The 2001 Leonids Meteor Storm 2001 over Japan

Hiroshi Ogawa and Shigeo Uchiyama

In 2001, many Japanese observers saw a Leonids meteor storm on November 18 UT. During this event, although the parent comet (55P/Tempel-Tuttle) had passed three years ago, many fireballs, trains, and meteors were observed. The maximum of Leonids activity was a HR of 2300 and a ZHR of 4500 around 18^h10^m UT on November 18. The Leonids peak in 2001 was very flat. Therefore, the high activity lasted for a long time. We also analyzed ZHRs per magnitude class. We found that the ZHR for fireballs of magnitude −2 or brighter was nearly constant. So, no increase of fireballs was seen because of the encounter of the various dust trails.

1. Introduction

In 2001, the Leonid meteor stream was expected to show us its most impressive appearance of this epoch thusfar. Many researchers published predictions. Robert McNaught and David Asher predicted that the Earth encountered three main dust trails [1]. Other researchers, Esko Lyytinen and Van Flandern scrutinized seven dust trails [2]. Both researchers predicted the main peak to occur around 18^h00^m–18^h20^m UT on November 18. Hence, the best observational sites were in East Asia and Australia. Japan was one of the best places, geographically. The ZHR prediction of ZHR was about 7600–8000 [3,4].

First, the Earth would encounter the 1766 dust trail in North and South America, and then the 1699 and 1866 dust trails in East Asia and Australia.

In Japan, many observers prepared for the Leonids big appearance. We searched for the best place taking into account the weather, light pollution, etc. On the maximum night (November 18 UT), we saw a Leonids meteor storm. Members of the general public saw the storm, too. Also, several projects were set up for the 2001 Leonids (visual, radio, video, photo, etc.). We observed by each observational method. Many useful data could be obtained. These data are being collected and analyzed now. Actually, some of the visual and radio meteor observations have already been analyzed.

2. Observations

Many observers prepared themselves in order to catch the Leonid meteor storm. Observational projects or networks were set up and all observational methods were used.

Visual observation is the major observational method. The *Nippon Meteor Society* (*NMS*) recommended a standard format for the Leonid reports. This format required date, start time, end time, effective observational time, the number of Leonid meteors seen, limiting magnitude, cloudiness, observational site, field of view, and name of observer. The time interval was not decided upon, but we recommended 5-minute intervals. Some observers reported 1-minute intervals. We collected information about meteor magnitudes every 30 minutes.

Via the *Nippon Meteor Society*, 72 observers reported flash data. The total number of observations up to now is 2145, but more observational data will be reported. Besides, about 2000 high school students in Japan observed the Leonids during the same night. This project is called Astro-Classroom for High-School Students of the World (Astro-HS) [5].

Also, about 80 radio meteor observers registered Leonids since November 1 (Leonids 2001 Project by Radio Meteor Observation, coordinated by Hiroshi Ogawa) [6]. Mr. Daiyu Ito and Mr. Yasuo Shiba set up the network for photographic observation, and Mr. Masayuki Toda and Mr. Masayuki Yamamoto set up the meteor train observing campaign. Besides these efforts, video observations were made. In the "Astro-Classroom for High School Student of the World" project, high-school students observed visually, by radio, and by video observation. In particular, video observation by high-school students were carried out at 40 sites.

3. Results

HR and ZHR curve of the 2001 Leonids from visual observations

Visual observational data were reported by 72 members (2145 entries). For the period November 10–24, they are summarized in Table 1 and Figure 1. the ZHRs are calculated by the usual formula, taking $r = 2.2$ and $\gamma = 1$. The total observing time amounts to 14 788 minutes, or more than 246 hours, and the total number of Leonids seen to 131 957.

Table 1 – Daily Leonid result from visual observations. N_{data} is the number of data entries; the ZHR was calculated with $r = 2.2$ and $\gamma = 1.0$.

Time (UT)	N_{data}	LEO	T_{eff}	$\overline{\text{HR}}$	$\overline{\text{ZHR}}$
Nov 10, 18^h00^m	11	60	558^m	6	10
Nov 11, 18^h00^m	1	3	60^m	3	19
Nov 12, 18^h00^m	2	24	100^m	15	22
Nov 13, 18^h00^m	3	33	180^m	11	23
Nov 14, 18^h00^m	6	71	360^m	12	19
Nov 15, 18^h00^m	4	72	223^m	20	37
Nov 16, 18^h00^m	22	157	993^m	9	31
Nov 17, 18^h00^m	70	521	2098^m	17	73
Nov 18, 18^h00^m	1774	130562	8576^m	1191	2478
Nov 19, 18^h00^m	14	97	180^m	20	65
Nov 20, 18^h00^m	2	41	120^m	21	33
Nov 21, 18^h00^m	6	112	360^m	19	17
Nov 22, 18^h00^m	4	57	240^m	11	14
Nov 23, 18^h00^m	6	80	360^m	10	12
Nov 24, 18^h00^m	7	67	380^m	11	12

The observers were as follows:

Atsushi Kisanuki, Akemi Oono, Daisuke Ishikawa, Daiyu Ito, Hidekatsu Mizoguchi, Hideki Yasui, Hirokazu Fukushima, Hiromichi Yoshidome, Hiroshi Ogawa, Hiroshi Yamamoto, Hirotaka Serizawa, Hiroyuki Katoh, Hiroyuki Kodama, Hiroyuki Nishimoto, Hiroyuki Okayasu, Hiroyuki Shioi, Hitoshi Izumi, Ikuko Yamamoto, Karimu Kuragaki, Katsuhiko Nozaki, Katsuhiro Yoshizaki, Kazuaki Shiotani, Kazuhiro Osada, Kazuhiro Sumie, Kazumi Terakubo, Keiko Higuchi, Ken-Ichi Fushimi, Kenya Kawabata, Kiyohide Nakamura, Koetsu Sato, Kouji Naniwada, Masaaki Yoshimura, Masafumi Suzuki, Masahide Nishihashi, Masumi Shimizu, Mikiya Sato, Minoru Shimizu, Mitsuaki Kato, Mitsue Sasaoka, Misaki Kanetaka, Miyuki Ozawa, Naoto Mawatari, Norihiro Nishitani, Noriko Yoshimura, Risa Fujimoto, Ryousuke Morita, Sachiko Akiyama, Seiichi Yoshida, Seishiro Jin, Shigeo Uchiyama, Shin-ichiro Izuhara, Shinichiro Yanagi, Shoichi Tanaka, Shouhei Usui, Takashi Sekiguchi, Takuya Kashiki, Takuya Maruyama, Tatsuya Yamane, Tetsuya Nakamura, Tomoko Sato, Tomomi Jin, Tooru Nishino, Tsukoukou Tenmonbu, Wakaba Kobayashi, Yasuhiro Tonomura, Yasuko Toya, Yasuo Hayami, Yasushi Inagaki, Yoko Yamanami, Yuiko Watamoto, Yukichi Hattori, and Yumi Izuhara.

On November 15 UT (the morning of November 16 in Japan), HR and ZHR increased. But next morning, although there were many observers, the HR and ZHR were smaller again. Also, there were more bright meteors on November 15 than on November 16.

Table 2 and Figure 2 contain data for every 5 minutes.

From these results, the maximum of the Leonids in 2001 occurred on November 18, 18^h10^m UT, $\lambda_\odot = 236\overset{\circ}{.}457$ (J2000.0). The trend towards maximum had already begun when the radiant rose (around 14^h UT). When the radiant was very low, many long Leonids meteors were observed. Then, the number of meteors steadily increased. Around 17^h25^m UT, the value of the HR arrived at 1000. The activity stayed above that threshold until 19^h50^m UT, i.e., for two and a half hours. An HR of 2000 or more was observerd from 18^h00^m UT until 18^h25^m UT, i.e., for about 25 minutes. After maximum, high activity kept continued with ZHR-levels around 1700. From 19^h50^m onward, twilight began in Japan, but many observers still saw a lot of meteors during twilight.

Table 2 – Visual Leonid results for five-minute intervals (see also Table 1).

Time (UT)	$\lambda_\odot$ (J2000.0)	$N_{\rm data}$	LEO	$T_{\rm eff}$	$\overline{\rm HR}$	$\overline{\rm ZHR}$
Nov 18, 16^h00^m	236°366	16	170	63^m	192	663
Nov 18, 16^h05^m	236°369	24	381	114^m	264	862
Nov 18, 16^h10^m	236°373	23	408	113^m	297	837
Nov 18, 16^h15^m	236°376	29	561	164^m	313	949
Nov 18, 16^h20^m	236°380	24	423	96^m	338	916
Nov 18, 16^h25^m	236°383	27	576	135^m	358	963
Nov 18, 16^h30^m	236°387	28	785	172^m	373	1018
Nov 18, 16^h35^m	236°390	30	794	158^m	408	1183
Nov 18, 16^h40^m	236°394	29	666	122^m	411	1116
Nov 18, 16^h45^m	236°397	31	959	155^m	495	1352
Nov 18, 16^h50^m	236°401	26	730	110^m	538	1278
Nov 18, 16^h55^m	236°404	30	1100	142^m	613	1569
Nov 18, 17^h00^m	236°407	34	1123	129^m	646	1628
Nov 18, 17^h05^m	236°411	47	1661	245^m	551	1376
Nov 18, 17^h10^m	236°415	38	1674	168^m	793	1796
Nov 18, 17^h15^m	236°418	42	2099	215^m	878	1946
Nov 18, 17^h20^m	236°422	40	2231	199^m	974	2134
Nov 18, 17^h25^m	236°425	51	3230	280^m	1002	2222
Nov 18, 17^h30^m	236°429	41	2575	161^m	1266	2744
Nov 18, 17^h35^m	236°432	48	3772	238^m	1319	3060
Nov 18, 17^h40^m	236°436	42	3409	177^m	1442	3174
Nov 18, 17^h45^m	236°439	44	3815	210^m	1463	3205
Nov 18, 17^h50^m	236°443	38	4266	194^m	1732	3645
Nov 18, 17^h55^m	236°446	39	4805	209^m	1884	4150
Nov 18, 18^h00^m	236°450	40	4890	183^m	2018	3908
Nov 18, 18^h05^m	236°453	51	7840	384^m	1837	3819
Nov 18, 18^h10^m	236°457	49	6709	213^m	2278	4520
Nov 18, 18^h15^m	236°460	54	7428	257^m	2119	4499
Nov 18, 18^h20^m	236°464	49	6630	222^m	2131	4281
Nov 18, 18^h25^m	236°467	55	7715	280^m	1976	4083
Nov 18, 18^h30^m	236°471	49	5202	220^m	1714	3444
Nov 18, 18^h35^m	236°474	47	4909	219^m	1626	3266
Nov 18, 18^h40^m	236°478	46	4315	189^m	1651	3150
Nov 18, 18^h45^m	236°481	54	5540	278^m	1506	2992
Nov 18, 18^h50^m	236°485	36	3211	164^m	1431	2619
Nov 18, 18^h55^m	236°488	39	2956	203^m	1149	2098
Nov 18, 19^h00^m	236°492	25	1939	116^m	1371	2275
Nov 18, 19^h05^m	236°495	33	2325	163^m	1182	2138
Nov 18, 19^h10^m	236°499	30	1621	122^m	1093	1798
Nov 18, 19^h15^m	236°502	28	1573	133^m	1090	1608
Nov 18, 19^h20^m	236°506	29	1677	126^m	1135	1862
Nov 18, 19^h25^m	236°509	31	1798	145^m	1097	1666
Nov 18, 19^h30^m	236°513	26	1445	104^m	1179	1768
Nov 18, 19^h35^m	236°516	27	1629	125^m	1188	1753
Nov 18, 19^h40^m	236°520	23	1194	96^m	1186	1806
Nov 18, 19^h45^m	236°523	26	1431	115^m	1157	1821
Nov 18, 19^h50^m	236°527	17	794	99^m	547	1684
Nov 18, 19^h55^m	236°530	17	714	92^m	484	1357
Nov 18, 20^h00^m	236°534	8	680	40^m	907	2116
Nov 18, 20^h05^m	236°537	9	635	45^m	847	1966
Nov 18, 20^h10^m	236°541	9	567	45^m	756	1907
Nov 18, 20^h15^m	236°544	8	407	40^m	611	1757
Nov 18, 20^h20^m	236°548	6	254	30^m	508	1350
Nov 18, 20^h25^m	236°551	6	135	30^m	270	1082
Nov 18, 20^h30^m	236°555	4	46	20^m	138	681
Nov 18, 20^h35^m	236°558	4	39	20^m	117	827
Nov 18, 20^h40^m	236°562	3	12	15^m	48	802
Nov 18, 20^h45^m	236°565	3	17	15^m	68	1277
Nov 18, 20^h50^m	236°569	3	14	15^m	56	1223
Nov 18, 20^h55^m	236°572	2	12	10^m	72	1274

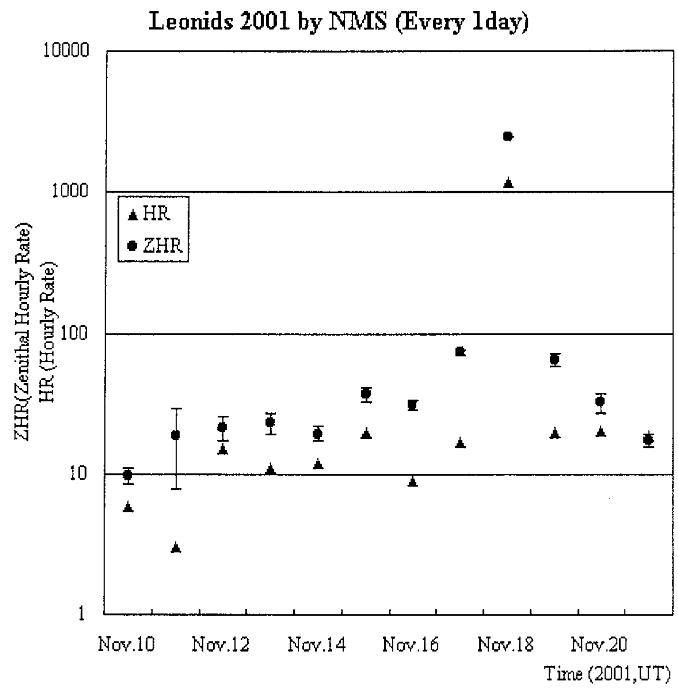

Figure 1 – HR and ZHR curve of the 20001 Leonids from visual observations. The vertical axis is logarithmic.

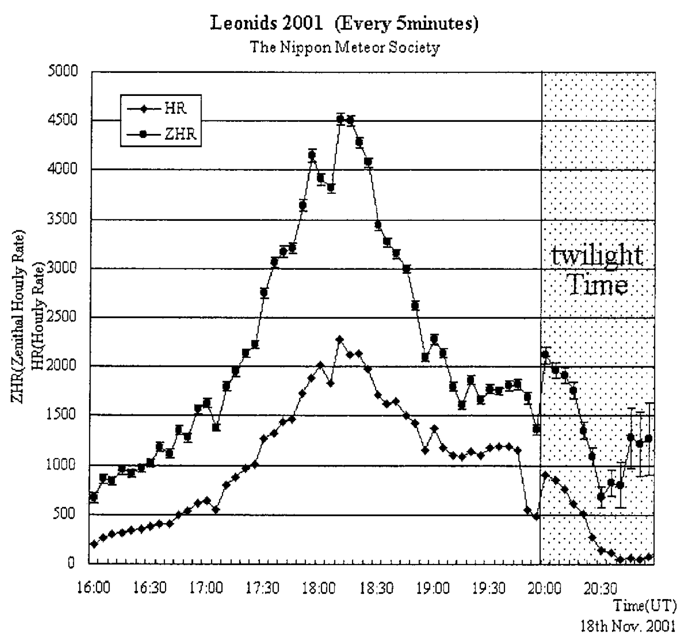

Figure 2 – HR and ZHR curve of the 2001 Leonids every five minutes from visual observations. The right side is the twilight time.

There are two clear peaks. One is the main peak, at $18^{h}10^{m}$ UT. The other peak is at $17^{h}50^{m}$ UT. The main peak is most probably related to the 1866 (4-rev.) dust trail. Other peaks of more dust trails are not clear. However, some results by some observers from one-minute interval graphs indicate another peak around $17^{h}35^{m}$ UT. Perhaps, this peak is caused by the 1699 (7-rev.) dust trail (9-rev.).

The 17^h50^m UT peak may be due to another dust trail or may be part of main peak. Lyytinen and Van Flandern predicted the 1699 (9-rev.) dust trail encounter at 18^h08^m UT. Therefore, it is possible that this peak is the 1699 dust trail. Like these, predictions of Leonids 2001 by many researchers resemble observational results.

ZHRs per magnitude class

Many observers reported remarkably more bright meteors between 15^h and 17^h UT than between 18^h and 19^h on the Leonid storm night of November 18. Therefore, we analyzed magnitude distribution data reported from Japanese observers, and calculated ZHRs per magnitude class, using the formulae ZHR $= NC/T_{\text{eff}}$ and $C = KF/\sin h$, with N the number of meteors in the magnitude class under consideration, T_{eff} the effective observing time, F the possible field obstruction factor, h the radiant elevation, and $K = P_{6.5}/P_{\text{lm}}$, with $P_{6.5}$ and P_{lm} are the perception probability for the magnitude class under consideration when the limiting magnitude is 6.5 and the observed limiting magnitude, respectively [8]. These ZHRs are then averaged using a weight factor of T_{eff}/C.

The following persons contributed to this analysis:

Kazuhiro Osada, Takema Hashimoto, Kenya Kawabata, Koetsu Sato, Minoru Shimizu, Masumi Shimizu, Hiroyuki Okayasu, Masayuki Oka, Daiyu Ito, Syoichi Tanaka, and Shigeo Uchiyama.

Koetsu Sato and Masumi Shimizu observed from China. Others were in Japan. Because Kazuhiro Osada has a wide field of view, he counts exceptional many meteors, not only faint ones but also brighter ons. He was even not able to record magnitudes between 18^h00^m and 19^h00^m UT, because he counted so many meteors (126 in one minute at maximum). So, we used individual perception correction for him only.

Results are shown in Tables 3 and 4 and in Figure 3.

Table 3 – Numbers of Leonids in each magnitude class on November 18.

Time (UT)	Obs	-3^-	-2	-1	0	+1	+2	+3	$\overline{\text{Lm}}$	$\overline{h}$
15^h45^m	6	14	17	18	33	48	77	77	5.60	19°9
16^h15^m	10	62	58	75	88	124	187	253	5.71	24°5
16^h45^m	10	86	78	96	122	234	281	281	5.66	29°0
17^h15^m	10	88	83	170	302	481	640	758	5.65	35°2
17^h45^m	9	60	100	205	358	640	951	1252	5.68	42°1
18^h15^m	9	50	66	134	264	584	1057	1049	5.49	46°7
18^h45^m	8	40	78	119	223	407	861	904	5.50	52°4
19^h15^m	10	105	115	201	326	480	758	876	5.57	58°5
19^h45^m	11	73	109	167	249	408	583	609	5.56	63°5

Table 4 – Average 2001 Leonid ZHRs per magnitude class on November 18. Solar longitudes refer to J2000.0

Time (UT)	$\lambda_\odot$	-3^-	-2	-1	0	+1	+2	+3
15^h45^m	236°354	12	15	16	34	54	115	112
16^h15^m	236°375	22	25	36	42	64	124	184
16^h45^m	236°396	23	29	36	55	117	177	183
17^h15^m	236°417	18	18	42	89	162	303	386
17^h45^m	236°438	9	21	47	101	218	531	642
18^h15^m	236°459	19	25	55	111	272	652	825
18^h45^m	236°480	14	27	44	86	175	494	658
19^h15^m	236°501	19	21	43	74	122	283	361
19^h45^m	236°522	14	24	39	61	117	245	293

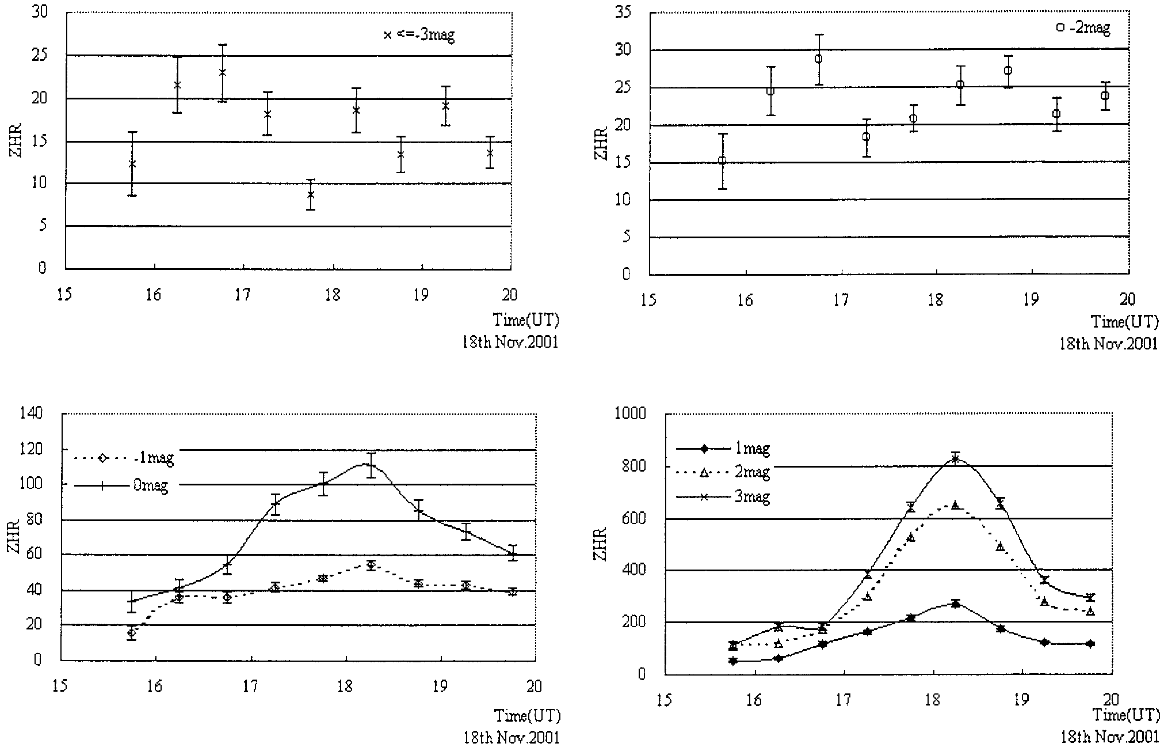

Figure 3 – ZHR profiles for Leonids of magnitude −3 or brighter (*left top*), magnitude −2 (*right top*), magnitude −1 and 0 (*bottom left*), and magnitude +1 to +3 (*bottom right*).

We only used data with radiant elevation over 15°. Also, we made no calculate for meteors of magnitude +4 or fainter, because they are strongly affected by limiting magnitude and individual perception. Figure 3, *bottom left* and *bottom right*, show the rise, peak, and fall of activity for meteors between magnitudes −1 to +3. The peak around 18^h15^m UT was caused by the 1866 and 1699 dust trails [1,4]. Figure 3, *top left* and *top right*, however, show that the activity of meteors of magnitude −2 or brighter appears to be nearly constant. It is difficult to assume that bigger meteoroids were diffused more widely than smaller one. Magnitude estimation errors are unlikely, as Sirius (−1.5) and Jupiter(−2.5) were in the sky. We therefore conclude that meteors of magnitude −2 or brighter meteors were caused by the background and that the 1866 and 1699 trails contain almost no meteoroids resulting in meteors of magnitude −2 or brighter.

As mentioned above, fainter meteors show a clear rise, peak, and fall. Now, we compare their rise and fall ratio. Therefore, we normalized the ZHR graphs for each magnitude class by reducing the average ZHR to 1. (Figure 4). The result of this procedure shows that rise and fall rates for meteors of magnitudes +1 to +3 are almost the same and steeper than for meteors of magnitude −1 or 0. The Earth encountered the 1866 and 1699 dust trails simultaneously, so we cannot guess how these trails affected the ZHRs for each magnitude class separately. However, our result indicates that these trails consist of mainly of meteoroids producing meteors of magnitude +1 or fainter.

Radio meteor observations

In the context of the Leonids 2001 project by radio meteor observation, many data were reported. The number of observing sites is about 80 in 13 countries. In Japan only, the number of radio meteor observer sites is already about 65. Most of the Japanese observers use the 53.750 MHz frequency. Starting on November 15 UT, some long echoes were observed. On the evening on November 17 UT, many long echoes were observed. After that, around 8^h00^m UT on November 18, the number of echoes in the USA increased, indicating the approach of the the first peak, which occurred around 10^h30^m–11^h00^m UT.

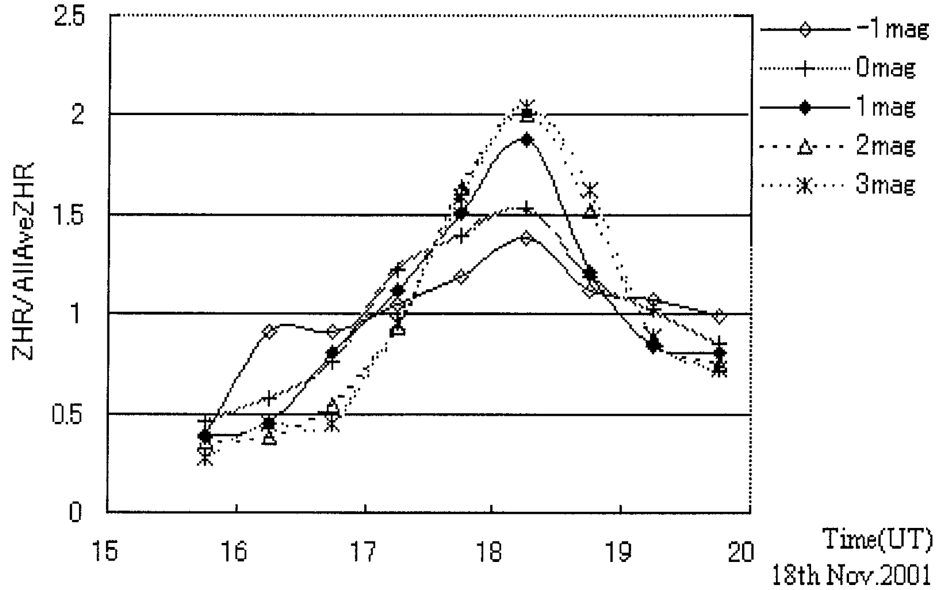

Figure 4 – Relative ZHR profiles for meteors of magnitudes between −1 and +3. Average ZHRs of each class were normalized to the value 1.

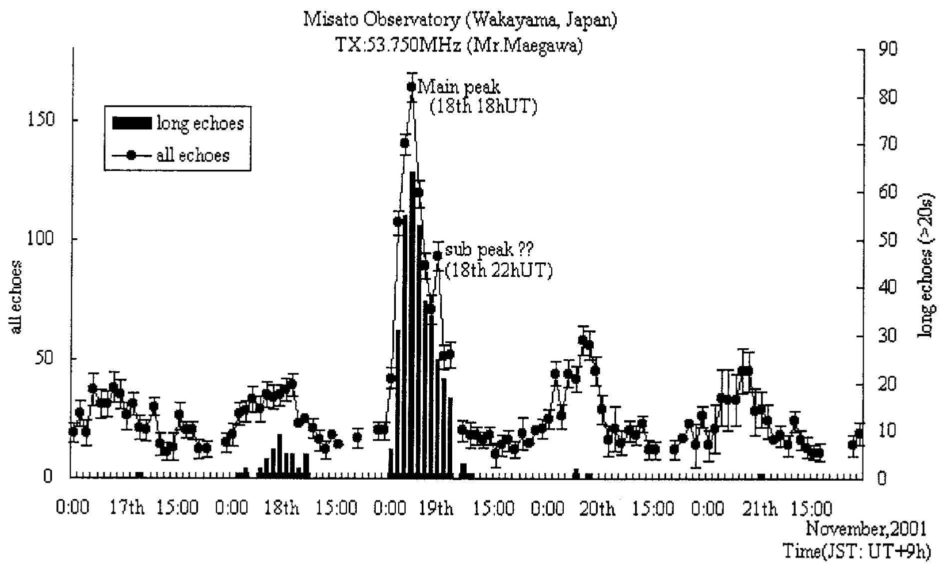

Figure 5 – Result of radio meteor observations of the 2001 Leonids by the Misato Observatory.

Around 14^h00^m UT, the number of echoes increased clearly in Japan. Then, from 15^h30^m UT onward, many long echoes were observed. One hour later, around 16^h30^m UT, most radio meteor observers could no longer count the number of echoes because of intermittent long echoes. Figure 5 is the graph by Misato Observatory (Wakayama, Japan). Notice there is an additional peak at 22^h UT. Also, Miss Kayo Miyao found this unexpected peak. Tetsuharu Sasaki, Seiji Fukushima, Toshihiko Masaoka, and Okayama-Asahi High School observed this peak, too. Other observers could not count the number of echoes because too many long echoes were observed. Exactly the fact that until around 21^h00^m UT, almost none of the observers could count the number of echoes, and that counting resumed around 22^h00^m UT could have caused this additional peak. We are now discussing the reality of this peak.

4. Discussion

At this time, the 2001 Leonids leave many questions.

First, the activity of the 2001 Leonids remained high for al long time. Generally speaking, the peak of the Leonids is supposed to be sharp, because this is a young meteor stream. At this occasion, however, we saw that high activity (ZHRs of 1000 and more) persisted for more than three hours (from 17^h30^m UT on November 18). In Japan, morning twilight began at 20^h00^m UT, so from our visual observations only, it is hard to tell how long exactly high activity lasted.

Radio meteor observations indicate that high activity lasted from 16^h30^m UT of November 18 to 0^h00^m UT on November 19 (i.e., for seven and a half hours). Why was this high activity seen? Also, the results of the *Nippon Meteor Society* clearly show the main peak. This peak was probably caused by the 1866 dust trail. Other dust trail peaks were not clear, however, such as the 1699 dust trail peak. Where there any sub-peaks?

Next, the parent comet passed three years ago. Therefore, big particles that can give rise to fireballs were gone with the parent comet. However, many fireballs and meteor trains were observed. There is the possibility of a resonance phenomenon. There are 14 resonance areas on the orbit of Tempel-Tuttle. In 1998, we encountered one of them. The next resonance area was supposed to be encountered in 2001 [7].

Besides, many strange meteors and phenomenon were observed. For example, about 50 meteors were observed at the same time; a meteor faded and brightened again (or were this two meteors?), wide radiant, etc. We are discussing many questions now.

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Authors' addresses

Hiroshi Ogawa, The Nippon Meteor Society, 36-47 Nakane, Kutsukake, Toyoake, Aichi, 470-1101, Japan, e-mail `ogawa@nms.gr.jp`.

Shigeo Uchiyama, The Nippon Meteor Society, 453 Kashiwa, Kashiwa, Chiba, 277-0005, Japan, e-mail `uchiyama@nms.gr.jp`.