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METRO campaign in Japan II: Three-dimensional structures of two Leonids meteor trains in early stage

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Abstract: In order to clarify the three-dimensional structures of the persistent meteor train, the simultaneous observations of the Leonids trains were carried out in the meteor train observation (METRO) campaign in Japan during 1998–2001. As was predicted by some researchers, the Leonids meteor showers/storm were observed in these four years, and we could detect a lot of persistent meteor trains within a few of hours near the each maximum encounter. Through the METRO campaign, the 36 groups of simultaneous observations were successfully detected including several examples from multiple stations. In this paper, the couples of three-dimensional structures of the persistent trains in the early stage are analyzed, and the existence of tube structure of the persistent meteor train was experimentally proved by the high-resolution simultaneous observations from multiple stations.

1. INTRODUCTION

The meteor train is an interesting object because the interaction between the meteor and the upper atmosphere is displayed by this phenomenon and hence it reflects the information about the meteor itself. The three-dimensional structure of the meteor train and its tiny structure are important aspects to be studied. However, there have been few studies of the meteor train because the observed samples of the meteor trains were limited due to their seldom appearance. The wide field observation by all-sky camera cannot obtain its tiny structure so that it is difficult to take snapshots of the persistent meteor train automatically in high quality.

In order to obtain simultaneous observations of the persistent meteor train, the meteor train observation (METRO) campaign was organized in Japan. The campaign began in 1998 when the meteor shower of the Leonids was first expected due to the return of its mother

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comet of Tempel-Tuttle (55P). We have asked the amateur observer in Japan to observe the meteor trains in the Leonids shower. The main purpose of the campaign is to obtain the altitude distribution and the three-dimensional structure of the meteor train using the precise triangulation of the simultaneous observations. The investigation of its tiny structure is the purpose of the campaign as well. The spectrum of the meteor train should be measured to clarify its luminescence mechanism, however, it was not treated in the campaign.

In the past decades, the meteor train has been observed as a tracer of the upper atmospheric wind. Liller and Whipple (1954) measured the wind using the detailed observation of the meteor train, however, the precise triangulation of the meteor train itself was not obtained. Three-dimensional structure of the meteor train was reported by Jenniskens and Rairden (2000) and Kelley et al. (2000) based on the two simultaneous observations. However, the structure in the early stage was not observed in these studies.

2. OBSERVATION

In the METRO campaign, we called for the observations of the persistent meteor train to many amateur meteor observers all over Japan. It successfully resulted in the dramatic increase of the simultaneously observed images of the persistent meteor train. According to the previously obtained samples, the optimum conditions for the meteor train detection have been shown to the collaborators using the web pages (Yamamoto et al,(1998)) and having kindly supports by astronomical publications (Toda and Yamamoto (1999); Toda and Yamamoto (2001)). The observation is focused on the persistent meteor train which can be seen over 30 seconds from its appearance. There is no particularly targeted field of sky for the simultaneous observation, however, we asked for the collaborators for pointing the field of view to the meteor train, once it appears. We can detect the first shot of each meteor train within 15 seconds over 200 km area from each observation site by this method. Along the instructions of the campaign, almost all observers used prevalent cameras for 35 mm film with wide aperture lenses with theirs focal lengths of 50–200 mm. To take the clear snapshots of the rapidly moving meteor train in the sky, the exposure time is limited within a few seconds, so that the observation with high sensitivity is required. We called for the photographs using highly sensitive black-and-white negatives, which have a capability of the extended development. Since the highly sensitive color negatives have become popular and effectively implemented in their sensitivity and resolution, many observations by highly sensitive color negatives were also reported to the campaign, leading to some interesting points. In addition, highly experienced observers successfully obtained the magnificent images of the meteor train by the cooled CCD camera and digital camera as well as the interesting movies by the video camera with an image intensifier.

The obtained images had good time accuracy because the importance of time accuracy have been announced to the observers. Best cases had one-second accuracy, though the images of unexpected long exposure with an accuracy of a few tens seconds were also reported to the campaign. We selected the images with high time resolution and accuracy for the analyses, but others were also useful for the estimation of appeared altitude and the morphology of the meteor train. The method is described by Toda et al. (2002, this issue) more in detail. The typical triangulation method is applied to the three-dimensional analyses and the altitude estimations using simultaneously obtained high-resolution images. The calculation method about the analysis of the meteor trajectory was shown by Terada (1984). The correction method of the distorted images using the coordinates of the background stars shown by Ohnishi (1984) was applied, resulting in the good accuracy of the analyses.

3. RESULTS

In the first three years of the campaign, we successfully obtained 5 simultaneously detected meteor trains images and in 2001, a lot of fireballs of the Leonid storm were observed all over the East Asia region, leading the detection of lots of samples of the persistent meteor train in Japan: the dramatic results of 36 simultaneously observed persistent trains and nearly 100 samples of the meteor train detected by single site. The results of the METRO campaign during 1998–2001 is summarized by Toda et al. (2002, this issue). In this paper, the three-dimensional analyses of the two bright meteor trains observed in the Leonid periods in 1998 and 2001 are investigated.

3.1 Persistent meteor train "Izu" observed in 1998

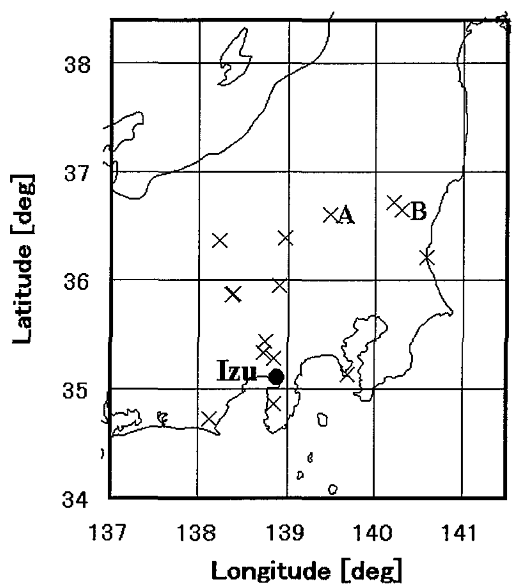

Fig. 1: The location of the observation sites and the persistent train Izu in 1998 projected on the map.

This train appeared at 04:13:55 LT (=UT+9) on Nov. 18, 1998, over the Izu area, Shizuoka prefecture in Japan. The parent fireball was seen at -8 magnitudes of brightness by many meteor observers and people who expected the meteor shower. It became the most famous meteor train in Japan. The images observed simultaneously from 17 independent sites were reported to the METRO campaign. This was the first result of the persistent meteor train simultaneously observed from more than ten sites (Figure 1). The image examples are also shown in a related paper (Toda et al. (2002, this issue)).

In the triangulation analysis, we selected the images shown in Figure 2. The image of Fig. 2(a) was taken by Shigeo Uchiyama at Awano, Tochigi pref. (point A in Fig. 1) and the image of Fig. 2(b) was taken by Johji Aizawa at Miwa, Ibaraki pref. (point B in Fig. 1), respectively. These are the first shots of their sequential images that began from 15 seconds after the appearance. The time coincidence and the similarity of the two images were quite good. The three-dimensional structure derived from the triangulation is shown in Figure 3, where the superimposed fireball trajectory was calculated by Takashi Sekiguchi (Private communication,

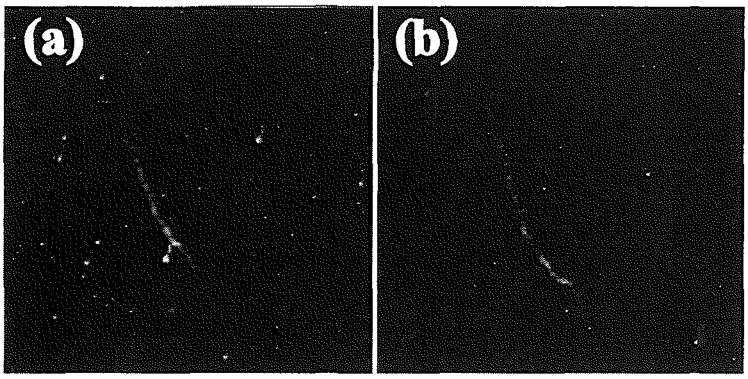

Fig. 2: The images of the train Izu observed from two of the observation sites. These images were detected only after 15 seconds from the appearance.

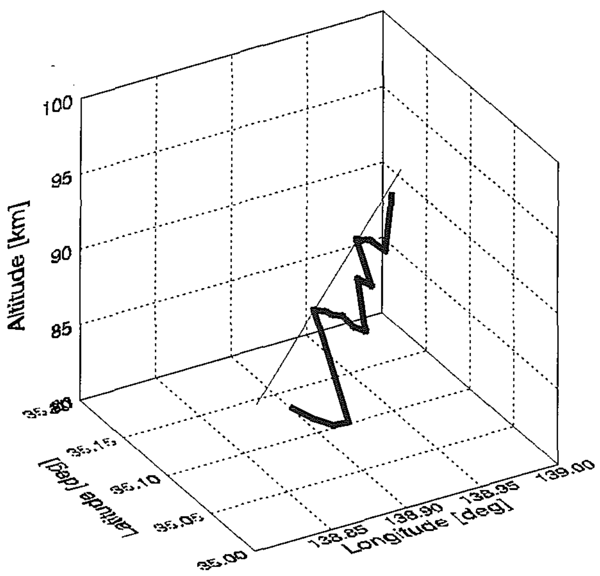

Fig. 3: The three-dimensional structure of the train Izu after 15 seconds from its appearance.

1998). In a glance, we can find its large-scale spiral structure whose axis is almost on the injection trajectory.

3.2 Persistent meteor train "Saku" observed in 2001

This train appeared at 01:47:24 LT on Nov.19, 2001, over the Saku district, Nagano pref. Parent fireball was observed at −8 magnitudes. The train was the biggest one among a lot of persistent meteor trains detected in Leonid period in 2001, and the largest number of the observations was reported to the METRO campaign. The simultaneous observations of the meteor train from 23 independent sites shown in Figure 4 were collected. As the first result of the METRO campaign in 2001, the three-dimensional analysis of this train is presented in this

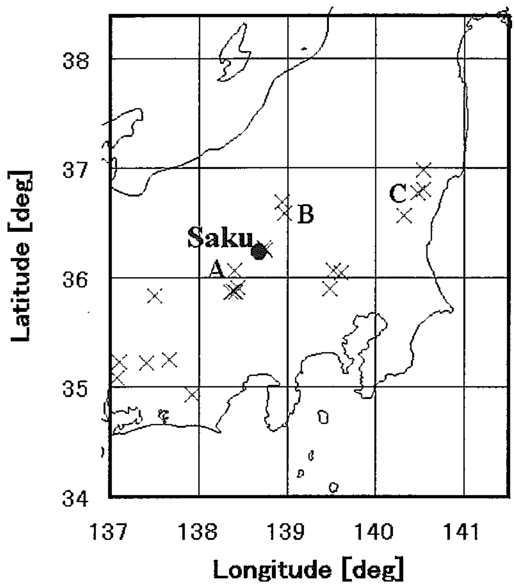

Fig. 4: The location of the observation sites and the persistent train Saku in 2001.

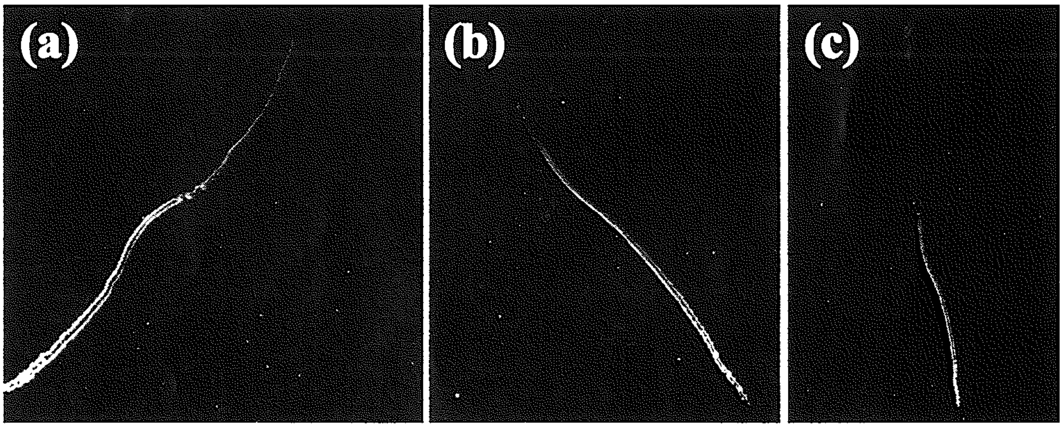

Fig. 5: The images of the train Saku observed from the three observation sites only after 15 seconds from the appearance. The explanations of images (a) and (b) are written in the text. The image (c) was observed by Yasuo Takeda from Daigo, Ibaraki, using 85 mm, F/2.0 lens with no iris. Color negative of ISO 1600 was used.

paper. Here, we use two images shown in Figure 5. One image shown in Fig. 4 (a) was taken by Satoshi Suzuki at Yachiho, Nagano pref., and the image shown in Fig. 4 (b) was detected by Youiti Ishiduka at Takayama, Gunma pref., respectively. The both images are extracted from their sequential observations. Note that another image sequence with more high spatial resolution was taken by Ishiduka (See Higa et al. (2002, this issue)) and the spectral observation of the train Saku was also reported by Suzuki et al. (2002, this issue). It is interesting that these images were observed from almost anti-parallel directions each other in the projected location

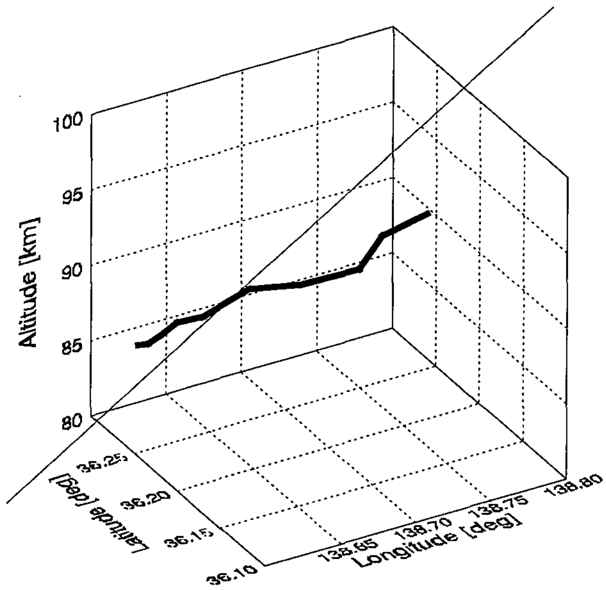

Fig. 6: The three-dimensional structure of the train Saku after 15 seconds from its appearance.

on the map.

The calculated result at 15 seconds after the appearance of the parent fireball is shown in Figure 6. Here, the superposed fireball trajectory was presented by Takashi Sekiguchi (Private comm., 2001). This also shows large-scale spiral-like shape near the incident trajectory; however, the amplitude was not expanded so much.

4. DISCUSSIONS

In the METRO campaign, we successfully obtained the simultaneous observation results in the very early stage of the persistent meteor train. Here, we present the firstly analyzed three-dimensional train structures in the early stage at 15 seconds after their appearances. The calculations were carried out using the images of two magnificent persistent trains named Izu and Saku, respectively. The both results show the large-scale spiral with respect to their parent's trajectories, though their amplitudes were rather different.

The distance of one spiral period of the each structure was about 7 km along the trajectory axis and the radius was about 5 km for the Izu and about 2 km for the Saku. The spiral form implies that the structure is resulted in the atmospheric gravity waves in the mesosphere region. However, we can clearly see that these large-scale spirals were formed symmetrically with respect to the fireball trajectory. It can be confirmed especially in the case of train Saku, which came into the Earth's atmosphere with the small incident angle due to the low radiant point at that time: the wave-like structure is formed within the limited altitude region. In the case of the train Izu in 1998, the radius of 5 km at 15 seconds after its appearance implies that the train plasma needs to be moved as fast as 300 m/s. This speed cannot be explained only by the mesospheric neutral wind, so that some other effects caused by the interaction between the meteoroid and the atmosphere has to be considered.

This interaction should be considered as the followings: the turbulence caused by the rapid flow with respect to the injected meteor, the wake structure formed just after of the collapsing meteoroid, the asymmetrical shape of the meteoroid, the destruction stage of the fragile structure of the meteoroid. The spin motion of the meteoroid itself might be considered as the cause, as well. The investigation about the large-scale and small-scale structures of the persistent meteor train is significant because the information about the meteoroid itself is included in these structures. More observation results of the persistent train targeted especially to its small-scale structures, the comparison with model studies and the comparison with the results of artificial tri-methyl-alminum (TMA) trails released from the sounding rockets (e.g., Larsen et al. (1998)) will reveal the detailed mechanism of forming the meteor train structures.

The three-dimensional analyses of the small-scale structures of the persistent meteor train were not treated here. More simultaneous observations with very high spatial/time resolution using the telephotographic lens are desired for this analysis. Some examples of the high-resolution images from one observation site have been already obtained in the METRO campaign during the Leonids periods in 2000 and 2001. These images were worthy for the morphological study by Higa et al. (2002, this issue). The optimum condition of the simultaneous observation by high-resolution instruments will reveal the current subject.

One more interesting aspect of the persistent meteor train is the tube structure. The train Saku was seen as the double striation shape. This feature observed in many persistent trains has been assumed and explained by the tube structure (Trowbridge (1907); Jenniskens and Nugent (2000); Kelley et al. (2000)). The images shown in Fig. 5 (a) and (b) were observed from the points of A and B plotted on the map of Fig. 4, respectively. These images clearly show the typical structure of the double striations. Another image of the Saku is indicated in Fig. 5 (c) and it also shows the shape of double striations. This image was detected 5 seconds later from the point C on the map. All of the other images of train Saku with high resolution show the same structure, as well. Thus, the existence of the tube structure of the persistent meteor train was successfully proved by the simultaneous observations of the METRO campaign. The important aspect extracted from these color images is that the tube structures were found in the bluish portion of the train. Although the spectrum of the train is not treated here, the bluish color implies that it was illuminated by Neutral atoms of Mg, Ca, and Fe. Hence, it cannot be explained by the tube model of the chemical reaction with FeO and ozone. It implies that the early-stage persistent train is strongly affected by the interaction between the atmosphere and the meteoroid materials.

Then, a question is arisen whether the tube structure of the meteor train is general structure in all cases. The numerous samples of the meteor train obtained in the METRO campaign show that the single striation structure of the meteor train also exists. The statistical description about the tube (double striations) or non-tube (single striation) structure derived by the METRO campaign was shown by Higa et al. (2002, this issue). There seems to be some unknown effects and/or thresholds of forming the tube structure of the persistent meteor train. It would be revealed in future analyses.

5. CONCLUSION

Since 1998, the METRO campaign has been carried out focusing on the simultaneous observation of the persistent meteor train and a lot of images of persistent meteor train were successfully obtained owing to the kind collaborations by many amateur meteor observers all over Japan. The first simultaneous observation with more than 10 stations was obtained in 1998 and more results were obtained in 2000 and 2001. In this paper the three-dimensional analyses of the persistent train were calculated for the two magnificent examples named Izu and Saku. The results of the large-scale spiral structures with respect to the parent fireballs' trajectory imply that the structures were affected not only by the atmospheric gravity waves but also by the interaction between the atmosphere and the meteoroid. Moreover, the first experimental proof of the existence of the tube structured persistent train was successfully made using the advantage of the simultaneous observation form multiple stations. The tube structure of the bluish portion of the trains was also proved. However, the existence of another case of the non-tube structure of the meteor train was existed, as well. The METRO campaign targeted to the specific observation of the persistent meteor train leaded to the largest number of images and some worthy findings of the meteor train. Future observation campaigns and analyses might reveal the more information about meteor train and the meteoroid itself.

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