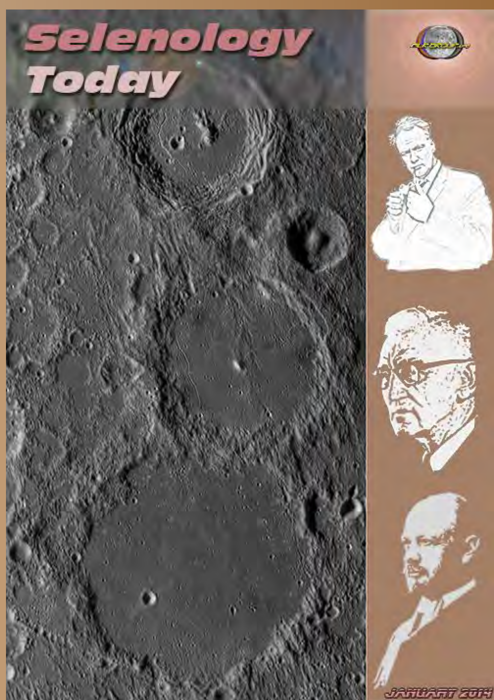

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TRANSIENT LUNACY

By Thomas Dobbins and William Sheehan

The maverick British cosmologist Fred Hoyle (1915-2001) recounted that his Cambridge University colleague R. A. Lyttleton (1911-1995) was chronically annoyed "by the convention that it was bad form for an observational astronomer to be challenged on the grounds of competence, whereas theoreticians were routinely challenged in ways that implied incompetence almost to the point of imbecility."[1] In response to Lyttleton's complaints, the mathematician Hermann Bondi (1919-2005) volunteered to survey the astronomical literature in order to determine who made the most egregious errors -- theoreticians or observers. Confirming Lyttleton's suspicions, Bondi found that observers were guilty of the worst blunders. He wrote a paper to that effect that was rejected twice by the Council of the Royal Astronomical Society not because it lacked merit, but simply out of fear of causing wide-spread offense in the astronomical community.

There has seldom been a greater disparity between theory and observation in the entire history of astronomy than in the field of lunar studies during the second half of the twentieth century. This fact is supremely ironic because the Moon is not only the sole celestial object so close at hand that can be surveyed from a geologist's perspective through the eyepiece of a telescope, but it is the only other world that humans have visited.

As early as 1837, Wilhelm Beer (1797-1850) and Johann Heinrich von Mädler (1794-1874) published a Moon map accompanied by a gazetteer with detailed descriptions of craters, mountains, and other surface features that was regarded as so exhaustively thorough and accurate that it virtually paralyzed further studies of the Moon for years. Hailing the work as "an imperishable monument," the great German astronomer Friedrich Wilhelm Bessel (1784-1846) declared: "Selenography has here done what was left to do."[2]

Beer and Mädler's work also established a consensus that the Moon was "to all intents an airless, waterless, lifeless, unchangeable desert."[3] If that were true, there seemed to be little point in observing it except for recreational sightseeing. Granted, larger telescopes would make it possible to chart the Moon's features in greater detail than the Beer and Mädler map, but that was a tedious, painstaking task that would appeal chiefly to obsessive-compulsives with a masochistic streak. As the British astronomer Richard Anthony Proctor (1837-1888) wrote:

> The principal charm of astronomy, as indeed of all observational science, lies in the study of change –- of progress, development, and decay, and especially of systematic variation taking place in regularly-recurring cycles… In this regard the Moon has been a most disappointing object of astronomical observation. [4]

During the nineteenth century and well into the twentieth, the overwhelming consensus among both astronomers and geologists was that lunar craters were of volcanic origin. The few who suggested that cosmic impacts might be responsible were generally regarded as eccentrics.

If you begin with the premise that the crater-studded surface of the Moon has been primarily shaped by extensive volcanism, it would only be natural to wonder if volcanic activity has died out completely. Granted, a small orb like the Moon would have cooled from its primordial fiery state far more rapidly than the Earth. But would all of its internal fires have gone cold? Even if large-scale lunar changes were a thing of the

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distant past, to the Reverend Thomas William Webb (1806-1885), one of the leading British amateur astronomers of the mid-nineteenth century, "this would not necessarily infer the impossibility, or even improbability, of minor eruptions, which might still continue to result from a diminished but not wholly extinguished force."[5] His countryman William Radcliff Birt (1804-1881) also suspected that "eruptive action still exists, although in a subdued form." [6]

Suggestions like these proved very enticing, and an intensive hunt soon ensued for alterations in the appearance of minor lunar features that might signify topographic changes. The results were at best inconclusive due to the confusing effects of the ever-changing interplay of light and shadow combined with the formidable uncertainties inherent in comparing drawings made by observers of differing visual acuity and artistic skill. One might imagine that the advent of photography would have provided the vital tool capable of settling the issue, but it did not.

Photography did enable astronomers to make exposures minutes or even hours in duration, accumulating the feeble light of stars and nebulae far beyond the grasp of any visual observer. Laborious visual searches for variable stars and asteroids and the traditional visual methods of astronomical photometry and spectroscopy were all rendered obsolete by photography in the span of only a few years. Recording lunar and planetary details on film was a different matter, however. Lunar and planetary observing has been compared to watching a movie in which the projector is out of focus except for a few occasional sharp frames thrown in at random intervals. To record even these comparatively bright subjects at a large image scale using photographic emulsions required exposures lasting appreciable fractions of a second to several seconds. In this seemingly brief span of time, atmospheric turbulence invariably effaced the finest details, even at the best observing sites on the steadiest nights.

While the human eye is not quite an instantaneous sensor, it requires only about one-fifteenth of a second to register an image. Visual observers were not only equipped with a superior sensor. They could retain impressions of the fleeting sharp views and disregard the blurry intervals, remembering what was glimpsed in the moments of clarity and committing it to paper. While they may have been hopelessly outclassed when it came to studying faint objects, when it came to recording lunar and planetary features visual observers enjoyed an insuperable advantage over photographers until the closing years of the twentieth century, when the long era of the supremacy of the eye-brain combination was brought to a close by the widespread availability of cameras based on "charge-coupled device" (CCD) sensors that replaced the photographic emulsion's grains of silver salts with a far more sensitive silicon chip.

As recently as the 1980s, the sharpest photographs of the Moon and planets taken

Figure 1: William Henry Pickering

through the world's largest telescopes failed to record details beyond the grasp of an experienced visual observer equipped with a 10-inch telescope, and the best photographic lunar atlases seldom contained images of features beyond the grasp of a telescope half that size. Consequently, studies of lunar topography remained the province of amateur astronomers equipped with instruments that, while modest in size by professional standards, were dis-proportionately effective.

The visual hunt for changes on the Moon culminated in the radical "new selenography" advanced by the Harvard astronomer William Henry Pickering (1858-1938) at the dawn of the twentieth century, "a selenography that consists not in the mapping of cold dead rocks and isolated craters, but in a study of the daily alterations which take place in small, selected regions."[7] Suffering from a proclivity to wildly misinterpret his eyepiece impressions, Pickering claimed that the Moon was active not only geologically, but meteorologically and biologically as well. In addition to fumaroles and geysers, he "saw" fogs, snowstorms, tracts of vegetation, and even moving swarms of migrating animals. Although these far-fetched notions resulted in Pickering's virtual ostracism from the professional astronomical community, they did find a receptive audience among amateur lunar observers. Pickering went to his grave supremely confident that "the observer will triumph over the man who depends exclusively on his reasoning faculty."[8]

Pickering's work so stigmatized lunar studies that the Moon was largely neglected by professional astronomers until the two decades following the end of the Second World War when Ralph Belknap Baldwin (1912-2010) and Eugene Shoemaker (1928-1997) established a firm theoretical foundation for the impact origin of lunar craters and effectively demolished the underpinnings of volcanic theories. A businessman with a Ph.D. in astronomy from the University of Chicago, Baldwin demonstrated that lunar craters and the craters formed by exploding aerial bombs and artillery shells all shared a characteristic range of depth-to-diameter ratios that fell along a neat logarithmic curve that, in his words, was "too startling, too positive, to be fortuitous."

Shoemaker determined that the crystals of the mineral coesite found in the sandstone deposits near Meteor Crater in Arizona had been created by subjecting quartz to enormous pressures that only the shock waves of a cosmic impact could generate. He soon applied his profound insights into the physics of impacts to the 100 kilometer-wide lunar crater Copernicus, the "monarch of the Moon." He immediately grasped that no conceivable volcanic process could have produced an explosion sufficiently powerful to expel millions of tons of debris across distances of hundreds of kilometers to form the formation's halo of secondary craters. Shoemaker also convincingly explained the crater's central peaks as the product of the violent rebound of shock waves and its terraced walls as the result of subsequent landslips of rim material.

It was becoming increasingly obvious that lunar craters were excavated almost instantaneously by explosions of stupendous violence and did not form gradually in a succession of volcanic eruptions. Yet many lunar observers tended to ignore these theoretical advances. In fact, the most active and influential lunar observers clung to the old volcanic ideas almost to a man.

The torch of Pickering's "new sele-nography" had passed to Walter Haas (b. 1917). A native of Ohio, Haas was trained as a mathematician and as a young man spent five formative months in 1935 at Pickering's private observatory in Jamaica. Twelve years later, Haas founded the Association of Lunar and Planetary Observers, an American organization modeled on the British Astronomical Association.

Unlike Pickering, Haas was to all appearances restrained, judicious, and cautious. But his association with Pickering had profoundly influenced his views on lunar conditions. In 1942 an unusually long article by Haas entitled “Does Anything Ever Happen on the Moon?” appeared in the ***Journal of the Royal Astronomical Society of Canada***. [9] He contrasted the prevailing amateur viewpoint with the overwhelming consensus among professionals, which he characterized with a reference to the seemingly dogmatic declaration by the astronomer Simon Newcomb (1835-1909): “The Moon is a world which has no weather, and on which nothing ever happens.” To the contrary, Haas opined, the observational record contradicted that bleak assessment: “The great majority of those astronomers who have made special observational studies of the Moon, so-called selenologists, have been of the opinion the changes do occur on the Moon or at least that there exist lunar phenomena not explicable by known physical laws.” [10]

Haas presented a sympathetic review of Pickering’s evidences for clouds, snowfalls, and vegetation. He maintained that the fluctuations in the visibility of details in the crater Plato, whose floor he had carefully mapped between 1935 and 1940, were probably due to local obscurations by “otherwise unrevealed lunar vapors.” [11] He concluded by recommending the study of lunar changes to his colleagues with the encouragement: “He who goes into this subject may decide that the Moon is much less dead than he has been told.” [12]

None of these studies broke new ground. The investigation into what the British lunar observer Rob Moseley has called the “dodgy reputation of Plato’s floor” dated back to the Bavarian astronomer Franz von Paula Gruithuisen (1774-1852), who had wondered if variations in the visibility of the craterlets dotting Plato’s floor might not be caused by the occasional presence of fog or mist. [13] Seldom stressed was the fact that the appearance of a crater like Plato changes very dramatically in the span of a few hours under sunrise or sunset conditions. The Sun travels through half a degree every hour from a lunar vantage point, so shadows can often be seen to advance or retreat within an interval of only a few minutes. At Plato’s latitude of 50^0 North, the terminator (the line of sunset or sunrise) sweeps across the lunar surface at a rate of about 10 kilometers per hour, and the crater’s appearance is also markedly affected by libration, the apparent slow wobble of the Moon due to its varying orbital velocity and other geometric effects that enables Earth-bound observers to glimpse portions of the normally averted hemisphere. Neglecting the all-important state of the Earth’s atmosphere, a nearly exact duplication of the same observing circumstances occurs not once every month, but only once every 18 years, the so-called saros interval when the Earth-Sun-Moon geometry recurs nearly identically. [14]

Haas’ counterpart in Britain was a Welsh civil servant trained as an engineer, Hugh Percy Wilkins (1896-1960), who served as Director of the British Astronomical Association’s Lunar Section from 1946 to 1954. A remarkably maladroit draughtsman, Wilkins unhappily chose for his life’s work the singularly uncongenial task of constructing the largest lunar map yet constructed on a scale of 300 inches to the Moon’s diameter.

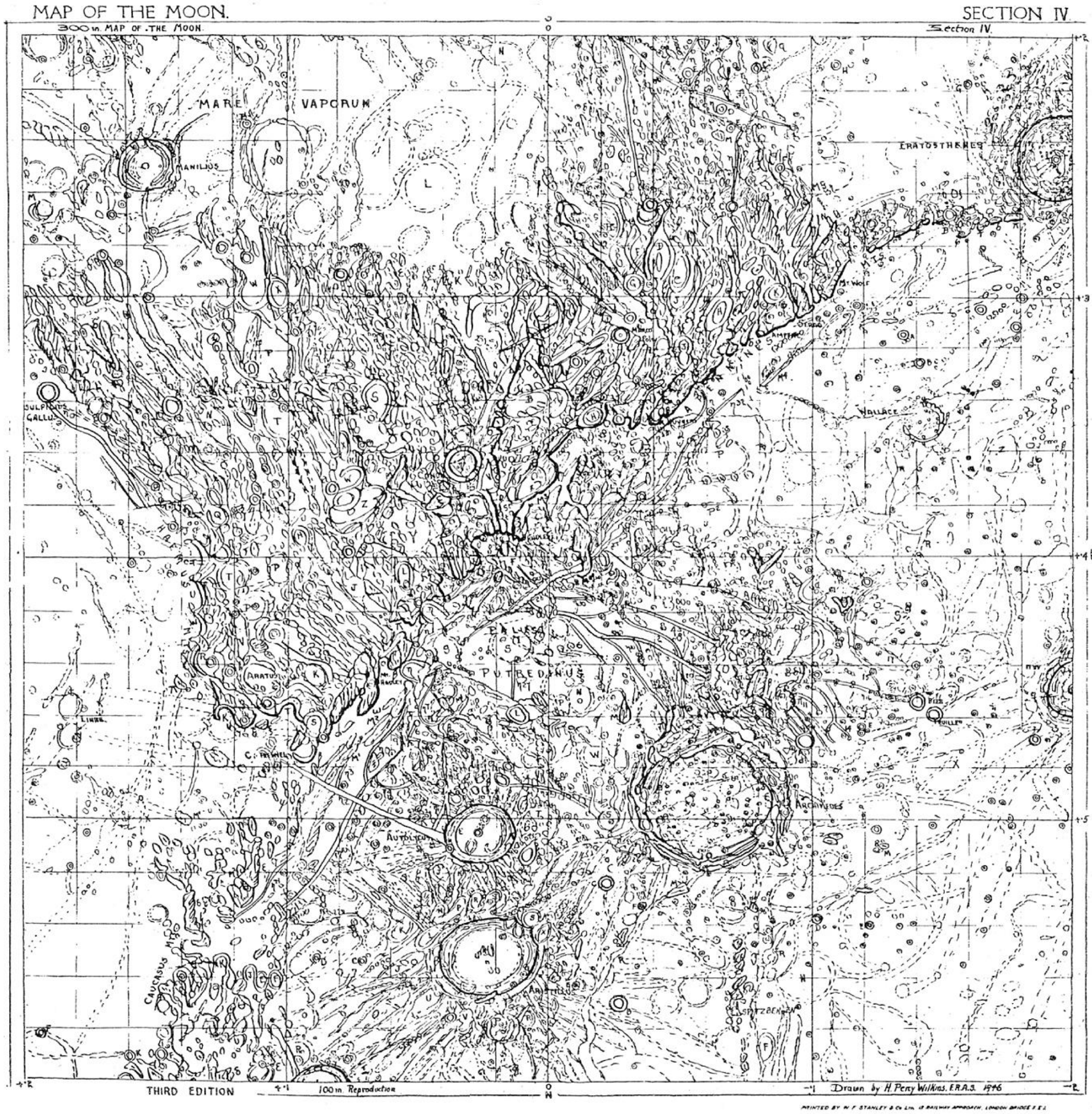

Figure 2: Section 4 of the H.P. Wilkins' 300-inch lunar map

It was, according to lunar geologist and cartographer Don Wilhelms (b. 1930), compiled from "detailed but very unrealistic line drawings laboriously prepared over decades." [15] Wilhelms was not alone in harsh appraisal. [16] In his classic monograph ***A History of Lunar Studies***, Ernst Both's verdict was that "neither positional nor artistic quality was at all commensurate with the quantity of detail represented." [17]

In 1953 Wilkins and an enthusiastic young colleague, Patrick Moore (1923-2012), began to observe the Moon with the great 33-inch Meudon refractor, Europe's largest, located in a suburb of Paris. Making the channel crossing from Britain to France on every available weekend, "their reports were read as eagerly as reports from the Front in wartime." [18]

Figure 3: Patrick Moore

Wilkins and Moore spent many hours closely examining central peaks in the hope of finding minute summit craterlets. Baldwin had calculated that only about 15 examples of such features ought to exist on the visible surface of the Moon if they were created by random impacts. [19] Wilkins and Moore found no fewer than 52, and they cited this number to buttress their belief that the central peaks were volcanic cones.[20] The lion's share of these purported summit crater pits have proven to be illusions, "merely the effects of shadows cast by parts of the peaks, which, in a large crater, cluster around a depression as do the points of a molar tooth." [21]

Wilkins's popular book **Our Moon,** published in 1954, is rife with strained logic. After recounting that on April 18, 1953, Moore had discerned a small pit never before recorded on the central peak of Theatatus, he remarked: "Now the newly-found peak is not so small as to justify our saying that it requires a large telescope to be seen. It should have been recorded by others but was not." [22] There were, not surprisingly, a host of similar instances, leading Wilkins to consider it likely some of them might have been newly-formed. The far more plausible explanation that these discoveries might be accounted for simply by the closer attention that later observers paid to such features seems to have eluded him. [23]

Wilkins also puzzled over the non-mystery of why the Scottish observer James Nasmyth (1808-1890), whose "instrument was certainly adequate to reveal the more minute features," found no domes on the Moon other than the one to the north of the crater Birt, near the showcase Straight Wall. [24] Wilkins and Moore managed to locate over a hundred of these rounded swellings with gentle slopes that rise several hundred meters above their surroundings, leading Wilkins to wonder if some of them were newly formed. As a case in point, he recalled that the skilled observer F. H. Thornton had found "a low dome with a summit pit" near the crater Picard on the Mare Crisium where the Reverend T. E. Espin had noted only a white patch marking a shallow depression. Wilkins wondered: "Is it possible that it has only become a dome recently? Has the ground here swollen up owing to the pressure of gas underneath?" [25] Of course, it would have been quite remarkable if, after aeons of existence, the Moon had somehow seen fit to begin sprouting domes like mushrooms after a rain just as observers began to train powerful telescopes on it!

The dusky radial bands on the interior walls of craters like Aristarchus, Birt, and Bullialdus are now recognized as soils darkened by solar radiation. Landslides downslope of surface rocks have exposed soils that have not yet darkened, forming the intervening brighter streaks. To Wilkins, however, these features posed yet another mystery. John Phillips (1800-1874) had recorded the bands in Aristarchus, but the others went unnoticed by even the most diligent nineteenth century observers. Yet by 1955 no fewer than 188 examples were known. [26] "All this is mysterious enough," wrote Wilkins, "almost sufficient for us to sympathize with the idea often expressed by Schroeter [Johann Hieronymous Schroeter (1745-1816)], that some of these appearances are caused by the 'Industrial Activities of the Selenites'! We cannot subscribe to this idea because without air to breathe it is exceedingly difficult to contemplate the existence of Selenites, let alone to speculate as to their possible activities, industrial or otherwise. It is equally difficult to explain these things on natural grounds." [27]

There were also obscurations and strange blue or violet glows, particularly around the brightest craters like Aristarchus and Proclus. Localized reddish glows were also not infrequently reported. In evaluating these observations, Wilkins hardly found a case that failed to satisfy his credulity. In the end it was this very credulity that led to his downfall.

In July 1953, John J. O'Neill, science editor of the New York Herald Tribune, was casually surveying the Moon through a 4-inch refractor when he noticed a slowly retreating, fan-shaped patch of light diverging from a narrow gap in the mountains along the "shoreline" of the Mare Crisium ("Sea of Crises"), the best preserved example of the Moon's great impact basins. He interpreted this feature as the rays of the setting sun streaming beneath "a gigantic natural bridge having the amazing span of about twelve miles from pediment to pediment." O'Neill's report created a brief sensation, but observers equipped with more powerful instruments quickly recognized the phenomenon as a striking example of those lunar illusions created by the interplay of light and shadow and relegated it to the status of a charming curiosity. Wilkins, however, had not only confirmed the presence of a colossal arch, but stubbornly defended the notion in the face of contrary evidence and a withering hail of criticism. A minor scandal ensued, culminating in an acrimonious debate at the November 1954 meeting of the British Astronomical Association's Lunar Section in London. Wilkins emerged from the meeting with his credibility irreparably damaged and soon afterwards resigned from the organization. [28]

Wilkins may have been thoroughly discredited, but many of his cherished ideas not only endured but flourished. With the Earthward hemisphere of the Moon mapped in exhaustive detail, what "useful work" remained for lunar observers equipped with modest telescopes who still aspired to make a contribution to science? An increasing number of amateurs and even a handful of professionals began to concern themselves with the luminous spots, colored glows, and obscurations of topographic features which, if taken at face value, seemed to indicate that the Moon is still volcanically active. Patrick Moore, who certainly did take them at face value, dubbed them "transient lunar phenomena" or "TLP." (The nomenclature "lunar transient phenomena" or "LTP" is also encountered in some recent literature.)

It would not be fair to tar all amateur lunar specialists of the era with the same brush. The German selenographer Philipp Fauth (1867-1941), who compiled the last and in many ways the best lunar atlas of the visual observing era, regarded reports of changes on the Moon as "fantasies" and lamented that "we witness over and over again how 'scientific' methods and time and effort are squandered on unprofitable problems." Harold Hill (1920-2005), whose pointillist depictions of lunar formations are unsurpassed in accuracy and aesthetic appeal, often expressed his disdain for "TLP merchants." Both of these talented iconoclasts spent thousands of hours at the eyepiece surveying the Moon during observing careers than each spanned more than four decades, yet neither managed to so much as glimpse a TLP.

One of the few professional astronomers to specialize in lunar work during these years was Dinsmore Alter (1888-1968), who left a professorship at the University of Kansas in 1935 to assume the directorship of the Griffith Observatory in Los Angeles.

Administered by the city's Department of Recreation and Parks, this institution was devoted to the popularization of astronomy rather than to research. A capable teacher and lecturer, Alter was a powerful stimulus to the growth of amateur astronomy in southern California. He wrote many articles and several popular books on the Moon, all liberally sprinkled with remarks like the

> There is no reason why there should not be a small leakage of gas from the rocks of the floor... of Plato and of other craters. Such an atmosphere well might turn to a "fog" as the moon cools toward sunset. With the sun still lower it might solidify, leaving the floor clear again. After sunrise the reverse process would take place. [30]

If this sounds like W.H. Pickering it is hardly coincidental, for Alter was an admirer of the fallen-from-grace Harvard astronomer. He confided to one correspondent: "W.H. Pickering was one of the most skillful observers who ever spent much time in an examination of the Moon."[31]

The Griffith Observatory's principal telescope was a 12-inch refractor, but Alter was often permitted to use the 60-inch reflector at

Figure 4: Dinsmore Alter

nearby Mount Wilson Observatory. With this powerful instrument he took hundreds of pairs of photographs of the Moon in violet and infrared light in the hope that localized lunar outgassing would be made evident by Rayleigh scattering, the phenomenon responsible for the blueness of the daytime sky on Earth. In 1871 the British physicist John William Strutt, Lord Rayleigh (1842-1919) had demonstrated that the scattering of a beam of light transmitted through a gas is inversely proportional to the fourth power of its wavelength. Hence, violet light with a wavelength of 400 nanometers is scattered 16 times more than infrared light with a wavelength of 800 nanometers. Alter hoped that even a very tenuous lunar cloud would be revealed as a localized blurring on violet plates that would not appear on the infrared plates. This technique is far from foolproof, however, for in violet light all lunar features are invariably rendered more diffuse by scattering in the Earth's atmosphere. At best, one might record a more pronounced

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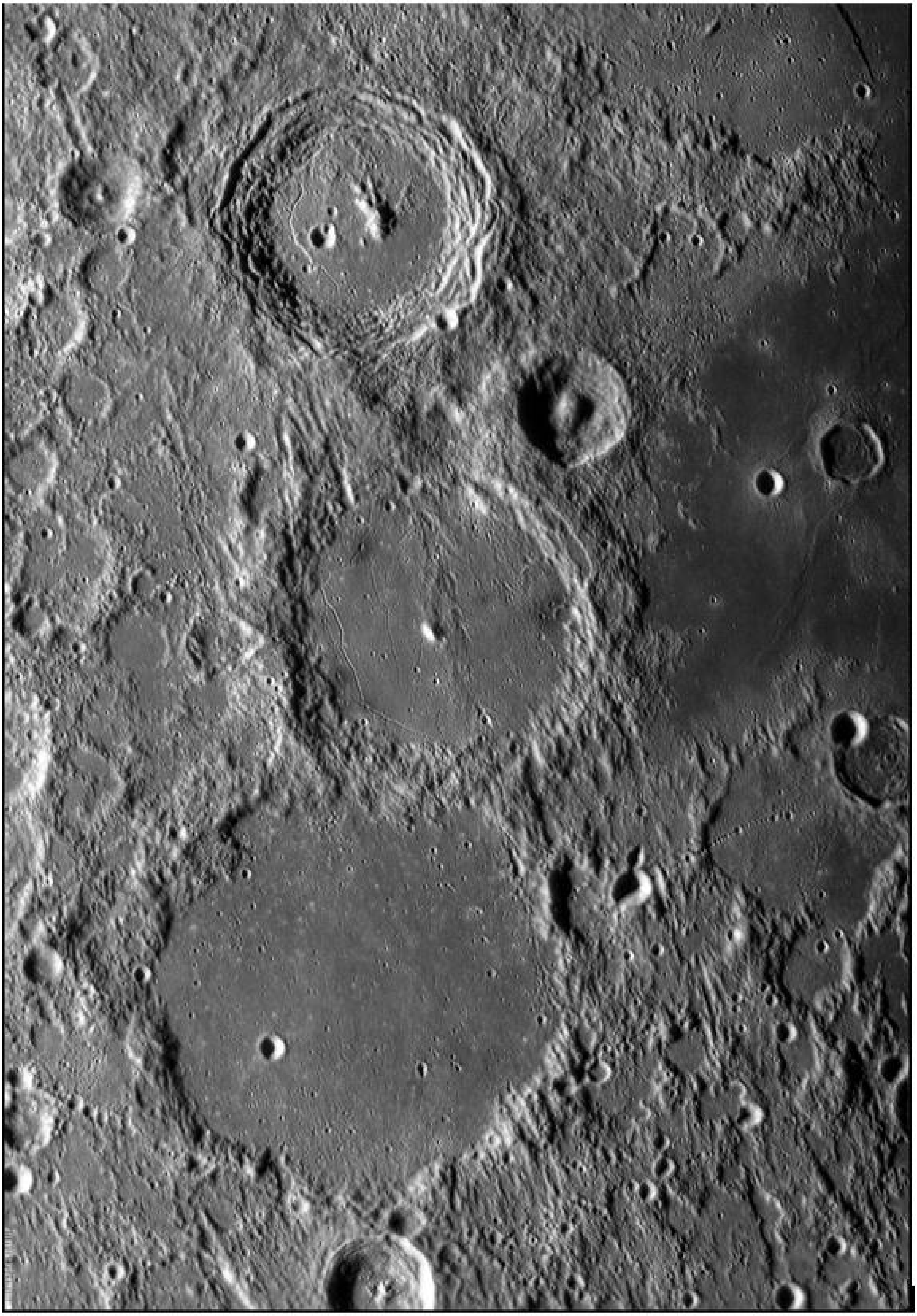

Figure 5: The crater Alphonsus under a high sun.
Image courtesy George Tarsoudis.

lack of clarity in a particular location that would signify the presence a cloud of gas or dust.

On the morning of October 26, 1956, Alter found the seeing "unusually good," recording in the observing log that the "fluctuations of the image, as observed visually with a telescopic power of about 700... were characterized by very small, extremely rapid vibrations." He exposed four pairs of plates at two minute intervals, each pair centered on the crater Alphonsus. This was the formation where W.H. Pickering had suspected that gases seeping from dark-haloed craterlets that punctuate a delicate network of cracks on the crater's floor along its interior walls supported the growth of vegetation that appeared as irregular dusky patches under a high sun.

Predictably, these features were well-defined in the infrared images but not in the violet images. For that matter, the same was true of many of the craterlets and hillocks in the adjacent craters Arzachel and Ptolemaeus. Nonetheless, Alter suspected that the blurring of the features on the floor of Alphonsus was slightly more pronounced than the blurring of comparably fine details elsewhere. The difference was admittedly very subtle, and Alter cautioned that "each observer must decide for himself whether there is a greater loss along the northern part of the rille than there is in other places. Such a loss, of course, would suggest outgassing from this rille, which contains the famous black spots of Alphonsus [which Pickering had imagined to be patches of vegetation], with one or more craterlets in the center of each." [33]

Few who examined Alter's photographs found his interpretation in the least bit persuasive. They would have been quickly forgotten had they not been followed by dramatic news from behind the Iron Curtain. A Russian astronomer, Nikolai Alexandrovich Kozyrev (1908-1983), announced that he had managed to capture on a photographic plate the spectral signature of a volcanic event in Alphonsus.

Intrigued by Alter's images, in the autumn of 1958 Kozyrev began to examine Alphonsus with the 50-inch Zeiss reflector of the Crimean Astrophysical Observatory, which was equipped with an excellent prism spectrograph. On the night of November 3, 1958, when the phase of the Moon was one day before Last Quarter and Alphonsus was well placed for observation not far from the terminator. Kozyrev placed the slit of the spectrograph across the central peak of the crater and opened the shutter of the camera to begin a 30-minute exposure. He kept his eye glued to the eyepiece of a 6-inch refractor mounted atop the

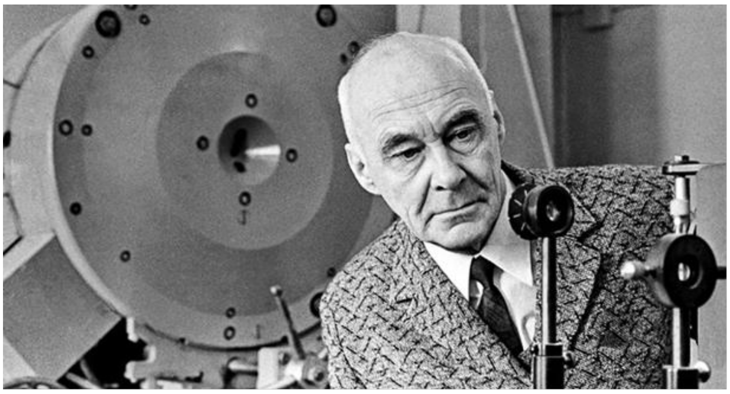

Figure 6: Alexandrovich Kozyrev

massive reflector that served as an auxiliary guiding telescope. The instrument's drive mechanism, geared to compensate for the Earth's rotation, was designed to keep the image of a star motionless in the field of view. With such a sidereal rate drive, the Moon's motion against the stellar background appears as a drift of half a second of arc per second of time in right ascension, while its drift in declination can exceed a quarter of a second of arc per second of time. Consequently, Kozyrev had to make frequent manual corrections to keep the slit of the spectrograph centered over the crater's central peak, a tedious and exhausting exercise.

While guiding the exposure, Kozyrev noticed that the central peak "appeared brighter and whiter than usual," until "suddenly, for a period of less than a minute, the brightness of the peak dropped to normal.” [34] It was late afternoon in Alphonsus at the time, so these setting sun impressions are hardly startling. He immediately halted the exposure and inserted a second plate to record the spectrum of the peak, now “in its normal state.” [35] This second exposure lasted ten minutes.

On the first plate, exposed when the central peak had appeared brighter, Kozyrev claimed that he could make out a set of faint emission bands centered at 474 and 440 nanometers in the blue region of the spectrum, but these features were absent on the subsequent comparison plate. He attributed these delicate bands to ionized molecules of diatomic carbon in a rapidly expanding, rarefied cloud of gas released from the central peak and excited to fluorescence by solar ultraviolet radiation. Curiously, the chemical composition of this gas was not similar to terrestrial volcanic emissions, but seemed to resemble the materials found in the nuclei of comets.

Kozyrev’s discovery was announced with considerable fanfare by the Soviet news agency TASS and soon appeared on page one of the New York Times, accompanied by remarks by the Director of Pulkovo Observatory, Alexander Alexsandrovich Mikhailov (1888-1983), that the observation demonstrated that the impact theory of the origin of lunar craters was “entirely erroneous.” [36] **Sky & Telescope magazine** rushed two articles into print in successive editions, one with reproductions of Kozyrev’s spectrograms. [37]

The sensational story prompted scores of amateurs and a few professionals to carefully scrutinize Alphonsus. The talented Greco-French observer Jean-Henri Focas saw nothing unusual through a 24-inch refractor at the Pic du Midi Observatory high in the French Pyrenees. Despite inferior telescopes and observing conditions, on that very night two American amateurs, H.F. Poppendiek and W.H. Bond, reported seeing a “diffuse cloud.” [38] In Britain, H.P. Wilkins (who remained active even after the O’Neill’s Bridge debacle) and G. A. Hole suspected a reddish-brown tint confined to a small area on the southern slopes of the central peak. [39] The preoccupation with the crater's central peak was inextricably intertwined with the erroneous notion that the feature is a volcanic mountain rather than the uplift created by the rapid elastic rebound that follows the excavation of the crater by an impact.

Several astronomers who examined Kozyrev’s spectrograms immediately suspected that the supposed emission bands were simply artifacts of faulty guiding. Guiding errors would be far less pronounced in the second comparison spectrum, which was exposed with the benefit of the half hour of practice guiding the first spectrum and for only one-third the length of time, accounting for its dearth of supposed emission bands.

Despite these suspicions, many quickly embraced Kozyrev’s report as unimpeachable objective evidence of volcanic activity on the Moon. Here at last was corroboration by an astrophysicist equipped with modern instruments, a vindication of amateur reports of obscuring mists and strange glows that had so long been received with scepticism and indifference by the professionals. Dinsmore Alter was especially effusive in his praise, writing: “Kozyrev’s spectrum is the most important single lunar observation ever made.” [40]

One might expect that witnessing even the rather quiescent emission of gases from a lunar volcano would be a once-in-a-lifetime chance occurrence, rather like catching a glimpse of the Loch Ness monster surfacing on a clear day. Eyebrows were raised less than a year later when Kozyrev announced that he had managed to record a second anomaly in Alphonsus, and this time nothing less than a full blown volcanic eruption. On the night of October

23, 1959, when conditions of illumination were very similar to those on November 3 of the previous year, he again trained his spectrograph on the central peak of Alphonsus and made a 15-minute photographic exposure. This time there were no "peculiarities in the appearance of the crater" noted through the eyepiece of the guiding telescope, so no comparison spectrum was made. [41] The blue emission bands were absent, but to Kozyrev's eye there was a very slight "uniform increase in contrast" between 530 nanometers in the yellow region of the spectrum and 660 nanometers in the orange region of the spectrum. He interpreted this subtle contrast enhancement as the thermal radiation emitted by an otherwise unseen flow of hot lava "at least equal in scale to large eruptions of terrestrial volcanoes." [42]

This time reaction to Kozyrev's announcement was considerably more muted. Much of the credence that had been placed in Kozyrev's first report seems to have been attributable to a lack of familiarity with his other work and to ambiguities in the translations of his communications. Certainly many accounts of his observations were stealthily improved in the retelling. By far the most common embellishment was that he had only employed the spectrograph after seeing a reddish cloud or glow on the central peak of Alphonsus on the fateful night of November 3, 1958. The actual sequence of events can be more accurately characterized as a case of "seek and ye shall find."

With the Cold War at its height at this time, direct exchanges between Western scientists and their Soviet counterparts were limited. During a visit to the University of Chicago's Yerkes Observatory in 1959, one of Kozyrev's colleagues, the accomplished spectroscopist Valerian Ivanovich Krassovsky (1907-1993), confided to his host Gerard Kuiper (1905 -1973) that not only were Kozyrev's spectrograms "defective," but that Kozyrev himself was "personally unstable." [43] Few could have imagined the ordeal that may have prompted this appraisal.

At the height of the Great Terror, the NKVD, Stalin's dreaded secret police, arrested and deported a quarter of the population of Leningrad. They also descended on nearby Pulkovo Observatory, heralding a purge of the scientific community. Kozyrev was among the majority of members of the Pulkovo staff who were arrested on the basis of accusations of an ideological nature made by a disgruntled graduate student. Those arrested were subjected to cursory hearings without the formal presentation of charges or legal representation, often with confessions extracted by torture. Some of the condemned were summarily executed, while others received 10-year prison sentences. Wives and other family members received 5-year sentences as "enemies of the people."

At first Kozyrev was held in solitary confinement in a freezing punishment cell for several months, then locked up with an insane cellmate for more than a year. In 1938 he was sent to a labor camp at Norilsk in Siberia, where a fellow inmate denounced him for his belief in an expanding universe, a view that was incompatible with Stalin's version of Marxist-Leninist dogma. This offense brought a sentence of an additional ten years at hard labor for "hostile counter-revolutionary propaganda," which Kozyrev appealed. Admitting that a miscarriage of justice had occurred, in 1942 the Supreme Court of Soviet Russia changed the sentence to execution by firing squad! For several months Kozyrev endured the horrific strain of expecting to be shot at any moment until a second appeal resulted in the revocation of the death sentence. The sole survivor of the arrested members of the Pulkovo staff, he was finally released in January of 1948 and set to work trying to rebuild his shattered career, which had been interrupted during the years that are

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usually the most creative period in the life of a scientist. [44]

Doubts about Kozyrev's lunar spectra are certainly strengthened when they are considered in the context of some of his other spectrographic "discoveries." In 1954 Kozyrev had announced that he had obtained high-dispersion spectrograms of a glow emanating from the night side of Venus – the elusive "ashen light" reported by visual observers of the planet for over three centuries. These spectra, he reported, contained a host of emission lines as well as absorption bands. Two of these features he attributed to neutral and singly ionized molecular nitrogen. [45] While the reality of the ashen light continues to be debated to this day, many of its proponents reacted with incredulity to Kozyrev's claim that the emission he recorded was 50 times brighter than the "airglow" that occurs at altitudes of 60 to 120 miles in the Earth's atmosphere, where atoms and molecules of rarefied gases excited by sunlight release radiant energy at night as they gradually revert to their ground state. It is notable that Kozyrev reported that the spectral signature of ionized oxygen was absent on his plates, because the best recent data suggests that it is excited oxygen that produces a very feeble glow high in the atmosphere of Venus that fluctuates in intensity and shifts position from day to day. [46] Even at their brightest, these emissions are beyond the grasp of instruments like those employed by Kozyrev.

In 1955 Kozyrev had published a bizarre claim that the characteristic ochre color of Mars is not imparted by surface minerals but is caused by the optical properties of the planet's tenuous atmosphere. On the basis of observations made the previous year, he alleged that a layer of greenish atmospheric haze makes the brighter regions of Mars appear reddish and the darker areas greenish. [47] This notion was so flagrantly at odds with well-established facts that it was largely ignored.

In 1963, four years after his observation of a supposed volcanic eruption in Alphonsus, Kozyrev reported that he had repeatedly recorded the emission lines of ionized molecular hydrogen in spectra of the crater Aristarchus. [48] He surmised that the gas was escaping from the Moon's interior, which certainly seemed implausible for a small, rocky world so depleted in volatile elements.

In 1964, Kozyrev reported that he had detected an atmosphere of hydrogen surrounding the planet Mercury that must be continually replenished by the solar wind. [49] The ultraviolet spectrograph aboard the Mariner 10 space probe did detect a hydrogen halo during its flyby of Mercury a decade later, but it proved to be a trillion times more rarefied that the one postulated by Kozyrev and far below the threshold of his spectrograph.

Kozyrev's spectrographic observations call to mind the sporadic reports of nonexistent radiations that enliven the history of modern physics, especially the sad case of the sincere but self-deluded René-Prosper Blondlot (1849-1930), a highly reputable physicist at the University of Nancy who made valuable contributions to Maxwell's theory of electromagnetism. In 1903 Blondlot announced the discovery of a one of "five octaves" of unexplored radiation between the infrared and visible regions of the spectrum. He christened this radiation "N-rays" in honor of their native city. Supposedly emitted by X-ray tubes, incandescent filaments and the gas mantles used for domestic lighting, according to Blondlot N-rays exhibited several very peculiar properties. Unlike other forms of electromagnetic radiation, N-rays were not diffracted when they passed through a small aperture like a pinhole. Most materials that were opaque to visible light were transparent to N-rays. (Water and rock salt were notable exceptions. N-rays were capable of passing through many inches of aluminum, but were blocked by the thinnest iron foil. Heated wires and electric sparks glowed more brightly when N-rays fell on them. After being exposed to N-rays, the human eye became more sensitive to visible light.

Prior to the First World War, the physical sciences were subject to a degree of nationalist chauvinism that would be regarded as appalling today. The Gallic ego was still bruised discovery of X-rays only eight years earlier by a German physicist, Wilhelm Roentgen. While British and German physicists were dismayed by Blondlot's reports almost to a man, in the intellectual climate of the time it is perhaps understandable that N-rays were enthusiastically embraced by the French academic establishment. A torrent of papers supporting Blondlot soon appeared in French scientific journals like the prestigious Comptes Rendus. Chemists reported that N-rays were given off during certain chemical reactions. (Strangely, the order of the addition of the reactants played a role.) Biologists reported that plant and animal tissues were emitters of N-rays. Physiologists determined that the N-ray flux from the human brain increased during mental exertion. Jean Becquerel (son of Henri Becquerel, the discoverer of radioactivity) reported that anesthetics not only suppressed the emission of N-rays from living organisms, but from heated pieces of metal as well. [50]

In 1904 the French Academy awarded Blondlot the prestigious Prix Leconte, valued at five times his annual professor's salary. (The runner-up was Pierre Curie.) Nevertheless, his experiments could not be duplicated by most investigators abroad and skepticism began to grow even in France. The coup de grace was administered by the brilliant Johns Hopkins University experimental physicist Robert W. Wood (1868-1955), who stealthily removed an aluminum prism from Blondlot's spectroscope during a visit to his laboratory. Wood reported in the English journal Nature that the absence of this essential component did not diminish Blondlot's ability to "see" the spectral lines of N-rays on a phosphorescent screen. Although Blondlot's faith in the reality of N-rays never wavered, papers on the subject soon disappeared from the scientific literature.

Serious questions are also raised by Kozyrev's forays into experimental physics. Prior to his arrest in 1937, Kozyrev had been regarded as one of the most promising figures in Soviet astrophysics, but during his decade of imprisonment he had been cut off from all news and publications and remained unaware of the discoveries being made in quantum mechanics and nuclear physics. Consequently, when he struggled to recover his place in science, his ideas were completely outmoded.

In 1951 Kozyrev began a prolonged series of experiments using gyroscopes, torsion balances, and pendulums in the physical laboratory of the Pulkovo Observatory that was inspired by ruminations about the nature of time during his dreary years in captivity. The results served as the underpinnings of Kozyrev's unorthodox theories of "causal mechanics." Time, he claimed, possesses a variable spatial density and can be shielded against by interposing a variety of organic materials, calling to mind the gravity-shielding properties of the alloy "Cavorite" in H.G. Wells' First Men in the Moon. Stars are powered not by thermonuclear reactions, but by the energy generated by the "flow of time" in any rotating body. (It should be noted that this notion had predisposed Kozyrev to believe that the Moon must be volcanically active more than a decade before his Alphonsus observations and had led him to embrace Dinsmore Alter's claims of obscurations on the crater's floor.) Information can be propagated instantaneously through space, in violation of Special Relativity. The gyroscope experiments suggested that the distance from the equator to the north pole of a rapidly rotating planet should be perceptibly smaller than the distance from the equator to its south pole. Kozyrev claimed that he was able to measure this nonexistent asymmetry in photographs of Jupiter and Saturn. [51]

The controversy surrounding causal mechanics spilled over into the pages of **Pravda** in 1959, when harsh criticism by some of the Soviet Union's preeminent physicists appeared in the nation’s leading newspaper. Early the following year, the Soviet Academy of Sciences appointed a special commission to investigate Kozyrev’s claims. The nine members of the commission unanimously concluded that logical and mathematical underpinnings of causal mechanics were untenable, and that the quality of Kozyrev’s experimental evidence was sorely lacking. Many of the laboratory experiments suffered from errors arising from a variety of electrostatic and thermal effects. [52] The purported asymmetry of the globe of Jupiter was the result of nothing more than the lack of perfect symmetry of the planet’s atmospheric belts with respect to its equator.

This prolonged recitation of Kozyrev’s chronic failings as an interpreter of observational and experimental data may seem unduly harsh, perhaps even tedious, but it is necessary because his observations of Alphonsus continue to be cited as compelling evidence that the Moon is still volcanically active. Usually the tale is told in a distorted form and seldom with even a passing reference to the peculiarities of his other work. But during the early 1960s Kozyrev's lunar spectrograms galvanized not only the amateur astronomical community but NASA as well, particularly after reports by two lunar cartographers at Lowell Observatory dispelled many lingering reservations and became the second most celebrated TLP case.

Early on the evening of October 23, 1963, two cartographers from the Aero Chart and Information Center working on a lunar mapping project sponsored by the U.S. Air Force turned Lowell Observatory’s famous 24-inch Clark refractor on the craters Aristarchus, Herodotus, and nearby Schroeter’s Valley. The region was under a high angle of solar illumination that was poor for discerning topographic relief, but favorable libration afforded an opportunity for James Greenacre and Edward Barr to inspect the interior of the craters and check the proof copies of the charts they had prepared.[53]

Figure 7: James Greenacre and Edward Barr at the tailpiece of Lowell Observatory’s 24-inch Clark refractor.

Unfortunately, the rising gibbous Moon hung only 25 degrees above the eastern horizon. Not surprisingly, the seeing was very turbulent, producing a “boiling” image. Greenacre recounted: “At first the seeing quality was rated about 2 on a scale of 10. In the next few minutes it improved somewhat, with moments of 3 and 4 seeing during which I zoomed the eyepiece to about 500 power." [54]

Recourse to such a high magnification under poor seeing conditions certainly belies a lack of observing expertise, but now Greenacre noticed a “reddish orange color over the domelike structure on the southwest side of the Cobra Head [the shallow ruined crater at one end of Schroeter’s Valley]. Almost simultaneously I saw a small spot of the same color on a hilltop across Schroeter’s Valley [about 25 miles away, according to a sketch he later prepared]. Within about two minutes these colors had become quite brilliant and had considerable sparkle.” [55]

Twenty-five minutes later an “elongated pink streak appeared along the interior rim of Aristarchus [some 20 kilometers from the farther of the two spots], which did not sparkle like the other two spots.” During the next five minutes, all three features took on a “light ruby red” hue, giving the impression of “looking into a large polished gem ruby,” but they remained invisible through the 6-inch refractor that served as the large telescope’s finder. Suddenly it became apparent that the colors were beginning to fade and within ten minutes “everything seemed the same as before the color phenomena were first noticed.” [56] Three hours after the reddish glows subsided, continued surveillance revealed the presence of a persistent violet or purple-blue color along the northern and western rim of Aristarchus.

It was as if Mount Shasta, Mount St. Helens, and Mount Hood in the Cascade Range had somehow all erupted and then subsided in unison. There can be little doubt that Greenacre’s reddish glows have a very mundane explanation that arises not on the Moon but in the Earth’s atmosphere. When the Moon or a bright planet is viewed at a modest elevation above the horizon, its telescopic image exhibits a blue fringe along its top edge and a red fringe along its bottom edge. Similarly, bright stars are spread out into tiny

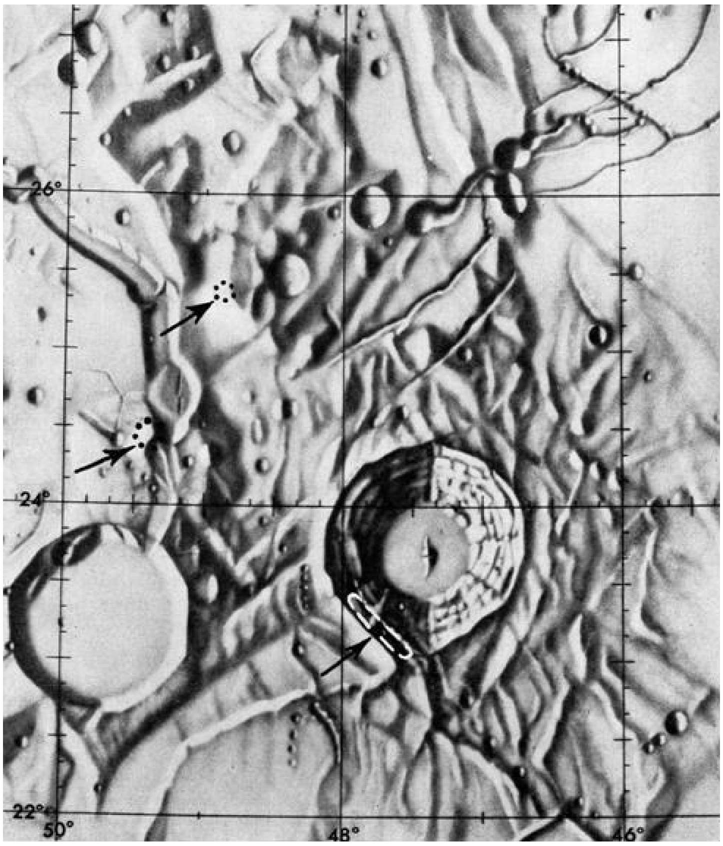

Figure 8: The ruddy glows seen on October 23, 1963 are denoted by arrows and dashed lines superimposed on the rectified U.S. Air Force chart of the Aristarchus region. North is at top.

vertical spectra aligned at a right angle to the horizon. This phenomenon, known as “differential atmospheric refraction” or “atmospheric prismatic dispersion,” is caused by the greater refractive index of air at shorter wavelengths, which causes the blue component of the image to be lifted to a greater extent than the red component. At an altitude of 40 degrees, the separation between blue and red light is usually about one second of arc, so visually the spurious colors are readily apparent only for objects at or below this altitude. [57] The stratification of air into discrete layers of differing temperature and density during temperature inversions and winter anticyclones can markedly accentuate atmospheric dispersion, however. [58]

Large telescopes are more vulnerable to atmospheric prismatic dispersion than small ones for the simple reason that one arc second of dispersion cannot be resolved with a 4-inch aperture but represents twice the resolving power of a 9-inch instrument. In addition, the spurious colors appear brighter in larger instruments. [59] The blue component is often attenuated or even absent because atmospheric scattering and absorption is so much more pronounced at shorter wavelengths. Hence the Moon often appears golden or even squash-orange when it hangs low in the sky.

When Greenacre first sighted the glow, it was through a deep yellow (Wratten 15) filter that was routinely employed for lunar observing because it effectively blocked the defocused purple haloes that appeared around all bright objects, produced by the chromatic aberration suffered by the old refractor's doublet objective lens. The presence of this filter combined with the Moon's low altitude handily explains why only the spurious ruddy color was seen, while atmospheric turbulence accounts for the "flowing motion" and "considerable sparkle" of the features that Greenacre described.

A large aperture achromatic doublet like the instrument employed by Greenacre and Barr is remarkably ill-suited for assessing any "delicate" color phenomena. Doublet refractors made with ordinary flint and crown optical glasses suffer from chromatic aberration that scatters secondary spectrum across lunar and planetary images, reducing contrast. A doublet achromatic objective brings two widely separated wavelengths of light, typically in the red and blue regions of the spectrum, to a common focus. Intermediate wavelengths in the yellow-green region of the spectrum come to focus at an appreciably shorter distance from the objective. However, the human eye is far more sensitive to yellow-green light and focuses on the image formed by those rays. Consequently, the defocused red and blue rays appear as a magenta haze that is most evident as a purple halo surrounding bright objects. In order to keep the magnitude of this annoying color error negligible in conventional achromats, the focal ratio of the objective must be no less than three times the lens diameter measured in inches. This formula, proposed by the prolific British astronomical writer J.B. Sidgwick, yields the following f-ratios and focal lengths: 3" f/9 (27"); 4" f/12 (48"); 5" f/15 (75"); 6" f/18 (108"); 8" f/24 (192").

The chromatic aberration of the 24-inch f/16 Clark refractor exceeds that of a 6-inch f/5 achromat, so it is hardly surprising that a dense yellow Wratten 15 filter was employed whenever lunar mapping was conducted. Once that filter was removed, it is anything but surprising that the Lowell observers saw a "purple-blue" hue along the rim of brilliant Aristarchus. The authors have observed the Moon through the 24-inch Clark and can personally attest that the "signal" of any purple-blue coloration on or near the lunar surface would be utterly impossible to distinguish from the overwhelming "noise" of that instrument's pronounced secondary spectrum.

In a "stop the presses" report that appeared in the December, 1963 issue of Sky & Telescope, the magazine's editors included remarks by Lowell Observatory Director John S. Hall that vouched for Greenacre's qualifications as an observer but cautioned that "since he [Greenacre] was unable to recognize these colored areas in the 6-inch finder, it seems that similar phenomena may be beyond the reach of most amateur telescopes." [60]

Only one month later, Greenacre and Barr witnessed a second color anomaly at Aristarchus under virtually identical lighting conditions through the 24-inch refractor. [61] Once again, the rising gibbous Moon was only 25 degrees above the eastern horizon early on the evening of November 27, 1963 when Greenacre spotted a "light ruby red" glow about 12 miles long and 1.5 miles wide stretching along the rim of Aristarchus. Observatory Director John Hall was summoned to the dome and was able to make out a ruddy glow that he described it as "delicate."

The cautious Hall immediately telephoned the observing station on Anderson Mesa a dozen miles to the southeast, where Peter Boyce, a freshly minted University of Michigan Ph.D., was preparing for a night of spectrophotometry with the 69-inch Perkins reflector. Hall informed Boyce that another color phenomenon was taking place near Aristarchus and asked him to turn the big reflector on the Moon and see if he could detect anything unusual. Peering through the slit of a spectrograph that was impossible to remove in a timely fashion, Boyce reported that he "suspected" a feeble reddish spot in a location that was in decent agreement with Greenacre's.

Meanwhile, back in the dome atop Mars Hill in Flagstaff, Greenacre, Barr, Hall, and a fourth observer found that the glow was invisible through the 12-inch refractor that rode piggyback atop the 24-inch refractor, but remained visible for 75 minutes through the big refractor. It slowly faded as the Moon gained elevation, precisely the behavior one would expect if atmospheric dispersion were responsible. A camera was hurriedly installed at the focus of the 24-inch refractor and dozens of frames of 70mm Panatomic-X black-and-white film were exposed. None registered any trace of the glow, even when the negatives were measured with a densitometer. Greenacre and Barr continued to watch the Aristarchus area until the following dawn without seeing the color anomaly reappear.

Boyce recalls that Hall was acutely sensitive to the fact that the reputation of Lowell Observatory had not yet fully recovered from its founder's sensational accounts of a network of artificial canals on Mars, and was perturbed when Greenacre announced this sighting to the press with considerable fanfare despite the lack of corroborating photographic evidence. [62] Hall's fears were unfounded, for the report was taken at face value and elicited few critical comments. The readers of Sky & Telescope were informed: "The possibility now emerges that small, transient reddish blotches on the Moon are fairly frequent phenomena. However, adequate study may require highly experienced lunar observers with telescope larger than 12 inches." [63]

In fact, even an 8-inch aperture has proven quite capable of replicating the Greenacre-Barr observations. In 2011 Jim Phillips and Raffaello Lena reported that CCD images of Aristarchus obtained in April of that year under lighting conditions similar to the 1963 events recorded an elongated reddish area running along the western rim of Aristarchus that corresponded very closely to the principal glow reported by Greenacre and Barr. [64] Phillips and Lena concluded that "atmospheric dispersion is the logical explanation for the reddish color sightings."

The Greenacre-Barr reports of reddish glows gave a tremendous boost to NASA's "Moon-Blink" project, then in its infancy. The idea behind "Moon-Blink" was quite straightforward. If the fleeting colored glows on the Moon were beyond the grasp of small apertures, color filters promised to reveal them. A color filter is the optical analog of a semi-permeable membrane, passing light of certain wavelengths and blocking others. If an object appears equally bright through red, green, and blue filters, one may suppose that it is in fact gray, but if it appears perceptibly darker through a blue filter than through a red one, one may infer that it has a warm color from the red end of the spectrum. Observers equipped with small telescopes were encouraged to view the Moon through red and blue filters mounted on a rotating disc so that they could be rapidly alternated, the brainchild of the British lunar observer Peter K. Sartory. [65] With the aid of such a device, a reddish glow will appear to flicker or blink on and off.

At first, a trickle of positive blink reports came in, but they soon grew to a maddening torrent. Despite the quantity of reports, the case for TLP was by no means strengthened by the rigorous standard of the old legal maxim “Testis unis, testis nullus.” “Single witness, no witness.”

Frustrated by the host of uncorroborated TLP reports made by solitary amateurs, in 1964 NASA scientist Gerald Guter organized a network of amateur lunar observers and ham radio operators across the United States. When a TLP was detected, the observer would telephone a ham radio operator, who would relay the report to a ham in a distant city who, in turn, could telephone another observer. Some hams arranged telephone “patches” that allowed observers to converse directly with one another. Christened the “Argus-Astronet” after the creature with a hundred eyes in Greek mythology, its organizers touted it as an astronomical analog of the “Distant Early Warning (DEW) Line” of Arctic radar stations poised to detect incoming Soviet bombers and missiles. [66] The University of Arizona’s Lunar and Planetary Laboratory in Tucson, Lowell Observatory in Flagstaff, and the Corralitos Observatory near Las Cruces, New Mexico all agreed to participate in the program.

Located on a hilltop in the desert half an hour’s drive from Las Cruces, New Mexico, the Corralitos Observatory was established by NASA for the express purpose of conducting systematic surveillance of the Moon in the hope of detecting and recording TLP. Operated by personnel from Northwestern University, the centerpiece of the facility was a 24-inch Cassegrain reflector equipped with a sensitive, state-of-the-art image-orthicon television camera. A motorized three-color filter wheel permitted lunar features to be successively examined in violet, green, and red light. Observers sat in a climate-controlled room beneath the telescope where they watched a monochrome television monitor in seated comfort to minimize fatigue. The monitor displayed a detailed image measuring six arc-minutes square, about 1/25 of the lunar disc. The entire visible hemisphere of the Moon could be examined in three colors at a resolution of one second of arc once every 15 minutes.

Figure 9: J. Allen Hynek

Piggybacked a top the reflector rode a 5-inch refractor equipped with its own television camera and monitor. This instrument was equipped with a filter that blocked visible light and transmitted infrared wavelengths in order to record any thermal anomalies like a volcanic eruption or meteorite impact.

As a check on the observer’s visual inspection, the television monitor was frequently photographed. (At the time, videotape recording devices were prohibitively expensive and usually only found in large commercial television studios. The first affordable video cassette recorder would not appear on the market until 1974. [67])

The Corralitos telescopes operated every clear night when the Moon was well-placed in the sky. The observatory staff monitored the Argus-Astronet radio network, fully prepared to immediately verify and record any TLP report. After three years of operation, during which over 3,000 hours of lunar surveillance were logged, Josef Allen Hynek (1910-1986), Chairman of the Northwestern University Astronomy Department, reported that "no localized lunar events were detected" even though "color changes extending two or three seconds of arc, and even more compact brightenings, should have been detectable." [68]

On several occasions the Corralitos staff failed to confirm events when they were alerted by the Argus-Astronet visual observers, "even when the changes were of a nature that ought to have been easily detectable by the image-orthicon system." As Hynek was learning from his role as scientific consultant to the U.S. Air Force's Project Blue Book UFO investigation, for true believers the absence of evidence is seldom evidence of absence, an attitude reminiscent of the taunt by the flamboyant newspaper and television seer Criswell at the close of Ed Wood's infamous 1959 movie **Plan 9 from Outer Space**: "Can you prove it didn't happen?"

The negative Corralitos results are far less widely known than another NASA-sponsored project of that era that produced the bible of TLP literature, the **Chronological Catalog of Reported Lunar Events**, issued in 1968. Barbara Middlehurst (1915-1995) of the University of Arizona and Goddard Space Flight Center and Patrick Moore, Wilkins's acolyte and later director of the Armagh Planetarium in Northern Ireland, had started to compile TLP reports independently, but their lists proved to be so similar that they were combined into a single collection of 579 "temporary changes on the Moon."

Published by NASA, the effort conveyed the impression of being authoritative. Moreover, the authors suggested that rather than merely producing a collection of raw, undigested reports, they had been selective, and "as far as possible... eliminated reports of events that, for one reason or another (e.g., possibly because of special lighting effects, multiple reflections, and changes of appearance caused by libration), are considered to be spurious." [70] There is no mention, however, of the effacing of fine detail by atmospheric turbulence, nor of atmospheric prismatic dispersion or instrumental chromatic aberration, despite the fact that the vivid colors so often reported were extremely suggestive of these causes. Middlehurst and Moore's claim to have culled unreliable data was in fact quite ludicrous, for out of hundreds of reports perused, they saw fit to exclude precisely six! The overwhelmingly negative results from the Corralitos Observatory were not deemed worthy of mention, and four reports by visual observers were included without noting that the Corralitos instruments had been unable to confirm them after timely alerts were issued.

Some reports were accepted simply on the basis of "the high stature of the observer as a scientist." That being the case, perhaps it is not surprising to find listed a 1650 report by Johannes Hevelius (1611-1687) of the "red hill," Mons Porphyrites, the crater long since designated as Aristarchus, which in the Danzig astronomer's primitive non-achromatic refractor always displayed a reddish hue imparted by chromatic aberration that led him compare the brilliant feature to Aetna, Heckla, and Vesuvius. A pair of 1671 observations by Giovanni Domenico Cassini (1625-1712) of the hardly mysterious permanent patch of bright soil that is widely known today as the "Cassini White Spot" are included, replete with Cassini's description of a “small white cloud” near the crater Pitatus. A 1787 account by William Herschel (1738-1822) of the craters Aristarchus, Copernicus, and Kepler illuminated by Earthshine as “volcanoes in eruption” was even included without critical comment.

The reader also encounters less familiar names. There are, for instance, the “observers at Worms” who saw a star-like appearance on the dark side of the Moon in 1540; a “friend of Weidler” who saw an appearance like lightning on the face of the Moon during a solar eclipse in 1738; and “Beccaria’s nephew and niece” who saw a “bright spot” (not more explicitly described) on the disc of the fully eclipsed Moon in 1772.

It is worth noting that no fewer than 108 of the reports in the catalog -- almost one in five! -- were sightings by the Baltimore amateur astronomer James C. Bartlett, Jr. of a “blue radiance” or “violet glare” in and around brilliant Aristarchus, observed during the years 1949 to 1967 with small telescopes of only 3 to 5 inches aperture. The brightest feature on the lunar surface, Aristarchus is particularly prone to exhibit spurious colors due to both atmospheric prismatic dispersion and instrumental chromatic aberration. That the secondary spectrum of a doublet refractor would introduce a “blue radiance” or “violet glare” is obvious, but reflectors cannot be regarded as immune, for the simple oculars of Ramsden and Huygenian design that were widely employed at this time suffer from readily perceptible color errors, especially at appreciable distances from the center of the field of view, an optical aberration known as “lateral color.”

Bartlett’s observations represented a veritable embarrassment of riches. The sheer quantity of his sightings should have deepened suspicions about their quality. According to Bartlett, the color anomalies at Aristarchus were “rather consistently visible.” Why, then, were they not confirmed by other observers? To this pointed question Bartlett could do no better than reply that “the phenomenon -- which is a delicate one at best -- cannot be seen at all by those whose vision is less sensitive in the blue end of the spectrum. [71] If Bartlett’s recurring glows were real, they should have been easily confirmed photographically using blue-sensitive emulsions or with a photoelectric photometer. They were not.

The Middlehurst and Moore catalog seemed to show a clear tendency of TLP to avoid the rugged, crater-saturated lunar highlands and cluster along the edges of the maria, the large, dark, relatively flat basins that the earliest telescopic observers mistook for seas. These areas are rich in the long, narrow valleys or cracks known as rilles (from the German word for “grooves” or “furrows”), so this finding to support the notion that TLP represented emissions of gas from beneath the lunar crust, the explanation favored by Middlehurst and Moore. [72] Undoubtedly feedback skewed the statistics from which this inference was drawn, for when events were reported in Alphonsus and Aristarchus, these formations were soon singled out for a disproportionate level of scrutiny. In fact, the alleged proclivity of TLP to occur at the periphery of the maria turns out to be strong evidence that atmospheric prismatic dispersion is responsible for the colored glows. As the British lunar observer L.E. Fitton explained:

> Any bright or extended area of the lunar surface may be considered to consist of an infinite number of point sources, each of which produces its own spectrum. Since in the bright area all such spectra overlap, the colors re-mix to white and ‘edge colors’ cannot appear until the bright area interfaces with a dark area, a situation which may not occur until the lunar limb is reached if the area in question is in the ‘highlands’ regions, where in high Sun conditions there are few such interfaces... Where adjacent point sources share similar brightness or darkness, as in the highlands or plains generally, the spectra

> produced must be appropriately bright or dim, and will therefore re-mix to low albedo white in the plains and to high albedo white in the bright highlands. At a bright/dark interface [i.e., on the periphery of the maria] the edge-color produced by the 'last alignment of point sources' representing the limit of the bright area cannot be neutralized by the far dimmer spectra of the adjacent dark area and hence the edge color persists. [73]

That the TLP myth continued to grow seems to have been the result of a lapse of critical judgment distinctly reminiscent of the fairy tale of the Emperor's New Clothes. Reports peaked in 1969, the year of the first manned landing, and the Apollo astronauts were even enlisted in the search. That year Kozyrev reported that his recent spectrograms of Aristarchus contained features that he attributed to the presence of ionized molecular nitrogen and hydrogen cyanide. [74] He speculated that the release of these gases on the Moon might be related to a terrestrial earthquake that occurred the previous day, both events triggered by tidal stress, but by now his pronouncements elicited few comments. [75]

A 1971 revision of the original catalog by Moore added another 134 reports. By 1978, through the efforts of another NASA-funded scientist, Winifred Sawtell Cameron, the number had grown to a whopping 1,468. It was an exercise in pure Baconian empiricism, consistent with the philosophy that Wilkins and Moore had advocated years earlier in their book **The Moon**: "Selenography must be founded on observation, not on preconceived and often erroneous conceptions; let us be observers first and theorists afterwards." [76]

The data gleaned from the Apollo missions and subsequent unmanned spacecraft have reinforced view the Moon is a long-dead, inert world, changeless save for the occasional random impact. In his definitive history of the lunar geology **To A Rocky Moon: A Geologist's History of Lunar Exploration**, a work that has been justly hailed as "the 'Double Helix' of the Moon," Don Wilhelms of the U.S. Geological Survey's Branch of Astrogeology wrote:

> The many features of craters long thought to be internally generated succumbed one by one during and after the age of lunar exploration… There may be a few calderas on the Moon, but they are very few and relatively small… Even if some light-toned plains someday prove to be volcanic, volcanism can never assume the major role in the formation of the Moon's features that many investigators once thought it had. Cosmic impact rules the Moon. [77]

Heat-flow probes deployed by the Apollo astronauts revealed that the Moon is "cool or cold and was never very hot except early in its history," according to Wilhelms. In addition, the infrequent moonquakes emanating from 700 kilometers below the lunar surface that were detected by the seismographs installed by the Apollo astronauts are so feeble that if their annual energy were released in an instant it would pass unnoticed on Earth, indicating the virtual absence of internal activity today. In the light of this hard data, one can only agree with Wilhelms' verdict: "Whatever the real or psychological cause of transient phenomena, it is not volcanism." [78]

It would seem that the fortunes of the TLP true believers should have been inextricably intertwined with evidence of ongoing lunar volcanic activity. One would have expected the credibility of TLP reports to rise and fall with the viability of such notions, yet they have managed to survive despite Occam's Razor, which holds that among competing hypotheses the simplest one with the fewest assumptions should be selected.

According to the Irish social historian William Edward Hartpole Lecky (1838-1903), in 1660 the majority of educated Englishmen believed in magic and witchcraft, but by 1690 the majority disbelieved it, and by 1720 believers in sorcery had become an insignificant minority. [79] A comparable paradigm shift is only occurring regarding TLP. As the time-honored explanation of the venting of gases from the lunar crust became increasingly untenable, other explanations, often vague or at best suggestive, have been advanced: the electrostatic levitation of dust particles; localized thermoluminescence of surface materials; the fluorescence of soils induced by solar ultraviolet or corpuscular radiation; triboelectric or piezoelectric effects, or some combination of these phenomena. As recently as 1991 the veteran British lunar observer J. Hedley Robinson wrote: “I am of the opinion that tidal strains or thermal shocks causing outgassing and producing a piezoelectric effect might be the most plausible explanation.” [80]

Late in February 1994 the Clementine spacecraft had entered lunar orbit on a two-month mapping mission. To assess the Moon’s surface mineralogy, over two million digital images were obtained at several wavelengths in the visible region of the spectrum as well as in ultraviolet and infrared light. During the mission, telescopic observers monitored the Moon for TLP in the hopes that the Clementine might provide confirming data from close range. Among the events reported was a “possible obscuration” lasting 40 minutes on April 24 near the Cobra Head, the site of the famous Greenacre-Barr sighting at Lowell Observatory three decades earlier.

An October 1999 announcement by Bonnie Buratti of the Jet Propulsion Laboratory caused a brief flurry of excitement. [81] She reported that her comparison of “before” Clementine multispectral images taken on March 3 and “after” images taken on April 27 revealed that two locales near TLP site had become “distinctly redder.” [82] **Sky & Telescope** Senior Editor Kelly Beatty touted Buratti’s discovery as “the first unambiguous confirmation of a spontaneous change in a feature on the Moon.” [83]

This seeming vindication of TLP was short-lived. Less than two months later, Buratti issued a retraction, admitting that the color change went away when the Clementine images were accurately calibrated and corrected for lighting geometry.[84] In a subsequent paper in the journal **Icarus**, Buratti and three of her colleagues from the Jet Propulsion Laboratory wrote: “We find no evidence for LTP on any Clementine images… An earlier reported change in the Cobrahead region, based on a preliminary analysis, is probably spurious.” [85]

Lamenting the decline of the manned space program after the triumph of the Apollo missions, Don Wilhelms wrote: “Americans have notoriously short memories and attention spans.” [86] Sometimes, perhaps, they are too long. In the same paper, Buratti and her colleagues reached the incredible conclusion that the “hundreds of reliable observations of LTP in or near the Aristarchus area in recent decades,” including several “reported during the Clementine mission itself,” constituted evidence for “residual volcanic activity on the Moon” despite the fact that they found “nothing in the Clementine images to indicate recent geological activity” in the region! After reviving the decades-old notion that the boundaries of the maria and the central peaks of large craters “may serve as regions of crustal weakness from which gases escape,” they lamely argued:

> Even without the observation of obvious lunar transient events in the Clementine database, reasonable but not compelling evidence, as well as plausible mechanisms, exist for LTP. Although these events occur in certain types of area, it is

> easily argued that other similar areas are devoid of LTP. It is important to remember that LTP are due to geologic phenomena, and that they occur on geologic time scales (if they exist). It is quite possible that LTP just have not occurred in these similar regions during the 100 or so years humankind has been closely scrutinizing the Moon. [87]

Once again, the absence of evidence is not taken as evidence of absence. We can only marvel at the authors' ability to reconcile "hundreds of reliable reports… in recent decades" with phenomena that are alleged to only "occur on geologic time scales." [88]

Sean Carlson, author of the monthly column "The Amateur Scientist" in **Scientific American** for many years, offered the following sage advice to seekers after TLPs:

> Doing good science is all about not fooling yourself… Experimentalists who work in laboratories often build into their procedures consistency checks to help ensure that they don't fool themselves. But visual observers like selenographers don't have that luxury; they are limited to only what they see. And that makes observing the Moon, and other forms of purely visual observation, a game for only the most cautious and self-skeptical scientists. [89]

Martin Mobberly of the British Astronomical Association, an active member of the British Astronomical Association Lunar Section's TLP network for eleven years (1980-1991), recalls:

> I was determined to photograph, and later videotape, craters during TLP alerts, in order to try to prove or disprove what was happening... The imaging situation in the 21st century is far removed from the situation in the early 1980's when I was a keen lunar observer. In those days the human eye could easily see more detail than a photograph could capture. Now the situation is reversed. A stacked composite of hundreds of webcam frames can capture all the details that even the keenest observer can see, and more…and guess what..? Mysteriously, there are virtually no TLP being reported! I think this reveals TLP for what they really are: effects of the Earth's atmosphere. [90]

In recent years several teams of observers have methodically conducted "repeat illumination studies" of TLP reports from the Middlehurst, Moore, and Cameron catalogs. Under lighting conditions that closely replicate the original observations, several TLPs have been revealed to be fleeting, low-angle illumination effects rather than physical changes on the Moon.[91]

A dedicated cadre of observers continues to stand watch, awaiting the next outbreak of glows around Aristarchus or outgassing in Alphonsus. Their quarry has continued to elude them despite the fact that legions of amateur astronomers have been equipped with sensitive video cameras for two decades. During meteor showers, video recordings of meteoroid impacts on the Moon by independent observers are now almost a matter of routine, despite the fact that these phenomena are of much shorter duration than TLP.

The ongoing TLP vigil bears tribute to the powerful allure of an old Moon, the Moon of the nineteenth century, a Moon that in the end belongs not to science but to romance. Like Coronado's search for the Seven Cities of Cibola or Quiros' pursuit of the Great Southern Continent, their quest is inspired by illusions. One may admire their persistence and even understand their reluctance to abandon the quest, but it is a quest that is every bit as much of an anachronism as Percival Lowell's network of irrigation canals on Mars.

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Pilkington, Far Out: 101 Strange Tales from Science's Outer Edge (New York: Disinformation, 2007), pp. 31-32.

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GLR investigation: A plausible explanation for Transient Lunar Phenomenon. Red Glow in Aristarchus

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Abstract

The Geologic Lunar Research group has been investigating previous reports of Transient Lunar Phenomena (TLP) in order to provide a scientific explanation for the phenomenon reported. This article describes the investigation by the GLR of a famous report by Greenacre and Barr of a red glow in Aristarchus (Greenacre, 1963) with the conclusion that atmospheric dispersion or chromatic aberration is the logical explanation for the color phenomenon reported.

Introduction

Aristarchus has long been an object of interest for lunar observers. It is the brightest crater on the Moon and reddish glows have been reported off and on over the years. On May 4, 1783 and again in 1787-1788, Sir William Herschel using a 9" Newtonian of his own making, described a red glow in or near Aristarchus. He stated “May 4, 1783. I perceived in the dark part of the Moon a luminous spot. It had the appearance of a red star of about the 4th magnitude. It was situated in the place of Hevelii Mons Porphyrites (Aristarchus), the instrument with which I saw it was a 10 feet Newtonian Reflector of 9 inches aperture”. He reported additional phenomenon on May 13, 1783 and in April 1787 (Middlehurst, 1964). Multiple reports of reddish glows and other color phenomenon in the area of Aristarchus are reported in the NSSDC (National Space Science Data Center) catalog by Cameron (1978). The scientific community had ignored many of these observations until the reports by Greenacre and Barr.

On the night of October 29, 1963 (October 30 1963 01:30 UT) James A. Greenacre and Edward Barr, using the 24-inch achromatic refractor at Lowell Observatory reported seeing three short-lived reddish spots near Aristarchus (Greenacre, 1963). While observing the area of Aristarchus with the 24-inch and using a Wratten 15 (deep yellow) filter a reddish orange color was noted over the dome SW of the Cobra Head. Simultaneously he was able to see an additional area of color on a hilltop across Schroter’s Valley. There was considerable “sparkle” to the color, which he noted might be due to the poor seeing. Seeing was 2 on a scale of 10 with moments of 3-4 seeing. The Yellow filter was then removed. A third area of color was then noted, “…an elongated streak pink along the SW interior rim of Aristarchus…” (See Fig. 4).

On November 27, 1963 (November 28, 1963 00:30-01:45 UT), Greenacre and Barr reported seeing another ruby red spot in the same area (Greenacre, 1964): “ This feature, like the others, seemed a light ruby red, according to Mr. Greenacre. It was larger than the previous ones, being about 12 miles long and 1 1/2 miles wide on the rim of Aristarchus. The coordinates were determined with the aid of the Orthographic Lunar Atlas; it extended from Xi = -.682 to - .685 and from Eta = +. 391 to +. 398.” The glow lasted for 1 1/4 hours with four observers using the Lowell 24" refractor including the director of Lowell Observatory, John S. Hall who described

the color as being ”delicate”. 70mm B&W film was exposed with no changes identified. Mr. Greenacre noted that he had observed other bright areas of the Moon at the time without detecting any color thus ruling out atmospheric dispersion.
These observations were also reported in several journals and books, e.g. New Scientist (1964) and Observing the Moon by North (2000).

General overview about TLPs and planned observing session

There is no commonly accepted physical explanation for TLPs, and some authors even question if they are due to processes local to the Moon at all. In fact GLR group has previously observed a few historic TLP reports, finding that when the exact same illumination conditions (including librations) occur, that the TLP reappears. This proves that these particular TLPs are simply fleeting illuminations of a crater's floor that occur only with specific conditions. Although the Cameron catalog include observational weights, recent publications about shadow effects (Lena and Cook, 2004; Lena et al., 2007; Lena, 2010) show how these can contribute to misinterpretation of TLPs, and imply that many of these rankings could be doubtful (cf. discussion section). Moreover two advances in technology permit every entry in the TLP catalog (Cameron, 1978) to be examined under conditions identical to each observation. Lena (2010) demonstrated that also the Kaguya and LRO global DEM obtained by the LTVT software package are able to simulate specific observations. In fact some temporary illumination of several TLPs can be shown by the simulation to be due to the geometry of rim and floor. This new capability can show which classic TLPs are repeatable (and used to disprove past TLP reports) and which cannot be explained that way (Lena, 2010). Moreover a systematic investigation of a large set of observations during local lunar sunrise or sunset has not been undertaken so far and the nature and reality of TLPs is still an open problem for the professional lunar science community.

The re-observations and recreations of TLPs can demonstrate their real nature (Wood, http://lpod.wikispaces.com/February+5%2C+2011

and

http://www.astronomynow.com/astrofest/fri1505.html).

Cameron (1972) divides TLPs into four categories:

1) “brightenings”: white or color-neutral increases in surface brightness;

2) “reddish”: red, orange or brown color changes with or without brightening;

3) “bluish”: green, blue or violet color changes with or without brightening;

4) “gaseous”: obscuration, misty or darkening changes in surface appearance.

An overview about the lunar transient phenomena, including a study using Clementine images, was reported by Buratti et al. (2000). The authors used Clementine multispectral images acquired both before and after suspect TLPs reported by a terrestrial team of amateur astronomers organized to observe the Moon during the mapping phase of Clementine. As described by Buratti et al. (2000), none of these four suspect events shows clear morphological or spectral changes that could be attributed to the reported TLPs.

Moreover the Cobra Head region of the Aristarchus plateau was extensively examined including refined calibrations for the Clementine UVVIS camera. Using this calibration Buratti et al. (2000) state that their preceding measurement, describing measurable changes in the spectral reflectance (Buratti et al., 1996), was spurious and there is neither observable change nor evidence for the preceding 15% increase in the ratio R_{415}/R_{1000}.

The NSSDC (National Space Science Data Center) catalog includes all reported phenomena regardless of the perceived weight of the observation.

Several programs, primarily by groups of amateur astronomers, but sometimes involving professional researchers, have made organized observations of the Moon. These projects have been organized with the ALPO (Association of Lunar and Planetary Observers), the BAA (British Astronomical Association) and GLR (Geologic Lunar Research) group. The BAA organized observations of the Moon on Friday, April 15, between 19:00 and 21:00 UT, when the Aristarchus and Herodotus area of the Moon matched the same illumination, to within ± 0.5°, as that observed during the TLP seen by Greenacre and Barr from Flagstaff observatory on October 30, 1963 (Cameron catalog, entry #778). Unfortunately, in Italy and in several European Countries was cloudy. Moreover, on the same day, on April 15, 2001 at about 02:50 UT (with higher uncertainty in timing) it was stated that the Moon matched the same illumination of the second event observed by Greenacre (November 28, 1963 00:30-01:45 UT) which is reported in Cameron catalog under the entry # 775. Phillips was able, using an 8" F/9 TMB apochromatic refractor with 5X Powermate and Skynyx color webcam, to image Aristarchus in order to investigate this second event.

Results and discussion

The image (north at the top and west to the left) was taken on April 15, 2011 at 02:05 UT, before of the inferred time for the observation carried out, under a higher solar angle, at Flagstaff. Hence in this observation we have not evidence of additional spots showed in the drawing published in Sky and Telescope (Greenacre, 1963, cf. Fig. 4). We used the image taken by Phillips in order to investigate an eventual chromatic dispersion in the Aristarchus region.

After stacking and performing routine wavelet processing in Registax the image was examined. A reddish zone is clearly seen on the W rim of Aristarchus with a bluish area noted as well (Fig. 1).

An enhanced image (increased color saturation) is shown in Figure 2. In Photoshop the image was examined in the blue, red and green channels. A shift of the blue and red channels was easily seen. Shifting the channels to proper alignment shows no color within the image, as shown in Figure 3.

This confirms that chromatic or atmospheric dispersion is a logical explanation for the reddish color sightings within Aristarchus.

The drawing published in Sky & Telescope (Greenacre, 1963) is shown in Fig. 4.

The image shown in Fig. 2 was thus transformed in rectified view, using LTVT software package (Mosher and Bondo, 2006), and superimposed onto the drawing reported in Figure 4. The digital image was then stretched and rotated to give the best superimposition among the other selected features. The superimposed map, shown in Fig.5, was created using Photoshop.

The result shows that the elongated red area in the western rim of Aristarchus reported by Greenacre corresponds to the reddish zone clearly seen in our CCD image. However the CCD image displays that the chromatic dispersion is clearly extended to the western rims of the nearby craters and features having high albedo. On the opposite case, the drawing and the observation made by Greenacre show the color only on the western rim of Aristarchus crater. As a final remark, a picture of the described events is lacking so that we cannot be sure what Greenacre and Barr saw and drew for the surrounding region during their observation carried out on October 30 1963 and November 28 1963, respectively. Our data show that the most likely explanation for the reddish color

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sightings within Aristarchus is a chromatic or atmospheric dispersion. Of course we never will know the true because prominent colour for radial chromatic aberration is seen elsewhere and this simply was not reported by Greenacre and Barr, also thought they only used a visual observation.

Sagan wrote: extraordinary claims require extraordinary proof. So far, we don't have even ordinary levels of proof for TLPs, nor the written text of Greenacre, based on a visual observation, can be considered an extraordinary proof. Our data, at least, can be profitable for observers to try to understand what they see on the Moon. Greenacre observation is just lacking of a photograph, or other extraordinary proofs.

Figure 1. Aristarchus region. Image taken by Jim Phillips (see text for detail).

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Figure 2.
Enhanced image with color saturation.

Figure 3.
Result obtained shifting the channels (R, G, B) to proper alignment.
No color is detectable.

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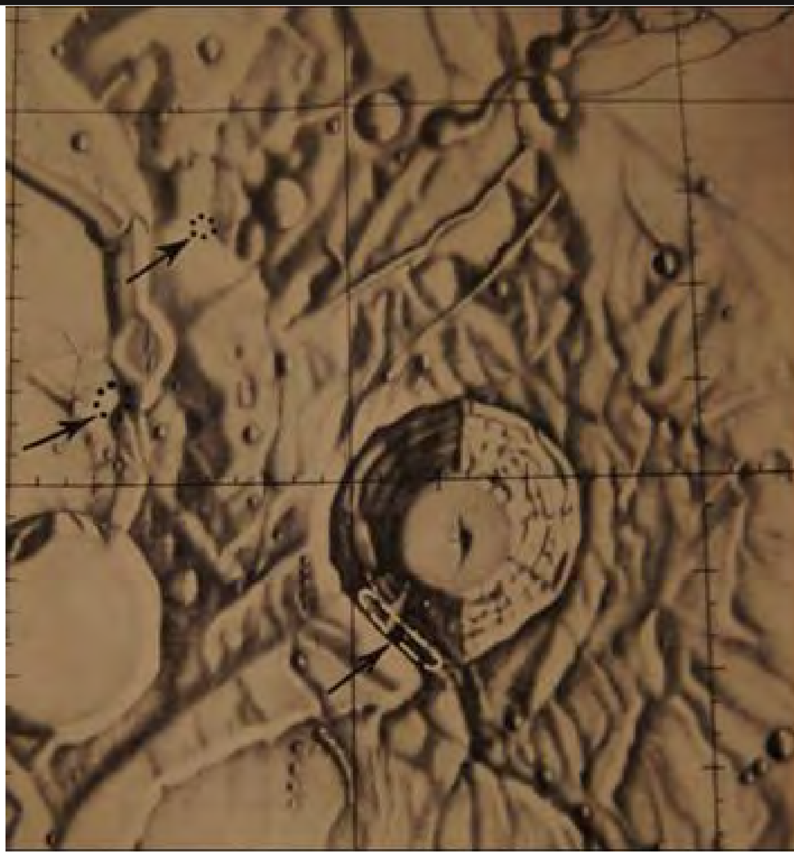

Figure 4.
The drawing published in Sky & Telescope, December 1963 “A Recent Observation of Lunar Color Phenomenon”,p. 316- 317.

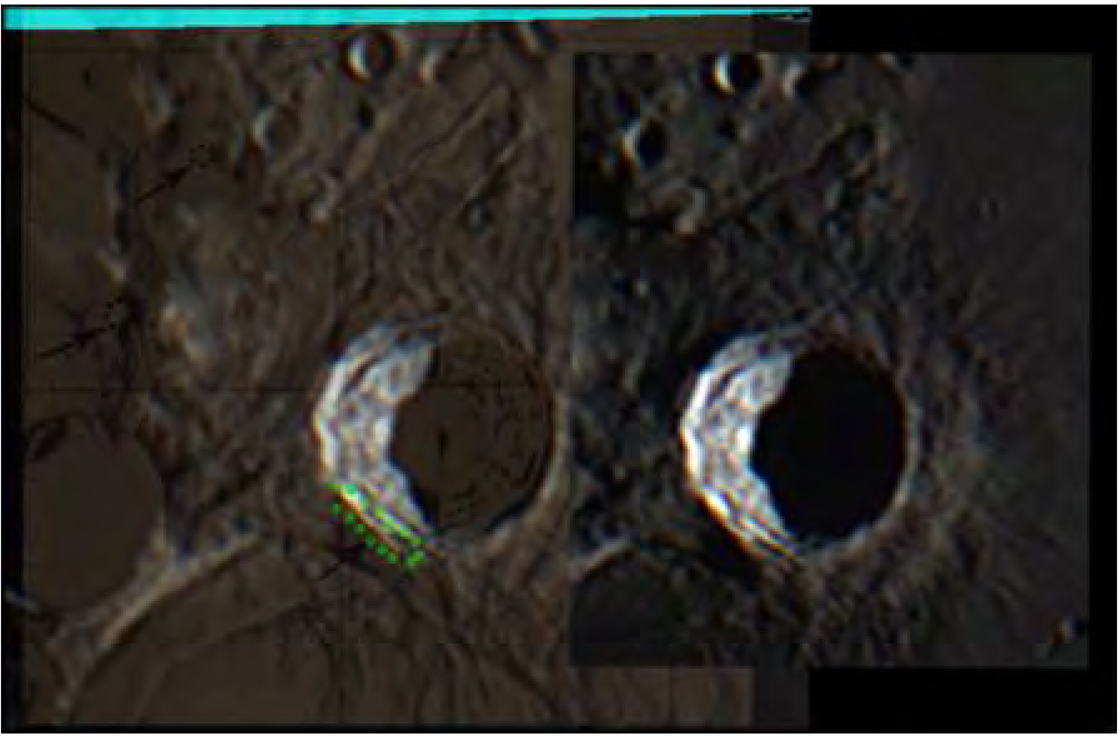

Figure 5.
Comparison including the superimposed map (see text for detail).

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Targets for Further Exploration

For additional information about these elusive features see LPOD for Sept. 29, 2013 http://lpod.wikispaces.com/September+29%2C+2013)

Equipment
Telescope 10 inch @f/6.3, Camera Unibrain fire-i 785, Filters Red, Barlow 3X.

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Targets for Further Exploration

For additional information about these elusive features see LPOD for Oct. 18, 2013 (http://lpod.wikispaces.com/October+18%2C+2013).

Equipment
Telescope 10 inch @f/6.3, Camera QHY 5L-II, Filters Red, Barlow 3X.