NOTES

Visual observations of 1998 Leonids in Delingha and their preliminary analysis

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Abstract On the basis of the observational data obtained by the Sino-Dutch Joint Leonids Observation Team at Delingha Station of Purple Mountain Observatory from Nov. 13 to 18, 1998, and those obtained in other places of China during the same period, the distribution characteristics of the 1998 Leonids are analyzed and a three-layer structure of the meteoric shower encountered by the Earth is proposed.

Keywords: **Leonids, *ZHR*, mass distribution.**

On the early morning of November 13, 1833, and in the northeast of the United States, a very spectacular Leo meteoric storm with more than 50 000 meteors per hour was observed. This aroused astronomers' enthusiasm of research and promoted the birth of modern meteor astronomy. The parent body of the Leo meteoric group is the 55P/Tempel-Tuttle comet, whose period is about 33.25 a. Due to the resonance perturbations of Uranus[1] and Jupiter[2], only the meteoroids, which very closely surround the comet, do not escape. Therefore, once in about 33 years a rather strong Leo meteoric shower may be seen on the Earth. In 1995—2001 comes another maximum year of the Leonids. According to predictions, the best places of observations of the 1998 Leonids are in China and the western part of the Pacific Ocean [3]. On the basis of an agreement of cooperation between the Chinese Academy of Sciences and the Dutch Ministry of Science and Culture, the Purple Mountain Observatory and the Dutch Meteor Society organized a joint team of observations. Beginning on Nov. 13, 1998, observations in 6 consecutive nights were carried out in Delingha area of Qinghai Province of China. In that period, the weather in that district was rather fine, and the joint observation team have obtained ideal results[4].

1 Observational method

The Dutch Meteor Society is at present one of the largest meteor organizations in the world. Its level and instruments of observation are of the first class in the world. Our cooperative observations have acquired a large amount of visual, photographic and video materials. This note is mainly devoted to the analysis and discussion of the visual observational data. The method of visual observation is as follows. The observer holds in hand a tape recorder, lies on his (her) back, looks up at the sky, and quickly dictates the characteristics of each meteor: its classification (e.g. Leonid, Taurid or sporadic meteor), brightness (in stellar magnitude) as well as other properties (the meteor's speed, color, whether there is a trace left, etc.). These data are kept in the tape recorder, which has the function of simultaneously recording the time. After the observation, the records are put down in writing.

We carried out observations at two sites with a distance of 65 km (the Delingha Station with east longitude 97°43′42.5″, north latitude 37°22′41″ and 3 275 m a. s. l.; the Ulan Station with east longitude 98°23′48″, north latitude 37°08′52.3″ and 3 299 m a. s. l.). Visual meteors generally appear in heights between 80 and 110 km. When simultaneous observations are made for one and the same meteor at such two sites, the orbital elements of the meteor can be determined.

2 Observational results and their reduction

During the first peak, which appeared 16 h earlier than prediction and was not visible in the western Pacific region, the returning meteoric shower mainly consisted of bolides. However, Delingha is located in western China and the conditions of observation in that place were very favorable. Moreover, the Sino-Dutch observation team made sufficient preparations. So the observations achieved complete success. Now let us take Jos' observation as an example. In the three early mornings of Nov.

17, 18 and 19, he observed altogether 1 786 meteors. Among them there were 1 249 Leo meteors (including 69 bolides) and 394 sporadic meteors, which cannot be ascribed to any meteoric group. There were also 124 Taurus meteors and 19 Monoceros α meteors. The brightest meteor even attained −12 magnitude. By calculation, its weight might be 4.4 kg. In our team there are many observers, who have 20—30 years' observational experience, and this is the first time for them to get such plentiful results.

(i) Reduction of the *ZHR*. The zenith hourly rate (*ZHR*) is the result of normalization of the observational data obtained by various observers in different conditions. Our results of reduction are shown in fig. 1. The formula of calculation is

$$ZHR = \frac{N_{\text{leo}}}{T_{\text{effective}}} \times \gamma^{6.5 \cdot Lm} \times (\sin(hr))^{-\alpha} \times C_p^{-1},$$

where $T_{\text{effective}}$ is the effective time in that period of observation; N_{leo} is the number of Leo meteors observed in that period; *Lm* is observer's limiting visual magnitude in the process of observation and it depends on the weather conditions during observation; *hr* is the angle of altitude of the radiant; the exponent α is used to revise the altitude angle and it is taken to be 1.4[5]; C_p and γ are, respectively, the susceptibility of the observer and the distribution factor of meteor number in accordance with stellar magnitude. The last two quantities may be explained in the following.

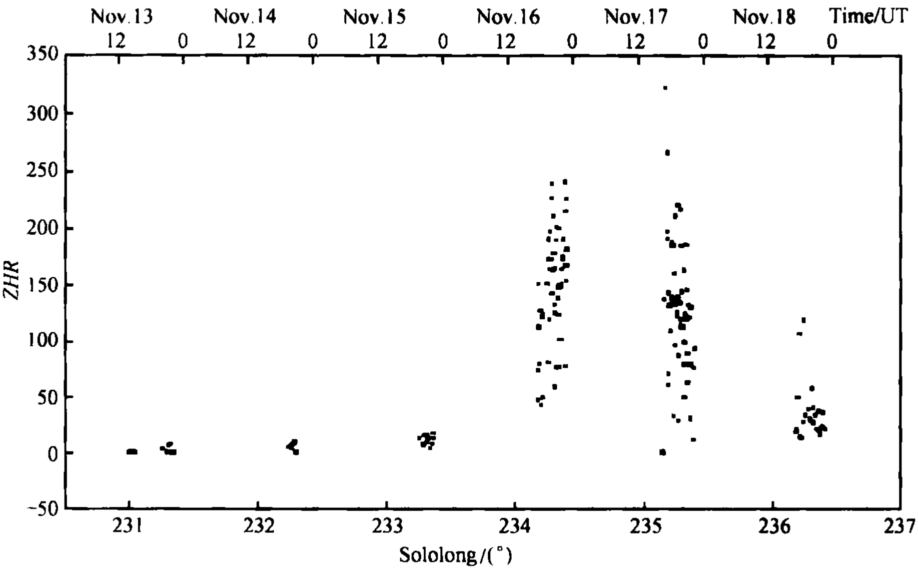

Fig. 1. The *ZHR* distribution obtained for the meteoric shower observed in Delingha in 1998 (a synthesis of visual data of 6 observers including Zhao Haibin and Marco).

C_p varies with the observers and it can be measured with the number of observed sporadic meteors. At local time 0^{h} in a fine night in August in the Northern Hemisphere or in February in the Southern Hemisphere, if *Lm* is 6.5, then for an observer who finds 10 sporadic meteors per hour, his C_p is 1.0. When the number of observed sporadic meteors per hour is less than 10, C_p <1.0. For more than 10 sporadic meteors, C_p >1.0. For most observers, C_p is in the range of 0.4—2.5[5—7].

γ is also called the stellar magnitude distribution factor of meteoric group χ [8], i.e.

$$\gamma = \chi = n(m+1)/n(m) = \frac{N(m+1)P(m)}{P(m+1)N(m)}.$$

Its value may be derived from the observed distribution of meteor number with magnitude $N(m)$, which has been revised with the standard possibility function $P(m)$. Its range of variation is in general 1.7—3.8. For sporadic meteors, γ=3.4. For the 1998 Leonids the distribution of γ given by international joint observations is illustrated in fig. 2. In the vicinity of λ=234°—235°, γ=1.4; and in the vicinity of

λ=235°—236°, γ= 2.0. In our reduction, we take γ= 1.4. From the reduction and study of visual and radar observational data in other districts of China, we have found that near the first peak γ has the same value as mentioned above. Near the second peak, it is evidently larger and attains 3.43. This implies that at this time the chief constituents of the meteoric group were small grains.

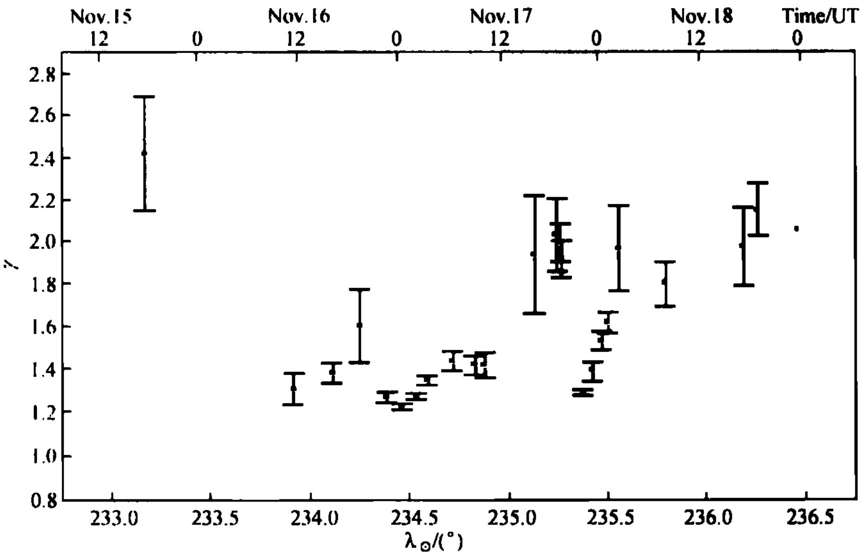

Fig. 2. The distribution of γ obtained from reduction of international joint observations of 1998 Leonids (the data of Sino-Dutch Observation Team have become the important basis).

(ii) Mass distribution. Our observed mass and flux distributions of Leonids as well as the distribution of meteor number with stellar magnitude are shown in table 1 and fig. 3. Among the mass, brightness and radial velocity of a meteor, there exists the following relation[9, 10]:

$$\log M(m_v) = 6.06 - 0.62 * m_v - 3.89 \log V_\infty(\mathrm{km/s}) - 0.67 \log(\sin(hr)),$$

where $M(m_v)$ is the mass of a meteor of magnitude m_v in units of g, m_v the visual magnitude of the meteor, V_∞ the visual velocity of the meteor (i.e. the linear velocity with which the meteor enters the

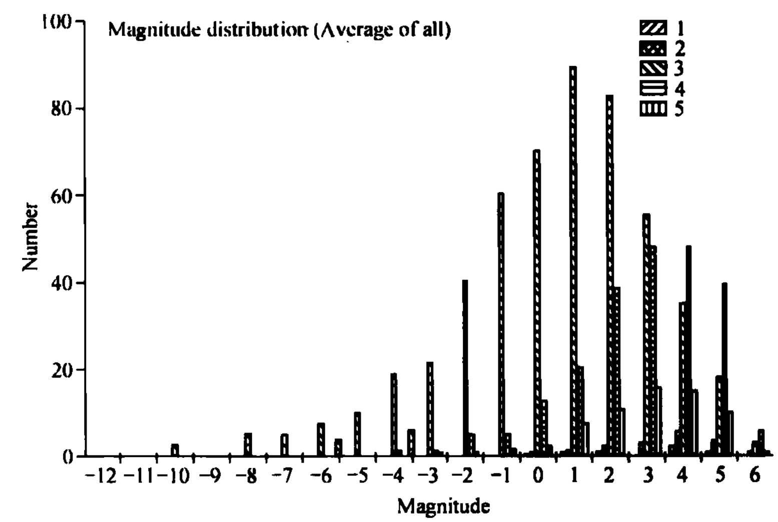

Fig. 3. Distribution of the number of Leo meteors according to stellar magnitude on Nov.14—19. 1, Number (14/15); 2, number (15/16); 3, number (16/17); 4, number (17/18); 5, number (18/19).

Table 1 The mass and flux distributions of Leonids[a)]

Observer	Observation period/UT	Effective time/h	Number of Leonid	Mass influx of Leonid /g • h^{-1}	Number of sporadic meteors	Mass influx of sporadic meteors /g • h^{-1}	Relative density of Leonid
Marco	13//19:35—22:50	3.10	22	0.033 7	67	50.071	0.001 53
	15//19:00—22:30	3.18	47	0.088 3	72	17.63	0.001 88
	16//17:35—22:50	3.72	508	2 256.356 4	115	10.405	4.441 65
Haibin Zhao	17//16:30—22:51	5.45	555	3.879	131	6.507	0.006 99
	18//19:38—22:40	2.76	128	40.728	76	6.361	0.318 19
Carl	14//19:08—20:47	1.65	6	0.044	38	2.36	0.007 33
	15//19:52—22:14	2.37	17	0.162	50	4.130	0.009 53
	16//17:22—22:50	4.29	436	1 135.66	58	2.191	2.604 72
	17//16:20—21:15	4.50	182	3.466 7	50	5.345	0.019 05
	18//20:18—22:40	2.37	42	47.247	41	3.249	1.124 93
Jos	14//19:21—20:27	1.17	6	0.079 5	26	2.310	0.013 25
	15//19:27—22:09	2.5	25	0.056 5	42	3.026	0.002 26
	16//17:00—23:02	5.7	783	387.756	152	4.776	0.495 22
	17//16:18—21:27	4.75	312	4.009	98	3.347	0.012 85
	18//16:27-23:00	6.03	154	4.522 4	144	4.471	0.029 37
Marc	15//20:40—22:52	2.2	23	0.153	36	4.251	0.006 65
	16//17:17—22:57	4.14	321	1 618.833 6	55	11.930	5.043 10
	17//17:04—22:27	4.78	193	6.634	79	6.674	0.034 37
	18//17:05—22:17	4.11	47	4.439	54	11.076	0.094 45
Arnold	14//19:45—20:45	1	8	0.048 3	41	3.734	0.006 04
	16//17:00—23:00	6	604	1 068.258 8	114	3.051	1.768 64
	17//17:00—22:30	5.5	223	6.098	97	3.876	0.027 35
	18//17:15—19:00	1.75	25	1.589	53	22.23	0.063 56

a) The observational data of Marco and Zhao Haibin, Carl, Jos, Marc as well as Arnold are listed separately. The various columns are consecutively the time interval of observation (UT) and effective time of observation, the number of Leo meteors and mass flux in the respective time interval, the number of sporadic meteors and mass flux. The last column presents the relative density factor, which is the ratio of average meteor densities obtained by one and the same observer at different time intervals, and it is not the real meteor density.

atmosphere, in units of km/s), and hr the altitude of the radiant. Within a certain range of mass, we may suppose that brightness is proportional to kinetic energy, and the influence of the radiant's altitude (taken to be $hr = 4.5°$) may be neglected. Then the following approximate formula is obtained:

$$\log M(g) = \log M(0) - 0.4^{*} m_{\mathrm{v}},$$

where $M(0)$ is the mass of a meteor of magnitude 0. For Leo meteors, $M(0)$ = 0.07 g, V_∞=71.95 km/s. For sporadic meteors, $M(0)$ =5 g, V_∞= 25 km/s[11].

As seen in fig. 3, in 14/15UT and 15/16UT the stellar magnitude of the main part of the meteoric shower was 4. In 16/17UT it was 1—2, and in 17/18UT it was 3, 4 and 5. (So the average density of meteors significantly diminished.) In 18/19UT it was 3 and 4, and the magnitude of a few meteors was 2. The average density somewhat increased, but it was still less than that in 16/17UT.

Let us suppose that the meteoroid is a spheroid with uniform density. Then the distribution of its density with brightness is as follows[9,11]:

$$0.5\ \mathrm{g/cm^3}: \quad (\log(M(m_{\mathrm{v}}))= -4\text{—}+1),$$
$$1.0\ \mathrm{g/cm^3}: \quad (\log(M(m_{\mathrm{v}}))= -8\text{—}-4),$$
$$1.5\ \mathrm{g/cm^3}: \quad (\log(M(m_{\mathrm{v}}))= -8\text{—}-11),$$

From this, the contrast relations between the brightness and size of Leo meteors and those of sporadic meteors may be deduced (table 2). Because the velocity of Leo meteors is higher than that of sporadic ones, the size of the former is much smaller than that of the latter with the same brightness.

Table 2 The relations of brightness and size between Leo and sporadic meteors

Visual magnitude	Diameter of Leo meteor	Diameter of sporadic meteor	Classification
<–4 m	2 cm	9 cm	bolide
< 0 m	0.6 cm	3 cm	photographic meteor
<+5 m	1.1 mm	0.5 cm	visual meteor
<+8 m	0.4 mm	2 mm	video meteor
<+13 m	100 μm	400 μm	radar meteor
<+18 m	20 μm	80 μm	interplanetary matter
<+25 m	2 μm	8 μm	fragments in space

3 Results and analysis

This meteoric shower took place in the process of penetration of the Earth through the Leo meteor belt. It can be seen in fig. 1 that from 13/14UT to 14/15UT and 15/16UT the value of *ZHR* was always less than 25. This implies that the Earth encountered with the meteor group, but did not enter its densely populated district. In the time interval of 16/17UT and 17/18UT, the value of *ZHR* sharply increased (surpassing 30). This shows that the Earth entered and was penetrating the dense district. In 18/19UT, *ZHR* dropped, and the Earth left the dense district.

16/17UT which the Earth entered is the aggregation region of large grains in the Leo meteoric group. Bright meteors occupy a large percentage in all the meteors observed by us, and among them there are as many as 42 bolides. According to the reduction of Arlt[12] (see fig. 4), the peak occurred at $1^h 40^m$ UT ($9^h 40^m$ Beijing time) on Nov. 17. Our observations were made before the peak. As seen in fig. 1, in 16/17UT the value of *ZHR* had a tendency of increase, and in 17/18UT—a trend of decrease. The peak took place just on Nov. 17, and the *ZHR* attained maximum in the forenoon of this day. This is in agreement with international observational data.

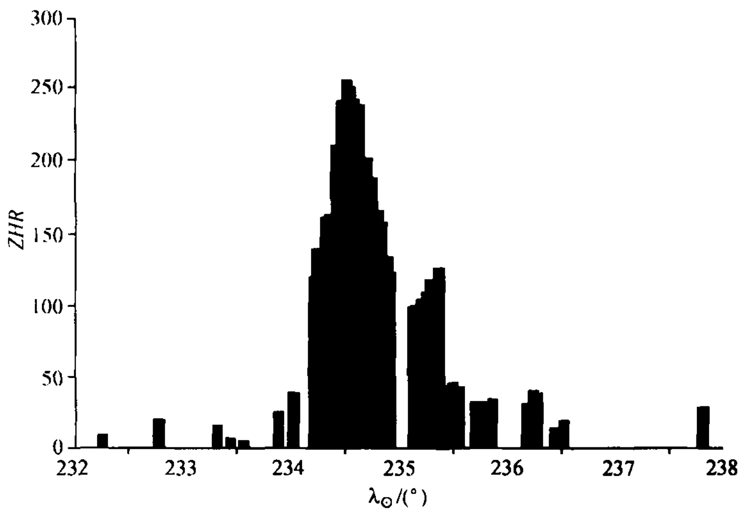

Fig. 4. Distribution of *ZHR* obtained from international joint observations (including the data of Sino-Dutch observations).

The peak of the meteoric shower, observed by He Youwen et al. in Xinxiang Prefecture of Henan Province of China with high frequency skywave radar, was in 17/18UT, and this agrees well with the predictions in refs. [3, 13]. The time interval of the peak is 19:00—21:00UT on Nov.17 (3:00—5:00 Beijing time on Nov. 18[14]). The brightness range of radio wave observations is larger than that of visual observations, and may reach meteors of magnitude +13. On Nov.18, the *HR* of visual meteors was 40—100/h while that of radio meteors attained 2 100—2 800/h[14]. According to the statistics of Leonids in the past, $\gamma = 3.0$ [15]. If the value of γ in 17/18UT in November of this year is taken to be 2.0, then the limiting stellar magnitude of radio observations should be +9—+10. Moreover, 95% and more meteors must be +7—+10 magnitudes. If we take γ to be 3.4, then the limiting stellar magnitude of this year's radio observation should be +9, and more than 97% meteors must have +7—+9 magnitudes. For most meteors in this range of stellar magnitude, visual observations are useless. Therefore, in this time interval, the peak of visual meteors was not observed.

As seen in table 1, although there exist systematic differences among various observers, the following may be got from the data of every observer: Among meteors in 16/17UT and 18/19UT big grains occupy a rather large percentage, the mass flux in unit time is comparatively high. Although the *ZHR* value in 17/18UT is rather high, the mass flux of the meteoric group is comparatively small. This implies that most grains are small. The same conclusion may be inferred from fig. 3. In 14/15UT and 15/16UT, the main members of the meteoric shower had a stellar magnitude of 4; in 16/17UT, they had magnitudes 1 and 2 while in 17/18UT they had magnitudes 3, 4 and 5. Hence, in comparison with 16/17UT, the mean density of meteors significantly decreased. In 18/19UT, they were of magnitudes 3, 4 and 2, and the mean density was somewhat increased, but it was still less than that in 16/17UT. We think that according to the distribution of grains, the belt of the meteoric group penetrated by the Earth in this time has a structure of three layers. In the first layer, the number of meteoric grains is large and big grains are abundant. In the second layer, the number of grains is still larger, but most grains are small. In the third layer, which is rather far from the center of the meteoric belt, the number of meteors is less, yet large grains are comparatively numerous.

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