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Catalogue of Persistent Trains I: Meteor Train Images during 1988–1997 and the Development of an Optimum Observation Technique

Masayuki TODA*, Masa-yuki YAMAMOTO**, Yoshihiro HIGA*,
and Jun-ichi WATANABE

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Abstract

Images of persistent meteor trains successfully detected by amateur observers in Japan during 1988–1997 were archived. The archive contains 122 images for 37 persistent meteor trains including six simultaneous image sequences from multiple-site observations. Photographic technique for detecting the fine structure of the faint luminescence of meteor trains was established in this period. It became clear that snapshots of short exposures are valuable for the morphological study of persistent trains. As a result of the application of this technique, spatial and time resolved images of persistent trains were gradually improved during 1988–1997, leading to the MEteor TRain Observation (METRO) campaign in Japan.

Key words: Persistent meteor train, Imaging, Simultaneous observation, Amateur observers, METRO campaign.

1. Introduction

Meteor trains are identified as faint and thin luminous plasma clouds that can be seen after the appearance of bright meteors. Most of meteor trains usually disappear within a few seconds; however, some meteor trains can present from 10 minutes to 1 hour. These long-lasting trains are defined as persistent trains. However, the detailed mechanism of the luminescence of persistent trains has not been clarified yet. Persistent train phenomena are so rarely observed that the archived images are very valuable for the investigation of the morphology of persistent meteor trains.

Such persistent trains were reported by general public from ancient times (Watanabe and Nagasawa 2000). Persistent train drawings, shown in Figures 1-1 to 1-3, were quoted from ancient personal notes or diaries, which were written in 19th century (the “Edo” era) in Japan. Figures 2-1 and 2-2 are recent sketches recorded by amateur observers in 1982 and in 1992, respectively. The former image shows a spiral structure whereas the latter is a “chopsticks” shaped train. Strong motivation to observe meteor trains in detail was led by these strange images. Assuming the former appeared at 100 km altitude above the observer, the both of diameter and repetition wavelength of the small-scale spiral can be found to be about 900 m. In order to investigate detailed morphology of persistent trains, photographical observations using telephoto lens are necessary. Due to the rapid morphological change of meteor trains, quick aiming at persistent trains and short exposures less than 5 seconds are very significant.

Meteor train observations have been led by amateur observers because large amount of their observations could detect the exceedingly rare and unexpected phenomena. The photographic technique applied to detect the faint luminescence of meteor trains was the following: high-sensitivity film of ISO 1600 or grater (frequently with intensifying development), wide aperture lens of F=2.8 or brighter, and short exposure time. Typical instrumentation for meteor train observations is shown in Figure 3. Initially, a 50 mm lens of F=1.4 was mainly used, whereas a 200 mm telephoto lens for detailed imaging was used in 1997. Meteor train imaging method as well as photographic resolution and sensitivity had been gradually improved during 1988–1997, leading up to the MEteor TRain Observation (METRO) campaign in Japan during the Leonids’ storm period 1998–2002 (Toda et al. 2003).

In this catalogue part I, images of persistent meteor trains which had been successfully photographed by amateur observers in Japan during the period 1988–1997 are archived. The results obtained during 1998–2002 will be published in the catalogue part II (Higa et al. 2004).

2. Image archives

37 observations of persistent trains obtained between 1988 and 1997 in Japan were archived. About half of the images were photographed by the authors. The other images were observed by a few pioneers in their own trials and were collected afterward. Table 1 is an observation summary containing the following information: name of the parent meteor shower, observed date and time, observer, number of obtained images, focal length f and F-number of lens used, observation site (city or town, prefecture), and image sequence code.

2.1 Code of image sequence

The observation code of each image is based on the name of the parent meteor shower, observation date and time, observer, and photographical conditions.

(examples)

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123456789012345678901234567 (column numbers)
O198810220231_yamanami1CF01
L200111190116Btodamasa2MF01
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* Meteor Train Observation Campaign, 1–16–13, Izumi, Suginami, Tokyo 168–0063, Japan.

** Kochi University of Technology, 185, Miyanokuchi, Tosayamada, Kochi 782–8502, Japan.

Table 1. List of archived persistent trains. All cases (37 sequences for 29 trains) were observed in Japan during 1988–1997, including 6 groups of simultaneous observation from multiple sites (Train 3, 4, 11, 18, 19, and 23). Images archived in Figures 4-1 to 4-8 are numbered by 'No.' and 'Images' of this table. Code of each image sequence is labelled by the rule described as the text of subsection 2.1. Though the number listed in the column of 'Images' means whole obtained samples, not every image was archived in Figures 4-1 to 4-8. Some data were quoted from referred articles (Ueda 1988, Noda 1993, Toda 1993, and Shiba 1998).

No.	Train	Shower	Observation date	Time with error	Observer	Images	f	F	Observation site	Code of image sequences
1	1	Orionids	Oct. 22, 1988	02:31:19±2s	Y. Yamanami	3	50	1.4	Yuni, Hokkaido	O 198810220231_yamanami1CF01
2	2	Orionids	Oct. 22, 1988	03:15:30±2s	S. Suzuki	4	50	1.4	Yuni, Hokkaido	O 198810220315_suzukisa1CF01
3	3	Orionids	Oct. 22, 1988	04:04:02±2s	S. Shiraishi	3	85	2.0	Hoshino, Fukuoka	O 198810220404_shiraish1CF01
4					T. Minobe	6	55	1.8	Takazaki, Miyazaki	O 198810220404_minobeta1CF01
5	4	Orionids	Oct. 22, 1988	04:08:41±2s	S. Suzuki	11	50	1.4	Yuni, Hokkaido	O 198810220408_suzukisa1CF01
6					O. Watanabe	7	50	1.4	Atsuma, Hokkaido	O 198810220408_watanabo1CF01
7	5	Leonids	Nov. 18, 1990	03:16:53±2s	M. Toda	1	50	1.4	Gotemba, Shizuoka	L 199011180316_todamasa1MF01
8	6	Leonids	Nov. 18, 1991	04:08:45±15s	M. Toda	10	105	1.8	Gotemba, Shizuoka	L 199111180408_todamasa1MF02
9	7	Taurids	Nov. 18, 1991	05:01:48±2s	K. Maeda	video	24	1.4	Kiyotake, Miyazaki	T 199111180501_maedakou1MV01
10	8	Perseids	Aug. 13, 1993	02:49:10±10s	T. Noda	1	50	2.0	Yamamoto, Miyagi	P 199308130249_nodatsuk1CF01
11	9	Perseids	Aug. 13, 1994	01:33:30±30s	H. Yamanaka	2	50	1.4	Zao, Miyagi	P 199408130133_yamanaka1MF01
12	10	Perseids	Aug. 13, 1994	01:42:30±30s	M.-Y. Yamamoto	5	50	1.4	Zao, Miyagi	P 199408130142_yamamoto1MF01
13	11	Leonids	Nov. 19, 1995	01:38:00±2s	M. Toda	37	105	1.8	Gotemba, Shizuoka	L 199511190138_todamasa1MF01
14					H. Shioi	7	55	1.8	Nosaka, Chiba	L 199511190138_shioihir1MF01
15	12	Leonids	Nov. 19, 1995	about 02:30	S. Suzuki	3	50	1.8	Minamimaki, Nagano	L 199511190230_suzukisa1CF01
16	13	Leonids	Nov. 19, 1995	about 03:00	S. Suzuki	1	50	1.8	Minamimaki, Nagano	L 199511190300_suzukisa1CF01
17	14	Leonids	Nov. 19, 1995	03:33:30±30s	M. Yamasaki	4	50	1.2	Koishiwara, Fukuoka	L 199511190333_yamasaki1CF01
18	15	Perseids	Aug. 13, 1996	01:32:50±2s	M.-Y. Yamamoto	3	50	1.4	Zao, Miyagi	L 199608130132_yamamoto1MF01
19	16	Perseids	Aug. 13, 1996	02:02:32±2s	M.-Y. Yamamoto	4	50	1.4	Zao, Miyagi	L 199608130202_yamamoto1MF01
20	17	Orionids	Oct. 22, 1996	about 04:00	S. Suzuki	12	50	1.2	Fujinomiya, Shizuoka	O 199610220400_suzukisa1CF01
21	18	Leonids	Nov. 17, 1996	04:11:27±2s	M.-Y. Yamamoto	13	50	1.4	Yamamoto, Miyagi	L 199611170411_yamamoto1CF01
22					A. Narita	5	50	2.0	Daigo, Ibaraki	L 199611170411_naritaat1CF01
23	19	Leonids	Nov. 17, 1996	05:15:50±2s	S. Suzuki	20	50	1.2	Fujinomiya, Shizuoka	L 199611170515_suzukisa1CF01
24					C. Shimoda	5	135	2.8	Asahi, Nagano	L 199611170515_shimodac1MF01
25					M. Kobayashi	1	85	1.4	Oizumi, Yamanashi	L 199611170515_kobayash1CF01
26	20	*sporadic*	Nov. 3, 1997	03:29:09±10s	N. Tanaka	2	50	2.0	Kitago, Miyazaki	S 199711030329_tanakana1CF01
27	21	Leonids	Nov. 18, 1997	01:51:49±5s	S. Suzuki	3	50	1.2	Fujinomiya, Shizuoka	L 199711180151_suzukisa1CF01
28	22	Leonids	Nov. 18, 1997	02:01:30±30s	S. Suzuki	1	50	1.2	Fujinomiya, Shizuoka	L 199711180201_suzukisa1CF01
29	23	Leonids	Nov. 18, 1997	02:42:26±2s	M. Toda	20	200	2.0	Gotemba, Shizuoka	L 199711180242_todamasa1CF01
30					M. Kobayashi	9	85	1.4	Oizumi, Yamanashi	L 199711180242_kobayash1CF01
31					S. Suzuki	5	50	1.2	Fujinomiya, Shizuoka	L 199711180242_suzukisa1CF01
32	24	Leonids	Nov. 18, 1997	02:44:47±2s	M. Toda	11	200	2.0	Gotemba, Shizuoka	L 199711180244_todamasa1CF01
33	25	Leonids	Nov. 18, 1997	02:50:30±30s	M. Fujita	1	50	1.4	Iwanuma, Miyagi	L 199711180250_fujitami1CF01
34	26	Leonids	Nov. 18, 1997	02:56:15±2s	M. Kobayashi	5	85	1.4	Oizumi, Yamanashi	L 199711180256_kobayash1CF01
35	27	Leonids	Nov. 18, 1997	03:10:30±30s	M. Fujita	4	50	1.4	Iwanuma, Miyagi	L 199711180310_fujitami1CF01
36	28	Leonids	Nov. 18, 1997	03:48:30±30s	M. Fujita	3	50	1.4	Iwanuma, Miyagi	L 199711180348_fujitami1CF01
37	29	Leonids	Nov. 18, 1997	05:26:45±2s	K. Maeda	3	200	1.8	Kiyotake, Miyazaki	L 199711180526_maedakou1CF01

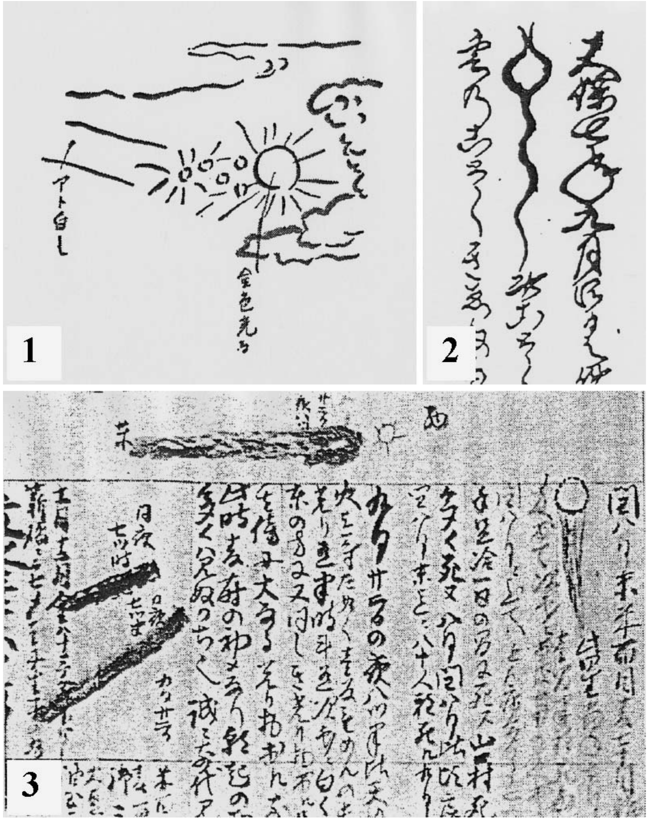

Fig. 1. Ancient sketches of persistent meteor trains. Figure 1-1 is quoted from “Tsurumura Nikki” (Diary of Mr. Tsurumura Kaneko) written in 1813 at Ishikawa prefecture. In description, the author wrote ‘In the dawn of Dec. 8, 1813, at about 6 o’clock, a fireball flew from east to west. It looked like a gold shinning gourd and slowly flew to northern west with remaining white fabric trail along the path.’ Figure 1-2 is quoted from “Kadoyashiki Kyusuke Oboegaki” (Notes of Mr. Kadoyashiki) written in 1836 at Iwate prefecture (Watanabe 1994). The author wrote that ‘A red luminescent cloud appeared in the west at about 2 or 3 o’clock at night in Oct. 13, 1836. Its shape was like this.’ Figure 1-3 was quoted from “Kitatani Hanzou Kiroku” (A memorandum of Mr. Kitatani) written in 1862 at Tokushima pref. The author wrote that ‘About 4 o’clock at night of Nov. 11, 1862, something luminescence like a fireball or a fire on grind stone was found in the sky at slightly southward from the zenith. Though it was a moonlit night, the light whose size was a bolt of silk cotton shined into my house for a while and the luminescence was lasting for about one hour. Then, it became white and disappeared.’ These ancient Japanese descriptions were collected by Watanabe and Nagasawa (2000) and Watanabe, Y. (private communication, 2003).

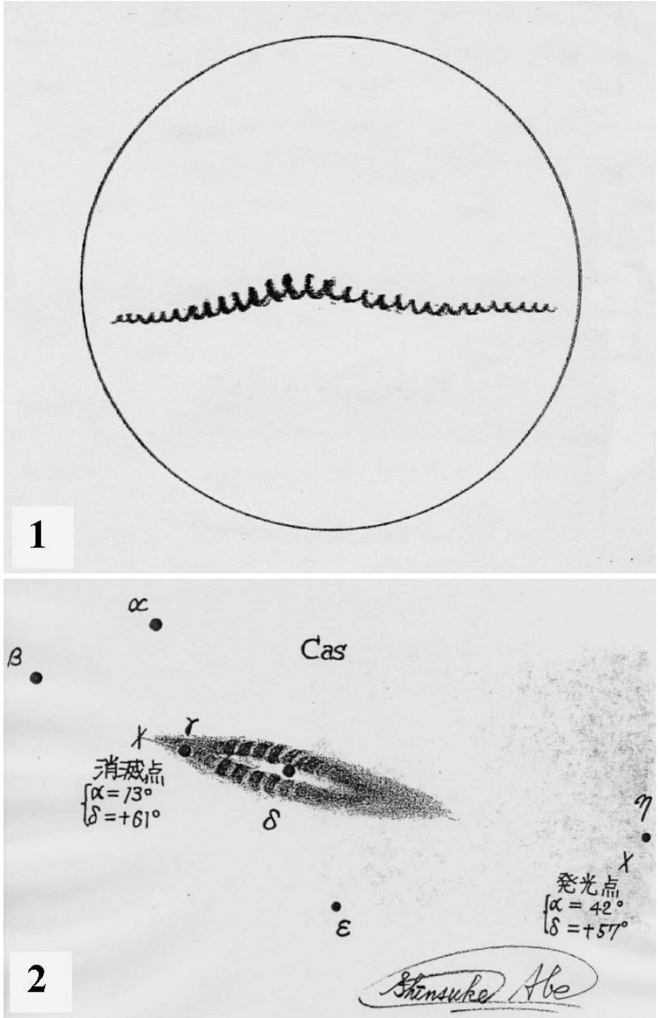

Fig. 2. Recent sketches of persistent meteor trains observed with a binocular. The persistent train shown in Figure 2-1 was observed 5–10 seconds after the appearance of an Orionids’ fireball of −8 magnitudes on Oct. 23, 1982 (Suzuki 1989). The field of view of 9×35 mm binocular was 7.3 degrees. The train shown in Figure 2-2 was observed after an Orionids’ fireball of −7 magnitudes appeared at 1:31:05 on Oct. 22, 1992. Description of “Dark-striped pattern was spreading as it sprang from the center to both sides. The empty space was found along the center line and diffused as time went by.” was added (Abe, private communication, 2003).

(explanations)

column 01 : Name of the parent meteor shower (‘L’ : Leonids, ‘O’ : Orionids, ‘P’ : Perseids, ‘T’: Taurids, and ‘S’ : sporadic meteor)
column 02–13 : Observation date and time:
- 02–05 : Year (YYYY)
- 06–09 : Month and day (MMDD)
- 10–13 : Hour and minute (HHMM) as Japan Standard Time (JST=UT+9h)

column 14 : Alphabetical order if multiple trains appeared within a minute
column 15–22 : Observer name code (8 characters)
column 23 : Camera number for each observer
column 24 : Type of color (‘C’ for color imaging, ‘M’ for monochrome one)
column 25 : Type of camera (‘F’ for film, ‘D’ for digital device of CCD or CMOS, and ‘V’ for video)
column 26–27 : Image number of each sequence by 2 columns

2.2 Field of view of the image

All observations reported in the period 1988–1997 were taken with a 35 mm size photographic camera with an objec-

Fig. 3. Typical 35 mm size photographic cameras used for persistent train imaging. Wide aperture lenses were selected for detecting faint luminescence. Equipped lenses are a 50 mm lens of F=1.4 (left) and a 200 mm telephoto lens of F=2.0 (right), respectively. The camera with telephoto lens should be loaded with another sub-camera with a 50 mm lens because wide field of view is effective for determining the direction of field as well as for fail-safe operation. In addition, a steady single-grip and well-balanced camera platform is necessary for quick aiming. A photographic camera with autowinder and data backup system has great advantage for accurate persistent train imaging.

Table 2. Field of view of typical lens for 35 mm film camera.

Focal length (mm)	Field of view (degrees)
35	53.0×37.0
50	39.0×26.0
85	25.3×17.0
105	19.5×13.0
135	15.1×10.1
200	10.3× 6.8

tive lens except for sequence No. 9 (video observation with a Hamamatsu VB 1366B image inensifier. Focal length and F-number of lens and some other features were varied by each observer. The size of each field of view is proportional to the focal length of each selected lens. Typical focal lengths and corresponding fields of view are listed in Table 2. The field of view for each image sequence is written as ‘FOV’ in the Figures 4-1 to 4-8 because many samples are trimmed images.

2.3 Other parameters

In Figures 4-1 to 4-8, ‘Ts’ means start time of each exposure, counted from the appearance of the parent fireball. ‘Exp’ represents the exposure period for each snapshot. Because of the rapidly diffusing feature of persistent trains, images with short ‘Ts’ and ‘Exp’ are very significant for morphological study. Some observers selected larger ‘Exp’ near the end of their observation sequences in order to obtain clear images of faint long-lasting trains. Absolute observing time is also significant for multiple site observations. By using a tape recorder, click sound of cameras can be simultaneously recorded with sound of the time signal, so that the exposure timing of each snapshot was accurately obtained in many recent cases. Accurate time signal can be easily obtained whenever either a GPS receiver or a shortwave radio is available.

Meteor train images obtained in the period 1988–1997 are archived in Figures 4-1 to 4-8. Here, images are ordered by their appearance date and time. In this period, 37 persistent meteor trains were observed. Six groups of image sequences were successfully operated from multiple stations as well as 23 examples were observed from a single site. The archive contains at least one image for almost every sequence, however, not every image is shown in this paper due to the limitation of space. Electronic file archives of the 252 meteor train images are also available on the web site (Yamamoto et al. 2004).

3. Discussions

The archived persistent trains of Orionids in 1988 (Figure 4-1) were the first significant examples for simultaneous observation of the decade 1988–1997. Before 1994, several pioneer examples of photographical persistent train observations were taken with short exposure time within 15 seconds. In this trial period, the focal length of each observation was less than 105 mm, so that the spatial resolution of each train image was relatively insufficient. In 1995, simultaneous observation of a Leonids’ persistent train was obtained by two observers (Figure 4-3). However, the triangulation condition was insufficient because one observation was made with a long exposure time. In 1996, two successful multiple-sites observations of Leonids’ trains were carried out (Figures 4-5 and 4-6). The triangulation results of simultaneously observed trains were shown in Table 3. In 1997, three series of close-up Leonids’ train images were successfully taken with a 200 mm telephoto lens, so that two spiral-like train image sequences were clearly obtained (see Figures 4-7 and 4-8). Using two-sites simultaneous observation of the spiral-like train, Shigeno et al. (1998) reported triangulation results. In this observation period during 1988–1997, amateur observers successfully obtained significant results of persistent trains by repeated attempts with progressing the spatial/time resolution of each image, leading up to the subsequent observation campaign (Toda et al. 2003).

After the first simultaneous observations of the Orionids’ train, the following 10 years of effort were devoted to determining optimum technique for fine imaging with high spatial/time resolution, *i.e.*, short exposures less than 4 seconds with telephoto lenses longer than 200 mm. In this decade before the METRO campaign, there were 17 observers working to detect persistent train images. The total number of successful results was limited to 37 examples; however, these trials were very worthy to evaluate the observation technique to measure persistent train structures in detail.

Upper atmospheric wind with velocity up to 150 m s^{-1} was reported in the altitude range from 90 km to 100 km (Larsen 2002). The altitude range typically corresponds to the height of meteor train luminescence. Being affected by the rapid atmospheric stream, morphological changes of persistent trains were frequently observed with kink and/or large loop structures. Namely, simultaneous imaging of meteor trains with long exposure can reveal the wind velocity of the background atmosphere (Liller and Whipple 1954; Sugimoto 1984). However, in order to obtain the fine structures of persistent trains, rapid repetition of short exposure is required. Comparing the observations in 1988 with that in 1997 (See Table 1), exposure time was reduced from 15 s to 4 s and the focal length of the telephoto lenses changed from 50 mm to 200 mm. The field of view of a 200 mm lens was effective for detailed imaging. Spatial/time resolution of the images could be successfully improved by these technical advantages.

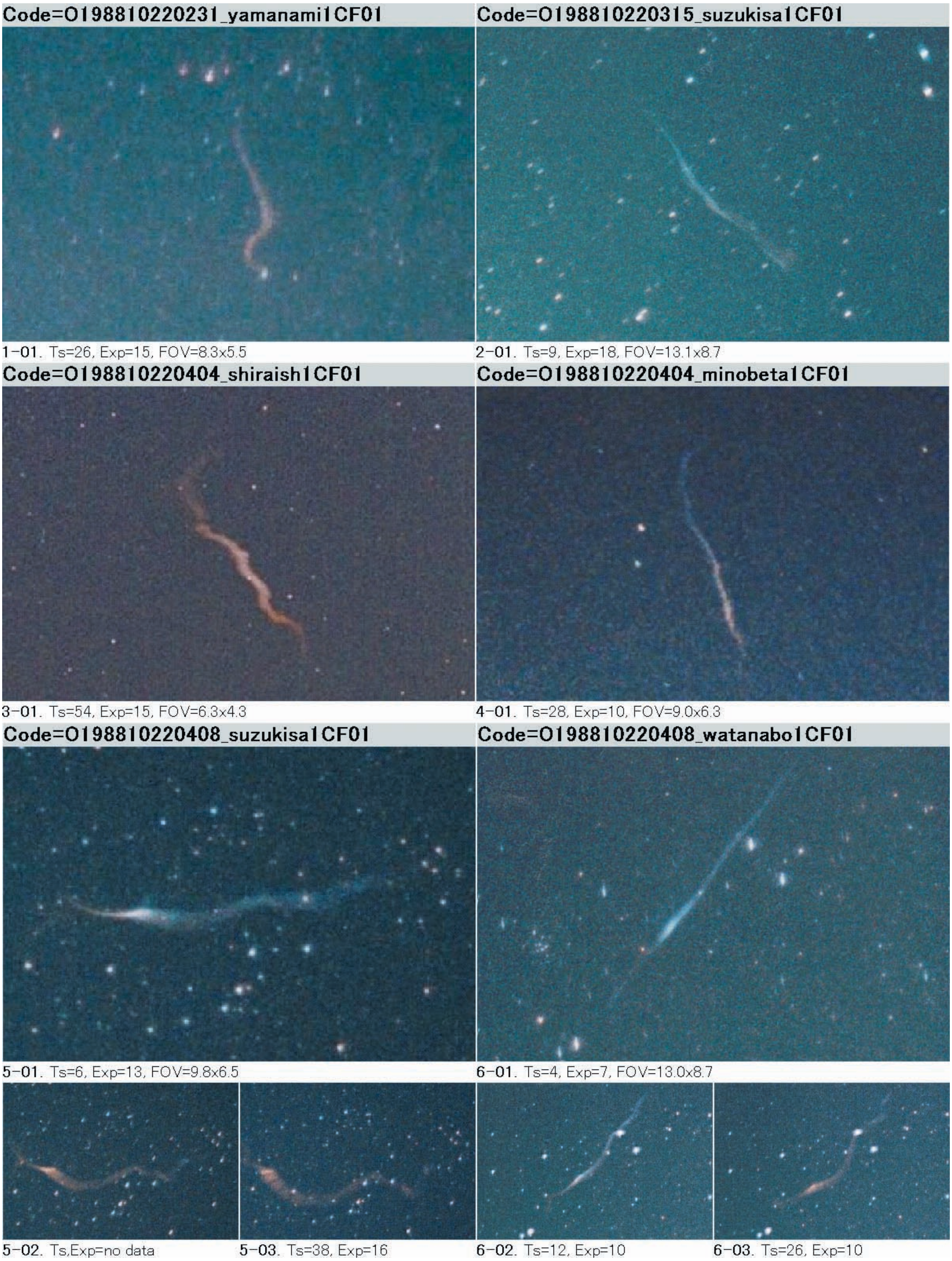

Fig. 4-1. Image sequences of the persistent train No. 1 to No. 6. Image sequences of No. 3 and 4 as well as No. 5 and No. 6 were simultaneously observed with each other.

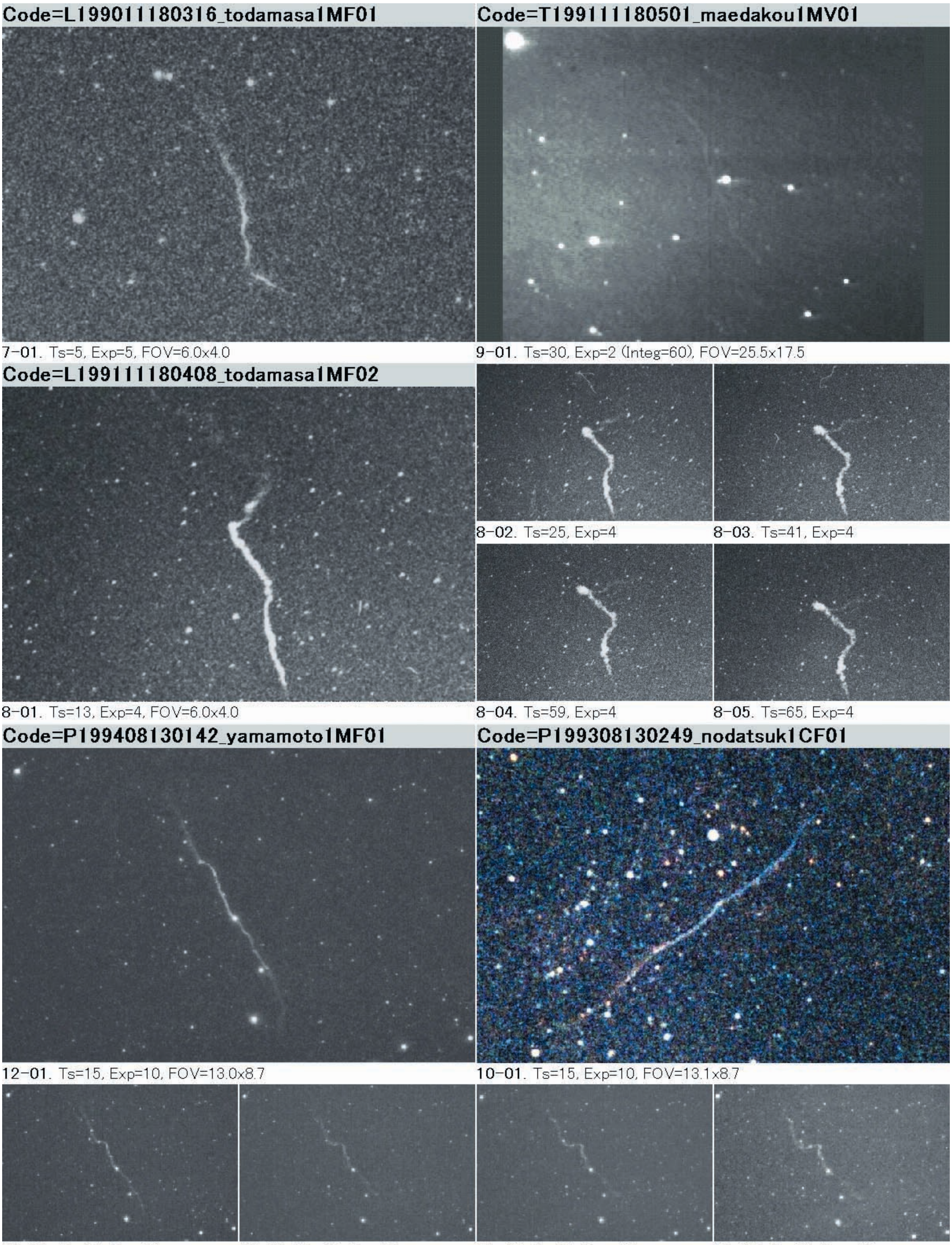

Fig. 4-2. Image sequences of the persitent train No. 7, 8, 9, 10, and 12.

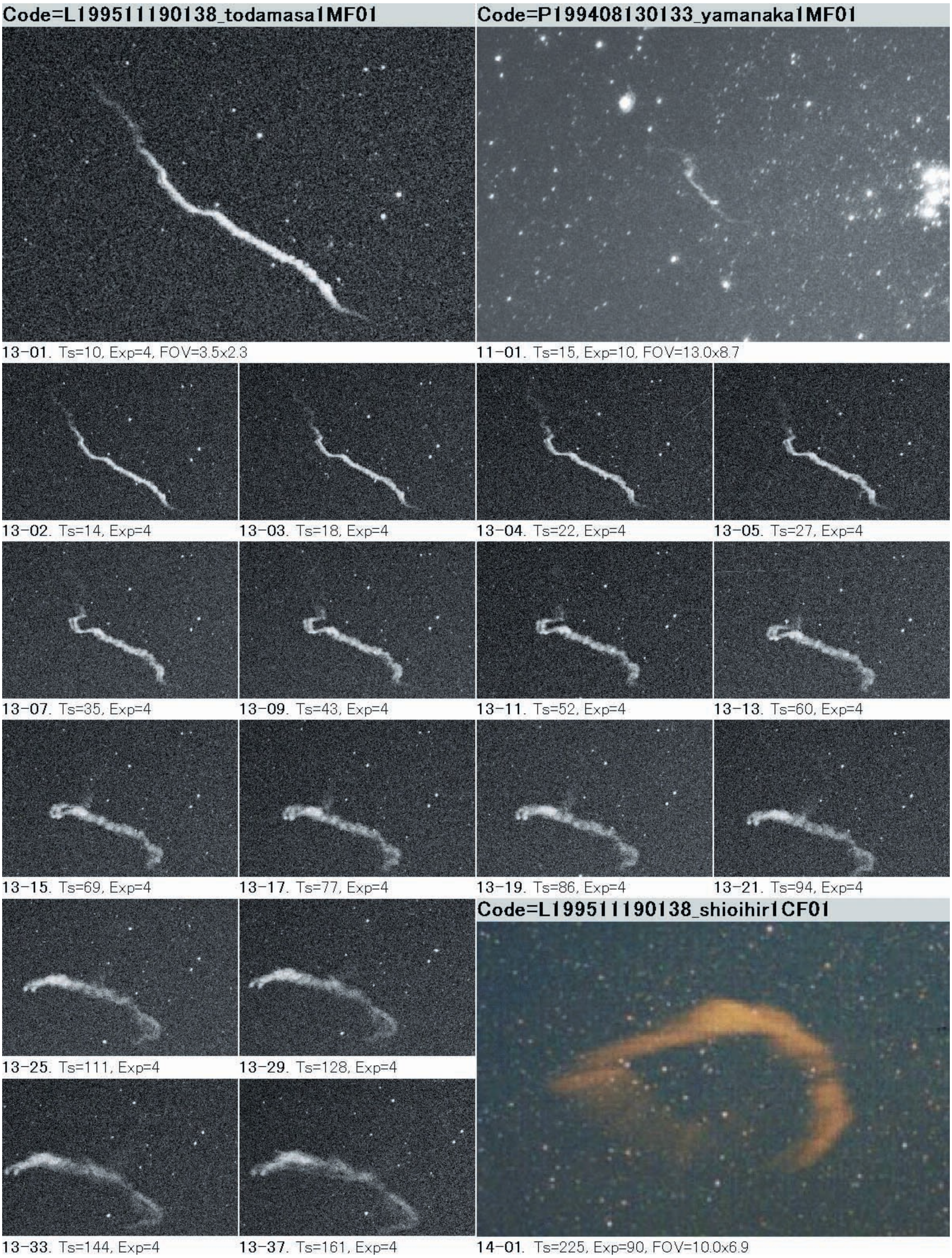

Fig. 4-3. Image sequences of the persistent train No. 11, 13, and 14. A two-sites simultaneous observation was established betwen No. 13 and No. 14.

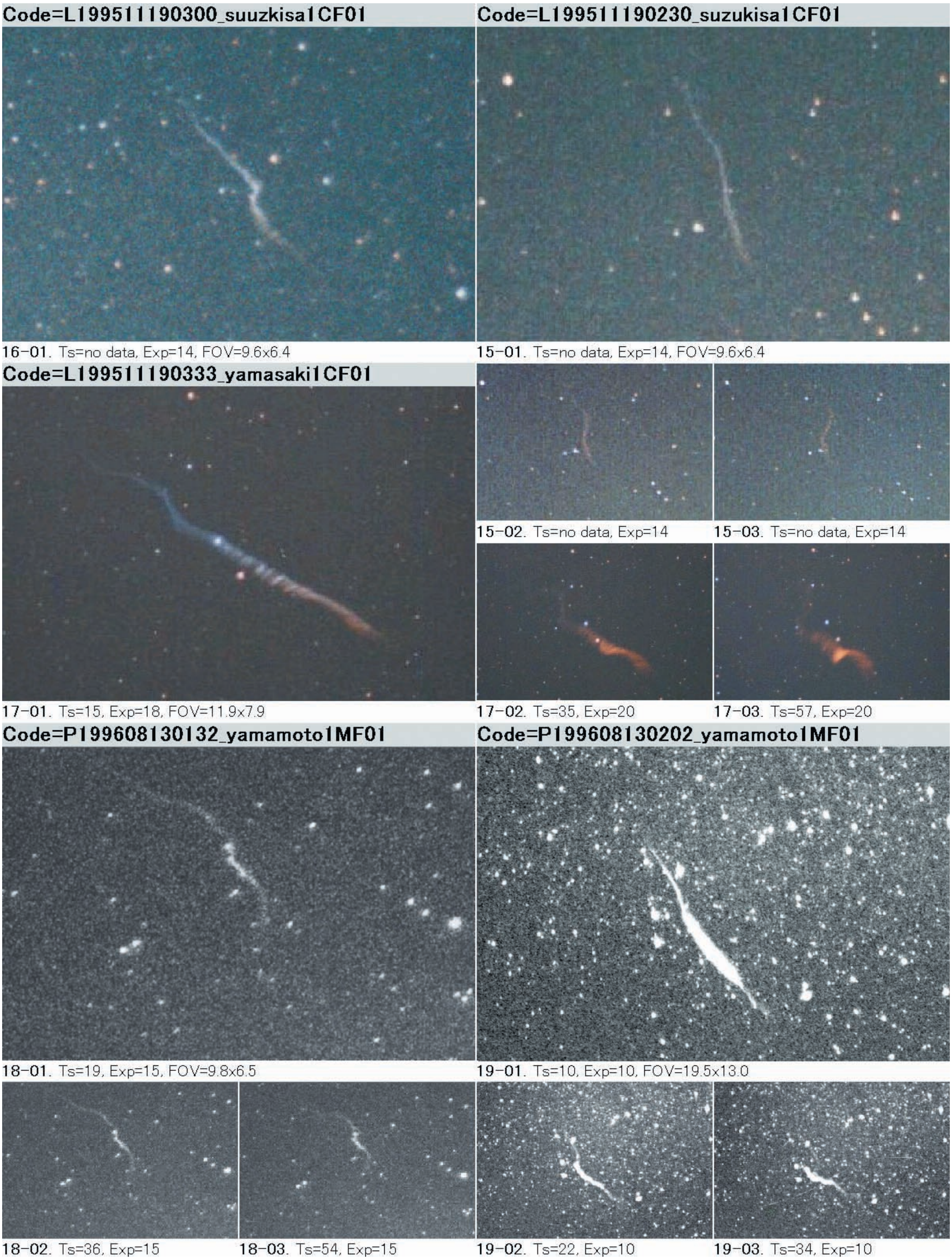

Fig. 4-4. Image sequences of the persistent train No. 15 to No. 19.

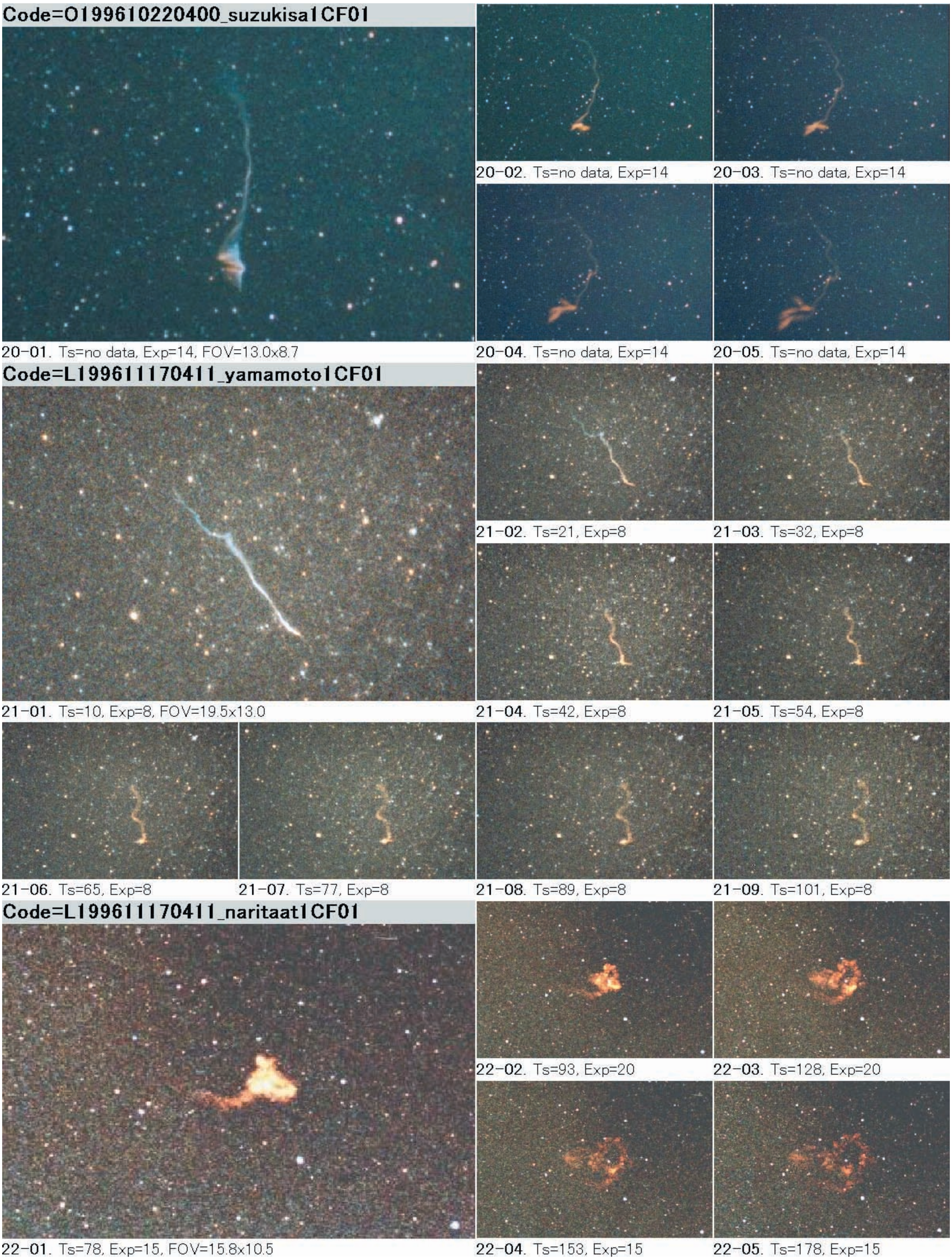

Fig. 4-5. Image sequences of the persistent train No. 20, 21 and 22. Simultaneous two-sites observation was established between No. 21 and No. 22.

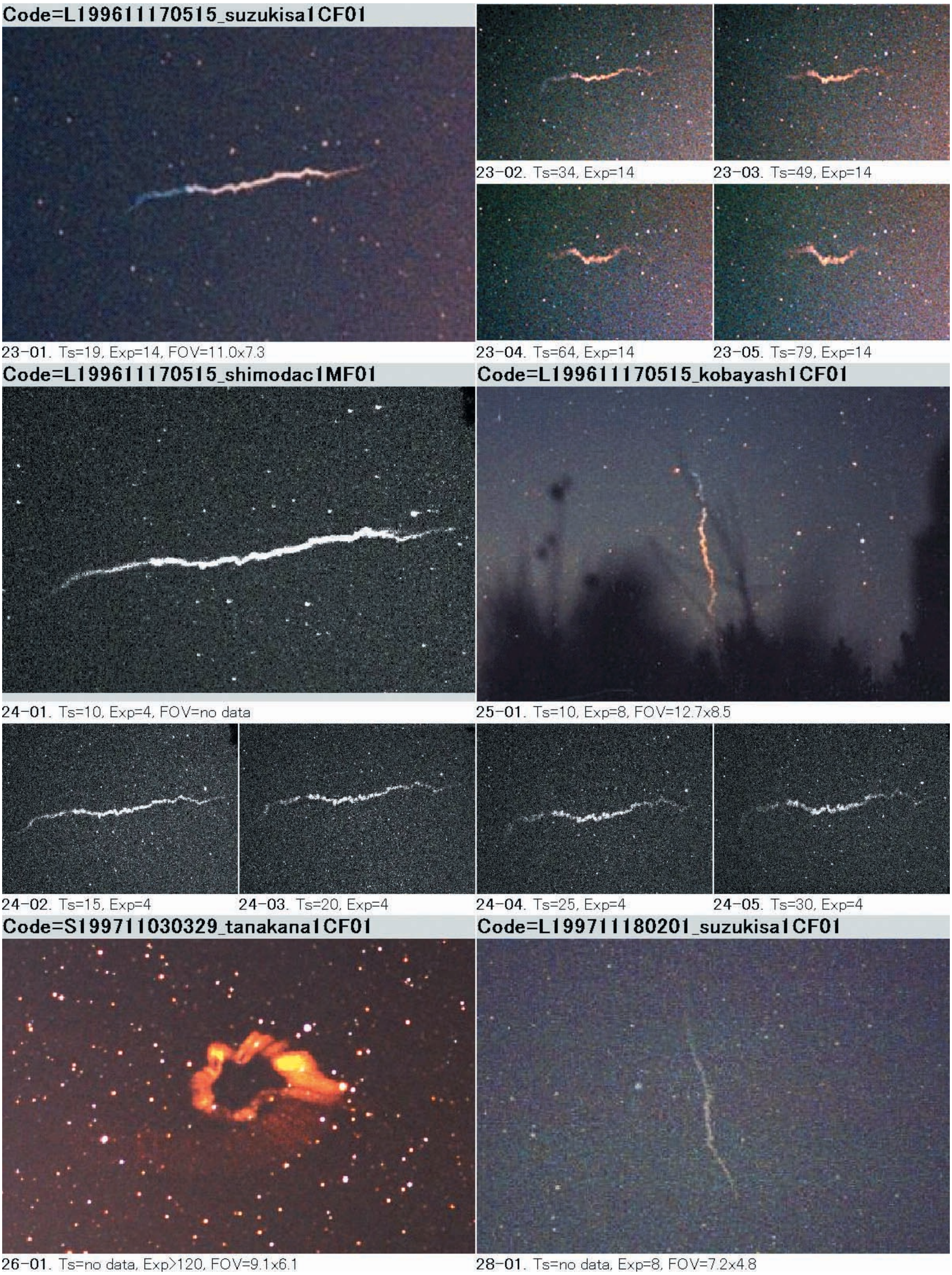

Fig. 4-6. Image sequences of the persistent train No. 23, 24, 25, 26, and No. 28. Image sequence of No. 23, 24, and 25 were simultaneously observed with each other.

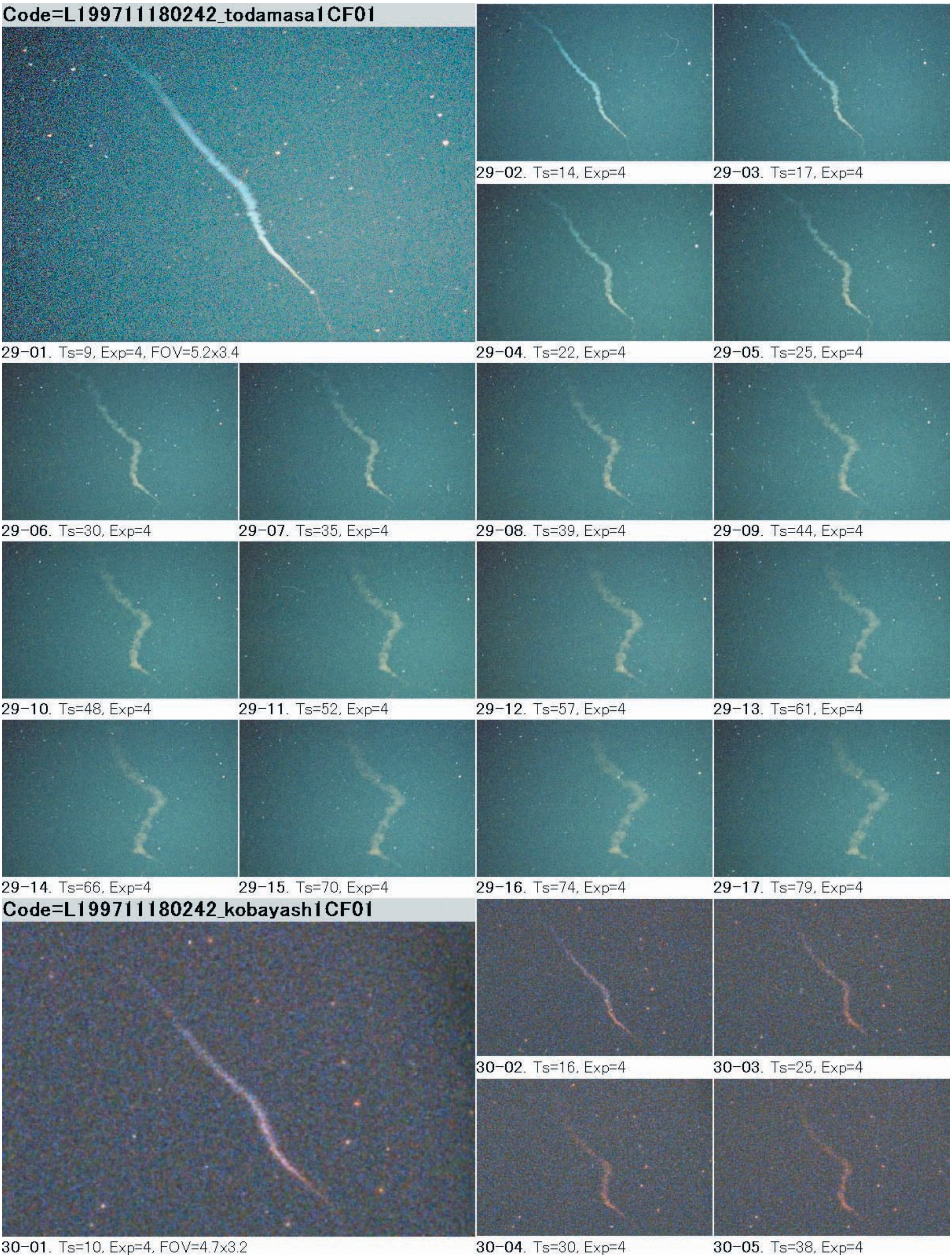

Fig. 4-7. Image sequences of the persistent train No. 29 and 30. Including image sequence of No. 31, a three-sites simultaneous observation was established.

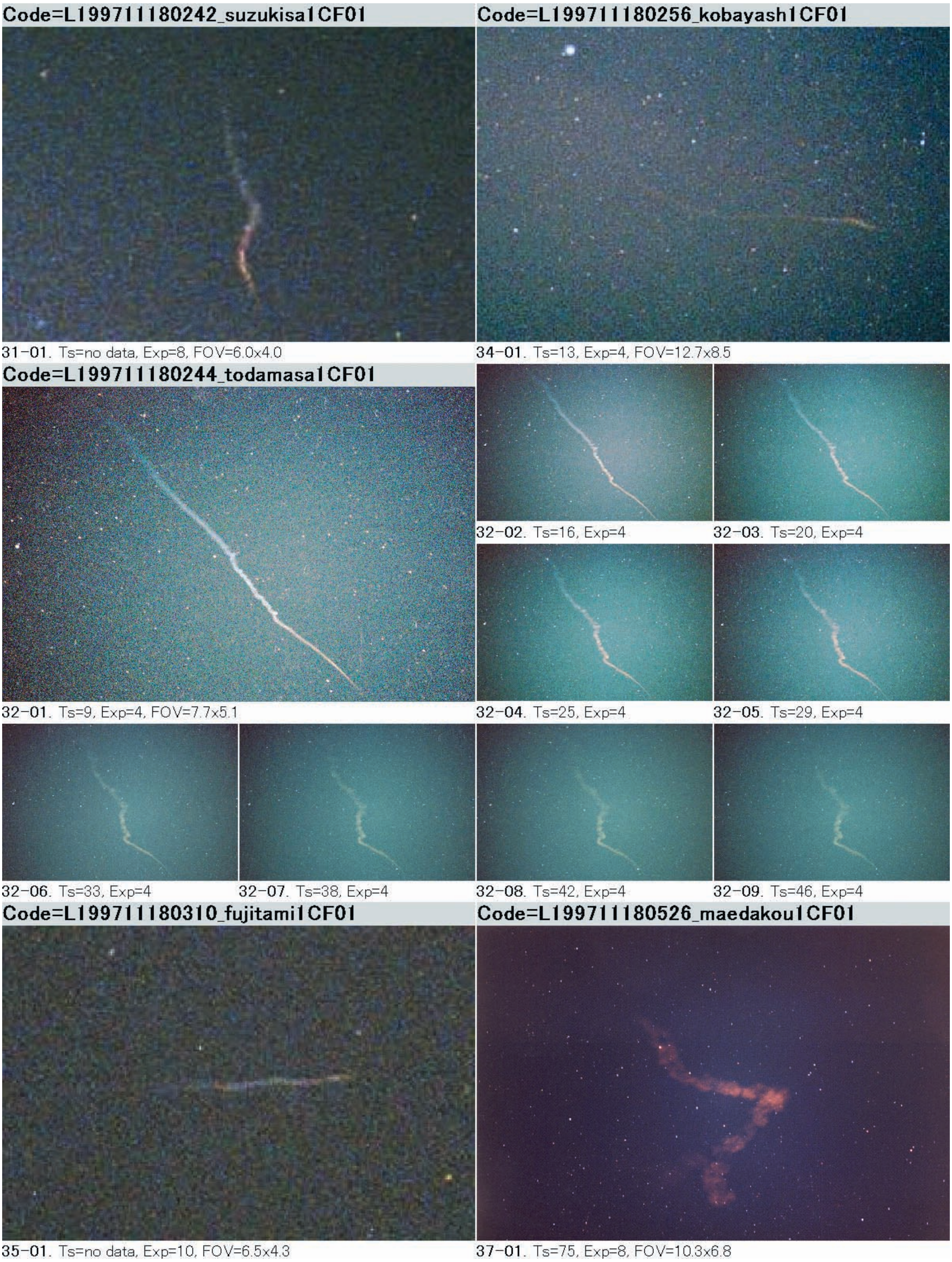

Fig. 4-8. Image sequences of the persistent train No. 31, 32, 34, 35, and 37. Image sequence of No. 31 was simultaneously observed with No. 29 and 30.

Table 3. Triangulation results of simultaneously observed persistent trains. 'Tm' means time from appearance of parent meteor. Triangulation results of trains 3, 4, 19, and 23 were quoted from referred articles by Urasaki (1989), Suzuki et al. (1989), Suzuki (1998), and Shigeno et al. (1998), respectively. Residual error of train 23 was calculated by Shigeno (2003, Private communication). Residual error of train 10 was relatively large because of low time consistency between two independent observations as well as low time resolution of long exposure image of No. 14-1 (See Figure 4-3). Note that the top and bottom ends of a persistent train are ordinarily faint and rapidly disappeared. Therefore, if 'T_m' at triangulation time were less than 30 s, the top altitudes of trains 3, 11 and 18 might be about 5 km higher as well as the bottom altitudes might be a few km lower.

Train	3	4	11	18	19	23
Parent meteor shower	Orionids	Orionids	Leonids	Leonids	Leonids	Leonids
Observation date (JST)	10/22/88	10/22/88	11/19/95	11/17/96	11/17/96	11/18/97
Triangulation time (JST)	04:05:04	04:08:51	01:42:30	04:12:50	05:16:05	02:42:37
T_m at triangulation time (s)	62	10	270	83	15	11
Top altitude (km)	100	109	101±3	98±1	100	102±0.3
Bottom altitude (km)	84	88	86±1	88±0.2	75	89±0.2
Real length of train (km)	19	23	25	11	26	18
Average train width (m)	580	660	1400	750	810	460

Snapshots with short exposures enabled us to clarify some tiny structures of persistent trains. Knot structures or spiral-like turbulences were found in many cases. Typical width of the tiny structure was about 400–1000 m in the first shot of each sequence. "Chopsticks" type structures were rarely detected in this observation period 1988–1997; however, if higher spatial resolution were realized, clear "chopsticks" structures might be detected in some cases. The morphological classification of persistent trains was introduced in another paper in detail (Higa et al. 2003). Other large-scale wave or loop shapes were also seen. The 3-dimensionally analyzed results of these shapes might be interpreted as large-scale spirals (Yamamoto et al. 2003). Using the results of multiple-site observations, altitude distribution of persistent trains can be obtained. Six triangulation results of persistent trains were listed in Table 3. Highest top altitude was 109 km whereas lowest bottom was 75 km. Real length and averaged width of each train were also shown.

Applying high-sensitivity color films with short exposures, color information was also available in recent train images. At about 30 seconds after parent fireball appearance, the color ordinarily changed from bluish-white to orange. The transition was usually seen bottomward first, probably depending on the composition of in-situ atmosphere and the parent meteor. It was also found that the shape of meteor trains changed rapidly within 30 seconds of the appearance of parent fireball and remained relatively stable afterward. Therefore, observations of the first 30 seconds are very important to understand not only the morphology of the persistent train but also its emission mechanism. Using the observation style applied here, every amateur observer can contribute meteor train observations because commercially produced instruments are sufficient for the observations. Though the observation method requires human response time, observers can direct a lens to a meteor train within about 10 seconds.

This archive part I includes the persistent train images of meteor showers of the Orionids, the Perseids, the Leonids, and the Taurids, together with that of sporadic meteor obtained in the period 1988–1997. The decade was roughly corresponded to an encounter "rush" of perihelion passage of each parent comet: the comet "1P/Halley (Feb. 9, 1986)" for Orionids, the comet "109P/Swift-Tuttle (Dec. 12, 1992)" for Perseids, and the comet "55P/Tempel-Tuttle (Feb. 28, 1998)" for Leonids, respectively. Although a difference of train structure due to parent meteor showers was not clearly confirmed, detection rate of persistent trains for Leonids was larger than for other showers. Leonids' fireballs of the same magnitude could easily generate persistent trains. It is probably because the Leonids' fireballs have the feature of rapid incident velocity, *i.e.*, larger energy. Many failure trials experimentally indicated that meteors fainter than -2 magnitudes may not generate clear persistent trains; however, fireballs brighter than -4 magnitudes can effectively generate brilliant and long-lasting trains.

4. Conclusion

Persistent train photographs observed in Japan during 1988–1997 were archived. 37 results obtained by amateur observers successfully contributed to the morphological study of the exceedingly rare phenomena of persistent meteor trains. The imaging technique using 35 mm size photographic cameras with high-sensitivity films was established in that 10 years period. With the efforts of many amateur observers in Japan, the technique was developed to a systematic observation of the METRO campaign for obtaining multiple-sites simultaneous imaging of persistent trains. The catalogue of persistent trains is valuable for clarifying the generation and luminescence mechanisms of persistent trains as well as the composition and microstructure of parent meteors. Moreover, the train image sequences including the information about the interaction between penetrating meteor and surrounding atmosphere can make a contribution to investigating the upper atmospheric dynamics.

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