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4.6 Observing Electromagnetic Radiation by Leonid Impacts on the Moon

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ABSTRACT

The observation of the electromagnetic radiation associated with Leonid meteorite collision on the moon was attempted around the 1999 Leonid maximum on November 18. The Kashima 34 m radio telescope was pointed at the moon and X-band signals were recorded on November 15, 16, and 18. Optical "flash" events caused by meteorite impacts were observed during this Leonid maximum[1][3]. Although the data around the flash events was studied, none of the events were accompanied by X-band radiation. The reason why no radiation was observed is thought to be that the antenna observed the lunar center, whereas the flash events were observed near the edge of the moon. This result suggests that we may have to wait for a better observational chance when the lunar shadow region is bombarded by meteorites during the Leonid maximum. It is also advisable to track the lunar shadow region where flashes are expected to be observed, instead of the lunar center.

Keywords: Leonid meteorite, The moon

1. Introduction

The Leonid meteor stream is an astronomical phenomenon that occurs on or around November 18 in an average year. The number of meteors that appear is known to vary with a period of around 33 years. Since November 18, 1999 corresponded to the peak in this 33-year cycle, a variety of scientific observations were made to take advantage of this opportunity. For example, the light emitted by meteorites striking the surface of the moon was successfully observed by pointing a video camera at the unlit part of the moon's surface[1][3]. During this 1999 Leonid maximum, we used the Kashima 34 m radio telescope to observe the moon's surface in an attempt to measure the radio waves emitted as a result of such impacts. If light and radio waves can be used to ascertain the timing of these impacts on the moon surface and the amount of energy released, this data would be invaluable for verifying the theory of impact crater formation. Attempts have also been made to employ meteor impacts as a tool for "lunar prospecting"[2], and it is thought that successful radio-frequency observations of these impacts will be extremely useful for estimating the energy involved.

Section 2 of this paper discusses the positional relationship of the sun, the meteor dust and the Earth at the predicted peak of the 1999 meteor stream, and describes the predicted outcome of the lunar surface impacts. Section 3 describes the observation method. In Section 4, we discuss the lunar impact phenomena observed during this Leonid meteor stream. And in Section 5, we discuss the results of these observations and consider what sort of criteria should be selected when making the observations in order to obtain useful data on lunar impacts.

2. The Positional Relationship of Astronomical Bodies During the 1999 Leonid Maximum

The Leonid maximum of November 18, 1999 took place around 9-10 days after a new moon. Figure 1 illustrates the positional relationship of the Earth and moon at this time. Here, we will consider the motion of the moon and the meteor dust stream using a geocentric coordinate system. Since the meteor stream dust follows a retrograde orbit, it moves very fast relative to the Earth at a relative velocity of 72 km/s[2]. On the other hand, the velocity of the moon's revolution relative to the Earth is just 1.0 km/s. It is thus estimated that the velocity of the dust particles relative to the moon is roughly 72 ± 1 km/s. Accordingly, the effect of the moon's rotational motion relative to the meteor stream dust is negligibly small. Furthermore, one should also consider the scenario in which the dust strikes the Earth first and then continues on to strike the moon. Since the distance between the moon and the Earth is 3.8×10^5 km, the time between the dust passing close to the Earth and arriving at the moon is predicted to be at most 5.3×10^3 seconds. Since the peak of the 1999 Leonid meteor stream on earth was expected to occur at around 02:00 UT on November 18, it was thought that the peak lunar surface strike rate would occur at around 04:00 UT. We therefore decided to record data by directing the 34 m antenna at the moon for as long as possible starting at around 04:00 on November 18. Details of the observation equipment and method are described in the next section.

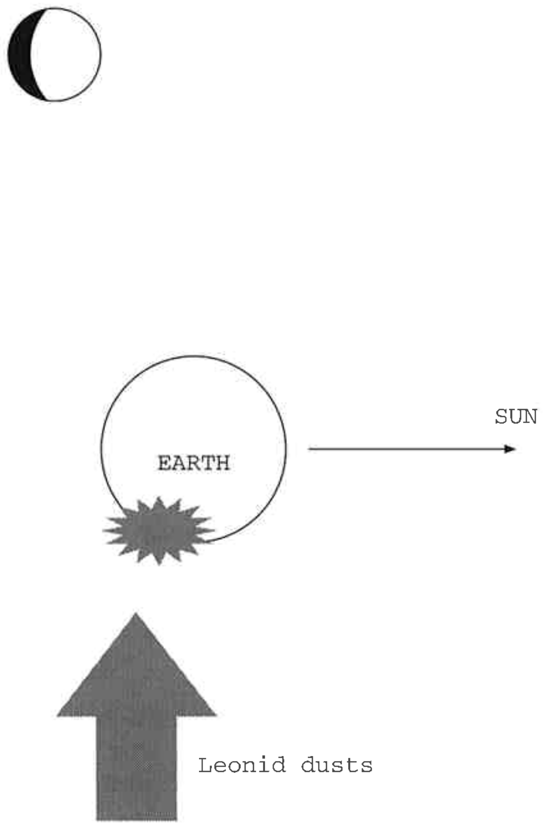

Fig. 1 A schematic view of the Earth-moon system during the Leonid meteor stream peak (November 18, 1999). After colliding with the Earth, the dust particles in the Leonid meteor stream arrived at the moon, which approached them from almost directly behind the Earth

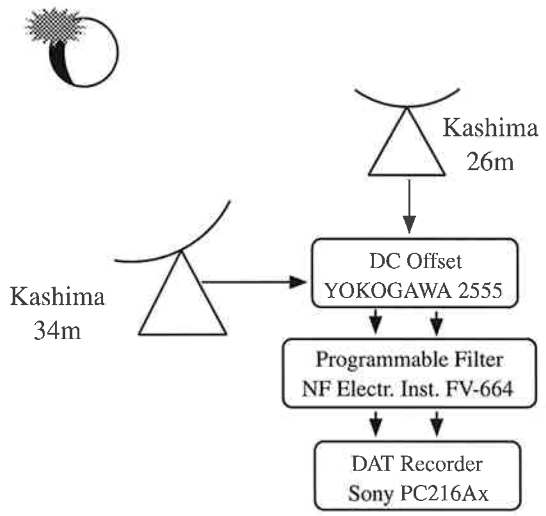

Fig. 2 A schematic view of the equipment used to observe and record the Leonid meteor stream. On November 15 and 16, the Kashima 34 m antenna was used for S-band and X-band observations, while on November 18 the 34 m and 26 m antennae were used for X-band observations (the latter observing the zenith for use as a reference). The data from these observations was recorded on DAT media.

3. Observation Equipment and Observation Method

To detect lunar surface impacts caused by the Leonid meteor stream, we used the observation/recording equipment shown in Fig. 2. The Kashima 34 m antenna was used to observe the lunar surface in the X-band and S-band between 10:34 and 12:00 UT on November 15 and between 06:56 and 13:16 UT on November 17, and the data for each band was recorded on channel 1 and channel 2 of a recorder. On November 18, when the lunar impacts were expected to occur, observations were made between 05:20 and 15:10 UT, with the data of X-band lunar surface observations by the 34 m antenna recorded in channel 1 and, for comparison purposes, the data obtained by observing the zenith with the 26 m antenna of the Geographical Survey Institute (GSI) was recorded in channel 2. The data obtained from these lunar surface observations includes a large DC offset due to the moon, so this was removed using a DC offset filter (Yokogawa 2555) and a programmable filter (NF Electronic Instruments FV-664, 10 kHz through, Gain 20 dB). Table 1 lists the equipment used for the observations and recording, and Table 2 lists the observed time intervals and physical quantities.

To track the lunar surface with the 34 m antenna, we used the Field System 9 (FS9) software, which is the international standard geodetic VLBI observation control software. In FS9, software for tracking the center of the moon is provided as standard, and using this it was easy to track the center of the moon. The results of these observations and the summarized results of optical observations performed at other research establishments are presented in the next section.

Table 1 The equipment used for the Leonid meteor stream observations

Receiver antenna	Kashima 34 m radio telescope (X-band, S-band) (center of lunar surface) Kashima 26 m radio telescope (X-band) (used to observe zenith for reference purposes)
DC Offset	YOKOGAWA 2555
Recording equipment (DAT)	SONY PC216Ax (48kHz sampling, 2 channels)
Programmable filter	NF Electronic Instruments FV-664 (10 kHz through, Gain 20 dB)

Table 2 The timing of observations and the recorded physical quantities

Observation timing	DAT Channel 1	DAT Channel 2
November 15, 10:34-12:00 UT	34 m X-band (lunar surface)	34 m S-band (lunar surface)
November 16, 06:56-13:16 UT	34 m X-band (lunar surface)	34 m S-band (lunar surface)
November 18, 05:20-15:10 UT	34 m X-band (lunar surface)	26 m X-band (zenith)

Table 3 Summary of observed flashes[(1)(3)]. "Magnitude" refers to the magnitude of a celestial body of comparable brightness.

Event ID	Discoverer	Event UT (Nov. 18)	Magnitude	S elenographic Long.	Lat.
F[(1)]	D. Palmer	3:05:44.2	5	65W	40N
D[(1)]	D. Palmer	3:49:40.4	3	68W	3N
E[(1)]	D. Palmer	4:08:04.1	5	78W	15S
A[(1)]	B. Cudnik	4:46:15.2	3	71W	14N
B[(1)]	P. Sada	5:14:12.9	7	58W	12N
C[(1)]	P. Sada	5:15:20.2	4	58W	20N
[(3)]		11:07:46 (±2)	4	(Dark side)	
[(3)]		13:54:25 (±2)	4	(Dark side)	
[(3)]		14:14:30 (±2)	4	(Dark side)	

4. Observation Results and Discussion

At the peak of the Leonid meteor stream on November 18, 1999, several "flashes" were observed on the lunar surface as a result of impacts. Between 03:05 and 05:15 UT there were six flashes with magnitudes ranging from 3 to 7[(1)]. There were also three flashes of approximately magnitude 4 between 11:07 and 13.54 UT[(3)]. These optical observations are summarized in Table 3.

We tried to examine what sort of radio waves are observed by the Kashima 34 m radio telescope during the time intervals in which these flashes were observed. For six of these events[(1)], the Kashima 34 m antenna was unfortunately in the process of switching position from other observations so the observation had not yet begun, and we were unable to identify the phenomena in the X-band. For the remaining three events[(3)], because we were observing the lunar surface during the corresponding time interval, we were able to check whether or not radio waves were observed in conjunction with the flashes. However, there were no phenomena corresponding to the flashes in the observed data, even though the impacts had released enough energy to allow even optical observation. Possible reasons for this absence of radio frequency observations are discussed below.

Figure 3 shows an enlarged view of the lunar surface during the time interval when flashes were observed. The unlit part of the moon is toward the left side of the figure. The locations where the six events A-F[(3)] shown in Table 3 were observed are marked with the symbols A-F. All six of these events were observed at locations close to the edge of the moon. Although the precise locations of the other three events[(3)] are not given, they were reportedly observed in the unlit part.

The small shaded circle at the center of the moon corresponds to the half power beam width when observations were made of the central part of the lunar surface in the X-band with the 34 m antenna. The size of this HPBW is 0.073°. The apparent radius of the moon at this time was 15'43"[(4)]. As this figure shows, the X-band observations made with the Kashima 34 m antenna could only cover a narrow region at the central part of the lunar surface. This region was brightly lit by the sun, so it was impossible to observe flashes with a peak intensity of around 3rd magnitude or less. It is also important to note that the actual flashes were observed in the unlit parts far removed from the region observed by the 34 m antenna. These factors seem to be the major reasons why we were unable to observe the radio waves associated with these flashes. Taking this into account, we will

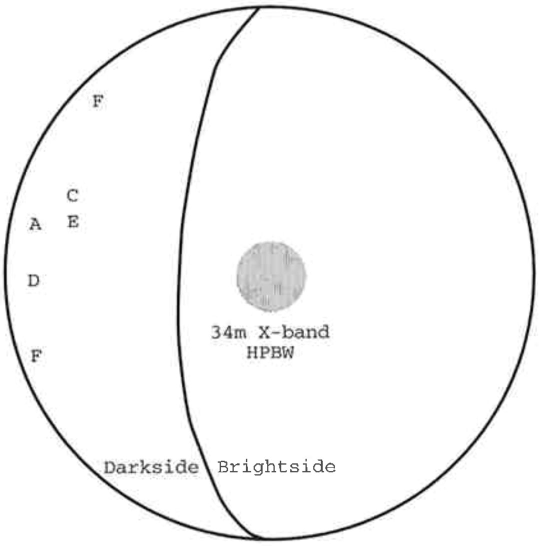

Fig. 3 The locations of the observed flashes (A-F) and the X-band half beam power width (HBPW) of the 34 m antenna.

discuss the criteria that should be selected for successful simultaneous observation of flashes and radio waves.

First, we will consider the frequency of impacts. Since the Leonid meteor stream dust particles have a retrograde orbit and encounter the Earth-moon system more or less head-on, we can expect impacts to occur most frequently on those parts of the lunar surface that face in the same direction as the Earth is moving.

Next, we will consider the amount of shade on the observed part of the lunar surface. The flashes are rather dim compared with the sunlit part of the lunar surface, so the observation conditions are better when the unlit part of the moon appears to have a large extent when seen from the Earth. In particular, it should be sufficiently dark near the center. The period in which these conditions of impact frequency and darkness are both satisfied is around 3 days after a new moon. Accordingly, the best opportunity for observing these impacts would be when the peak of the Leonid meteor stream arrives on or around 3 days after a new moon.

Furthermore, even when the center of the moon is bright as in the present case, it is possible to track the dark regions close to the edge of the moon by applying a suitable offset to the antenna tracking. Since a peak in the Leonid meteor stream is a phenomenon that only occurs once every 33 years, one would have to wait several centuries for such an event to coincide with the moon being around 3 days after a full moon. If this sort of tracking method is used, there should be a greater chance of making simultaneous observations with the flashes, and it should be possible to provide useful data for explaining the processes involved in the release of energy by impacts.

5. Conclusion

We have tried using the Kashima 34 m antenna to observe the impact of meteors on the lunar surface during the peak period of the Leonid meteor stream on November 18, 1999. Although three flashes occurred during the period in which the central part of the lunar surface was being observed in the X-band[3], we were unable to observe radio waves originating from the lunar surface impact sites. This is thought to be because the flashes were observed at separate locations to the region actually observed by the antenna.

Since several flashes were actually discovered by optical observations, it is reasonable to assume that the same phenomena can be observed at radio frequencies. Such observations should be possible if they can be made during an advantageous period (i.e., when the meteor stream peaks close to the third day after a new moon), or if the radio telescope is pointed at the unlit part of the lunar surface by applying a suitable offset to the antenna tracking instead of simply observing the center of the lunar surface.

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