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Meteor train observation (METRO) campaign in Japan I: Evolution of the campaign and observation results during 1998–2001

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Abstract: We have been conducted the meteor train observation (METRO) campaign in Japan since 1998, and fruitful observations were collected from many amateur observers during 1998–2001. The purpose of the METRO campaign is to detect many train images from multiple stations and to investigate their height distribution, three-dimensional forms, and detailed structures. We have called for the popular photographic observations of the persistent meteor trains with the optimum condition. We obtained 5 examples in first three years. And in 2001, the Leonids meteor storm was observed over East Asia as was predicted by some researchers, so that the observers in Japan could fortunately encounter lots of bright fireballs with meteor trains within a few hours, resulting in the 242 sequence images for the 134 independent persistent trains. It was the first vast-amount-of observation of the persistent train over 100 detections in one night. There were confirmed the 36 simultaneously observed meteor trains as well as the 98 examples detected from single site. In this paper, we present the method of the METRO campaign and its evolution during the four years.

1. INTRODUCTION

The meteor train is formed like a cloud after the appearance of bright fireball along its trajectory. The persistent meteor train has longer duration time of its luminescence over 30 seconds. In rarely case, it can be observed over decades of minutes with changing its shape in the sky. Study of the meteor train began in the late of the 19th century by way of collecting some sketches of the persistent trains observed with the telescope but by naked eye. These typical examples were shown in the early research by Trowbridge (1907). In this study the height distribution, the color, the double nucleus structure, and the dissipation feature were reported. The tube model was also assumed to explain the double nucleus form. Liller and Whipple (1954) observed the first clear sequence of the persistent meteor train by the super Schmidt camera with very large aperture (F/0.65) using a smart method. Shigeno et al. (1998) found the 200

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m scale spiral structure in the height range from 89 to 92 km by an successful simultaneous observation of the meteor train in Leonids 1997. Jenniskens and Nugent (2000) showed structures of the knot and loop on the double striations style train observed simultaneously from two stations and suggested a tube structure model of the train. Kelley et al. (2000) showed the high spatial/time resolution images.

Because of the short duration time of its faint luminescence, the detection of the meteor train is difficult and the previous observations were limited. Moreover, there has been no observation campaign targeted to the simultaneous detection of the persistent meteor train having collaborations with many amateur meteor observers in public. We firstly conducted the meteor train observation (METRO) campaign during the Leonids period in 1998. The purpose of the METRO campaign is to obtain the clear images of the meteor train simultaneously observed from multiple stations so as to investigate the height distribution, the three-dimensional structures, and the fine structures of the persistent train, as well as its statistical study.

We selected the meteor train of the Leonids for the target of the METRO campaign because: 1) Leonids has the largest incident velocity of 71 km/s to the Earth, 2) There have been empirically confirmed that the bright meteor of Leonids more frequently produce the persistent meteor trains than the other meteor showers, 3) There were some reliable predictions of the appearance of the Leonids meteor storm in 2001 (e.g., McNaught and Asher (1999)). The main subject of the METRO campaign is to detect the persistent train structures in the early stage because the small-scale structure such as the spiral shape is observable within 30 seconds from the appearance (Shigeno et al. (1998)). According to the previous image samples successfully obtained during 1990–1997, the optimum photographic condition of the clear detection of the train images was determined and has been announced to the many contributors thorough the METRO campaign.

2. OBSERVATION METHOD

In the METRO campaign, the simultaneous observations of the persistent meteor trains were targeted. The popular cameras with 35 mm film are selected as the instruments because we have been called for the observations by for the amateur observers widely in public. Using the wide aperture lens with aperture ratio is smaller than 2.8, the high-sensitivity negative, and the short exposure time were recommended to the observer and the sequence observation of the trains with rapid repetition shortly after the end of the luminescence was announced. For the very bright persistent train whose duration is over a few minutes, the sequenced images with a certain period were also suggested to carry out so as to obtain the wider observation period. We cannot predict the location of the meteor train before the appearance, hence, in order to detect the first shot of the persistent train in its early stage, the most important point of our observation method is to prepare the instruments before the appearance and to watch the sky carefully.

The focal length of lens is free to select. For example, the lenses of 28–58 mm are useful for determining the motion in whole of the train comparing with the background constellations. Otherwise, the telephoto lenses of 85–300 mm have an advantage of detecting the higher resolution images for fine structures. Four examples of the persistent meteor trains detected by the lenses with different focal length are shown in Figure 1. It also shows the evolution of the photographic detection method of the early-stage meteor train, before and during the METRO campaign. The high-sensitivity films and short exposure are significant condition to detect the rapidly moving faint trains. We select the negatives with sensitivities more than ISO 1600 with extended developments as well as the rapid repetition of the short exposures within 5 seconds.

If the optimum photographical condition is well known, the observers can detect the clear images of the persistent train in success. Based on the previous detection results before 1997, the optimum condition for the persistent train detection have been determined and have been announced through the campaign. The optimum exposure condition is shown in Table 1. It depends not on the focal length of lenses, but on the aperture ratio of lenses and the final sensitivities. Note that the recent observations in the METRO campaign included the images taken by the cooled CCD camera and the digital camera as well as the movies taken by video camera with an image intensifier.

It is important to keep the exact exposure timing in standard time for the case of the simultaneous observation with the rapid repetition of short exposures. To obtain the better time accuracy by many collaborators, we announced the simple recording method of both the exposure timing and the standard-time signal using the tape recorder with a time keeping items, i.e., the standard-time broadcasting by short-wave radio or the handy phone. By the highly trained observers, the cameras and video cameras with time recording capability were used with time keeping items for the accuracy. Thus the time accuracy of the short-exposure images attributed within a few seconds Thus, in many confirmed cases, $\cdots$.

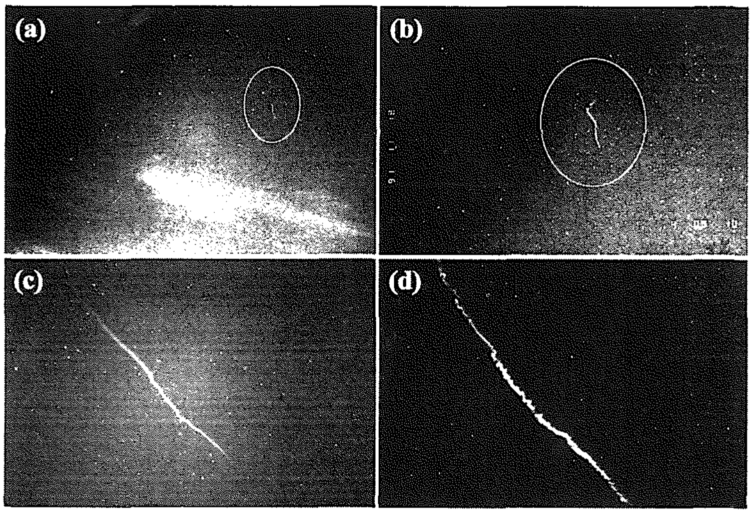

Fig. 1: Example images of the persistent meteor train of Leonids taken by four different focal lengths. (a) A meteor train image with 50 mm lens (FOV: 39 × 26 degrees) taken by Toda in 1990. (b) 105 mm lens (19.5 × 13) by Toda in 1991. (c) 200 mm lens (10.3 × 6.8) by Toda in 1997. (d) 300 mm lens (6.8 × 4.5) by Higa during the METRO campaign in 2000.

3. RESULTS

In first three years of the METRO campaign from 1998 to 2000, we successfully obtained five examples of the simultaneously observed meteor trains. From the results, we found that these meteor trains appeared within the altitude range from 81 up to 97 km. The telephotographic example of Leonids train in 2000 (See Figure 1 (d)) showed the fine spiral structure which was reported by Shigeno et al. (1998). According to the observed images by color negative, the

Table 1: The optimum condition of persistent train detection. One can find the optimum exposure time in case of certain sensitivity (ISO number) and aperture ratio of the instruments.

ISO	F/2.0	F/2.8	F/4.0
1600	4 s	8 s	16 s
3200	2	4	8
6400	1	2	1
12800	0.5	1	2
25600	0.25	0.5	1

train showed bluish color in the higher portion and bluish white in the lower part during the very early stage of it. However, it gradually changed into orange in whole of the train. We called the former as the early-stage persistent train and the latter as the stable-stage persistent train, respectively. It was also found that the threshold of this color changing is at about 30 seconds from the appearance. Moreover, the Leonids meteor storm in 2001 over Japan area leaded the numerous appearances of the persistent trains, resulting the 98 samples of meteor train observed from single site as well as the 36 samples observed from multiple stations.

3.1 METRO campaign in 1998

In this year, the Leonids meteor shower of ZHR=130 was observed in Japan. A magnificent persistent meteor train with its duration time was over 40 minutes appeared at 04:13:55 LT (UT+9) over Izu area after a –8 magnitudes fireball. In the campaign, the first simultaneous observation result from multiple sites was successfully obtained (Figure 2). The train was simultaneously observed by 17 collaborators from 14 independent sites in wider area in Japan: within 250 km apart from Izu. The results were summarized that 1) over 200 images of the persistent train were obtained, 2) the three-dimensional form was derived by triangulation analyses, 3) the large-scale spiral structure with its radius of 5 km was confirmed (See Yamamoto et al. (2002, this issue)).

3.2 METRO campaign in 1999

Leonids of ZHR=180 was observed in Japan. There were few bright meteors with the persistent trains this year, however, the three examples of simultaneous observation from a few sites as well as two samples from single site were obtained. The results in 1999 were summarized that 1) multiple examples of the simultaneous observation were firstly attained in this year, 2) height distribution was obtained for the three examples.

3.3 METRO campaign in 2000

Leonids of ZHR=50 was observed. Only one example of the simultaneous observation was obtained for a persistent train which appeared at 03:35:31 LT over the Shirakawa area in Fukushima pref. The train was detected from 14 stations. One clear image of the spiral structure of the early-stage persistent train was detected. The campaign was expanded to the Perseids, Orionids, and Geminids from this year and the persistent train by Geminids was obtained in success.

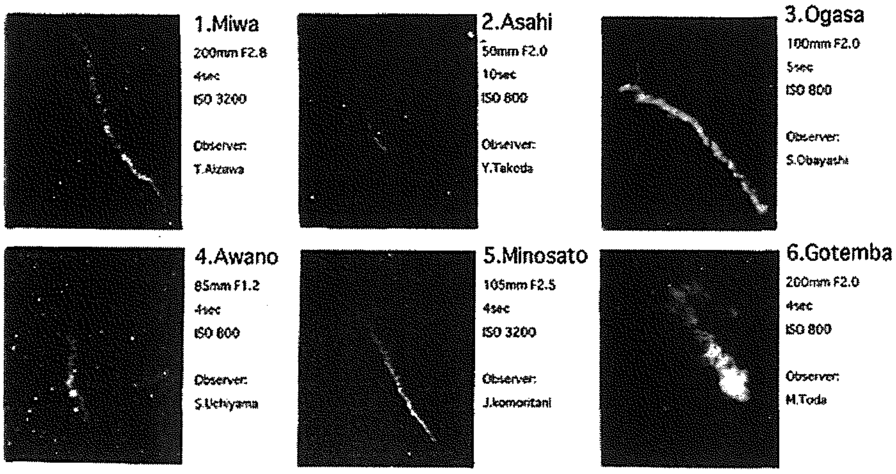

Fig. 2: The first example of the simultaneously detected images of the persistent train. The 6 images were obtained from independent sites. Note that the detection time and resolution were different in each other.

3.4 METRO campaign in 2001

As was predicted by several researchers, the Leonids meteor storm with ZHR=3400 was observed in Japan. We widely appealed the METRO campaign and the collaborator network including 25 independent stations from Hokkaido to Okinawa was organized before the encounter. At the Leonids storm night in 2001, over 1000 images of the 242 meteor trains were detected by 39 collaborators. From the careful investigation about the numerous images of the persistent trains, the 36 samples of the simultaneous observations and the 98 single-site observations were finally confirmed. The results are summarized that 1) the high spatial/time resolution image sequences of the meteor train were successfully detected by the trained collaborators using the telephotographic lenses over 200 mm with the condition of 1 second exposure and the high-sensitivity negatives, 2) more than 10 movies of the persistent meteor train were collected by the CCD video camera with an image intensifier and 400 mm telephoto lens, 3) the morphology of the persistent meteor train was studied especially for the early-stage train (See Higa et al. (2002, this issue)),and 4) the largest persistent train named “Saku” was simultaneously observed from more than 20 stations at 01:47:24 LT over Saku area in Nagano pref. The triangulation analysis of the train Saku was reported by Yamamoto et al. (2002, this issue) and the tube structure of the persistent train was firstly confirmed by this experimental result.

The distribution of the meteor trains and the observation sites are plotted on the maps in Figure 3. The collected numbers of examples in the METRO campaign in Leonids during 1998–2001 were summarized in Table 2.

4. DISCUSSIONS

Since 1998, the observations of the meteor train have been called for in the METRO campaign mainly focused on the persistent trains in the expected Leonids shower or storm. We promoted the simultaneous observation campaign to the amateur observers in public via the web pages (Yamamoto et al,(1998)) as well as the astronomical articles in Japan (e.g., Toda and Yamamoto (1999); Toda and Yamamoto (2001)). We announced the required in-

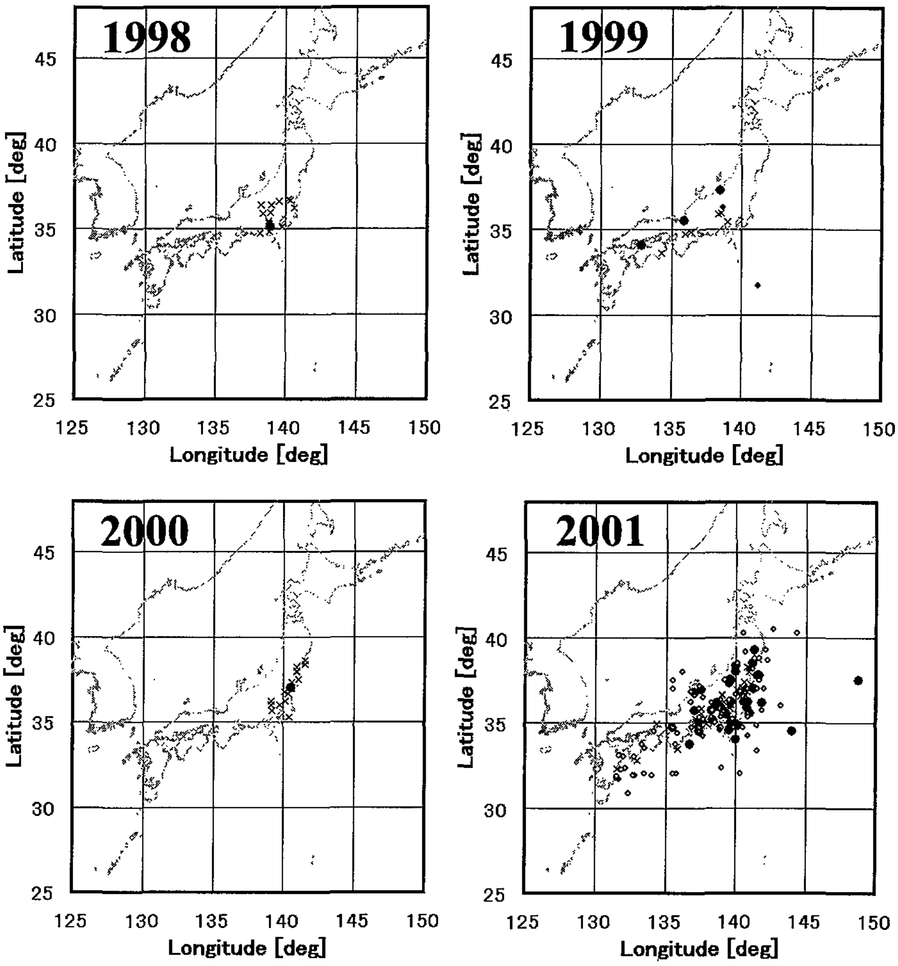

Fig. 3: The distribution of the observed meteor trains and the observation sites in the four years' METRO campaign. In each panel, the closed and open circles show the location of the persistent trains observed by multiple sites and single site, respectively. The crosses are the observation stations.

struments, the optimum photographic condition, and the time keeping method in the web site before the meteor showers. In order to collect the observations as much as possible, the feedback to the collaborators was also carried out just after the observation period via Internet by frequent updating of the observation lists reported to the campaign.

We selected the camera with 35 mm negative for the main observation instrument because it was spread all over the country and used in popular by many amateur observers. If the optimum condition is satisfied, this cheaper and easier observation method can lead the sufficient results. The network observations by many earnest collaborators with various instruments yielded the numerous simultaneous observations of the persistent trains never obtained before. The evolution of the high-sensitivity negatives in these decades enables us of detecting the faint train images with high time/spatial resolution by the general telephoto lenses with the aperture ratio of smaller than 3.5.

Table 2: The collected numbers of the persistent meteor train in the METRO campaign in Leonids during 1998–2001.

Year	1998	1999	2000	2001	Total
All observed trains	1	5	1	134	141
Simultaneous observation	1	3	1	36	41
Single-site observation	0	2	0	98	100

One of the subjects of the METRO campaign is to detect the high-resolution images of the early-stage trains and reveal the fine structures. In this viewpoint, Liller and Whipple (1954) obtained the early-stage trains but the resolution for the detailed structures was not sufficient. Kelley et al. (2000) detected the high-resolution images but for the stable-stage persistent train after 82 seconds from the appearance. The early-stage persistent train images successfully obtained in the METRO campaign resulted in the morphology of the meteor train.

The observations with the high-sensitivity color films by many observers yielded the numerous clear color images of the persistent meteor train. Though the spectrum information of the meteor train was not obtained, the observations with color films were sufficient for pursuing the time variation of the color. The color information effectively gave the two stages of the persistent train: it seemed to be classified into the early- and stable-stage trains before and after 30 seconds from its appearance, respectively. Namely, the bluish color trains were seen only within the early stage, however, the orange color trains were continuously seen in stable stage. The fine structures like knot, spiral, and/or mesh were found mainly in the early-stage persistent trains.

The upper atmospheric wind also can be derived from the simultaneously observed image sequence. Especially in 2001, the persistent meteor trains appeared at the several locations within the short time period, so that the wind system in the mesospheric region will be revealed by tracking method of the meteor trains in future analyses.

5. CONCLUSION

The structures of the persistent meteor train rapidly in motion were revealed by the multiple-sites simultaneous observations. Since 1998, the METRO campaign has been evolutionally driven by the kind collaborations of the large-population amateur observers in Japan with their earnest spirits. The early-stage trains were focused on as the main target of the campaign and the numerous images of the persistent trains were successfully observed during the four years' campaign in 1998–2001, resulting the 41 simultaneous observations with the 100 examples of the single observation (Table 2). The statistical study of the persistent train morphology and the three-dimensional structure analyses were derived from the numerous images obtained in the METRO campaign. The more simultaneous observations of the persistent meteor train with higher resolution as well as the future comparison with model studies are desired in order to clarify the generation mechanism of the detailed structures.

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REFERENCES

Higa Y., Toda M., Yamamoto M.-Y., Fujita M., Suzuki S., Ishizuka Y., Maeda K., 2002, ISAS rep. SP, 20, TBD.

Jenniskens P., Nugent D., 2000, Earth Moon and Planets, 82–83, 471.

Kelley M.C., Gardner C., Drummond J., Armstrong T., Liu A., Chu X., Papen G., Kruschwitz C., Loughmiller P., Grime B., Engelman J., 2000, Geophys. Res. Lett., 27, 1811.

Liller W., Whipple F.L., 1954, In boyd and seaton, eds. rocket exploration of the upper atmosphere, Pergamon Press., 112.

McNaught R.H., Asher D.J., 1999, WGN, 27, 85.

Shigeno Y., Toda M., Kobayashi M., 1998, WGN, 26, 220.

Toda M., Yamamoto M.-Y., 1999, Tenmon-Guide, 10, 190 (in Japanese).

Toda M., Yamamoto M.-Y., 2001, Gekkan-Tenmon, 11, 101 (in Japanese).

Trowbridge C.C., 1907, ApJ 26, 95.

Yamamoto M.-Y., Toda, M., 1998, http://www3.plala.or.jp/MY_Yamamoto/campaign/index.html (in Japanese).

Yamamoto M.-Y., Toda M., Higa Y., Fujita M., Suzuki S., 2002, ISAS rep. SP, 20, TBD.