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Radiants and orbits of the 2001 Leonids

By

Yoshihiko SHIGENO*, Hiroyuki SHIOI*, and Tomoko SHIGENO*

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Abstract: The storm occurred on November 18, 2001 as McNaught and Asher forecast, and double-station observation of the Leonids with photographs and TV was carried out. 75 photographs and 35 TV images were obtained of the Leonids. The average radiant of all of the photographic meteors was right ascension of 154.39 (SD=0.12), declination of 21.45 (SD=0.09), and VG=70.60 km/s (SD=0.22). (SD is the standard deviation of the extent of the data.) The average solar longitude was 236.461 (J2000). According to the forecast, the radiants for 9 revolutions and 4 revolutions varied by approximately 0.084 degrees. The radiant error must be properly evaluated in order to confirm this. An error oval was used to evaluate the radiant error. It was understood that the radiant extended further than the forecast from using a sufficiently small radiant error. The separation timing and speed may have been more varied when the meteor material separated from the parent comet. The TV observation observed meteor material with a small mass. The observation obtained an extended radiant. This means that the meteor material with a small mass dispersed. This relational expression was obtained by learning from the photographs and TV that the brighter the meteor, the higher the beginning height and the lower the end height. Moreover, Our observation showed the highest height was over 173 km.

1. INTRODUCTION

According to McNaught and Asher's theory (McNaught & Asher 1999), 9 revolution dust trails were encountered at 17:24 (UT) on November 18, 2001, and the ZHR was 2000. The forecast was to encounter 4 revolution dust trails at 18:13 (UT) on the same date with a ZHR of 8000. The forecast was that the radiants of 9 revolutions and the 4 revolutions at that time varied by approximately 0.084 degrees from each other (McNaught & Asher 2001). We conducted double-station photographic and TV meteor observation in order to confirm this. The observation location (139.2E, 36.3N) was approximately 100 km north of Tokyo, the base line was 43.2 km, and the two spots lined up approximately north and south.

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* Y. Shigeno, H. Shioi & T. Shigeno
Meteor Science Seminar, 2024 Kizuki-Sumiyoshi, Kawasaki, Kanagawa, 211-0021 Japan
Electronic mail: `cyg@nikon.co.jp`
`ftp://ftp.imo.net/pub/data/msswg` `http://www004.upp.so-net.ne.jp/msswg/`

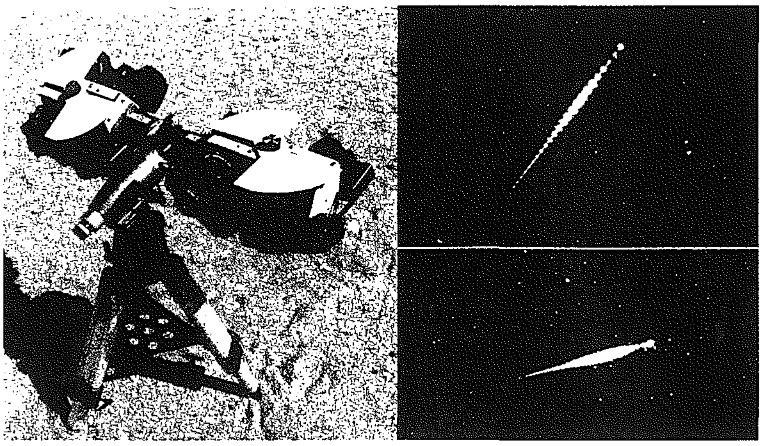

Fig. 1: The figure on the left shows the photographic observation equipment. The rotating shutter device is standard equipment in Japan, and we distributed about 130 sets. The figure on the right shows an example of a double station photographic meteor. ID: MSSQ9u on Nov 18 2001 at 18:25:14 (UT). Bright -4.4 absolute magnitude.

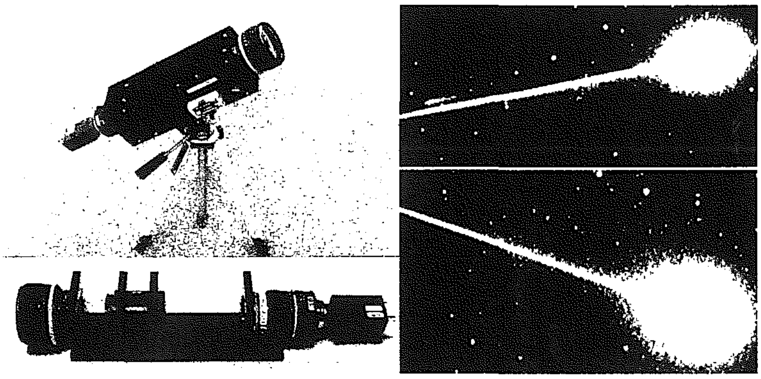

Fig. 2: The figure on the left shows the TV observation equipment. The device with the Image Intensifier (Delft High Tech XX1470 etc.) is standard equipment in Japan, and we distributed about 50 sets. The figure on the right shows an example of a double station TV meteor. ID: MSSJCJ on Nov 18 2001 at 19:25:37 (UT). Bright -7.3 absolute magnitude.

The equipment in Figure 1 was used for the photographic observation (Shigeno et al. 1997). Six Canon T-70 cameras with 50 mm F1.4 lenses and rotating shutters that have 50 breaks per second were prepared, and Kodak T-MAX400 film (EI: 1600) was used. The observation time was 66 minutes from 17:42–18:48 (UT). There were 100 simultaneous meteors, and 75 of them were analyzed. They were all Leonids. The average measurement error of the meteor path was 23 seconds.

The equipment in Figure 2 was used for the TV observation (Shigeno & Shioi 1996). The object lens was 85 mm F1.2, the field of view was 10.5 degrees × 8.5 degrees, the images were amplified by the Image Intensifier, and the limiting stellar magnitude was approximately 10. The images were taken with 410,000 pixel CCDs and recorded on Hi8 video cassette tape. The observation time was 3 hours and 3 minutes from 17:14–20:17 (UT). There were 150

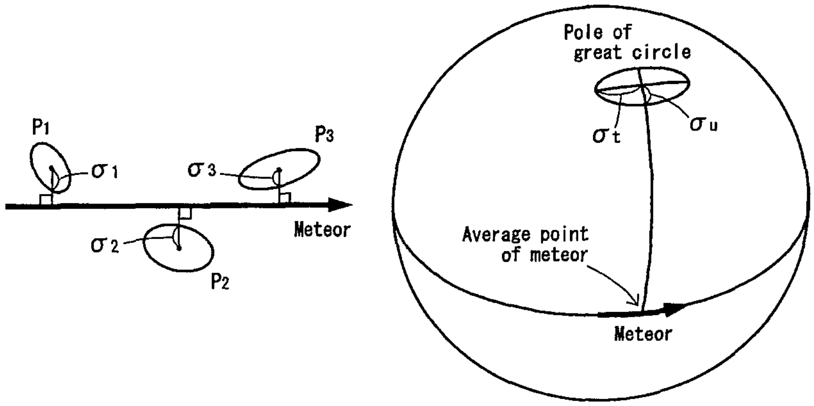

Fig. 3: The figure on the left shows the meteor path and the measurement point with the error displayed by the oval. The figure on the right is the meteor path and its pole of great circle. The error (standard deviation) making the meteor path move parallel is σ_u, and the meteor path slant error is displayed with σ_t.

simultaneous meteors, and 102 of them were analyzed. 35 of the meteors were Leonids. The average measurement error of the meteor path was 90 seconds.

2. EVALUATING RADIANTS WITH ERROR OVALS

As the radiants of 9 revolutions and 4 revolutions are very close, the radiant error obtained by the observation must be properly evaluated in order to confirm this difference. Therefore the radiant error was calculated with the method displayed in Figure 3. When measurement points for the meteor path are $P_1, P_2, \cdots, P_n$, then the individual points are assumed to have the errors shown with each oval. The $\sigma_1, \sigma_2, \cdots, \sigma_n$ here is the error (standard deviation) in the direction crossing each meteor path at a right angle at a measurement point. The error (σ_u) making the meteor path move parallel and the meteor path slant error (σ_t) are then presented in the formulas below, but x_i is the radian, which is the distance measured along the meteor path from the meteor path average position until each measurement point.

$$\sigma_u = \frac{1}{\sqrt{\sum_{i=1}^{n} \frac{1}{\sigma_i^2}}} \qquad \sigma_t = \frac{1}{\sqrt{\sum_{i=1}^{n} \frac{x_i^2}{\sigma_i^2}}}$$

In the pole of great circle of meteor path, the error oval has the size of σ_u in the direction facing the meteor path average position and the size of σ_t in the direction at right angles to the average position. Observe the same meteor from 2 or more points, and you can obtain the pole of great circle of meteor path and its error oval for each point. After obtaining radiants from the poles of great circle of multiple meteor path, you can also obtain the error oval of radiants with exactly the same method as above.

3. EXPANSION AND ERROR OF THE RADIANTS OBSERVED

All of the radiant error ovals obtained in the photographic observation are displayed in Figure 4. The size of the ovals is reduced to 1/5 in order to make them easier to understand. Small error ovals are gathered near the center and the large error ovals are spread over the periphery. In addition, the major axis pivot of the error oval radiates from the center, which clearly displays that the radiants deviate from the center due to the error.

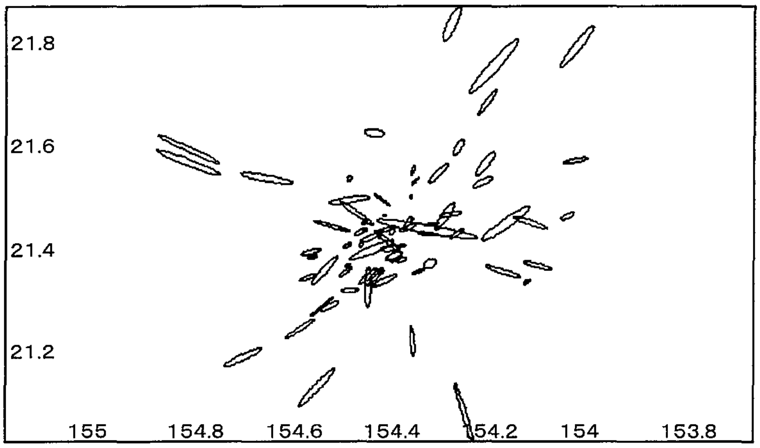

Fig. 4: All of the radiant error oval distribution obtained from photographic observation. (This figure is reduced to 1/5 of the oval size.)

Table 1: Radiants and orbits of the Photographic Leonid meteors. The upper line gives the averages, the lower line gives the expansion in the data in standard deviation.

DATE(UT) Y M D	S.Long deg	Co.Rad A.deg	SD deg	Co.Rad D.deg	SD deg	VG km/s	SD km/s	a AU	e -	q AU	Peri deg	NODE deg	i deg	(J2000)
2001 11 18.761	236.461	154.39	.11	21.45	.07	70.60	.49	9.71	0.898	0.986	173.9	236.5	162.5	All 75 met.
.012	.012	.12	-	.09	-	.22	-	-	.022	.000	.4	.0	.1	SD(+/-)
2001 11 18.763	236.462	154.41	.02	21.45	.02	70.57	.50	9.38	0.895	0.986	173.8	236.5	162.5	Precise 15
.011	.011	.06	-	.05	-	.23	-	-	.024	.000	.3	.0	.1	SD(+/-)

Table 1 displays the averages and expansions of the Photographic Leonid meteors. (All radiants and orbits have been opened to the public in our homepage.) The errors in the right ascension direction and the declination direction were individually obtained from the error oval. The radiant expansion (standard deviation) and the average error were obtained from all the meteors. The expansion was right ascension 0.12 degrees and the declination 0.09 degrees. The average error was right ascension 0.11 degrees and the declination 0.07 degrees. This means that the radiant expansion and the average error are approximately the same value in both the right ascension and the declination. It is known that the radiant expansion comes from the error.

The radiant expansion and average errors were calculated by sampling 15 meteors with error ovals of under 0.05 degrees. The expansion was right ascension 0.06 degrees and the declination was 0.05 degrees. The average error was right ascension 0.02 degrees and declination 0.02 degrees. In this case, the expansion was approximately 3 times the error. It can be said that the actual radiant expansion is obtained.

Meteors with errors of under 0.03 degrees were each measured 3 times in order to confirm this. The error ovals found from this are displayed in Figure 5. The oval size is exact. Identical meteors have error ovals overlapping each other. It is understood that the error ovals, for the most part, display the correct radiant errors. It also displays that the radiant expansion is larger than the errors.

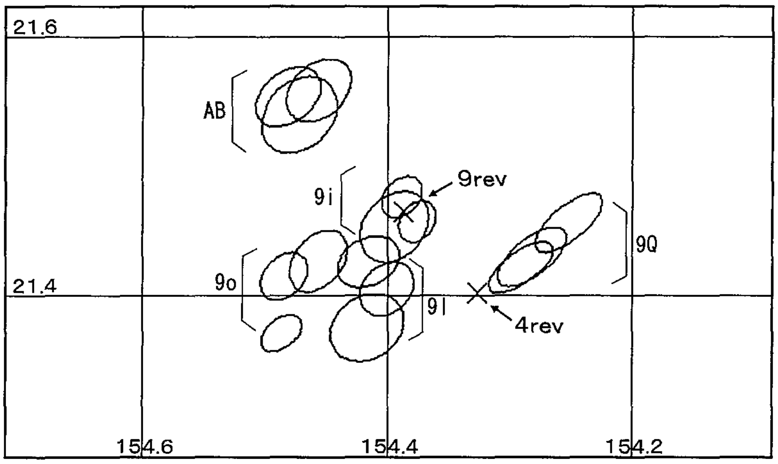

Fig. 5: The error oval distribution from measuring meteors with errors of under 0.03 degrees. Each meteor was measured 3 times. ID marks were recorded in order to display identical meteors. The probability of radiants existing in the error ovals is 47%. × marks the forecasted 9rev and 4rev radiant location.

4. DOUBLE-STATION TV OBSERVATION

Table 2: Radiants and orbits of the TV Leonid meteors. The upper line gives the averages, the lower line gives the expansion in the data in standard deviation.

DATE(UT)			S.Long	Co.Rad	SD	Co.Rad	SD	VG	SD	a	e	q	Peri	NODE	i	(J2000)
Y	M	D	deg	A.deg	deg	D.deg	deg	km/s	km/s	AU	-	AU	deg	deg	deg	
1995	11	18.747	235.976	154.05	.57	21.88	.25	71.0	1.9	18.3	0.946	0.985	173.4	236.0	162.3	3 meteors
		.021	.021	.25	-	.34	-	1.4	-	-	.141	.001	1.4	.0	.4	SD(+/-)
1998	11	17.783	235.237	153.71	.31	21.65	.21	70.8	1.3	12.6	0.922	0.984	172.0	235.2	162.6	6 meteors
		.020	.021	.29	-	.15	-	.8	-	-	.064	.001	1.0	.0	.4	SD(+/-)
1999	11	18.786	235.993	153.85	.38	21.57	.14	71.2	1.3	17.2	0.943	0.986	174.2	236.0	162.7	9 meteors
		.063	.064	.17	-	.07	-	.5	-	-	.049	.000	.4	.1	.1	SD(+/-)
2001	11	18.778	236.477	154.30	.38	21.50	.14	71.0	1.2	15.0	0.934	0.986	174.4	236.5	162.5	35 meteors
		.030	.030	.34	-	.15	-	.8	-	-	.072	.001	1.3	.0	.3	SD(+/-)

The Leonids have been under double-station TV observation since 1993 (Shigeno et al. 2000). The minutest meteors obtained in photographs are approximately magnitude 2, but they are approximately magnitude 8 with the TV. Compared with the photographs, TV enables observing the mass of smaller meteor matter. As the Leonids are very fast, however, the minutest meteors on TV are an absolute magnitude of approximately 5.

The averages and expansions of the TV Leonid meteors are displayed in Table 2. The radiant expansion is bigger than in the photographic observations. The radiant expansion and average error, however, are approximately the same value in both the right ascension and the declination. It is known that the radiant expansion comes from the error.

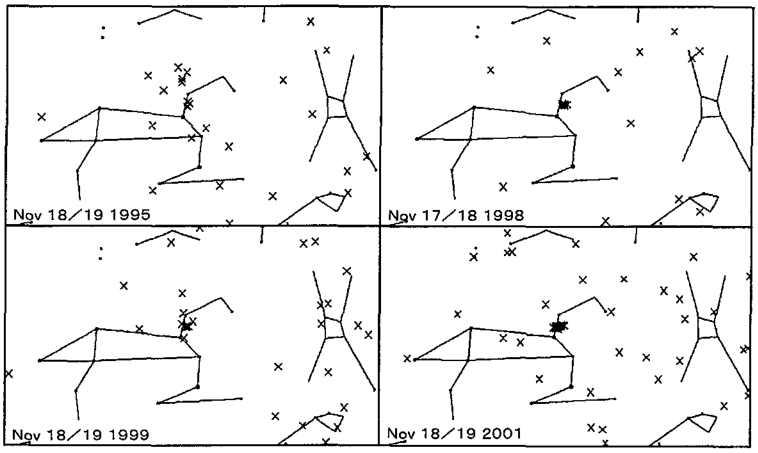

Fig. 6: *The radiant distribution of the periphery around the Leonids each year is shown.* × *marks the* radiant location.

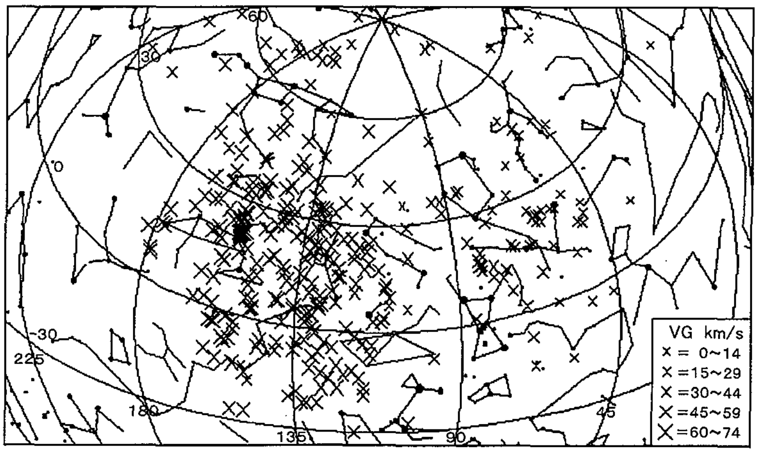

Fig. 7: The radiant distribution of the whole sky obtained at the time of the Leonids is displayed. Nov 18/19 1995, Nov 17/18 1998, Nov 18/19 1999, Nov 18/19 2000, and Nov 18/19 2001. As the speed is faster, the size of the × mark is larger.

The radiant distribution of the periphery around the Leo each year is shown in Figure 6. The radiants are concentrated in a narrow area in the photographs, but are scattered in a wide area on the TV. This means that the mass of the small meteor matter is scattered. In addition the radiant distribution of the whole sky obtained at the time of the Leonids is displayed in Figure 7. There is deep interest in observing a wide area of high-speed radiants as the vicinity of the Leo is in the direction of travel of the earth.

5. ALTITUDE DISTRIBUTION

The relationship of the absolute magnitude (Ma) of the Leonids for the beginning height (Hb) and end height (He) obtained in 2001 is displayed in Figure 8. The approximate expression according to a straight line is also displayed below. The measurement conditions for photographs were radiant height from 43 degrees to 56 degrees and for TV from 37 degrees to 71 degrees.

$Hb = 114.7–1.31 \times Ma$ $He = 95.0 + 1.83 \times Ma$ (Photograph)
$Hb = 125.9–2.79 \times Ma$ $He = 91.9 + 0.77 \times Ma$ (TV)

It was understood from the photographs and TV that the brighter the meteor, the higher the beginning height and the lower the end height. There are some reports of high beginning height TV observations (Fujiwara et al. 1998; Spurny et al. 2000; Brown et al. 2002), which are from 160 to 180 km. In our observation, the highest height was over 173 km.

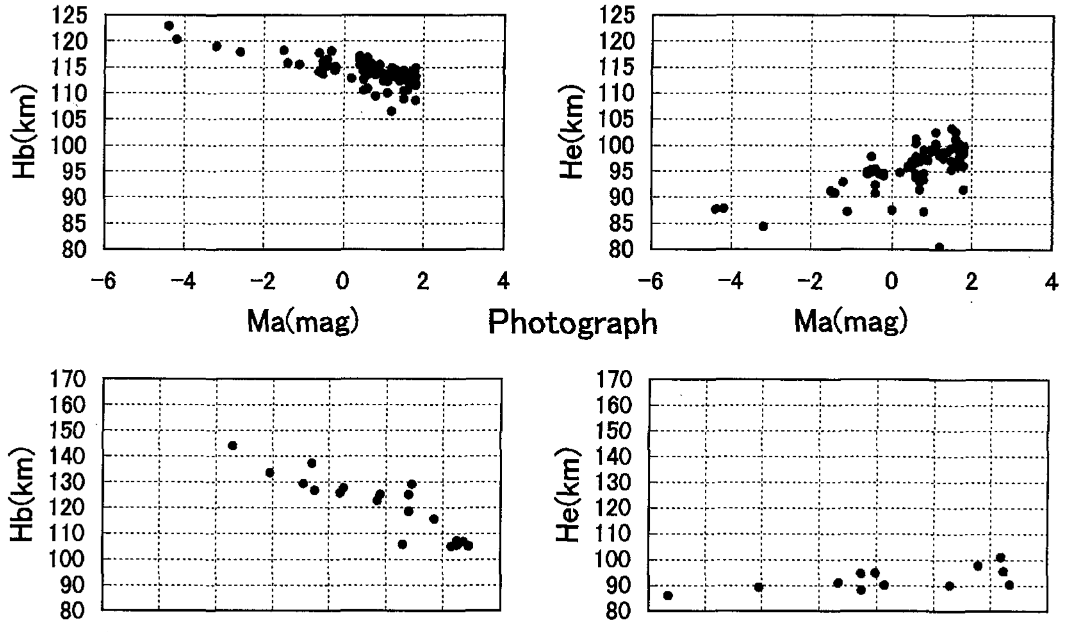

Fig. 8: The figure above is of photographic observation and the figure below is of TV observation showing the altitude distribution of the Leonids. The figure on the left shows the beginning height (Hb) with respect to the absolute magnitude (Ma) and the figure on the right shows the end height (He) for the absolute magnitude.

6. CONCLUSIONS

McNaught and Asher's forecast came out true, and double-station observation of the storm was a success. Error ovals were used to evaluate the radiant errors. Up until now, radiants were only noticed for either the right ascension direction or the declination direction error. Using the error ovals enabled displaying the slanted direction errors, and all the directional errors could be properly evaluated. As a result, these observations revealed that the errors were sufficiently small compared with the radiant extension. The radiant extension was larger than the predicted difference between 9 revolution and 4 revolution radiants. Therefore, it was learned that we could not decide from the observations which meteor belonged to the 9 revolution or the 4 revolution radiants. It appears that an estimate greater than the supposition in McNaught and Asher's theory is necessary. For example, when the meteor material separates from the parent comet, the separation timing and speed may be more varied.

Moreover, Uchiyama is assuming that the bright 9 revolution and 4 revolution meteors were few at this time (Uchiyama 2002). Because, the peak of 9 revolutions and 4 revolutions was not clear for a bright meteor. In a word, various revolutions seem to exist together in the photographic meteor. The result of this report can be explained by this idea.

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