The Institute of Space and Astronautical Science
Report SP No. 15, March 2003

Meteoroid Clusters in Leonids

By

Jun-ichi WATANABE*, Isshi TABE†, Hitoshi HASEGAWA‡, Takema HASHIMOTO§, Tetsuharu FUSE¶, Makoto YOSHIKAWA‖, Shinsuke ABE‖ and Bunji SUZUKI**

(1 February 2003)

Abstract: During the 2001 Leonids storm over Japan, several short-duration "outbursts" in which more than 20-40 meteors appeared in a few seconds, have been reported. The meteors in these events were extremely localized within a few hundred km, which suggest the recent fragmentation of meteoroids during the orbital motion in the interplanetary space. Considering the extent of the spatial distribution, we conclude that the fragmentation should have occurred at around the perihelion passage of the meteoroids just before encountering the Earth.

1. METEOROID CLUSTERS IN LEONIDS

In recent Leonids activities, several examples of the "clusters" of meteors have been reported. These clusters are defined in this paper such that many meteors appeared simultaneously within a few seconds. The first example was reported by Kinoshita et al(1999). Their video observation in 1997 Leonids, the apparition of the 100-150 Leonid meteors was recorded within two seconds. New examples have been reported in 2001 Leonid storm over Japan. One was occurred at 17h56m22s UT on Nov. 18, in which at least 15 meteors appeared within four seconds (Watanabe et al. 2002). Another was at 18h29m21s UT on Nov. 18, in which 38 meteors appeared within two seconds. In this paper we will show the result of the analysis of the latter case, and discuss on the origin of such clusters.

* National Astronomical Observatory of Japan, Mitaka, Tokyo 181-8588, JAPAN.
† Libra Co. Ltd., 4-5-9, Chuohrinkan, Yamato, Kanagawa 242-0007, JAPAN.
‡ ASTEC, Inc., 1-3-11 Koishikawa, Bunkyo-ku, Tokyo 112-0002, JAPAN.
§ Nippon Meteor Society, 7-28-1, Kinugaoka, Hachioji, Tokyo, 192-0912, JAPAN.
¶ Subaru Telescope, National Astronomical Observatory of Japan, 650 North A'ohoku Place, Hilo, HI 96720, U.S.A.
‖ The Institute of Space and Astronautical Science, 3-1-1 Yoshinodai, Sagamihara, Kanagawa 229-8510, JAPAN.
** Misato Tech. HS, 3-325, Hikonari, Misato, Saitama 341-0003, JAPAN.

2. CHARACTERISTICS OF THE CLUSTER

The cluster was recorded by a wide-field video camera system, which consists of a monochromatic CCD camera (WATEC Co., type WAT-100N) together with a CS-mount camera lens (f = 3.8 mm, F0.8, CBC Co.). This system realized the wide field of view as 80.6° × 65.0° with limiting magnitude of about 4. This video observation was originally performed by one of the authors(I.Tabe) for monitoring bright meteors of the Leonids activity. We noticed that the cluster was recorded at 18h29m21s UT on Nov. 18. The detailed analysis clarified that it contains at least 38 meteors within about two seconds.

2.1 Spatial distribution of meteoroids

We measured the time and position of 20 meteors, and reconstructed the space distribution of the meteoroids just before their entering the Earth's atmosphere. It is clearly shown that the meteors concentrated spatially on the order of 100 km. They distributed not spherically, but rather elongated along the direction of the radiant point. This may indicate the small trail-like structure of the meteoroids along the orbit.

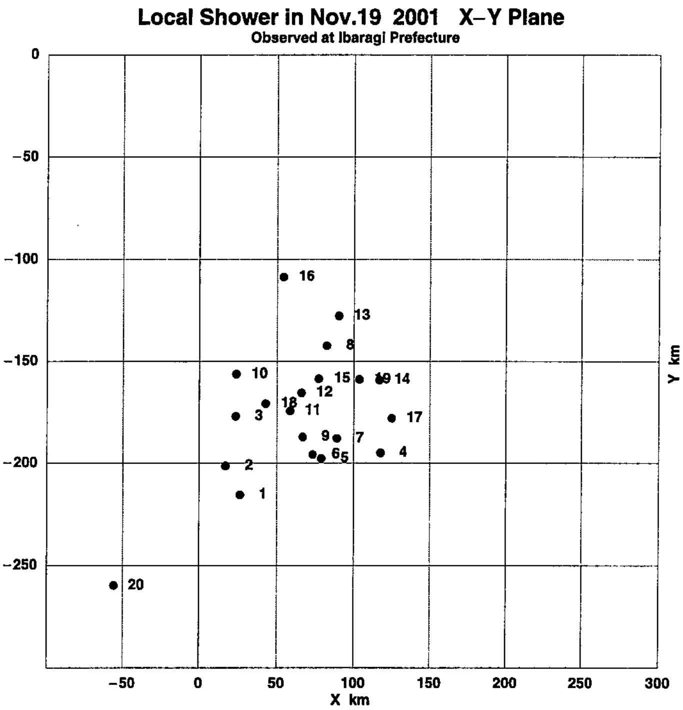

Fig. 1: Reconstructed spatial distribution of meteoroids in the cluster appeared at 18h29m21s UT on Nov. 18. The X-Y plane is perperdicular to the line of sight toward the radiant point.

2.2 Magitude distribution of meteoroids

We also measured the apparent brightness of each meteors. The result is shown in Table 1, where the brightness distribution is not unusual. It should be noted, however, that the apparition of the fainter meteors than 4 magnitude have been reported almost simultaneously at this epoch by telescopic video observations (Shiki et al. presented at Astron. Soc. Japan, Annual meeting 2002, private com.). Therefore, this cluster should have contained much fainter meteors.

Table 1: Magnitude distribution of the meteoroids in the cluster appeared at 18h29m21s UT on Nov. 18.

								Total No.
Magnitude	−2	−1	0	1	2	3	4	
No.	0	1	2	4	7	10	14	38

3. ORIGIN OF THE METEOROID CLUSTERS

The first idea on the origin of such concentrated clusters is that they are ejected as clusters directly from cometary nucleus. However, this idea seems to be impossible as follows. The activity of the parent comet 55P/Tempel-Tuttle depends strongly on the heliocentric distance (Watanabe et al. 2001), and the meteoroids' ejection are thought to be near the perihelion. If we assume that this cluster was ejected at around the perihelion passage in 1965, the difference of the arrival time of the meteoroids after one revolution is roughly order of $dT = 17.6 \times dv$ (days), where dv is the relative velocity of the each meteoroids (m/s). Then for keeping meteoroids within the time difference of a few seconds, we need an extremely small relative velocity such as 0.003 mm/sec. It is too small to be real space. The ejection velocity of the meteoroids are usually an order of at most 5–20 m/sec. Considering the random fluctuation of the energy deposit to the velocity at the ejection, the expected relative velocity should be the order of 30 cm/sec, which is much larger than the requested relative velocity. If we assume the much older epoch of ejection from the nucleus, the relative velocity should be much smaller. We conclude that such meteoroid clusters were NOT ejected directly from cometary nucleus, BUT born long time after the ejection. It is natural that we think it is caused by the fragmentation of the large meteoroids. The fragmentation of the small bodies in the solar system are well known from cometary nuclei(ex. Comet C/1999 S4 LINEAR, Weaver et al., 2001) to cometary dust particles(ex. Striae in the dust tail of Comet C/1995 O1 Hale-Bopp, Watanabe et al. 1997). The latter case are well explained by the fragmentation-related model(Sekanina & Farrel 1980, Nishioka & Watanabe 1990).

4. POSSIBLE FRAGMENTATION OF THE METEOROIDS IN SPACE

Then, where and when the fragmentation occurred ?

The first idea is that it happened just after the ejection from the nucleus. However, it is also impossible due to the similar discussion described in the previous section. For keeping meteoroids compact in space, we need also an extremely small relative velocity among the meteoroids.

The second idea is that it happened just before the entrance into the Earth. This is also unlikely due to the requirement of the large relative velocity for realizing the observed space dimension. If a meteoroid is assumed to be fragmented at the boundary of the Earth's magnetosphere ($\sim 30R_e$), the requested relative velocity of each meteoroids among the meteoroids is an order of 40 m/sec to reproduce the spatial extent of the meteoroids in the cluster. This value is unrealistic for fragments. After all, the fragmentation should be occurred at around the perihelion passage just before their encountering the Earth. If a meteoroid is assumed to be fragmented at the perihelion passage just before encountering the Earth, it takes about 6 days to reach the Earth. Then, the estimated relative velocity to reproduce the observed spatial extent is moderate value such as 20 cm/sec. The justification for this relative value will be published in forthcoming paper.

5. CONCLUDING REMARKS

We concluded that the observed clusters of meteors are the evidence of the meteoroids' fragmentations during their orbital motion, probably at around the perihelion passage just before encountering the Earth. However, the mechanism of the fragmentation is still unknown. The most possible mechanism is the thermal effect at the perihelion. Each meteoroid comes to the perihelion about every 33 years, when the volatile such as sodium or organic compounds may be partially evapolate. These volatile species may play an important role on bonding the much refractary particles in a meteoroid as the glue. If so, such phenomena of the clusters may be abundant in latest meteor trails. Until now, there is no report on such concentrated clusters in the 1766 trail observed in U.S.A. The clusters we observed are possibly within the 1866 trail. This may be indirect evidence of importance of the thermal effect for this phenomena. Further observation should be inevitably important to clarify the origin and the mechanism of the meteoroid clusters.

On the other hands, the origin of the non-isotropic spatial distribution of cluster meteoroids is also unknown. It may be due to the Earth's perturbation, or to the orbital alignment of the meteoroids by the orbital evolution, or to non-isotropic disruption such as tidal effect. However, the simple dynamical consideration on all these idea failed to reproduce the rather linear distribution. More comprehensive analysis should be done on the observed clusters including the much fainter meteors.

It is also interesting to look for samples of clusters having another level of the meteoroids concentration. It is sometimes said that meteor apparitions are not random. There may be more spread "clusters" which may not be recognized as clusters until now. There is an indication for the existence of such wide-spread clusters among the video data collected by the Astro-HS (Suzuki et al. 2003). Further analysis will be necessary for clarifying the nature of the clusters.

REFERENCES

Kinoshita M., et al., 1999, Geophy. Res. Letters 26, 41.
Nishioka K., Watanabe J., 1990, Icarus 87, 403.
Sekanina Z., Farrel J.A., 1980, Astron.J 85, 1538.
Suzuki B., et al., 2003, in this volume.
Watanabe J., et al., 1997, Pub. Astro. Soc. Japan 49, L35.
Watanabe J., et al., 2001, in Meteoroids 2001 conf. ESA-Sp-475, 175.
Watanabe J., et al., 2002, Pub. Astro. Soc. Japan 54, L23.
Weaver H.A., et al., 2001, Science 292, 1329.