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APPARENT LUNAR ACTIVITY: HISTORICAL REVIEW*

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Recent observations[1-3] of apparent activity on the moon have stimulated interest in such reports by earlier observers. A literature survey covering nearly four centuries has produced records of more than 200 sightings of apparent lunar activity; of these, 159 were dated and considered reliable. This material has been analyzed with respect to (1) solar activity as measured by monthly sunspot numbers, and (2) tidal action by the earth. The frequency distribution of the sightings around the lunar orbit shows well-defined peaks at perigee and at apogee.

Survey of the Material.—More than 200 records of observations of temporary bright spots, as well as of veils, obscurations, and brightening of the floors of craters and other small areas have been collected. A catalogue (available from either author on request) has been compiled, giving a brief description and date of the observation, the name of the observer or reporter, and the reference. Many of the events occurred in Alphonsus, Plato, Aristarchus and its surrounding area, Mare Crisium, and Theophilus; however, the location was not always given.

It is well known that the appearance of the lunar features is dependent on lighting and that librations and details of the topography can cause special lighting effects of a temporary nature. This is true particularly of the crater Plato at sunrise: there is a gap in the crater wall, the floor of the crater is unusually flat, and a ray of light striking the floor can produce the effect of a sudden glow of light from it. Multiple reflections can cause the illusion of bright spots in certain areas of the moon. The sudden illumination of a peak beyond the terminator can give the impression of a bright spot on the dark side. Earthshine, strongest just before and after New Moon, can produce unusual lighting effects. All such possibilities of spurious events have been considered, but relatively few reports have had to be discarded.

Reported changes in the topography have not been included because of uncertainty as to whether the changes were recorded at their first appearance so that the date of the record might lack significance. The reality of many of these has been often disputed (see e.g., ref. 4). Kopal and Rackham's photographs[5] of the so-called luminescence in the Kepler region have been omitted from the discussion here also. Many of the earlier observations used in the survey were made by well-known astronomers such as Argelander, Bode, W. Herschel, Olbers, Piazzi, F. G. W.

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Struve, and Tempel, and this has added to their weight. Similar details occur repeatedly (see, e.g., ref. 6).

Where possible, we have consulted the original reference; however, the new (1964) edition of Houzeau and Lancaster's *Bibliographie Général d'Astronomie*[6] was a reliable secondary source. It is a very valuable collection, since at least one of the authors, Houzeau, traveled extensively in many countries and was able to consult a large number of libraries and private book collections. J. H. Schroeter, an enthusiastic and careful German amateur astronomer of the eighteenth century and friend of William Herschel, also contributed contemporary reports of many observations between 1780 and 1790 in his *Selenotopographische Fragmente.*[7] The *Astronomischer Jahresbericht* contained many references to lunar events for the years 1899–1963.

The first report known to us of apparent lunar activity was recorded in *Harrison's Description of England* (see Lowes[8]). This refers to an event in March 1587: a bright spot on the dark side of the moon "directly between the pointes of her hornes, the mone being chaunged not passing five or six daies before." Dated records have been found of two events in the seventeenth century, 26 in the eighteenth, and 32 in the nineteenth. In this century, 98 events had been reported up to July 1965. The largest number of lunar events occurred in or near Aristarchus, where 49 observations were recorded. Fifteen accepted reports mentioned apparent activity in Plato; however, several other Plato reports were rejected by reason of the topography of the region which leads to the peculiar effects at sunrise mentioned earlier. In 22 dated records, the location was not given.

It is of interest to include a few of the descriptions of the observations as recorded. J. H. Schroeter[9] wrote in the *Astronomisches Jahrbuch* for 1792 that he observed on September 26, 1788, "a whitish bright spot shining somewhat hazily and 4″ to 5″ of arc in diameter, as bright as a star of 5th magnitude, about 1′ 18″ southwest of Plato and in the bright mountainous region bounding Mare Imbrium." It was visible for 15 minutes.

Another observer, R. Hart,[10] wrote in the *Monthly Notices of the Royal Astronomical Society:* "On the night of the 27th December, 1854, between 6 and 7 p.m., the moon was very bright. I had brought my 10-inch reflector to bear upon the moon; . . . I now turned my attention to the light part of the disk, and my eye was at once attracted by an appearance I had never seen before on the surface of the moon, although I have observed her often during these last forty years . . . there were two luminous spots, one on either side of a small ridge, which ridge was in the light and of the same colour as the moon; but these spots were of a yellow flame colour, while all the rest of the enlightened part was of a snowy white, and the mountaintops that were coming into the light, and just on the shadow side of these spots were like the light of the setting sun reflected from a window a mile or two off. I observed it for five hours . . . I called the attention of three gentlemen, my neighbors, and my own household, and they all described the appearance as I saw it myself, and have given above . . . "

Most of the observations were described as a "bright spot" or a "brilliant point," but 20 stated that the color was red or reddish. Color determination is a particular problem with visual observations and must be regarded as subjective.

Possible Correlation with Sunspot Numbers.—In a recent letter to *Nature,* Flamm and Lingenfelter[11] considered the possibility of a relation between the number of

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TABLE 1

RECORDS OF LUNAR EVENTS ACCORDING TO MONTHLY SUNSPOT RELATIVE NUMBERS[12]

Monthly mean sunspot no.	Aristarchus Events (from F. and L.) No.	%	Events from All Areas of Moon (J. B. and B. M.) No.	%	Total Months No.	%
0 to 30.0	13	59.1	37	35.9	1064	41.1
30+ to 60.0	4	18.2	26	25.2	691	26.7
60+ to 90.0	1	4.5	20	19.4	423	16.4
90+ to 120.0	1	4.5	8	7.8	220	8.5
120+ to 150.0	3	13.6	3	2.9	109	4.2
150+ to 180.0	0	0	5	4.8	52	2.0
180+ to 210.0	0	0	2	1.9	21	<1
210+ to 240.0	0	0	1	<1	5	<1
240+ to 270.0	0	0	1	<1	1	<1
Total	22	99.9	103	100	2586	100

occurrences of transient lunar events in the vicinity of Aristarchus and the yearly mean sunspot relative numbers. Sunspot counts were chosen as a convenient measure of solar activity by these authors, since yearly sunspot numbers are available from 1715, whereas statistics of solar flares were not available sufficiently far back to be used for their analysis. They deduced a negative (or inverse) correlation with solar activity; however, they did not analyze the general distribution of sunspot relative numbers.

A more detailed statistical investigation,[12] based on 103 events from the present survey and using monthly rather than yearly sunspot numbers, has been made. Monthly sunspot relative numbers have been tabulated from January 1749 until June 1964, covering 2586 months.[13, 14] The findings are given in Table 1 (from ref. 12). The number of observations in Flamm and Lingenfelter's analysis, shown in the second column, has now been increased to 22 to include the observations by Bode from March through May 1789 as three entries, and by Kosyrev in November and December 1961 as two; each was listed as a single entry by Flamm and Lingenfelter. Percentages of the total number of events are shown in the third column. Statistics for events in all areas of the moon are given in the fourth and fifth columns and indicate a trend similar to that observed for events in Aristarchus. The last two columns show the total number of months falling in each group of monthly mean sunspot relative numbers from January 1749 to June 1964. Over 41 per cent of these months had low sunspot numbers (0–30), whereas very few months had high sunspot activity. Comparison of the data shown in Table 1, particularly of columns 4 and 5 with columns 6 and 7, does not suggest a correlation between the occurrence of lunar events and the degree of sunspot activity but rather that the distribution of the events is a random one superposed on an asymmetric distribution of sunspot numbers.

Tidal Effects and Stresses in the Body of the Moon.—The mutual gravitational attraction of the earth and the moon is GMm/R^2, where G is the constant of gravitation, M and m the masses of the earth and the moon, and R the distance between their centers of mass. Disruptive stresses are set up in the lunar material through variations in this quantity from point to point, and for elements of the moon situated at mutual distance dR, the maximum stress component per unit mass tending to tear them apart is

$$S = \frac{2GMdR}{R^3}. \qquad (1)$$

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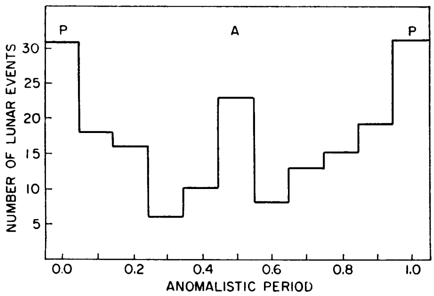

FIG. 1.—Frequency of lunar events with respect to anomalistic period. Each division equals 0.1 anomalistic period or approximately 2.76 days. Perigee is shown as *P*, apogee as *A*.

In a similar formula for stresses set up on the earth in the moon's gravitational field, M is replaced by m, and it is readily seen that the forces on the moon are greater by a factor of 81. The mean eccentricity in the moon's orbit, which affects the value of R, is small, 0.055, but by reason of the factor $1/R^3$, the change in (1) from perigee to apogee is of the order of 30 per cent. Stress changes through the anomalistic month are therefore significant.

Figure 1 shows a histogram in which the frequency of 159 dated lunar events is shown. The unit for the abscissa is the anomalistic month; perigee is taken as 0.0 and apogee as 0.5. The mean anomalistic month is 27.6 days, though the actual time from perigee to perigee can vary by several days. Each division of 0.1 month is equivalent to slightly less than 3 days.

The excess of events near perigee and apogee is much greater than could be expected as a result of chance and indicates a causal relation with tidal stress. At or near perigee, maximum cracking could be expected; at apogee, the point of maximum relaxation of the crust, a "squeeze" results.[15, 16] Conditions relatively favorable to instability of the lunar material might be expected at each of these times. A similar excess near apogee and perigee was found by Green[17] out of 25 events. The nature of a mechanism which might produce a bright spot in the dark portion of the moon is not at present clear, but internal causes seem likely and lunar volcanism is suspected. Whatever the mechanism, tidal forces are probably significant in relation to at least some of the events.

Lunar Phase.—The age of the moon (the number of days past New Moon) was computed for all dated events. Up to 1900, there is a large concentration of observations of such spots in the period before First Quarter, the majority being 3–6 days after New Moon; the concentration is not so pronounced for recent observations. This is certainly an effect of observational selection because of the convenience for observation of the 3- to 6-day moon during the early part of the evening. Except during eclipses, no lunar observers look at the moon at New Moon, as it is then in the daytime sky and very near the Sun.

Nearly all of the early observations are of points of light on the dark part of the moon. Only when telescopes of larger aperture became more commonly available to lunar observers did observations of changes on the illuminated part of the moon become possible for the majority of these. Also a given intensity change is easier to observe against a dark background than an equivalent change added to a bright one.

Summary.—Records of events of activity on the moon are more numerous than had been expected. The events are probably due to internal causes on the moon that are accelerated near perigee and apogee through tidal disruption. Our findings do not support any correlation with sunspot activity, contrary to results suggested by earlier workers.

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*LONGITUDINAL WAVES IN CUBIC CRYSTALS**

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A study will be made in this article of the purely longitudinal waves which can exist in the elastic regime of a cubic crystal. The waves will be viewed as weak structural discontinuities or pulses, and the work will be based on the following form of the elastic stress-strain relations for cubic crystals, namely,

$$\sigma_{ij} = \lambda e_{kk}\delta_{ij} + 2\mu e_{ij} + \alpha e_{km}\nu_a{}^k\nu_a{}^m\nu_{ai}\nu_{aj}, \qquad (1)$$

where the quantities λ, μ, and α are elastic moduli and the vectors ν_1, ν_2, and ν_3, whose components appear in the last set of terms, give the orientation of the crystal in the arbitrary rectangular coordinate system x to which the relations (1) are referred;[1] also the δ_{ij} are the Kronecker deltas, the σ_{ij} and e_{ij} are the components of the stress and strain tensors, respectively, and there is a summation on all repeated

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