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Seeing the impossible: meteors in the Moon

Martin Beech
Campion College, The University of Regina, Regina, Saskatchewan, S4S 0A2, Canada.
E-mail: Martin.Beech@uregina.ca

and

David W Hughes
Department of Physics, The University of Sheffield, Sheffield, S3 7RH, UK
E-mail: d.hughes@Sheffield.ac.uk

Abstract
Over the time span of a decade beginning circa 1940, numerous observers reported the apparent detection of luminous meteors in a supposed lunar atmosphere. These observations run counter to our present-day knowledge and it is now understood that the Moon has no gaseous envelope in which meteoroid ablation can occur. Before circa 1950, however, the presence of a tenuous lunar atmosphere, in which meteoroid ablation was theoretically possible, could not be ruled out by the available observations. It is argued here that the observers who reported the apparent detection of lunar meteors unconsciously 'molded' imperfect perceptions to fit a pre-existing, but flawed theoretical ideal. The term philosophical parallel is introduced to describe this phenomenon.

Key words: The Moon; lunar atmosphere; meteors; meteoroid impacts

1 INTRODUCTION

The light emission that results from vigorous meteoroid ablation may be potentially seen from any planet or moon with an atmosphere. While we are mostly familiar with the observation of meteors within Earth's atmosphere, they should also be observable in the atmospheres of Mars and Venus. The only planet, however, besides Earth on which a meteor trail has been observed, albeit with an *in situ* satellite camera, is that of Jupiter (Cook and Duxbury, 1981). The Moon is Earth's nearest large-body neighbour, and consequently it is the best place for Earth-based observers to look with the hope of recording extraterrestrial meteors – that would be, of course, if the Moon had a corporeal atmosphere.

To the modern observer it is well known that the Moon has no substantive atmosphere and that lunar meteors are an impossibility. Up until circa 1950, however, the situation was much less obvious, and indeed, several prominent observers did report observations of selenographic meteors. This is a remarkable situation. From our present-day advantage we might initially attempt to dismiss the claimed observations as absurd and hardly worthy of attention. This, however, would be too harsh a judgment on our predecessors and indeed, it is our contention that the situation is not so easily resolved. So, where does this leave us? We can, if nothing else, begin by ruling out the idea of fraud – essentially, the observers had nothing to gain by making the claims that they did. We are inherently left, therefore, with an interesting mystery: how can observers apparently 'see' something that is in reality physically impossible?

The human eye is not the most trustworthy of analytic instruments, and even the experienced observer will occasionally record something that is 'odd' – such as a flash or short-lived streak of light. Some of these 'odd' events are no-doubt real phenomena, but others (possibly the majority) are simply illusory. It is our contention that the solution to the lunar meteor problem lies in the process by which observers decide which of the 'odd' observational events to count as 'real' and which to dismiss as 'noise'. As we shall outline in detail below, the apparent observation of lunar meteors was a consequence of well-meaning observers being swayed by what we shall term the 'philosophical parallel'. That is, possibly illusory and certainly poorly-observed transient events, that under typical circumstances would have been ignored, were accorded a 'real' status because of a pre-existing theoretical ideal already known to the observers. In other words, observers sometimes 'witness' the things that they 'expect' to see. To understand how the philosophical parallel applies to the study of lunar meteors we have to first consider the development of ideas concerning the Moon's atmosphere.

2 THE MOON'S VANISHING ATMOSPHERE

If a planet or moon is to retain an atmosphere for any appreciable length of time, a balance has to be established between the diffusive effects of thermal molecular motion and the entrapping effect of gravity. To first order, the average velocity of the atmospheric gases must be less than the escape velocity. For the Moon the escape velocity is 2.4 kms^{-1} and its daytime temperature of about 350 K is sufficiently high that the escape-time for hydrogen and helium is just a matter of hours (Zeilik and Gregory, 1998). Heavier molecules of, for example, oxygen and carbon dioxide take longer to escape, but they still disperse in a time short compared to the age of the Solar System. What little exosphere the Moon does display is primarily produced through solar-wind implantation and subsequent release via sputtering and impact-driven vaporization (Potter and Morgan, 1988).

One of the earliest references to the possible existence of lunar meteors was made by the famed science fiction writer Jules Verne. In his fascinating book *Round the Moon*, published in 1870, Verne wrote, "... if the invisible disc [the Moon as seen by the explorers in their stranded spacecraft] had any atmosphere, the shooting stars would be seen passing through it" (Verne, 1870:101). Verne did not commit himself, or his fictional characters, to the detection of lunar meteors in his story, and indeed, at the time that he wrote *Round the Moon*, the idea of a substantive lunar atmosphere had been almost universally abandoned. Had the Moon's atmosphere, it was argued, been anything more than a mere wisp, one would have expected to observe twilight phenomena and possibly even clouds. In his *Unfinished Worlds*, Parkes (1887:152-153) described the Moon thus

> No quivering atmosphere, with swift moving clouds traversing its disc; no changing features on its rugged, broken-up surface, not any indications of life; but groups of conical elevations, and detached mountain ranges – as sharp and hard in outline as though they had been chiseled by the hand of some mighty sculptor – each one a silent record of the tragic history of a world now dead, but not destroyed.

While Parkes dismissed the Moon as an entirely 'dead' world, other astronomers felt that the presence of a lunar atmosphere had not been wholly ruled-out. John Herschel in his classic text *Outlines Of Astronomy* argued, for example, that "... we are entitled to conclude that the non-existence of any atmosphere at its edge dense enough to cause a refraction of 1 seconds of arc, i.e., having one 1980th part of the density of the earth's atmosphere" (Herschel, 1869: 358-359). American astronomer William Pickering also noted the absence of lunar refraction, and argued that his Jupiter occultation observations constrained any lunar refraction to be less than 0.5 seconds of arc. This value, Pickering continued, while extremely small still allowed for the Moon to have an atmosphere with a surface density 1/8000th that of Earth's at sea level (Pickering, 1892). At first glance Pickering's argument does not seem encouraging towards the possibility of lunar meteors, but as Pickering himself noted, meteors in Earth's atmosphere begin their luminous flight at an altitude where the atmospheric density is some 1/2 500 000th that at sea level (assuming ablation begins at 100 km). Pickering concluded, "... it will therefore be seen that the lunar atmosphere is quite sufficient to render luminous and destroy all the smaller meteors before they can strike the surface."

Pickering did not directly address the question as to why no lunar meteors had ever been unequivocally observed. This point, however, later became the focus of some interest. J W Gordon (1921), for example, raised the question of the non-detection of lunar meteors in the journal *Nature,* and his letter prompted a response from the well-known astronomer A C D Crommelin. While acknowledging that the surface density of the Moon's atmosphere must be small, Crommelin (1921) noted that because of the Moon's lower gravitational acceleration, the rate at which the Moon's atmospheric density decreased with height must be smaller than that found for Earth. Given this fact, Crommelin argued, even if the ratio of the lunar to Earth surface densities was as small as 1:10 000 then, all else being equal, the Moon's atmosphere would be denser than Earth's for heights above 40 miles (64 km).

Crommelin's argument concerning the variation in atmospheric density with height can be readily described by considering the properties of a hydrostatic, isothermal atmosphere. In such models, the atmospheric density, $\rho(h)$, at height h can be written as

$$\rho(h) = \rho_0 \exp(-g\,h / H_0) \qquad (2.1)$$

where ρ_0 is the surface density, g is the surface gravity and $H_0 = k\,T / \mu m_H$ (where k is the Stefan-Boltzmann constant, T is the temperature, μ is the mean molecular weight and m_H is the mass of the hydrogen atom). Since the Moon's gravitational attraction is about one sixth that of Earth's and assuming, as Crommelin did, that H_0 is the same in both atmospheres, the height at which the two are equal is

$$h = -H_0\,(5/6)\ln(\rho_{0M} / \rho_{0E}) \qquad (2.2)$$

where the M and E subscripts refer to the Moon and Earth respectively. Crommelin argued that $\rho_{0M} / \rho_{0E} \approx 10^{-4}$, and adopting a scale height of six kilometres for Earth's atmosphere, we find $h \approx 66$ kilometres.

It is important to note that Crommelin's assumption on the equality of H_0 in both atmospheres was, in fact, a forced assumption. The argument was necessitated since he knew nothing about the composition or temperature stratification of the supposed lunar atmosphere. Lincoln La Paz (1938:281) later picked up on this point and argued that

> It seems probable that the explanation of the efficacy of the rare lunar atmosphere as a shield against meteoritic bombardment as given by Pickering and Crommelin is the correct one; nevertheless, ... a final decision must await a recalculation of h [the height of equality given by equation (2.2)] on the basis of assumptions conforming more closely to the actual state of the lunar atmosphere, as revealed by modern observations and theory.

La Paz was, of course, correct in his summation, but it would appear that his reservations were largely ignored. For example, Ernst Öpik wrote to Patrick Moore in 1952, claiming

> Lunar meteors are quite probable. Considering the surface gravity of the Moon, which leads to a six times' slower decrease of atmospheric density with height, the length and duration of a meteor trail will be six times that on the Earth, if a thin atmosphere exists. (cited in Moore 1984).

That meteor trails would be six times longer, for the same initial meteoroid mass, in the supposed lunar atmosphere follows from a consideration of the classical theory of meteoroid ablation (Hughes, 1978). If the rate of meteoroid mass loss is considered to be proportional to the kinetic energy of the oncoming airflow, then the meteoroid mass at height h can be written as

$$m^{1/3}(h) = A - B\, H_0\, (\rho_0 / g)\, \exp(-g\, h / H_0) \quad (2.3)$$

where A and B are constants and the other symbols have their earlier meanings. In the derivation of equation (2.3) it has been assumed that the ablation takes place at constant velocity – to first order this is an acceptable approximation (ibid.). From equation (2.3) one can derive a correspondence between the heights h_E and h_M at which the same amount of mass has been ablated in Earth's atmosphere and in the assumed lunar atmosphere. We find,

$$h_M = (g_E/g_M)\, \{ H_0 \ln(g_E\, \rho_{0M} / g_M\, \rho_{0E}) + h_E \} \quad (2.4)$$

Once again, it has been assumed that H_0 is the same in each atmosphere. It follows from equation (2.4) that the meteor trail length, L, will be of order

$$L = h_{start} - h_{end} = (g_E/g_M)\, L_E \quad (2.5)$$

where L_E is the trail length in Earth's atmosphere and since $(g_E/g_M) \approx 6$, we obtain Öpik's result. In 1952, Öpik summarized the situation in his letter to Moore: "... the average duration of a meteor on the Moon will be two to three seconds. ... the average length of trail would be 75 miles [121 km] – and the meteors would therefore be very slow, short objects." (cited in Moore, 1984).

Equation (2.1) allows us to set a lower limit to the ratio (ρ_{0M} / ρ_{0E}) beyond which meteoroid ablation will not commence in any assumed lunar atmosphere. If $(\rho_{0M} / \rho_{0E}) < 10^{-7}$ then the density of the Moon's atmosphere will never exceed 10^{-7} kg/m^3, and consequently vigorous ablation will not occur. (Meteoroid ablation begins at a height of about 100 km in Earth's atmosphere, where the atmospheric density is of order 10^{-7} kg/m^3.) Most importantly, the lower limit to (ρ_{0M} / ρ_{0E}) establishes an observational constraint. If the observations reveal a ratio less than 10^{-7}, lunar meteors should not exist.

When Crommelin addressed the issue of lunar meteors in 1921, the available observations set a lower limit of about 10^{-4} to the ratio (ρ_{0M} / ρ_{0E}). Russell *et al.* (1926:170-171) state that, "... an atmosphere 10,000 times thinner than the earth's illuminated by full sunlight, would be more conspicuous than the dark part of the moon when lighted by the full earth." They did not suggest what the lower limit to (ρ_{0M} / ρ_{0E}) might be. In 1938, La Paz argued that an examination of the literature suggested $10^{-5} < (\rho_{0M} / \rho_{0E}) < 10^{-3}$. These early constraints were mostly based upon the non-detection of lunar atmospheric refraction, and from the supposed detection of twilight prolongations of the Moon's cusps (Pickering, 1892).

It was realized in the early 1940s that if the Moon actually had an atmosphere then the sunlight reflected to Earth, when the Moon was near first or third quarter phase, should be polarized. The presence, or not, of a lunar atmosphere could be established, therefore, upon the detection of a polarization component in the Moon's light. One of the first lunar polarization studies to be published was that by Fessenkoff (1943) where an upper limit of $(\rho_{0M} / \rho_{0E}) < 10^{-6}$ was established. The allowable upper limit to (ρ_{0M} / ρ_{0E}) was, however, pushed to lower and lower values by more and increasingly-refined polarization studies. In 1952 the French astronomer Andouin Dollfus was able to set an upper limit of $(\rho_{0M} / \rho_{0E}) < 10^{-9}$ and with this constraint he technically ruled-out the possibility of lunar meteors. Commenting upon the new results by Dollfus (1952), Öpik (1952) wrote, "... if this is correct, the lunar atmosphere would present no obstacle to the motion of meteors; these, including the smallest 'micro-meteors', would penetrate the lunar atmosphere un-hindered, and without perceptible luminous display before striking the ground." Interestingly, Öpik (1955) later argued that the upper limit to (ρ_{0M} / ρ_{0E}) could only be constrained to be less than 10^{-6}, allowing, once again, for the theoretical possibility of lunar meteors. In spite of Öpik's rather optimistic interpretation of the observations, subsequent studies have pushed the upper limit of the ratio (ρ_{0M} / ρ_{0E}) to less than 10^{-10}.

3 LUNAR METEORS

Many observers have reported seeing transient light phenomenon on the Moon. The compilation of anomalous lunar events collected by Corliss (1985) indicates that the majority of historic sightings involve the appearance of reasonably long-lived luminous 'spots'. Prior to the beginning of the twentieth century these transient lights were often interpreted in terms of volcanic activity.

It is interesting to note that Corliss finds a distinct dearth in the number of reported transient lunar events between 1902 to 1948. The reasons for the drop in apparent 'sightings' are probably many-fold. We speculate, however, that the decline in reports was related to the realization that the Moon was truly a geographically-dead world, and that its craters were not volcanic calderas. Corliss, however, is mistaken to say that no reports of 'strange' lunar events were made in the 46-year interval prior to 1948. Indeed, it was during the early 1940s that observers first reported seeing meteors against the Moon's disk. This observational activity coincides with the publication of the work of Lincoln La Paz (1938) in the widely-read magazine *Popular Astronomy*. It also coincides with the announcement of the first observational studies that suggested the Moon might, in fact, have a thin atmosphere.

During the early 1940s several members of the American Association of Lunar and Planetary Observers (ALPO) began conducting organized observational searches for lunar meteors. At that time the idea of such a study had great scientific merit; the unambiguous detection of lunar meteors would, for example, clearly indicate the presence of a lunar atmosphere. A null detection, on the other hand, would imply that the Moon had no or at least a very tenuous atmosphere. We note, however, that the null hypothesis is a rather vague one, given that it is not clear at what stage and at what level one could say it had been established.

The first published account of the sighting of a possible lunar meteor appears to be that by Walter Haas in 1943. Haas was then an observer at the University of New Mexico and editor of the *Strolling Astronomer*, the journal published by ALPO. Haas' account was based upon an observation made with a 6-inch telescope at near full Moon on 1941 July 10. His account reads: "I saw a tiny luminous speck move across the Moon's surface at a uniform rate ... The brightness was constant along the whole path, and the stellar magnitude was estimated to be +8. The duration was one second." By comparing the projected path across the Moon's disk with a lunar atlas, Haas estimated the trail length to be 63±10 miles (101±16 km).

After Haas' paper appeared in 1943, other sightings of lunar meteors followed. In 1948 Haas published a review and account of the lunar meteor statistics gathered by ALPO members (see Chant, 1948). Between 1941 and 1948 a total of ten lunar meteors had been recorded in 145 hours of observation. Haas wrote of the meteors observed that they, "... showed just the aspects which we would expect lunar meteors to exhibit" (cited in Chant, 1948). A summary of the lunar meteor observations is given in Table 1.

Of the 17 events listed in Table 1, three are described as flashes (all seen by the same observer) and these were interpreted as direct meteoroid impacts. The meteors that were recorded as moving had an average trail length of 52 ± 44 miles (we have excluded from this average the single observation by Schmidt since it is so discordant with the other estimates) and an average duration of 1.25 ± 0.75 seconds. The average visual magnitude of the observed meteors was +6.8 ± 2.7. We note that these averages

Table 1. Summary of candidate lunar meteors observed by ALPO members. The table is based upon data summarized by Haas (1947, 1952). The observer codes are 1: W. H. Haas. 2: R. G. Johnson. 3: C. P. Smith. 4: R. Schmidt. 5: L. T. Johnson. Note, L. T. Johnson reported a further three flashes, but gave no details as to their magnitude.

Year	Date (UT)	Trail Length (mile)	Duration (sec.)	Visual Magnitude	Observer
1941	July 10.24	63	1	+8	1
1942	Aug. 24.15	18	0.3	4	2
1943	Feb. 20.10	144	0.75	4	3
1943	Feb. 20.14	22	0.5	8	1
1944	May 5.17	15	1.5	7	1
1944	June 27.08	55	1	9	1
1944	Aug. 11.34	25	1.5	11	1
1946	June 10.10	500?	1	1	4
1946	June 22.10	35	1	8	1
1946	July 22.46	3	3	6	1
1951	Mar. 13.06	---	Flash	10	5
1951	Apr. 11.11	---	Flash	7	5
1951	May 9.07	---	1	---	5
1951	Sep. 28.46	80	---	---	5
1951	Oct. 26.37	---	Flash	6	5
1951	Oct. 26.40	110	2.5	---	5
1951	Nov. 4.99	---	2	---	5

do not tally with the numbers suggested by Öpik in his letter to Moore (see Moore, 1984), and we also note that Öpik appears to have either ignored or been unaware of the observations collected by ALPO.

The data collected between 1941 and 1946 were derived from 65.7 hours of systematic observing. The lunar meteors and flashes reported by L T Robinson in 1951 were recorded during 19 hours of lunar monitoring. The average detection rate for lunar meteors was apparently one event ever four hours. No month was favored for the sighting of lunar meteors, and only one lunar meteor was reported during the annual Perseid meteor shower (Haas; 1944, August 11). One might well expect, in fact, to see meteor flashes near the peak time of the Perseid shower since at that time the meteoroid flux is sizably enhanced at Earth and the meteoroid encounter velocity is high.

In his 1948 review of the available data on lunar meteors Haas argued that "... it is impossible to regard all the moving lunar specks as terrestrial meteors because of the extreme shortness of their paths" (cited in Chant, 1948). He also noted that "... the specks grow more common with decreasing brightness until we reach those so dim that most of them go unobserved. Our possible lunar meteors in this respect resemble terrestrial meteors" (ibid.).

At the outset of the lunar meteor programme Haas argued that the search would either reveal that the Moon had no atmosphere, in which case only impact flashes would be seen, or, that the Moon supported an atmosphere capable of producing luminous meteoric-streaks (Haas, 1943). By 1947, when he published his review in *Popular Astronomy*, Haas was faced with the potential problem that 17.5% of the observed events were flashes. In the observing time amassed by the ALPO observers, one would not expect to see so many 'face-on' meteors in the Moon's or, for that matter, Earth's atmosphere. Haas put a great deal of weight behind his own observations of luminous streaks – the indicators of a lunar atmosphere – and writing somewhat defensively in 1947, he commented (Haas, 1947),

> I feel as certain of the reality of the 7 specks that I recorded as I do of the reality of a third-magnitude terrestrial meteor observed with the naked eye under favorable conditions

Only one of the meteors that Haas recorded, however, was actually seen under conditions that were described as 'good'. The other observations were made when the conditions were described as being 'rather poor', 'poor' or 'fairly good'. The comments by Haas in 1947 are a far cry from those he made in 1943, when he pointedly noted, "... in seeking to explain such surprising appearances, one must bear in mind the possibility of illusion" (Haas, 1943:398).

Towards the close of the 1940s we begin to see a parallel developing between the apparent observation of lunar meteors and Percival Lowell's supposed and staunchly-defended observation of Martian canals (Sheehan, 1988), and with W F Denning's supposed detection of stationary meteor radiants (Beech, 1991). The parallel is one in which respected and experienced observers, who genuinely believed in the reality of their observations, continue to record events that were increasingly at odds with main-stream theory and practice. The adopted stance is essentially one of "I see it, therefore it is." This pragmatic, somewhat naïve approach can occasionally be a useful one to adopt, but it is also one that requires extra special examination. There is a fine distinction between the act of recording a genuinely-new phenomenon in low quality data and the act of unconsciously molding the observations, made under difficult conditions, to 'fit' some pre-supposed ideal. Indeed, Denning essentially realized this problem with respect to planetary observations, although he apparently did not see it as a problem when it came to meteor observations. For example, in discussing the supposed telescopic observation of faint surface features on the planet Saturn, Denning (1895) wrote:

> There is a distinct line of demarcation between what is absolutely seen and what is possibly seen or suspected. An object may only be glimpsed, and yet it is certainly seen. ... but with some objects the experience is different ... they flit about like an *ignis fatuus*, and are intractable to our utmost efforts. Obviously in such a case the observer has but one alternative, and that is to regard the objects as imaginary.

Denning is without doubt correct in his summation, but history appears to abound with observers who failed to follow his edict.

When the ALPO observers embarked upon their search for lunar meteors it was theoretically possible that they might actually record such events. And, indeed, by the close of their programme in the early 1950s the ALPO observers had recorded, all in good faith, a sizable number of lunar meteor candidates. In the meantime, however, the theoretical underpinning of their work had been completely eroded. The polarization studies conducted by Dollfus, and others, had placed such a low upper density limit on any possible lunar atmosphere that meteoroid ablation would not be expected. In short, lunar meteors were no longer tenable as reasonable theoretical entities by circa 1950. The collapse of the theoretical argument, however, does not explain why the ALPO observers actually 'saw' lunar meteors. We contend, however, that it was the philosophical parallel that distorted the observers' objectivity. From the outset of their study the ALPO observers knew that lunar meteors were theoretically possible, and consequently they started looking for events that resembled the theoretical expectation. In this way we contend the 'strange' and 'odd' sightings that would have been previously ignored (as presumably physiological in origin) were accredited the status of 'real' lunar events. And further, once one observer has reported seeing a certain phenomenon, it is then easier for other observers to believe that they are 'seeing' similar events. Sheehan (1988) describes a parallel situation with respect to Giovanni Schiaparelli's observation of Martian canals. Otto Struve, for example, is quoted as writing that it was a challenge to other observers to find them [Schiaparelli's canals] "... now that they knew they were there." (cited in Sheehan, 1988:124).

With the collapse of the 'theoretically possible' argument for the potential existence of lunar meteors, a second problem arose. The observers were left with a 'well-stocked' catalogue of events that had no apparent explanation. Under these circumstances one can either 'dig-in' and continue to claim that the events are real and "theory be damned" or one can just let the subject drop. It is this latter option that was ultimately adopted, but even so, sightings of lunar meteors were reported well into the 1950s.

4 DISCUSSION AND CONCLUDING REMARKS

The confusions of the philosophical parallel may flourish in any situation where theoretical precedent leads observation. It will especially flourish when the observations are difficult to collect and when they are made under less than idea conditions. This is the situation with respect to the apparent detection of lunar meteors.

Not only were the lunar meteor sightings made under mostly poor-observing conditions (according to the observers' notes), but initially at least the observers had two 'theoretical props' upon which to promote their work. Firstly, the Moon is continually subject to impacts by meteoroids – there is no question that this must be the case. And second, the available measurements could not rule out the presence of a lunar atmosphere in which luminous meteoric phenomena might be observed. Not only this, while it would seem that the motives of the observers were entirely genuine, it would appear that they did not expect to fail in their endeavours. In other words, they did not apparently allow for the possibility that no luminous events might be seen. As Haas (1943) argued, one would see either 'flashes' or 'luminous meteors.' There is no mention of the possibility of not seeing anything. Indeed, Haas addressed the question as to why so few observers had reported seeing lunar meteors and commented, "... an observer not mindful of the possibility of lunar meteors would be likely to attach little importance to their appearance" (Haas, 1947:272). This statement is, from our perspective, a pure distillation of the philosophical parallel.

Even when the theoretical support for the possible detection of luminous meteors was removed, the observers of lunar events could still cling to the unshakable argument that the Moon is continuously subject to meteoroid impacts. However, even then, their observations are not consistent with the measured meteoroid flux at one astronomical unit from the Sun. To see that this is the case we can make use of the flux model of Halliday *et al.* (1984). If we assume that the Moon encounters essentially the same meteoroid flux as Earth and consider a target area equal to half that of the Moon's surface (the visible area as seen from Earth), then the number N of meteoroids of mass greater than m(kg) that impact the Moon per year will be of order

$$\text{Log}\, N = -0.69\, \text{Log}(m) + 2.97 \qquad (4.1)$$

In (4.1) we have simply adjusted the meteoroid flux derived by Halliday *et al.* (1984) to a surface area appropriate to the visible disc of the Moon. So, for example, we would expect 933 impacts per year on the Moon's visible disc from meteoroids of mass m(kg) ≥ 1. We noted in section 3 that the implied lunar meteor event rate was 1 per 4 hours of observation. This rate is equivalent to the meteoroid flux at m(kg) ≥ 0.29. In Earth's atmosphere a 0.29 kg meteoroid would produce a meteor of peak visual brightness of –5, assuming an initial atmospheric velocity of 20 kms^{-1}. Meteoroids of the same mass but with higher velocities will produce even brighter meteors. If the Moon had an atmosphere, a 0.29 kg meteoroid would produce a meteor of peak visual magnitude about +13 when viewed from Earth. The range of reported lunar meteor magnitudes varied from +10 to +1 (see Table 1), with an average of +7. Clearly, the implied large meteoroid flux at the Moon is much greater than that observed at Earth, and this is not what we would expect.

Direct evidence for meteoroid impacts upon the Moon's surface has been recorded with the Apollo lunar seismometer network. Duennebier *et al.* (1976), for example, have described the occurrence of 'meteor' storms on the Moon (signified by periods of enhanced meteoroid impact activity), while Oberst and Nakamura (1991) have discovered the existence of meteoroid impact clusters that coincide with the times of maximum of annual meteor showers on Earth. None of these impacts, however, was linked to optical transients, but this was no doubt because no one was looking for such a correlation. It should, in fact, be noted that optical transients resulting from large meteoroid impacts on the Moon's surface are to be expected occasionally, and indeed, may yet be unambiguously detected with video-tape recording equipment (Beech and Nikolova, 1999). In this respect, we also note that some of the 'flash' phenomena reported by L T Johnson (see Table 1) may have been genuine impact events.

Lunar meteors are not the only luminous phenomena to be reported by selenographers. Transient Lunar Phenomena (TLPs) have been reported on numerous occasions throughout history (Middlehurst and Moore, 1967), and while these remain a largely unexplained phenomenon they do represent a bona fide lunar mystery, distinct from that of lunar meteors (Hughes, 1980, and Cameron, 1991). Also, the observed rate and observational characteristics of TLPs make them quite distinct from the observational 'qualities' ascribed to lunar meteors.

In conclusion, the lesson to be learned from the 'observed' yet non-existent lunar meteors is a simple, yet important one. Indeed, the issue highlights an essential human quality in the often de-humanized workings of science. The lesson is this: biased by a priori theoretical argument, observers can in all honesty record the desired theoretical ideal, and, as the lunar meteor narrative illustrates, astronomers can sometimes 'see' impossible things. We suggest that this effect be called the 'philosophical parallel'.

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Martin Beech is Associate Professor of Astronomy at Campion College, The University of Regina, Saskatchewan, Canada. His primary research interests are solar system astronomy, meteor physics, and cometary evolution. For relaxation, Martin makes polyhedron models and collects astronomy-related cards, stamps, and books.

David W Hughes is a Reader in Astronomy at the University of Sheffield, UK. He has spent his academic life researching into the minor bodies of the solar system and specifically into cometary decay, asteriodal evolution, cosmogony and the relationships between comets and meteoroid streams. He is author of *The Star of Bethlehem: An Astronomer's Confirmation* (Walker & Co., 1979).

Note added in proof:

Observations of possibly six lunar impacts were reported during the 1999 Leonid meteor storm. Captured on video tape, the transient light flashes that accompanied the propounded meteoroid impacts lasted about one thirtieth of a second and two were as bright as magnitude three.