Leonids Radiant Project 2001 in Japan†

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McNaught and Asher (2001) predicted the precise positions of radiant points due to the 4-rev (1866 yr.) and 9-rev (1699 yr) dust trails of the Leonids. To establish the dust trail theory and to measure the flux and magnitude distribution of very faint meteors, we performed deep imaging telescopic observations with the cooled CCD camera toward the radiant points of the Leonids. 7 sites in Japan performed such coordinated observations; (i) Akeno Observatory, Institute for Cosmic Ray Research University of Tokyo, (ii) RIBOTS at Bisei Observatory, (iii) RIMOTS at Miyazaki Univ., (iv) Kiso Observatory, Institute of Astronomy, The University of Tokyo, (v) KSC Schmidt, Uchinoura Space Center, Institute of Space and Astronautical Science, (vi) Miyazaki Univ., (vii) NAOJ Mitaka. We observed the Leonids meteor storm Nov.18 UT 2001, and succeeded to separate the radiant points due to the 4-rev and 9-rev dust trails (Yanagisawa et al. 2003, Torii et al. 2003). We also succeeded to detect the faint meteors under 10 magnitudes (Ohnishi et al. 2003). This paper describes the detailed observation circumstances and a highlight of preliminary results.

keywords: Leonids 2001, mass index, flux, Ham-band Radio Observation (HRO), beam antenna

1. Introduction

The Leonids is one of the most famous and the most active meteor showers. Its strong meteor activity occurs every ~ 33 years, corresponding to the orbital period of the parent comet 55P/Tempel-Tuttle. After the return of this comet in 1998, the Leonids were expected to show strong activity. Various worldwide observations such as the Leonid MAC campaign have been coordinated (Jenniskens et al. 2000). From these results, there was an important advance in theoretical studies on the structure of the spatial distribution of meteoroids in the meteor stream (McNaught, Asher 1999). Meteor streams originate from small dust particles ejected by the parent comets. The dust particles form tubular structures along the orbits of the comets, which are called *Dust trails.* Every time a comet returns, a new dust trail is formed along the orbit slightly shifted from the previous path due to the gravitational perturbation. When the Earth passes through such dust trails, Leonids meteor storm will occur (McNaught, Asher 1999; Lyytinen, van Flandern 1999).

In 2001, the Leonids had been expected to show the strongest meteor activity due to the dust trails which were formed by the 1866 return of the parent comet (4 revolution ago, hereafter we call 4-rev.) and the 1699 return (9 revolution ago, hereafter we call 9-rev.) over Japan. The model of Lyytinen et al. predicated major peaks for

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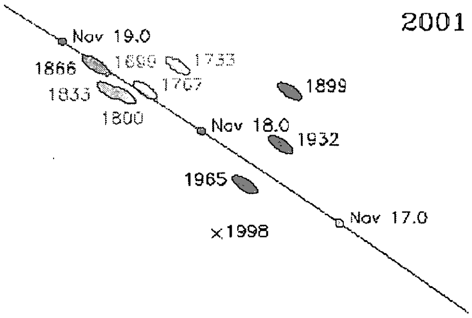

Fig.1 Prediction of Leonids storm 2001 from Dust Trail Theory by Mc Naught & Asher. Meteoroids in each trail move pretty much in the opposite direction to the Earth, except that their path is inclined at about 17 degrees and so just the positions where the trails intersect the ecliptic are shown. (from McNaught, Asher 1999)

18h03m UT and 18h20m UT on November 18 due to 9-rev. and 4-rev dust trail, respectively (Lyytinen and van Flandern 2000,Lyytinen et al. 2001). The model of McNaught and Asher resulted in 17h24m UT and 18h13m UT, respectively (McNaught and Asher 1999; McNaught and Asher 2001). The dust trails distribution in 2001 are shown in Fig.1 and detailed forecast of Leonids are listed in Table 1. Many studies predicted that Japan would be the best observational site for the Leonids.

At this opportunity, we projected the three observational plans to derive the physical quantities of the Leonids which we can measure only when the Leonids meteor storm would happen;
(1) To separate the 4-rev and 9-rev radiant point using a line detection method,
(2) To obtain the magnitude distribution of the faint meteor under 10 magnitude,
(3) To detect a faint glow of scattered sunlight from the 4-rev and 9-revdust trails.

Note that the radiant point due to Leonids dust tube is wider than the FOV of the telescopic observation. Then we need the very accurate radiant points predication for telescopic observation. McNaught and Asher (2001) calculated

Table 1 Time prediction of Leonids 2001 by McNaught & Asher, vs. Esko Lyytinen.

Time (UT) 18 Nov.	Dust Trail	ZHR	best sites
	MacNight& Asher		
9:55	1766 (7-rev)	800	America
17:24	1699 (9-rev)	2000	East-Asia, Australia
18:13	1866 (4-rev)	8000	East-Asia, Australia
	Esko Lyytinen		
10:28	1766 (7-rev)	2000	America
12:00	1799 (6-rev)	110	West-America
14:10	1833 (5-rev)	60	Hawaii, East-Australia
18:03	1699 (9-rev)	2600	East-Asia, Australia
18:20	1866 (4-rev)	5000	East-Asia, Australia
19:10	1666 (10-rev)	150	East,Central-Asia
19:10	1633 (11-rev)	150	East,Central-Asia

the coordinates of the two radiant points to be
$\alpha(J2000.0) = 10^h16^m43^s_.$
$\delta(J2000.0) = +21°39'00''$
due to 9-rev dust trail and
$\alpha(J2000.0) = 10^h17^m19^s_.$,
$\delta(J2000.0) = +21°36'00''$
due to 4-rev dust trail, and the peak time of Leonids activity due to 9-rev and 4-rev dust trail are at 17h 24m and 18h 13m on November 18 (UT) 2001, respectively. We adopted the predicted position of radiant point above, we performed the coordinated observation called *"Leonids Radiant Project 2001"* at Nov.18 2001, just the time of the Leonids meteor storm observed in Japan.

Many researchers have been realized the dust trail theory by the success of the peak time predication of the Leonids in 1999 and 2000. In the first project, we try to obtain the direct evidence of the dust trail theory using the *"Astrometric Observation"*; i.e. to measure the accurate radiant points due to each dust trails. Yanagisawa have been developed the new analysis on the CCD image called *the line detection method*, which enable us to detect 30 times fainter meteors than usual detection methods (Yanagisawa et al. 2002). We conducted for the separation the radiant points due to 4-rev and 9-rev dust trails, and carried out the coordinated observation for the line detection method from 17th to

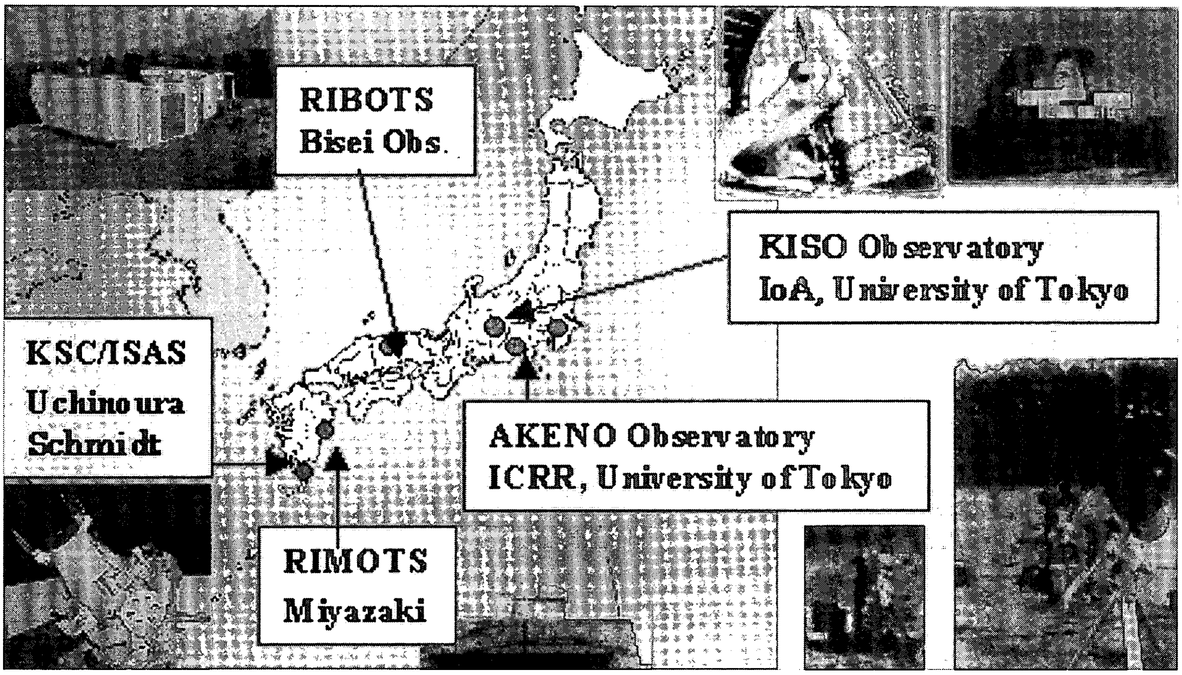

Fig.2 Observation Sites in Japan

Table 2 Location of observation sites

Telscope Name	Observation site	Affilication	Location
AKENO	AKENO Observatory	ICRR. Univ.Tokyo	N35°47′24", E138°28′35"
RIBOTS	Bisei Observatory	RIKEN	N34°40′28", E133°32′36"
RIMOTS	Miyazaki Univ.	RIKEN	N31°49′46", E131°24′51"
KISO SCHMIDT	KISO Observatory	IoA. Univ.Tokyo	N35°47′39", E137°37′42"
KSC SCHMIDT	KSC/Uchinoura	ISAS	N31°15′16", E131°4′46"
50mm & 300mm lens	Miyazaki Univ.	Miyazaki Univ.	N31°49′46", E131°24′51"
24mm wide field	NAO, Mitaka	NAO	N35°40′30", E139°32′16"

19th November 2001 using a pair of 16cm telescopes (Yanagisawa et al. 2003) and a pair of Nikon 180mm F=2.8 camera lens (Torii et al. 2003) at the Akeno Observatory of the Institute of Cosmic Ray Research, the University of Tokyo.

We succeeded to separate these radiant points. Its separation angle is $0.157° \pm 0.059°$ that agrees well with that of McNaught and Asher (2001). Yanagisawa (2002) showed the line detection method and the analysis in detail. See also Yanagisawa et al.(2003) and Torii et al.(2003).

The size distribution of dusts in the trails has been a particular interest, because it should be relevant to the formation and evolution of the dust trails. It was suggested that there are less faint meteors under the 5th magnitude from the Leonids 1999 (e.g. Arlt et al. 1999). To detect a faint meteor, we performed telescopic observations *"toward the radiant point"*. The angular velocity of meteor near the radiant point is so slow that we can detect the fainter meteors than that of other detection. This is the key point of this observation. Ohnishi et al. (2003) analyzed the RIMOTS, RIMOTS and AKENO observation, and Nishiura et al.(2002) analyzed the KISO 105cm Schmidt telescope observation.

The faint glow at the direction of the dust trail of comet 55P/Tempel-Tuttle was discov-

Table 3 Equipment parameters for radiant points separation

equipment	aperture	focal length	F	CCD	device size
Takahasi, ϵ160	160mm	530mm	3.3	N.I.L., FCC-104B	1K×1K back-illuminated
Takahasi, ϵ160	160mm	530mm	3.3	Apogee, AP7	512×512 back-illuminated
180mm camera lens	64mm	180mm	2.8	Apogee, AP7	512×512 back-illuminated
180mm camera lens	64mm	180mm	2.8	Apogee, AP6	1K×1K, enhanced

Table 4 Equipment parameters for faint meteor search

equipment	aperture	focal length	F	CCD	device size
AKENO 20cm	200mm	800mm	4.0	Apogee, AP6	1K×1K enhanced
RIBOTS	300mm	1000mm	3.3	SBIG, ST8E	1.5K×1K enhanced
RIMOTS	300mm	1000mm	3.3	SBIG, ST9E	0.5K×0.5K enhanced
KISO SCHNIDT	1050mm	3300mm	3.1	2KCCD	2K×2K back-illuminated
KSC SCHNIDT	500mm	750mm	1.5	—	70mm 150-foot film

Table 5 Video parameters for calibration of faint meteor magnitude

Video	lens	focal length	F	meteor limiting mag	star limiting mag.
WATEC Neptuen 100	Nikon	50mm	1.4	8.5	9.5
WATEC Neptuen 100	CBC	8mm	0.8	3.0	3.5

ered during the Leonid meteor shower in 1998 by the photometric observations at Mauna Kea, Hawaii (Nakamura et al. 2000). This is considered to be the scattered sunlight from submillimeter size dust particles located along the orbit of 55P/Tempel-Tuttle. To examine the orbital distribution of dust particles, we observed the direction of the dust trail on Nov. 18 2001 at Akeno Observatory (Usui and Ishiguro 2003).

This paper describes the detailed observation circumstances and presents the distribution of meteors from 7th to 12th magnitude combined the data of each sites.

2. Observation

7 sites in Japan performed the coordinated observations to search for faint meteors.

(i) Akeno Observatory, the Institute of Cosmic Ray Research, the University of Tokyo. We performed the telescopic observation toward the radiant points. In parallel, we performed the synchronous TV observation toward the radiant points because of the calibration of meteor magnitude between cooled CCD images and video image. From the site (a rooftop of Muon Station), we operated the remote controlled two robotic telescopes; RIBOTS and RIMOTS by internet. We also performed the coordinated observation for radiant points separation and the observation of the faint glow at the direction.

(ii) RIBOTs at Bisei Observatory, and

(iii) RIMOTS at Miyazaki University. RIBOTS and RIMOTS are robotic telescopes which aim to catch optical flushes and early afterglows from the gamma-ray burst. The robotic telescope system is composed of electric powered roof, 30cm telescope, cooling CCD camera and two PCs.

(iv) Kiso Observatory, the Institute of Astronomy, Faculty of Science, the University of Tokyo. We observed the radiant point using 105cm Schmidt telescope with 2KCCD camera, which is the largest aperture optical instrument for meteor detection toward the radiant point of Leonids.

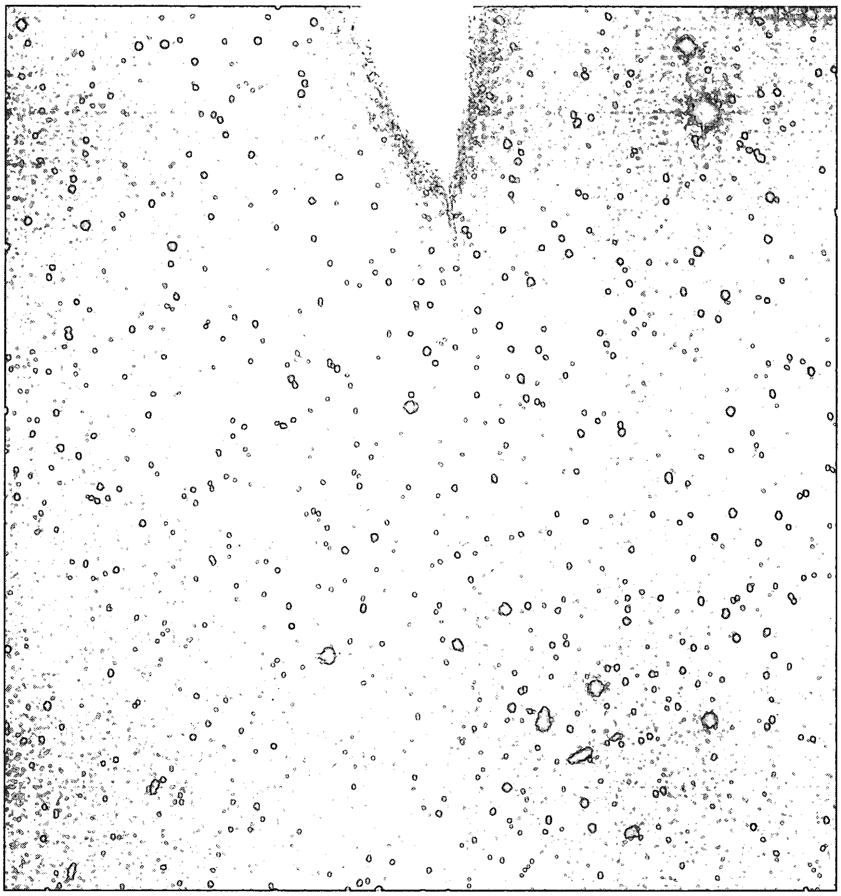

Fig.3 Akeno 20cm-(bright meteor)

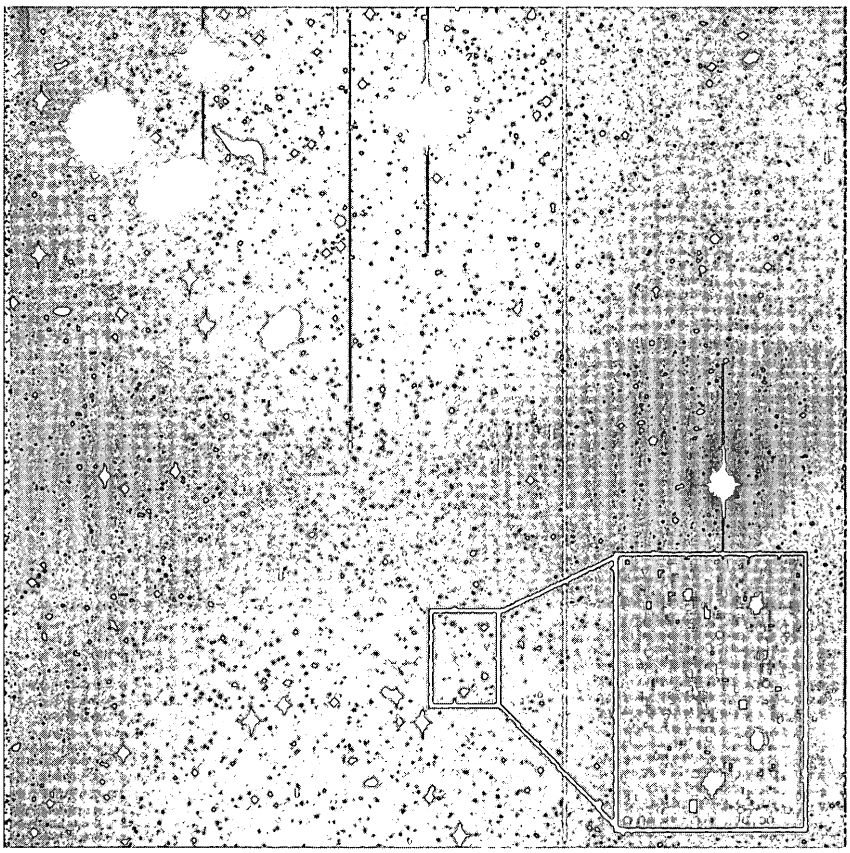

Fig.4 KISO Schmidt

Table 6 Observation parameters for Deep Survey of faint meteor

Name	field of view	exposure time(s)	total image	dead time(s)
AKENO	1.76° × 1.76°	20	757	2,3
RIBOTS	0.95° × 0.63°	15	411	20
RIMOTS	0.72° × 0.72°	15	306	40
KISO	0.71° × 0.71°	900	5	90
KSC	4.5° × 14°	180	30	—

Table 7 Detection number of faint meteor

Name	Meteor liming mag.	Star liming mag.	total time(s)	detection number
AKENO	11.0 ± 0.5	15	15140	31
RIBOTS	12.0 ± 0.5	16	6165	5
RIMOTS	12.8 ± 0.5	17	4590	4
KISO	11.5 ± 0.5	23	4800	1

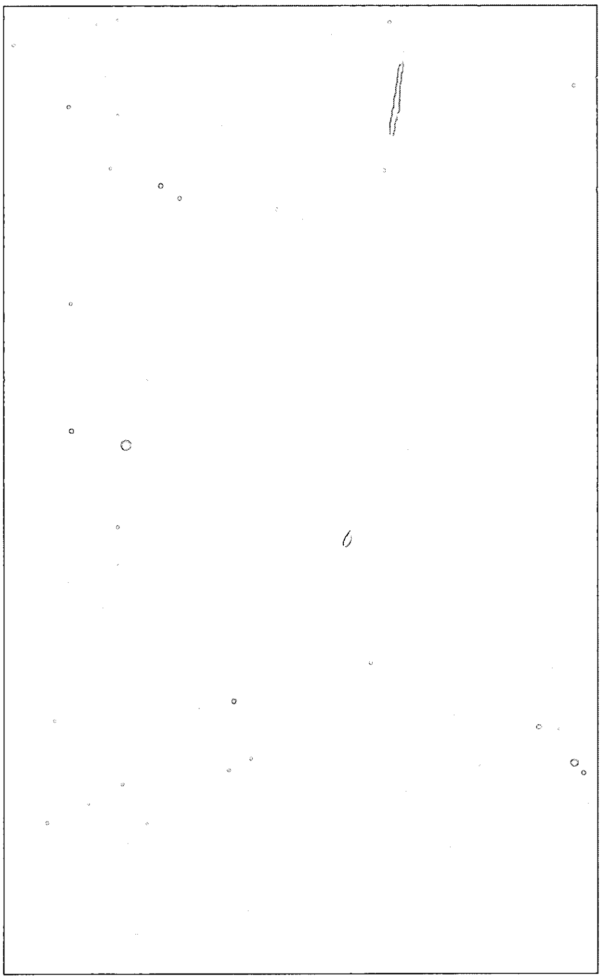

Fig.5 KSC Schmidt

(v) Kagoshima Space Center (Uchinoura), ISAS, Schmidt camera,
(vi) Miyazaki University , and
(vii) National Astronomical Observatory Japan, Mitaka.

The observation sites and equipments are illustrated in Fig.2 and the location is listed in Table 2. The telescope and CCD for radiant points separation and for the faint meteor search are listed in Table 3 and Table 4, respectively. Table 5 shows the video parameters for the calibration of faint meteor magnitude on the cooled CCD images. Fig.3 to Fig.5 show the example images obtained by observation. Using the line detection method, we can determine the very accurate trail of meteors.

The detail observation circumstances of each telescopes are listed in Table 6.

3. Faint meteor flux

We have detected the 40 meteors from Akeno, RIBOTS, and RIMOTS using PIXY2. The detection algorithm consists the following steps.
(1) Search for the candidates, which are not in the USNO-2.0A catalog and DSS data.
(2) They are long distance images (more than 10 pixels)
(3) There is no similar object in before and after flames.

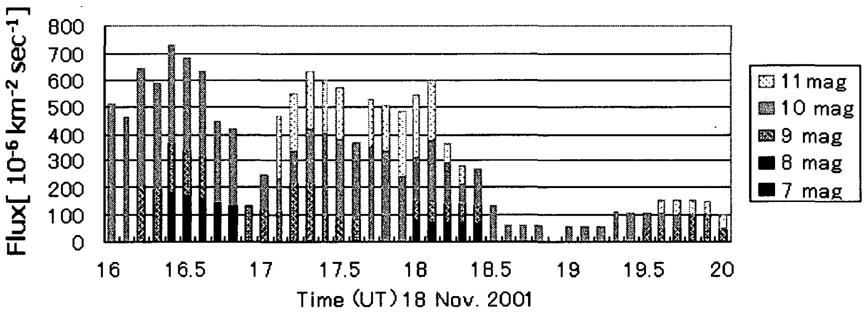

Fig.6 Time variation of faint meteors flux by AKENO 20cm telescope

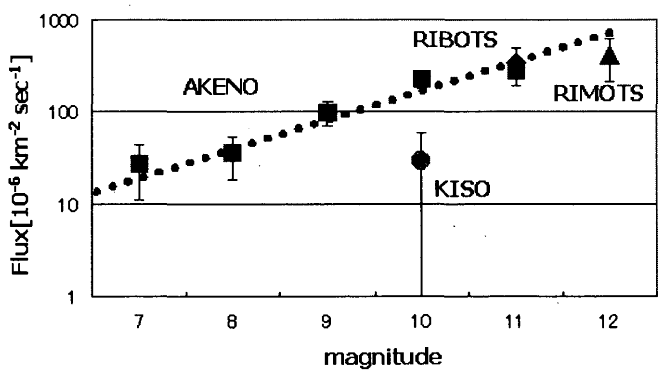

Fig.7 Flux of faint meteors in Leonids 2001

This data and KISO data (Nishiura et al. 2002) are summarized in Table 7.

Note that the magnitude of meteors on CCD images is shown by integral flux of light along the trail of meteor. On the other hand, usual visual magnitude of meteors is the peak magnitude of meteors. Then we have to transfer the magnitude of meteor from the CCD images magnitude to the visual magnitude. We conducted the video observation for the calibration of CCD magnitude by setting the same field of AKKENO 20cm telescope using a pair of WATEX Co. Neptune 100 with Nikon 50mm (F=1.4) and CBC 8mm (F=0.8) camera lens. This limiting magnitude of star is 10th magnitude (50mm, F=1.4), and we could compare only 2 brilliant meteors (7th magnitude on video) simultaneously. This value is consistent with the magnitude supposing that the duration of meteor is 0.5 second. Therefore, we adopt the magnitude that is normalized the duration of meteor is 0.5 second. We call this *CCD magnitude* Mccd.

Fig.6 shows the 30 minutes unit moving average of the flux of faint meteors by AKENO 20cm telescope. This magnitude indicates the Mccd. The peak flux is 6×10^{-4}km^{2}s^{-1}. The peak time of faint meteors is shift and its width at half height is longer than those of visual meteors. Though it is difficult to determine the peak flux time because of statistical uncertainty, the peak time of faint meteors is more than 30-60 minutes earlier than that of visual meteors. This indicate that the distribution of smaller meteoroids diffuse quickly than that of large one. Note that the detected meteors around 16.5h(UT) is a little brighter than that around 17.5~18.0h(UT). This trend may be happen in consequence of the property of the dust trails; e.g. a little brighter peak was caused by 9-

rev trail and fainter peak was caused by 4-rev trail.

We obtained the flux of faint meteors. Taking into account the zenith distance of the radiant points when we observed ($\sim 50°$) and on the assumption that the meteor detected was at an altitude of $\sim$ 115 km from the sea level (Fujiwara et al. 1998), this result is shown in Fig.7. A square indicates the flux by AKENO 20cm, and a triangle, an inverse triangle, a circle indicate the flux by RIBOTS, RIMOTS, and KISO Schmidt, respectively. From Fig.7, we found that the flux of faint meteors increases with the cumulative number exponent of 2.1 from 7th magnitude to 12th magnitude. And the flux was $4.3 \times 10^{-4} \mathrm{km}^{-2} \mathrm{s}^{-2} (\mathrm{mag} \leq +12)$.

Note that the size of meteoroid of 10th magnitude meteor is a several tenth μm (Pawlowski et al. 2001). A few $\times$ 10 μm is comparable size of dust grains for the zodiacal light. Such small meteoroids are not the meteoroids of 4-rev (1866 yr.) and 9-rev (1699 yr) dust trail, because it is considered that they cannot return around the orbit of dust trail due to the solar radiation pressure. However the time variation of observed faint meteors correlate the visual meteor. Then it is natural to consider that the faint meteor is mainly in the 4-rev and 9-rev dust trails. Thus we have to consider the physical mechanism to create such small meteoroids. This is the open question.

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