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LETTER

Wide-Field TV Observation of the Leonid Meteor Storm in 2001: Main Peak over Japan

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Abstract

We carried out a wide-field TV observation of the strong activity of the Leonid meteor shower from $17^{h}17^{m}$ UT through $20^{h}20^{m}$ UT on 2001 November 18. We detected 869 Leonid meteors, along with 32 non-Leonids. A broad peak of the activity was recognized at around $18^{h}25^{m}$ UT, when the peak influx rate of meteoroids was $1.4 \times 10^{-5}\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$ (mag $\leq +3$). The activity of this main peak was comparable to that of a storm observed in 1999 over Europe. The activity of this peak was rich in bright meteors, including fireball class. The magnitude distribution index was 1.5 ± 0.3 ($-3 \leq \mathrm{mag} \leq +1$). The relationship between the observed peak and several theoretical predictions is discussed. We also discuss an "outburst", which consisted of at least 15 faint meteors which appeared within four seconds at $17^{h}56^{m}22^{s}$.

Key words: comets: individual (comet 55P/Tempel–Tuttle) — interplanetary medium — meteors — solar system

1. Introduction

The Leonids is one of most active meteor showers that have occurred roughly every 33 years, which corresponds to the orbital period of the associated comet 55P/Tempel–Tuttle. After the return of this comet in 1998, the Leonids was expected to show strong activity, and various world-wide campaigns have been coordinated, such as the Leonid MAC campaign (Jenniskens, Butow 1999; Jenniskens et al. 2000), which resulted in great advance in meteor astronomy. Among them, there was an important advance in theoretical studies on the structure of the spatial distribution of meteoroids in the meteor stream. Many researchers began to realize that a meteor stream consists of several narrow dust trails, and each of them is made by meteoroids ejected at a particular return of the parent comet. Based on this concept, several researchers (McNaught, Asher 1999; Lyytinen, van Flandern 1999) performed a detailed calculation, which resulted in great success for reproducing the observed time profile of the Leonids activity. According to these so-called "dust trail" theories, the Leonid meteor shower was expected to show a strong display between $17^{h}00^{m}$ and $18^{h}30^{m}$ UT in 2001 November 18 (Jenniskens 2001; Lyytinen et al. 2001; McNaught, Asher 2001). The Earth would then pass through two dense dust trails which were formed by returns of the parent comet in 1699 and 1866. These predictions suggested that Japan would be one of the best observational site.

We tried to monitor the expected activities of the Leonids in 2001 by using a TV camera system. In this letter, the results of an analysis of our wide-field TV observation is described, while focusing on the main peak of the Leonid meteor shower in 2001.

2. Observation

Our TV observation was performed at the top of Mizuishiyama mountain, which is located at Iwaki city, Fukushima prefecture, Japan (37.°10 N, 140.°80 E, $H = 695$ m). One of the authors (J. Watanabe) selected this site with high expectations for a clear sky without any clouds due to a weather forecast. Besides some light pollution by the central part of Iwaki city in the eastern sky, where we avoided to point out TV system, the sky condition was almost perfect.

The main system which we tried to use in 2001 was a relatively long-focus camera system, which was the same as that used in our TV observation in 1998 (Watanabe et al. 1999), consisting of an image intensifier along with a monochromatic CCD camera. The merit of this system is to detect faint meteors; although the field of view is only 16.°6 × 11.°9 with a limiting magnitude of 8 by using a 35-mm camera lens as an objective lens.

Just after starting our observation, we realized that a number of bright meteors, including fireball class, appeared, and seemed to increase in activity with time. In such a case, this system is inappropriate to clarify the time profile of the global activity because the number of detected meteors may be small due to the narrow field of view, together with a possible small index of the magnitude distribution of the Leonids. Therefore, we decided to carry out a wide-field TV observation using a backup camera, which was a high-sensitivity monochromatic CCD camera (WATEC Co., type WAT-100N). If we experienced any trouble with the image intensifier of the system above mentioned, it could be replaced by this backup camera. In order to cover a wide field of view, and to detect bright meteors, we decided to use a lens with the shortest focal length which we had at that time, a CS-mount camera lens ($f = 3.8$ mm, F 0.8, HG3808AFCS-HSP, CBC Co.). The combination of the back-up camera with this lens gave a wide field of view of $80\overset{\circ}{.}6 \times 65\overset{\circ}{.}0$, along with a limiting magnitude of 3.5. This field of view was by about 26.5-times larger than that realized by the main camera system.

We struggled to set up this system, mainly because all of the power for the observation was supplied by a car battery. After confirming that there was enough power without stopping the long-focus camera system, we started this wide-field TV observation from $17^{\rm h}17^{\rm m}$ UT through $20^{\rm h}20^{\rm m}$ on 2001 November 18. The images were recorded at a rate of 33 ms, the regular time interval of the TV, by a video tape recorder of the Hi-8 type.

We analyzed the data obtained by this wide-field TV camera system, because we could recognize the activity clearly, which showed the existence of the main peak near the expected epoch. There were a few serious interruptions by the headlights of cars coming close to the observational site. Because each interruption was within 30 s, we did not count the number of meteors during this 30-s period during such interference, and took these lost times into account for the analysis, including the lost time for changing the video tape.

The camera was pointed to the zenith during the observation. In our field of view, there were several bright stars in Gemini and Auriga together with Jupiter and Saturn, which could be used for comparison stars for a magnitude determination of each meteor.

3. Analysis

3.1. *Time Profile of Activity*

In order to perform precise determinations of the meteor flux, we decided to use the data only in the central part of the field of view for three reasons. The corner of the field of view was hidden by a misplaced hood, and the corner field seemed to be less sensitive because of vignetting or darkening. Moreover, the number of meteors was too large to be counted if we took a full field of view, which would increase the possibility of an oversight. Therefore, we made a ring corresponding to a circle of $30\overset{\circ}{.}0$ radius, and put it on the screen of the inspection. We counted the meteors of which the starting point could be recognized within this circle, by replaying the recorded video tapes three times. The inspection was performed by the authors and several students (Mr. Yasuhito Mima, Mr. Nobuhiko Kusakabe, and Mr. Yukihiro Ishibashi). In some special cases, such as an "outburst" mentioned later in detail, we divided our field of view into four sections, and repeated the inspection of the video tape several times in order to identify all of the recorded meteors for each section. The number of meteors was recorded every one minute together with a rough estimate of the maximum brightness compared to the field stars.

Figure 1 shows a time profile of the Leonids at 10-min time intervals. The number of meteors were corrected to that expected for a one-hour interval, namely, the hourly rate (H.R.), by taking the time loss of the interruption into account. Because the elevation of the radiant changed with time, we needed to make a correction to the observed rates. Using the position of the radiant point (153°, +22°), the elevation was 40° at $17^{\rm h}$, and 73° at the end. The corrected number, $N_{\rm c}$ was derived using

$$N_{\rm c} = N_{\rm obs} \sin(h_{\rm c})^{-\gamma}, \tag{1}$$

where $h_{\rm c}$ is the elevation of the radiant point, and γ is a constant for a correction of the meteor trail length. We adopted $\gamma = 1.4$ (Jenniskens 1994) in this study. The time profile of the corrected number, namely the zenithal hourly rate (Z.H.R.), is also plotted in figure 1.

The activity peak is clearly located between $17^{\rm h}50^{\rm m}$–$18^{\rm h}30^{\rm m}$ UT. From the beginning of this observation, the numbers of Leonid meteors gradually increased until $17^{\rm h}50^{\rm m}$ UT, when we noticed a large jump. However, it should be noted that there was a peculiar "outburst" of faint meteors at $17^{\rm h}56^{\rm m}22^{\rm s}$ in our field of view. We could recognize at least 15 faint meteors which appeared within about four seconds. A few faint meteors could be recognized outside of our field of view on the screen. Except for these meteors, the number during this 10-min time interval was just 56, which corresponded to an H.R. of about 500. This value is midway between those values of the H.R. of $17^{\rm h}40^{\rm m}$–$50^{\rm m}$ and $18^{\rm h}00^{\rm m}$–$10^{\rm m}$. The sudden jump in the numbers is attributed to an "outburst", which is thought to have been a local phenomenon discussed later. Hence, the global activity seems to have gradually increased until the main peak at $18^{\rm h}00^{\rm m}$–$30^{\rm m}$. If we took a 5-min interval in the time variation, the peak was located in the time bin of $18^{\rm h}25^{\rm m}$–$30^{\rm m}$. After this peak, the number of meteors decreased down to about two thirds within the next 10 min. It stayed at an almost constant level of about 300 per hour from $19^{\rm h}00^{\rm m}$ until $19^{\rm h}50^{\rm m}$, and then suddenly dropped down to the level of 100. The observed peak is thought to be the main peak of Leonids 2001, because the derived scale of the activity of the other peak observed in U.S.A. was thought to be one half (IAU Circular No. 7755, 2001), at most.

3.2. *Influx Rate*

The influx rate of the meteoroids at this peak can be derived as follows. Because the radius of our field-of-view was 30°, assuming the average height of the observed meteors at 115 km above sea level (Fujiwara et al. 1997), our field-of-view corresponded to an area S of about $1.4 \times 10^4\,{\rm km}^2$. The influx rate ϕ for meteors (mag $\leq +3.5$) was derived using

$$\phi = N_{\rm peak}/S, \tag{2}$$

where $N_{\rm peak}$ is the corrected rate at the peak. The number of Leonids for a rate of $685\,{\rm hr}^{-1}$ gives $1.4 \times 10^{-5}\,{\rm km}^{-2}\,{\rm s}^{-1}$. The spatial number density could be derived by dividing this influx rate by the relative velocity of the Leonid meteoroids ($71\,{\rm km\,s}^{-1}$), which gives $1.9 \times 10^{-7}{\rm km}^{-3}$ at the peak.

Arlt et al. (1999) derived the influx rate for visual meteors

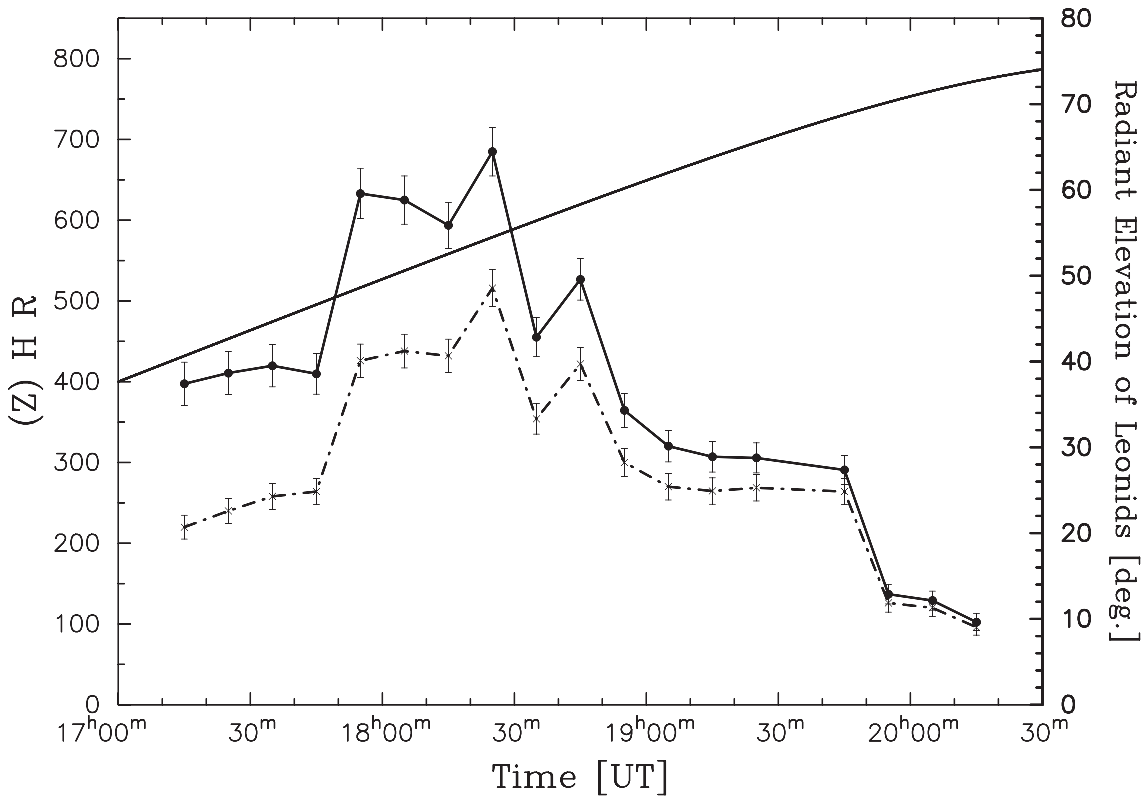

Fig. 1. Time variation of the number of Leonid meteors detected in our TV observation on 2001 November 18. The dash-dotted line is the raw number of meteors observed within a 15-min interval, and the solid line is the number after a correction for radiant-point elevation. The solid curve is the elevation of the radiant point.

Table 1. Magnitude distribution of the Leonids and non-Leonids.

	Number of meteors											Total number
Magnitudes	>-7	-6	-5	-4	-3	-2	-1	0	1	2	3	
Leonids	1	2	3	14	37	60	110	155	176	150	161	869
Non-Leonids	0	0	0	0	0	0	0	5	1	5	21	32

(mag $\leq +6.5$) as $1.4 \pm 0.3\,\mathrm{km}^{-2}\,\mathrm{hr}^{-1}$ for a storm peak in 1999. If we take the magnitude distribution index to be 2.3, as derived by Arlt et al. (1999), then the influx rate of the bright meteors (mag $\leq +3.5$) should be $1.2 \pm 0.2 \times 10^{-1}\,\mathrm{km}^{-2}\,\mathrm{hr}^{-1}$. This corresponds to $3.3 \times 10^{-5}\,\mathrm{km}^{-2}\,\mathrm{s}^{-1}$, which is almost comparable to the influx derived for the observed main peak over Japan in 2001.

3.3. *Magnitude Distribution*

We roughly estimated the magnitude of each meteor by comparing the brightest point in the trail on the TV monitor with several field stars. Although these estimates have a relatively large error, we can see a roughly apparent magnitude distribution, which is closely related to the mass distribution of the meteoroids in the meteor stream. The magnitude distribution of 869 meteors, along with 32 non-Leonids, is listed in table 1. In our camera system, we could not detect fainter meteors (mag $\geq +4$). The number of meteors, both in the Leonids and non-Leonids, near to the limiting magnitude was not small. This may be due to a decimal effect of the limiting magnitude, which may have been 3.7 or 3.8. It may be safely said that the number of 3rd-magnitude in this study included those of fainter meteors than 3 mag.

The Leonid meteors is far brighter than those in non-Leonids. The number of fireball-class meteors, if we define them as brighter than -4, is 20 in total, which corresponds to 2% of total numbers detected in our system. The magnitude distribution index should be derived from the data, except for both ends of brightness distribution, in order to avoid any uncertainty in the statistics. The derived magnitude distribution index is 1.5 ± 0.3 for meteors of magnitudes between -3 and 1. This is an average value for the Leonid meteor shower. It may be interesting to compare this property to those of other activity peaks observed in 1998–1999. The extremely low index of 1.2 was derived in the main peak at $23^{\mathrm{h}}30^{\mathrm{m}}$ UT on 1998 November 16 (Arlt 1998). In contrast, the index is much larger for two peaks in 1999. The main peak was observed over Europe, and the index was derived as 2.3 from visual observations (Arlt et al. 1999), and 1.8 from the video observation (Gural, Jenniskens 2000). The secondary peak was observed over Japan, and the derived index is a larger value, such as 2.9–4 (Watanabe et al. 2000). In the latter case, there was no fireball-class Leonids, and only 2 meteors were brighter than −1 among the total 428 Leonids (Watanabe et al. 2000). These differences suggest the different properties of the meteoroids among the trails contributing to the activities.

4. Discussion

The existence of the main peak at around 18^{h} UT of November 18 is clearly shown in this study. The solar longitude of this peak corresponds to 236.°46 (J2000.0).

McNaught and Asher (2001) predicted two possible major activities over Japan: one is $17^{h}24^{m}$ UT (236.°42) due to 9-revolution-old (1699) ejecta; the other is $18^{h}13^{m}$ UT (236.°46) due to 4-revolution-old (1866) ejecta. Lyytinen et al. (2001) also predicted two major peaks at $18^{h}20^{m}$ due to 4-revolution-old (1866) ejecta, and at $18^{h}03^{m}$ due to 9-revolution-old (1699) ejecta. It should be concluded that the observed main peak occurred due to those two dust trails, although the location of the observed peak does not exactly coincide with these predictions, and it is difficult to distinguish two components from this observation.

The plateau in the decreasing phase of the activity at 19^{h}–$19^{h}50^{m}$ UT may have been produced by broad components from much older trails. Lyytinen et al. (2001) included the non-gravitational effects on the orbital calculation of the parent comet, and expected that two old dust trails, 10 and 11-revolution-old (1666 and 1633), would contribute to the Leonids activity at around $19^{h}10^{m}$ at the level of Z.H.R. ~ 150, which were originally calculated to have occurred at $17^{h}23^{m}$–26^{m} UT without any non-gravitational effect. On the other hand, McNaught and Asher (2001) derived different times for these peaks as $17^{h}36^{m}$ and $18^{h}43^{m}$, respectively, using purely Newtonian gravitation. Further studies, including modeling or orbital calculations of the meteoroids, should be necessary to discuss the origin of such a structure after the main peak. It should be noted that the quoted times should not be directly compared with the observed peaks, because the times are predicted for the geocenter.

Various interesting phenomena, such as a persistent train and electrophonic sounds were observed during this storm in 2001. One of the remarkable phenomena was several "outbursts", during many faint meteors appeared for a few seconds within a local area of the sky, recorded in the TV observations. The first example of such outbursts was reported in the Leonids 1997, where 100–150 meteors appeared within two seconds (Kinoshita et al. 1999). In our case, 15 meteors appeared within about four seconds at $17^{h}16^{m}22^{s}$, and a few meteors belonging to this event could be recognized outside of our measured field of view. Moreover, other groups also using a long-focus TV camera system pointed out their detections of much fainter meteors which appeared almost exactly at the same time as we detected them in a narrow field of view. Using a similar camera system, I. Tabe et al. (2002, private communication) also found another example of such outbursts, which occurred in $18^{h}29^{m}20^{s}$, in which they detected about 50 meteors appearing in one second. These events are thought to be extremely localized phenomena. The spatial extent of the meteoroids belonging to each events seems to be concentrated in an order of a few hundred km. For example, these two events were observed only in the eastern part of Japan. There is no such report from the western part, even for a clear sky condition. Generally speaking, it is difficult to keep them compact for a long time after their ejection if they were ejected as independent meteoroids from the parent comet. Hence, natural ideas come up, such as fragmentation just before encountering the Earth. Cometary dust particles are usually thought to be fragile, and some indication on fragmentation after ejection exists on the dust tail structure of several comets (Watanabe et al. 1997). The origin of such outbursts should be studied in further detail for clarifying the evolution of meteoroids, which may be another clue to solve the origin of the interplanetary dust particles in the solar system.

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