Chin. J. Astron. Astrophys. Vol. 1, No. 3, (2001) 271–274
(http://www.chjaa.org or http://chjaa.bao.ac.cn)

Chinese Journal of
Astronomy and
Astrophysics

The Third Peak of the 1998 Leonid Meteor Shower

Yue-Hua Ma[1,2] ⋆ and You-Wen He[3]

[1] Purple Mountain Observatory, Chinese Academy of Sciences, Nanjing 210008
[2] National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012
[3] Radio-wave Propagation Institute of China, Xinxiang 453003

Received 2001 February 12; accepted 2001 February 28

Abstract The Leonid meteor shower in November 1998 was observed widely by astronomers. The first peak, rich in bright meteors, appeared about 16 hours before the predicted maximum of the main shower. The main shower was also observed by both optical and radio methods during 19:00–21:00 UT on Nov. 17, and the radio peak was over 2500 h^{-1}. About 18 hours after the main shower, an abnormal phenomenon in the ionosphere was detected by two separate ionosphere observing stations. And the very high abnormal phenomenon maintained over one hour. The phenomenon showed that the ionosphere was injected with a large amount of small dust particles that could not be observed in optical and radio. The observational results show that the Leonid meteor shower in 1998 had three peaks.

Key words: Meteors: Leonid meteor shower

1 INTRODUCTION

The Leonid meteor shower is a well-known periodic meteor shower. Its history is tied up with the development of the theory of meteor stream astronomy itself. It was the very strong showers of 1799 and 1833 that played a significant part in the recognition of the existence of meteoroid streams. These events started the observations of Leonid meteor shower and brought about the birth of meteoritics. It is known that the Leonid parent comet, 55P/Tempel-Tuttle, has an orbital period about 33.3 yr, and storms usually occur in years around the perihelion passage of the parent comet. Since comet 55P/Tempel-Tuttle passed perihelion on February 28, 1998, the Leonid meteor shower of 1998 was predicted (Brown & Jones 1996; Jenniskens 1996; Wu & Williams 1996; Yeomans et al. 1996; Arlt & Brown 1998) to be a strong shower but with no storms and the best prospect was in East Asia. In AD 935, the earliest Leonid meteor shower observed in China was recorded. There are many records about the shower and its parent comet in Chinese history. But in the 19th and 20th centuries, we Chinese could not see it until this time. So the Leonid meteor shower in 1998 attracted great attention in the field

⋆ E-mail: yhma@mail.pmo.ac.cn

of astronomy and space navigation. Great efforts were made using optical and radio means by professional and amateur astronomers and scientists to observe this event.

2 OBSERVATIONS

The optical method (visual) is easy and convenient and had been used widely. An overview of the 1998 Leonid activity was given by Arlt (1998) based on the visual records from 217 observers who came from 38 different countries and saw more than 4700 Leonids in 850 observing hours. An unexpected component rich in bright meteoroids had its maximum at November 17, $1^{\mathrm{h}}40^{\mathrm{m}}$ UT, about 16 hours before the predicted maximum of the main shower. The actual "storm" component is dark and tiny meteoroid stream with a peak at November 17, $20^{\mathrm{h}}30^{\mathrm{m}}$ UT.

The main radio observation in China was made at the Radio-wave Propagation Institute of China in Xinxiang, Henan. They detected the radio echoes reflected by the meteor trains. The peak of the radio meteor shower appeared during 19:00–21:00 UT, November 17, consistent with the prediction, and the peak was over $2500\,\mathrm{h}^{-1}$ (He et al. 1999).

Several ionosphere observing stations in China surveyed the ionization effect of the meteor shower during Nov. 14–20. About 18 hours after the main shower, an abnormal ionization effect was detected at the same time by two stations in Guangzhou and Hainan. And the very high abnormal phenomenon lasted over one hour (He et al. 1999). The phenomenon showed that the ionosphere was invaded by numerous very tiny meteoroids which could not be observed by optical and radio means. These tiny dusts can cause abnormal phenomena in the ionosphere (He & Xu 1997; He 1998).

The observational results above proved that the 1998 Leonid meteor shower had three peaks: The first enrichment of bright meteoroids had its maximum at November 17, $1^{\mathrm{h}}40^{\mathrm{m}}$ UT. The second with dark and tiny meteoroid streams appeared during 19:00–21:00UT, November 17, as predicted, and its radio peak was about $2500\,\mathrm{h}^{-1}$. The third one consisting of numerous very tiny meteoroids came into ionosphere at $13^{\mathrm{h}}15^{\mathrm{m}}$ UT, November 18.

3 THE EFFECT OF RADIATION PRESSURE

The first peak rich in bright meteoroids and about 16 hours before the main shower was explained by the ejection of dust grains into the 5/14 mean-motion resonance with Jupiter, principally during the perihelion passage of Comet 55P/Tempel-Tuttle in 1333 (Asher et al. 1999). Here we analyse only the reason why the third peak lagged about 18 hours behind the main shower.

It is well known that small meteoroids are principally subject to solar gravity and an anti-gravity force arising from the solar radiation pressure after they were ejected from their parent body, and they move basically along the original orbit. Different sized particles will have different orbital periods due to the different effects of solar radiation pressure on them and they will be gradually separated. The effect of solar radiation pressure is to 'weaken' the gravity, so that the quantity $GM_{\oplus}$ is replaced by $GM_{\oplus}(1-\beta)$, where $\beta = F_r/F_g$ (F_r: the force from solar radiation pressure, and F_g: the solar gravity) has the value $5.75 \times 10^{-5}/bc$ (Williams 1997), b being the radius and c the bulk density of the grain, both in cgs units. From the standard theory of Keplerian motion, we have the energy equation

$$\frac{1}{2}mV^2 - G\frac{M_{\oplus}m}{r}(1-\beta) = -\frac{GM_{\oplus}m}{2a'}(1-\beta)\,, \tag{1}$$

where G is the gravity constant, $M_\oplus$ the solar mass, m the mass of a meteoroid, r the heliocentric distance, V the orbital velocity of the meteoroid and a' the semi-major axis of its orbit.

From Equation (1), we get

$$V = [GM_\oplus(1-\beta)(\frac{2}{r}-\frac{1}{a'})]^{1/2}\,. \tag{2}$$

Solar radiation pressure cannot affect the kinetic energy of the ejected meteoroids, so the orbital velocity of the meteoroid at ejection should remain the same, thus we have

$$V^2 = GM_\oplus\left(\frac{2}{r_0}-\frac{1}{a}\right) = GM_\oplus\,(1-\beta)\left(\frac{2}{r_0}-\frac{1}{a'}\right), \tag{3}$$

where r_0 is the heliocentric distance of the point of ejection, a the semi-major axis of the cometary orbit.

From Equation (3), we have

$$a' = \frac{1-\beta}{1-\frac{2a}{r_0}\beta}a\,. \tag{4}$$

For a unit mass of the cometary nucleus, the standard theory of Keplerian motion gives

$$E = -\frac{GM_\oplus}{2a}\,, \tag{5}$$

and

$$a^3 = T^2\,, \tag{6}$$

where the semi-major axis a is in au and period T is in year.

In the weakened gravitational field, the energy of per unit mass of the meteoroids is

$$E' = -\frac{GM_\oplus}{2a'}\,(1-\beta)\;, \tag{7}$$

and the third Kepler law gives

$$a'^3 = (1-\beta)\,T'^2, \tag{8}$$

where T' is the orbital period of the meteoroids.

From Equations (8), (4) and (6), we get

$$T' = \frac{1-\beta}{\left(1-\frac{2a}{r_0}\beta\right)^{3/2}}a^{3/2} = \frac{1-\beta}{\left(1-\frac{2a}{r_0}\beta\right)^{3/2}}T. \tag{9}$$

In Eq. (9), β is dependent on both the size and bulk density of the meteoroids, hence the period also depends on these parameters.

Assuming the ejection occurs at perihelion, then $r_0 = q = 0.9766\,\mathrm{AU}$, and taking $a = 10.3375\,\mathrm{AU}$, the orbital period of the parent comet $T = 33.3\,\mathrm{yr}$. From Equation (9), we can get the periods of different sized grains in Table 1.

Table 1 Periods of Various Sized Grains, for $c = 3\mathrm{g\ cm^{-3}}$

Radius	Period
$b = 1.0\,\mathrm{cm}$	$T_{1.0} = 1.0005912T$
$b = 0.1\,\mathrm{cm}$	$T_{0.1} = 1.0059247T$
$b = 0.05\,\mathrm{cm}$	$T_{0.05} = 1.011909T$
$b = 0.02\,\mathrm{cm}$	$T_{0.02} = 1.030234T$

4 DISCUSSION

The size of shooting stars should be on the order of cm. The optical (visual) meteors should be larger than 1 mm, and the radio meteors can be smaller than 1 mm. The grains that caused the abnormal ionization effect must be still smaller.

Now we can give the differences of the periods from Table 1.

$T_{0.1} - T_{1.0} = 64.83$ days,
$T_{0.05} - T_{0.1} = 72.74$ days,
$T_{0.02} - T_{0.05} = 222.73$ days.

We can see from above that these differences of periods are at least of the order of tens of days, much longer than tens of hours if they formed at the same return. That the gaps of the three peaks being only more than ten hours shows that they may have been formed in different returns. According to Asher et al. (1999), the first peak was ejected in 1333, and McNaught and Asher (1999) also suggested that three Leonid dust trails encountered the Earth in 1998 and they had completed four, five and six orbits, respectively. The dust trails they mentioned are visual grains; the very small grains that caused the abnormal phenomenon in the ionosphere should be younger.

We only considered the effect of solar radiation pressure on the period. Indeed, the ejection velocity can also influence the change in period. But for very small grains, the solar radiation pressure is the primary factor. Our detailed investigation including ejection and other factors will be given in the future.

Acknowledgements We are gratefully thank Professor Xu Pinxin for his helpful discussion and important suggestion in the course of this work. Supported by the National Natural Science Foundation of China (No. 19873020 & No.49474242) and Minor Planetary Foundation of Purple Mountain Observatory.

References

Arlt R., Brown P., Bulletin 12 of the International Leonid Watch: Final Results of 1997 Leonids and Prospects for 1998, WGN, 1998, 26(2), 161
Arlt R., Bulletin 13 of the International Leonid Watch: The 1998 Leonid Meteor Shower, WGN, 1998, 26(3), 239
Asher D. J., Bailey M. E., Emel'yanenko V. V., MNRAS, 1999, 304, L53
Brown P., Jones J., In: B. A. S. Gustafson, M. S. Hanner, eds., ASP Conf. Ser. Vol. 104, Physics, Chemistry and Dynamics of Interplanetary Dust, Astron. Soc. Pac., San Francisco, 1996, p.113
He Youwen, Annual of Chinese Geophysics Society, 1998, 241 (in Chinese)
He Youwen, Ma Yuehua, Xu Pinxin, Chinese Journal of Radio Science, 1999, 14(2), 396 (in Chinese)
He Youwen and Xu Pinxin, Chinese Journal of Radio Science, 1997, 12(1), 65 (in Chinese)
Jenniskens P., Meteor Stream Activity III, Meteorit. Planet. Sci., 1996, 31, 177
McNaught R. H., Asher D. J., 1999, WGN, Journal of the IMO, 27, 85
Wu Z., Williams I. P., MNRAS, 1996, 280, 1210
Williams I. P., MNRAS, 1997, 292, L37
Yeomans D. K., Yau K. K., Weissman P. R., Icarus, 1996, 124, 407