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Leonids Radiant Project 2001

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Abstract: 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 faint meteors, we performed telescopic observations with the CCD camera, obtaining the high-resolution dust trail structure from the deep imaging of the radiant point. 7 sites in Japan performed such coordinated observations; (i) Akeno observatory, (ii) RIBOTS at Bisei observatory, (iii) RIMOTS at Miyazaki Univ., (iv) Kiso observatory, (v) KSC Schmidt, (vi) Miyazaki Univ., (vii) NAOJ Mitaka. We observed the Leonids meteor storm Nov.18 2001, and succeeded to separate the radiant points due to the 4-rev and 9-rev dust trails. We also succeeded to detect the faint meteors under 10 magnitude. This paper describes the detailed observation circumstances and presents a highlight of preliminary results. Mainly, we report the distribution of faint meteors from 7th to 12th magnitude combining the data of each sites. The cumulative flux of faint meteors is exponential growth with the index number of 2.0, and the flux $(4.2 \pm 2.1) \times 10^{-4}\mathrm{km}^{-2}\mathrm{s}^{-2}(\mathrm{mag} \leq +12)$. We have found no apparent cutoff in the magnitude range brighter than $\sim$ 12 mag.

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1. INTRODUCTION

The Leonids is one of the most famous and the most active meteor showers. Its strong meteor activity occurs every $\sim$ 33 years, corresponding to the orbital period of the parent comet 55P/Tempel-Tuttle. After the return of this comet in 1998, the Leonids was expected to show strong activity. And various worldwide observation 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) (McNaught, Asher 1999; Lyytinen, van Flandern 1999; Jenniskens 2001; Lyytinen et al. 2001; McNaught, Asher 2001). Many studies predicted that Japan would be the best observational site for the Leonids in 2001 which should be most active from 17h 00m and 18h 30m on November 18 (UT).

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 telescopic observation. Then we need the very accurate radiant points predication for telescopic observation. McNaught and Asher (2001) calculated the coordinates of the two radiant points to be $\alpha(\mathrm{J2000.0}) = 10^{\mathrm{h}}16^{\mathrm{m}}43^{\mathrm{s}}.2$, $\delta(\mathrm{J2000.0}) = +21°39'00''$ due to 9-rev dust trail and $\alpha(\mathrm{J2000.0}) = 10^{\mathrm{h}}17^{\mathrm{m}}19^{\mathrm{s}}.2$, $\delta(\mathrm{J2000.0}) = +21°36'00''$ 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), respectively. We adopted the 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 this first project, we tries 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 19th November 2001 using a pair of 16 cm telescopes and a pair of Nikon 180 mm F=2.8 camera lens at the Akeno Observatory of the Institute of Cosmic Ray Research, the University of Tokyo. We succeeded to separate the radiant points at the time of the Leonids meteor storm. 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 in this proceeding.

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. Kohama et al. (2002) described RIMOTS, RIMOTS and AKENO observation and the analysis in this proceeding.

The faint glow at the direction of the dust trail of comet 55P/Tempel-Tuttle was discovered 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 sub-millimeter 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 (2002) showed the results in this proceeding.

Thus 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 per-

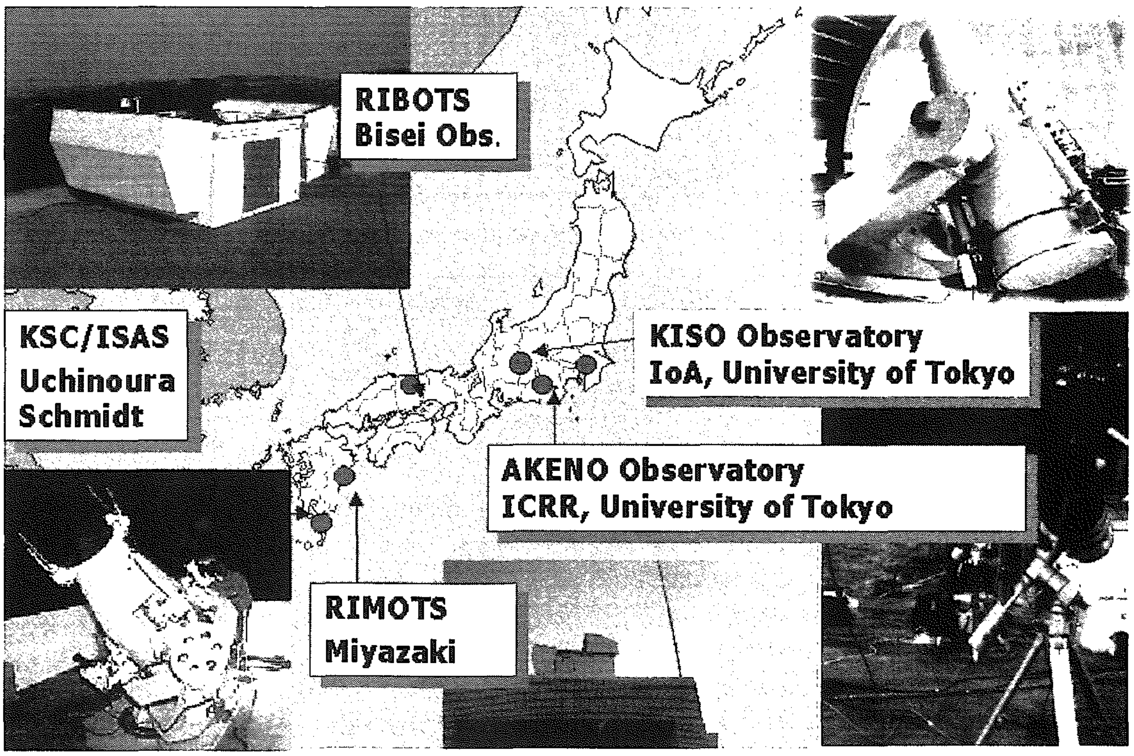

Fig. 1: Observation sites in Japan

Table 1: 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″
50 mm & 300 mm lens	Miyazaki Univ.	Miyazaki Univ.	N31°49′46″, E131°24′51″
24 mm wide fild	NAO, Mitaka	NAO	N35°40′30″, E139°32′16″

Table 2: Equipment parameters for radiant points separation

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

Table 3: Equipment parameters for faint meteor serach

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

Table 4: Video parameters for calibration of faint meteor magnitude

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

formed 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, 30 cm 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 105 cm Schmidt telescope with 2KCCD camera,

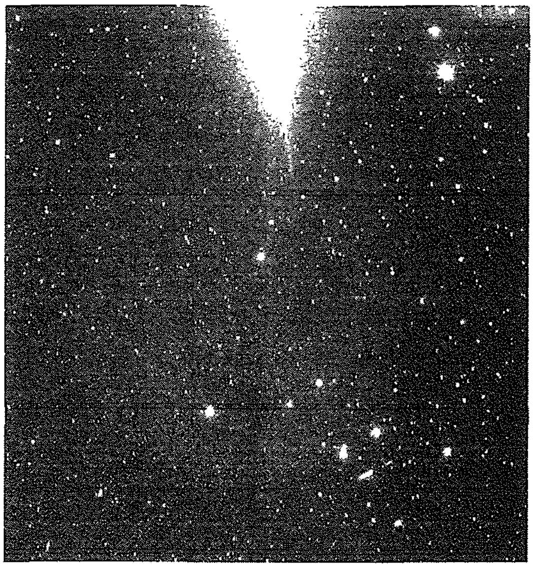

Fig. 2: Brightest meteor by Akeno 20cm-(0th mag.)

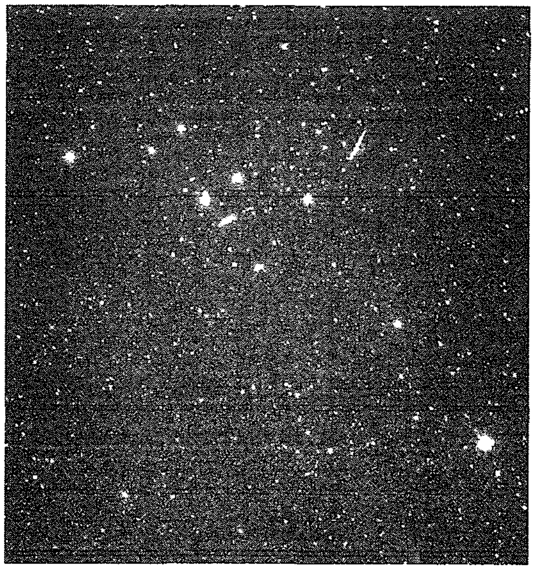

Fig. 3: Faint meteor by Akeno 20cm

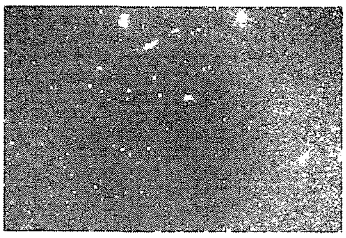

Fig. 4: Faint meteor by RIBOTS

Fig. 5: Faint meteor by RIMOTS

which is the largest aperture optical instrument for meteor detection toward the radiant point of Leonids. (v) Kagoshima Space Center (Uchinoura), ISAS, Schmidt camera, (vi) Miyazaki University, and (vii) NAOJ Mitaka.

The observation sites and equipments are illustrated in Fig. 1 and the location is listed in Table 1. The telescope and CCD for radiant points separation and for the faint meteor search are listed in Table 2 and Table 3, respectively. Table 4 shows the video parameters for the calibration of faint meteor magnitude on the cooled CCD images. Fig. 2 to Fig. 7 show the example images obtained by observation. Fig. 6 show the example image composite 50 images by 180mm, F=2.8 telephoto lens for the project 1. Using the line detection method, we can determine the very accurate trail of meteors.

The detail observation circumstances of each telescope are listed in Table 5.

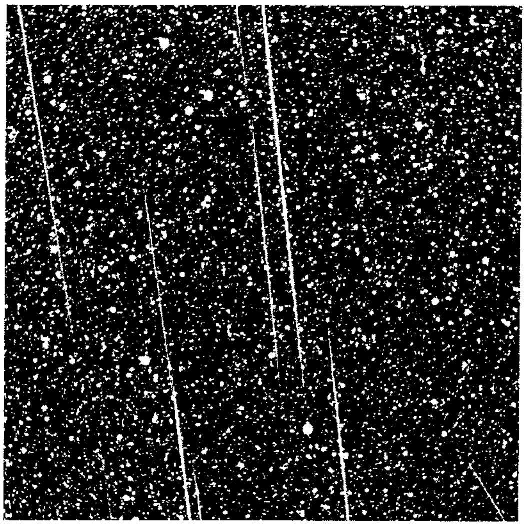

Fig. 6: Composite image of meteors by 180 mm camera lens

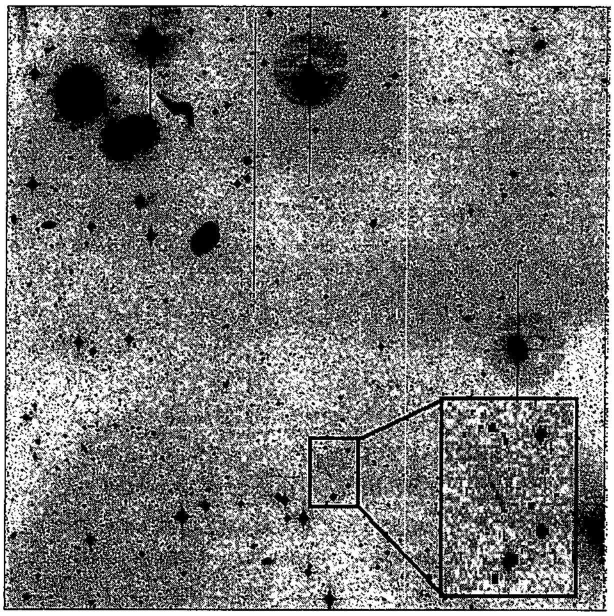

Fig. 7: Faint meteor by KISO Schmidt

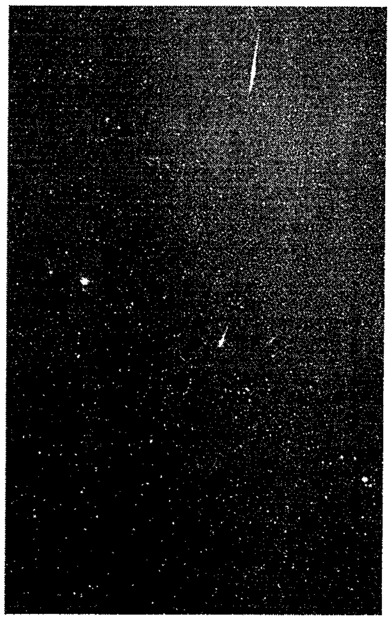

Fig. 8: 3 meteors by KSC Schmidt

Table 5: Observation parameters for Deep Survery of faint meteor

Name	field of view	exposure time(s)	total image	dead time(s)
AKENO	$1.76° \times 1.76° = 3.1□°$	20	757	2,3
RIBOTS	$0.95° \times 0.63° = 0.60□°$	15	411	20
RIMOTS	$0.72° \times 0.72° = 0.52□°$	15	306	40
KISO	$0.71° \times 0.71 = 0.5□°$	900	5	90
KSC	$4.5° \times 14°$	180	30	—

Table 6: 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

3. FAINT METEOR FLUX

We have detected the 40 meteors from Akeno, RIBOTS, and RIMOTS using PIXY2 (Kohama et al. 2002). 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.
This data and KISO data (Nishiura et al. 2002) are summarized Table 6.

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 20 cm telescope using a pair of WATEX Co. Neptune 100 with Nikon 50 mm (F=1.4) and CBC 8 mm (F=0.8) camera lens. This limiting magnitude of star is 10th magnitude (50 mm, 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. 9 shows the times variation of detected meteor by AKENO 20 cm and f=180 mm camera lens. A limiting magnitude of the meteor detection by camera lens is about 7th magnitude. Fig. 10 shows the times variation of detected meteor by AKENO 20cm, RIBOTS, and RIMORS. A limiting magnitude by AKENO is about 11th magnitude and that by RIMOTS and RIMOTS is about 12th magnitude. From the Fig. 9 and Fig. 10, we found that the time variation of detected meteors by camera lens have the same trend as that by visual observation. However, its peak width at half height is longer than that of visual meteor. Further, the peak width at half height is wider as the magnitude of meteor is fainter.

Fig. 11 shows the 30 minutes unit moving average of the flux of faint meteors by AKENO 20 cm telescope. This magnitude indicates the Mccd. The peak flux is $6 \times 10^{-4}\text{km}^2\text{s}^{-1}$.

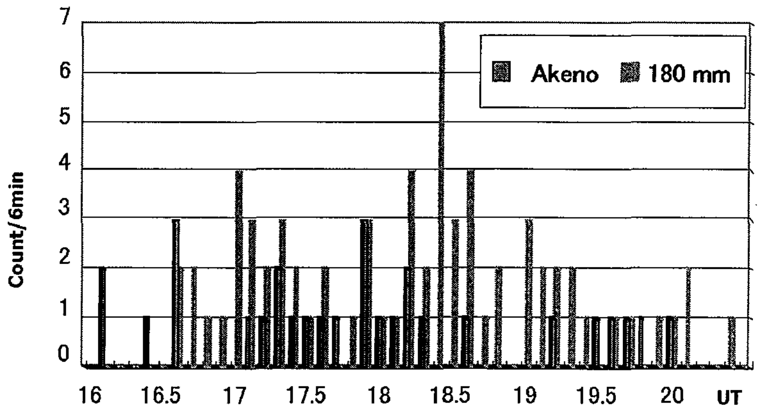

Fig. 9: Time variation of telephoto lens obs.

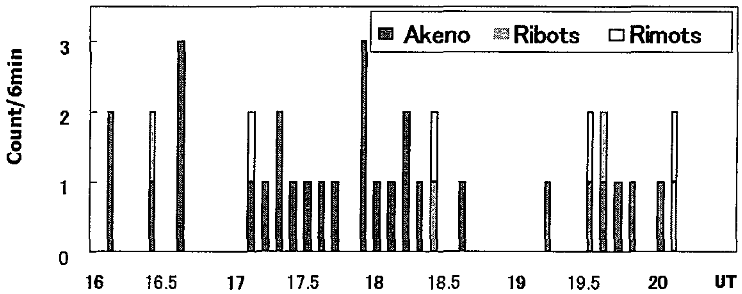

Fig. 10: Time variation of telescopic observation.

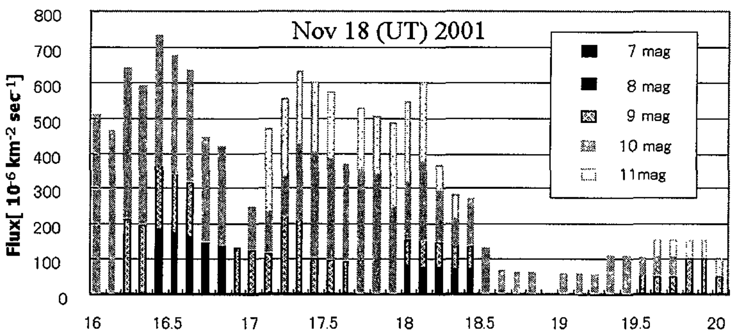

Fig. 11: RIBOTS

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

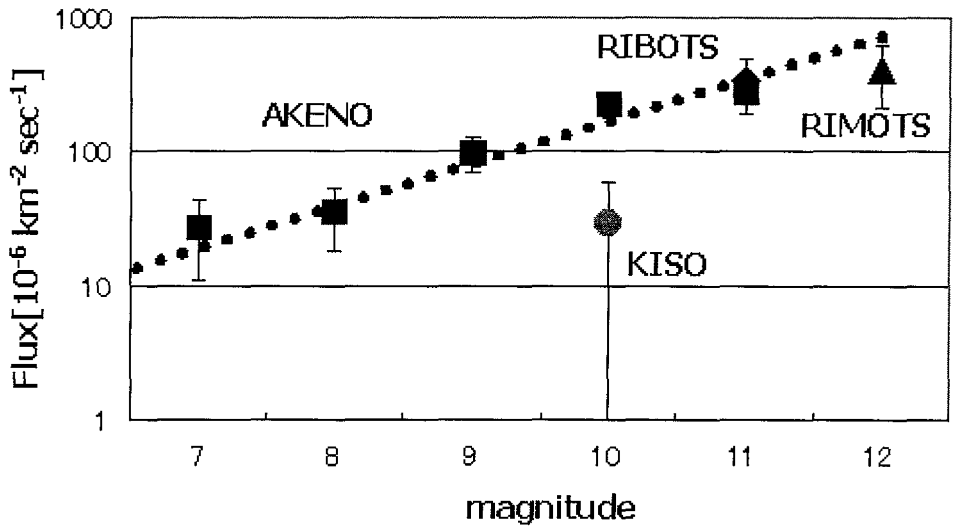

Fig. 12: Flux of faint meteors

4-rev trail.

We ontained 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. 12. A square indicates the flux by AKENO 20 cm, and a triangle, an inverse triangle, a circle indicate the flux by RIBOTS, RIMOTS, and KISO Schmidt, respectively. From Fig. 12, 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 $4.3 \times 10^{-4}\text{km}^{-2}\text{s}^{-2}(\text{mag} \leq +12)$.

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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