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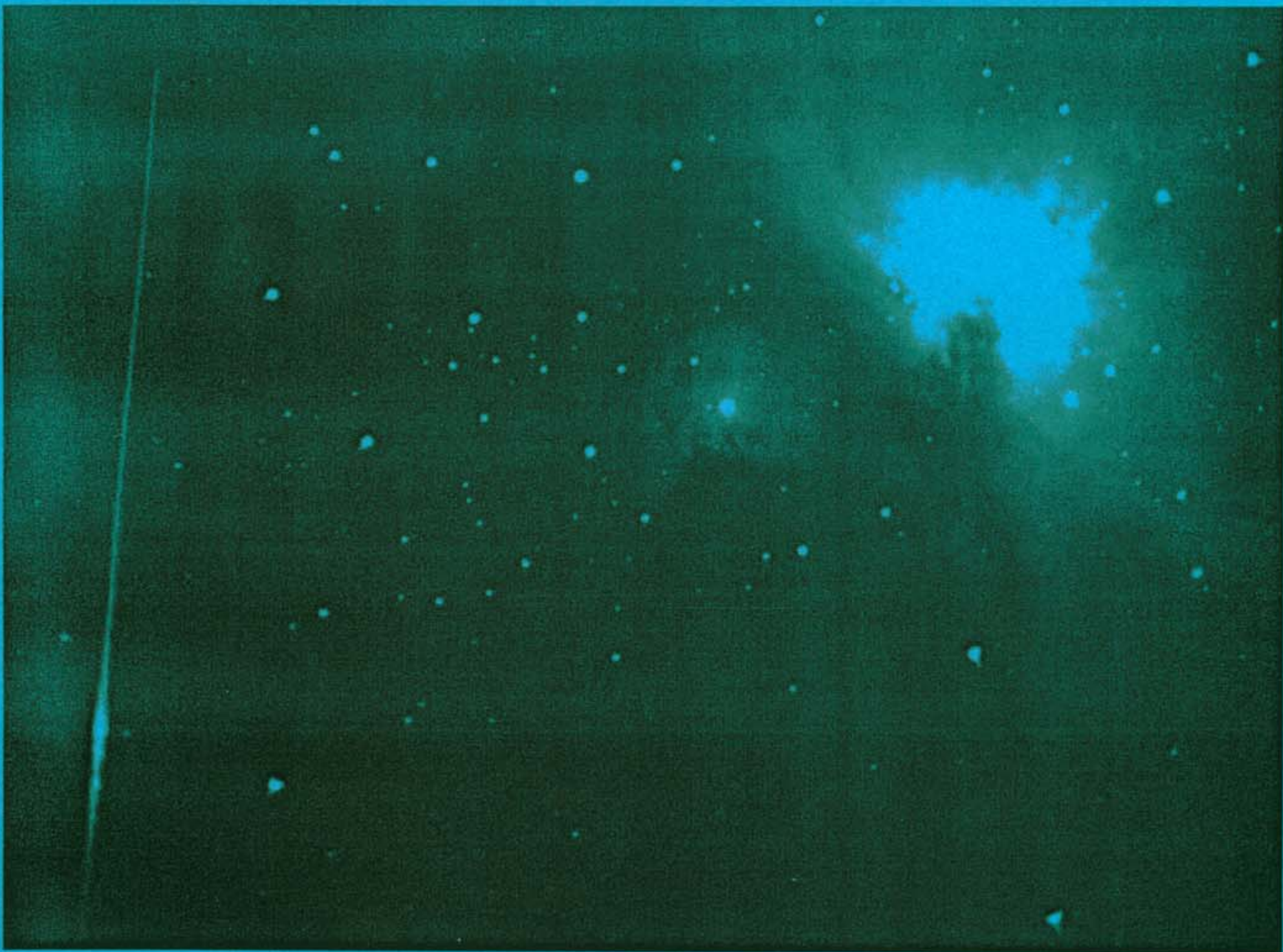

This amazing snap-shot of the Orion nebula M42 and a meteor was taken by Alberto Castro-Tirado (INTA/LAEFF) and Peter Patas within the *Spanish Fireball Network* (comm. by Josep Trigo-Rodríguez). The photo was taken on March 19, 1999 from the Network's CCD station in El Arenosillo (Huelva) at $21^{\mathrm{h}}02^{\mathrm{m}}$ UT. The exposure time was only 10 seconds! A telescope SC 30 cm (LX 2000) with $f/3.3$ and an ST-8 CCD camera was used; no filter was applied.

In this issue:

- Correlating video and visual observations
- Analysis of 2001 visual Leonids from Asia
- Piscids 2001 from video and visual data
- More on the 2001 Leonids

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WGN, Vol. 30, No. 3, June 2002, pp. 45–82

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Useful Information

The August issue *(WGN 30:4)*

The Journal offers the unique chance to publish a wide range of articles—from high-end particle simulations to useful observing experiences. Remember that the success of meteor science, very obvious recently in connection with the Leonids, is based on the combination of amateur and professional work. A personal description of observing experiences is as much required as a prediction of a Leonid meteor storm! The *August issue* will be edited in the beginning of August 2002. Contributions should be sent to *Marc Gyssens* before July 10.

Subscriptions and ordering of publications

Volume 30 (2002) of *WGN* is expected to contain at least 240 pages and costs 20 EUR, including non-airmail delivery. Ordering other *IMO* publications is done in the same way as paying subscription/membership fees. Changes of address and complaints about not receiving *WGN* should be addressed to the Treasurer, Ina Rendtel.

All addresses can be found on the inside of the back cover.

The 2002 International Meteor Conference

Frombork, September 26–29, 2002

Mariusz Wiśniewski, Arkadiusz Olech, Marcin Gajos, Kamil Złoczewski, and Aleksander Trofimowicz

The *IMC* 2002 will take place in Frombork—the city of Nicolaus Copernicus. The place for the *IMC* was not chosen accidentally. Frombork is a beautiful small town placed near the Vistula Bay with a nice view on the Vistula Sand-bar. The most important part of the town is the Cathedral Hill with many historical monuments including the Gothic cathedral, and the Copernicus tower, where the great astronomer was making his observations.

The 2002 *IMC* will take place in the days September 26–29, and it will be organized by the Polish *Comets and Meteors Workshop (CMW)*. The *CMW* is an astronomical organization founded in 1987. Its main goal is to coordinate the comet and meteor observations in Poland. Since 1994 the *CMW* is one of the most active groups of visual observers in the world.

Detailed information about getting to Frombork, the *IMC* hotel, the reduced fees and other important things are available at our web pages: `http://www.astrouw.edu.pl/~olech/pkim/imc2002/imc.html`. The registration fee including lodging, all meals, and the excursion is 100 EUR. **The deadline for the registration at 100 EUR is August 1, 2002.** We will provide the bus transport from Gdańsk to Frombork. If you have any problems, questions, suggestions or requirements do not hesitate to contact *Mariusz Wiśniewski, ul. Afrykanska 10/8, 03-966 Warszawa, Poland*, e-mail: `pkim@astrouw.edu.pl`, phone: +48-22-672-38-81, mobile phone: +48-501-02-45-49.

Renewal Information for IMO Membership/WGN Subscription

Ina Rendtel and Marc Gyssens

General information—The membership fees/subscription rates, were set to 20 EUR/USD for 2002. The increase in EUR accounts for increased printing costs. Please find the full price list in Table 1. You can become a supporting member by adding at least 10 EUR/USD per year to your membership.

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Type of subscription	2002	2002 + 2003
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Combined subscription (*WGN*, Report)	30 EUR/USD	60 EUR/USD
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Regular subscription with airmail delivery	40 EUR/USD	80 EUR/USD
Combined subscription with airmail delivery for *WGN* only	50 EUR/USD	100 EUR/USD

Letters to the Editor

Correlating visual and video observations

Alastair McBeath

Some recent articles in *WGN*, notably on video Leonid results from 2001 [1,2] have brought the problem of the discrepancy between observed visual and video magnitudes back to mind. I've commented on this in these pages before, most recently in [3]. The matter was first reported as a systematic problem with visual observations in 1994, specifically that visual estimates were too faint by $\sim$ 1–2 magnitudes, e.g. [4], although given the long history of examination of visual meteor results, this seems extremely unlikely. Subsequent investigations by Sirko Molau [5] suggested the accuracy of video magnitude measurements were systematically affected only by the angular velocity of the meteors detected, and that this actually made the video meteors appear fainter than they really were, thus the discrepancy with visual observations was apparently still worse!

The problem is undoubtedly related to the excess sensitivity of meteor video systems to infrared radiation (IR), compared to the human eye, which is effectively blind to IR. Tests of video systems for spectral sensitivity in [2,5] have so far used only stars. There are grounds for thinking this may not be an adequate source for comparison with meteors, which occur within the Earth's atmosphere. Infrared meteors have been photographed from the Earth's surface using IR-sensitive still camera film, for instance, while stellar IR investigations need high-altitude balloon- or aircraft-borne instruments or, more usefully, Earth-orbiting satellites.

Although it is often assumed almost all IR is absorbed by the Earth's atmosphere, there are several narrow spectral windows which allow some IR through. In addition, atmospheric IR absorption cuts out half the original amount only around 30–45 km altitude (wavelength-dependent), and for parts of the near-infrared in particular, this halving is achieved much closer to the surface, around 10–20 km altitude or below. This may help make the IR component of meteor spectra easier for video systems to detect than that from very distant stellar sources, especially given the enhanced video IR sensitivity, something which needs more investigation, particularly with regard to just how much IR meteors typically produce, and at what wavelengths.

For now, we can say that there is a definite and relatively consistent discrepancy between many perceived visual and video meteor brightnesses, such that video meteors typically appear brighter than a visual observer would estimate them by around 1.5 ± 0.5 magnitudes. This seems to have had the effect of making some recent video meteor events more or less undetectable for visual observers (e.g. the 2000 Ursid outburst—[3] and references). While video is a much more objective technique than visual observing, we should not assume that just because something has been detected by video, this is always automatically more correct than what the visual observers have found. The two techniques should be used to complement one another, not compete, and caution, as ever, should be employed in interpreting video results, as already with visual data.

References

[1] M. Beech, A. Illingworth, "SSFA 2001 Leonid Fireball Observations", *WGN* 29:6 (December 2001), pp. 200–205.

[2] S. Molau, P.S. Gural, O. Okamura, "Comparison of the 'American' and the 'Asian' 2001 Leonid Meteor Storm", *WGN* 30:1/2 (February/April 2002), pp. 3–21.

[3] A. McBeath, "The 2001 Ursids", (letter), *WGN* 29:3 (June 2001), pp. 67–68.

[4] S. Molau, "MOVIE—Analysis of Video Meteors", in: A. Knöfel, P. Roggemans (eds), *Proceedings IMC Belogradchik 1994*, IMO, 1995, pp. 51–61.

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May 22, 2002

Estimated ZHR Profiles of the 4-Revolution and 9-Revolution Dust Trails during the 2001 Leonid Meteor Storm

Shigeo Uchiyama

Many Japanese observers observed the Leonid meteor storm of 18/19 November 2001. It is thought that the storm was caused by the 4-revolution (1866) and 9-revolution (1699) dust trails of comet 55P/Tempel-Tuttle. Since the Earth encountered these trails at almost the same time, it is difficult to separate activities of these trails from the ZHR profile. However, the population indices of these trails are not the same. By estimating the population indices of these trails, the individual ZHR profiles of these trails can be estimated.

1. Introduction

It was predicted that the 4-revolution (1866) and 9-revolution (1699) dust trails would cause a Leonid meteor storm on November 18-19, 2001, and that the storm would be favorably seen in eastern Asia and Australia [1,2,3]. Many observers recorded the Leonid storm and ZHR profiles were determined [4,5]. I derived a ZHR profile, too (next Section). It is important to determine the activities of individual trails for the study of dust trails and the prediction for the 2002 Leonids. But the predicted peak times of the 4-rev and 9-rev trails were close and their meteors appeared at the same time, therefore it is almost impossible to separate the activities of individual trails from the ZHR profile.

It is expected that the population index r of the 9-rev trail is smaller than that of the 4-rev trail [3]. If their r-values are determined and if they did not change in the observing period, it is possible to estimate the activities of the individual trails from the magnitude data. Since their meteors appeared together, it is difficult to determine the r-values of individual trails. But their predicted peak times were not exactly the same time. The peak time of the 1699 trail was earlier, thus it is possible to estimate the r-values of individual trails to some degree.

In this work, I analyzed magnitude data reported by the following 12 Japanese observers:

> Takema Hashimoto (4.17 h), Daiyu Ito (2.69 h), Kenya Kawabata (3.33 h), Katsuhiko Mameta (3.55 h), Masayuki Oka (4.08 h), Hiroyuki Okayasu (3.5 h), Kazuhiro Osada (3.33 h), Koetsu Sato (3.16 h), Minoru Shimizu (4.47 h), Masumi Shimizu (3.6 h), Syoichi Tanaka (0.97 h), Shigeo Uchiyama (4.33 h).

Koetsu Sato and Masumi Shimizu observed at Shenyang, China, and the others observed in Japan. I used the data with radiant elevations above 15°. I did not apply topocentric time correction as described in [6], because the corrections did not exceed 1 minute in Japan, and did not exceed 2 minutes at Shenyang.

2. ZHR profile

In the previous paper [5], I got ZHRs per magnitude class. Here, I derived the ZHR by summing up ZHRs per magnitude class binned in 5-minute intervals. The result is available in Figure 1. The peak time is $18^{\mathrm{h}}17^{\mathrm{m}} \pm 3$ m UT, which corresponds to a solar longitude of $236\overset{\circ}{.}459 \pm 0.002$ (J2000.0), and the peak ZHR is 3120 ± 100. The peak ZHR that I derived is lower than the value in [5] and slightly lower than the value in [4]. I found a tendency that observers who did not record magnitudes counted larger number than observers who recorded magnitudes. That is possible when exceptionally many meteors appear. Therefore, that is why the ZHRs of this article are lower, I suppose. The ascending branch from half maximum to peak rates took 51 ± 4 minutes and the descending branch to half maximum lasted 41 ± 4 minutes. Then the full width at half maximum (FWHM) is 92 ± 6 minutes. It is thought that the peak was caused by the 4-rev trail mainly and the 9-rev trail encountered the Earth earlier. The reason of the ascending branch being longer may be the contribution of the 9-rev trail. However, it is difficult to separate each trail activity from the ZHR profile.

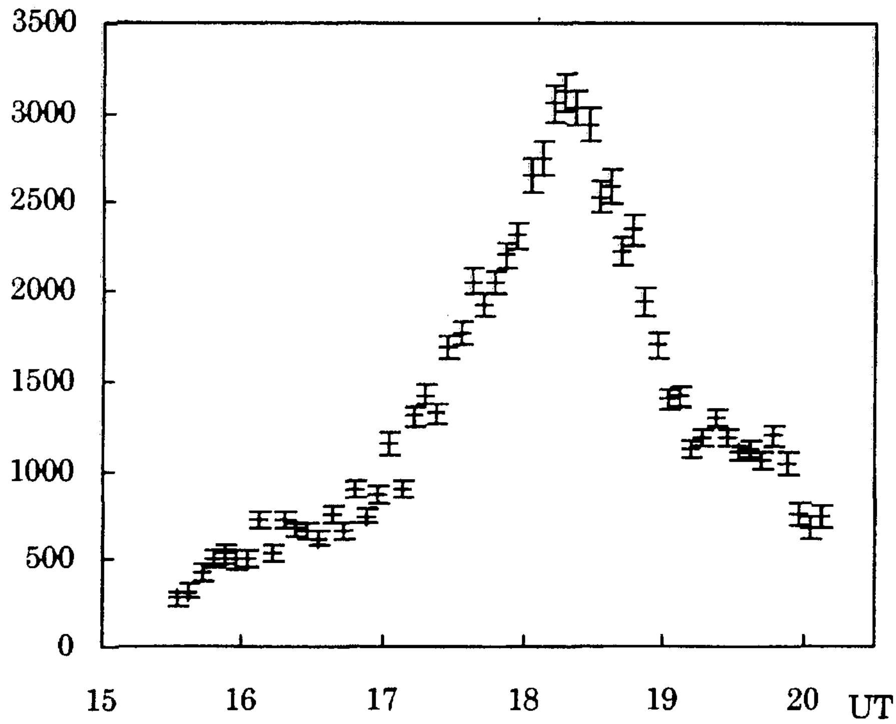

Figure 1 – Observed ZHR profile derived from data of 12 observers. The ZHRs are derived by summing up ZHRs per magnitude class binned in 5-minute intervals.

3. Population index for the magnitude range 0 – +4

Observed meteor numbers are not true meteor numbers. We must calculate the true zenithal hourly rate per magnitude class, $\mathrm{ZHR}_{\mathrm{t},m}$, to analyze the magnitude data. I obtained $\mathrm{ZHR}_{\mathrm{t},m}$ by the following formulae;

$$\mathrm{ZHR}_{\mathrm{t},m} = \frac{\sum_i N_m}{\sum_i (T_{\mathrm{eff},i}/C_{m,i})}$$

with

$$C_{m,i} = \frac{F_i}{P_{m,i} \times \sin h_{\mathrm{R},i}},$$

where N_m is the number of observed meteors in one magnitude class m, T_{eff} is the effective observing time, F is a possible field obstruction factor, P_m is the perception probability for the magnitude class [7], and h_{R} is the radiant elevation.

Figure 2 shows the relation between meteor magnitude and $\mathrm{ZHR}_{\mathrm{t},m}$ for various periods. The logarithmic scale of the vertical axis makes the relation almost linear.

In the previous article [5], I got ZHRs per magnitude class, and it was shown that the activity of bright meteors (magnitude −2 and brighter) was nearly constant. It is indicated that the 4- and 9-rev trails included few bright meteors. But the total ZHR of at least magnitude −2 meteors was around 40 which was too high for the annual activity of the Leonids. Therefore, it is indicated that there was a source of bright meteors. That might be old diffused trails or a resonance region, although I cannot conclude on that.

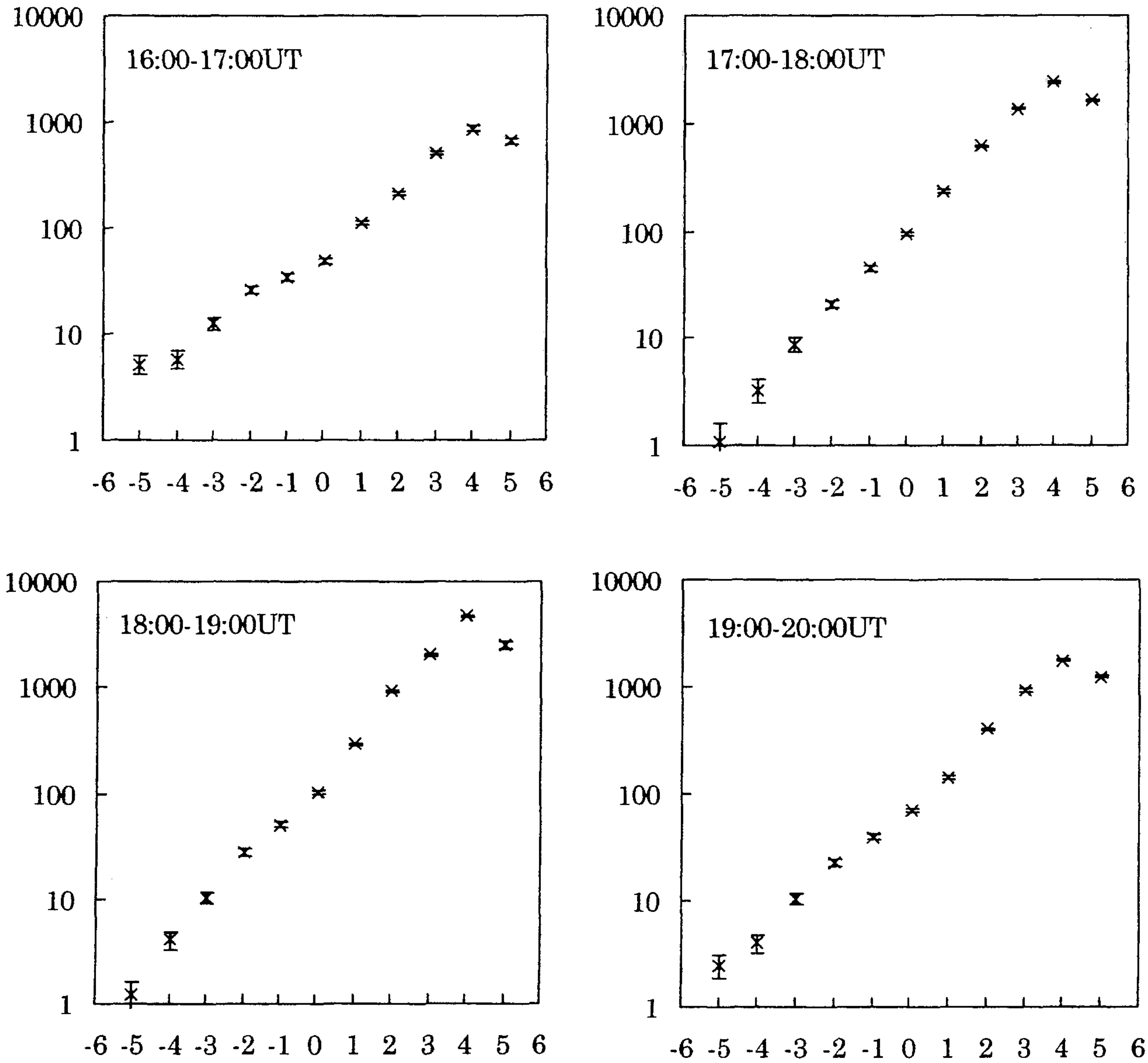

Figure 2 – Relation between meteor magnitude and $ZHR_{t,m}$ for various periods. The horizontal axis is the meteor magnitude, and the vertical axis is the logarithmic scale of $ZHR_{t,m}$. While $ZHR_{t,m}$ of the magnitude range 0 – +4 are good fits to straight lines, $ZHR_{t,m}$ of bright meteors are slightly larger than the values on the regression lines of the magnitude range 0 – +4.

Then it is thought that the Leonid storm contained meteors from five sources, (1) the 4-rev trail, (2) the 9-rev trail, (3) the 10- and 11-rev trails [1,2,3], (4) the annual background, and (5) a source of bright meteors.

Since the ZHR value was already above 280 at the beginning time of the analysis and was over 700 near then end time, the influence of the annual background activity can be neglected. As we want to know the activities of individual trails, we have to reduce the influence of the source of bright meteors. If you look at Figure 2 carefully, you can see that the $ZHR_{t,m}$ of the magnitude range 0 – +4 fits well to a straight line, and the numbers of bright meteors are slightly larger than the values on the regression lines for the magnitude range 0 – +4. They indicate that there were meteors by a source of bright meteors, too.

Then, I used the meteors of the magnitude range 0 – +4. It is thought that the numbers of meteors from a source of bright meteors would be much fewer than from the dust trails in this range.

Population indices for the magnitude range 0 – +4 are calculated by the regression method. On the left hand side of Figure 3 there is the result binned in 5-minute intervals and shows a large scatter. For the 2001 Leonids, storm level activity was expected, and too many meteors appeared actually, thus many observers counted meteor numbers and did not record magnitude data. Only 12 observers reported detailed magnitude data, and the amount of data is insufficient for a short-term resolution analysis such as 5-minute intervals. On the right hand side of Figure 3 there is the result binned in 30-minute intervals shifted by 15 minutes.

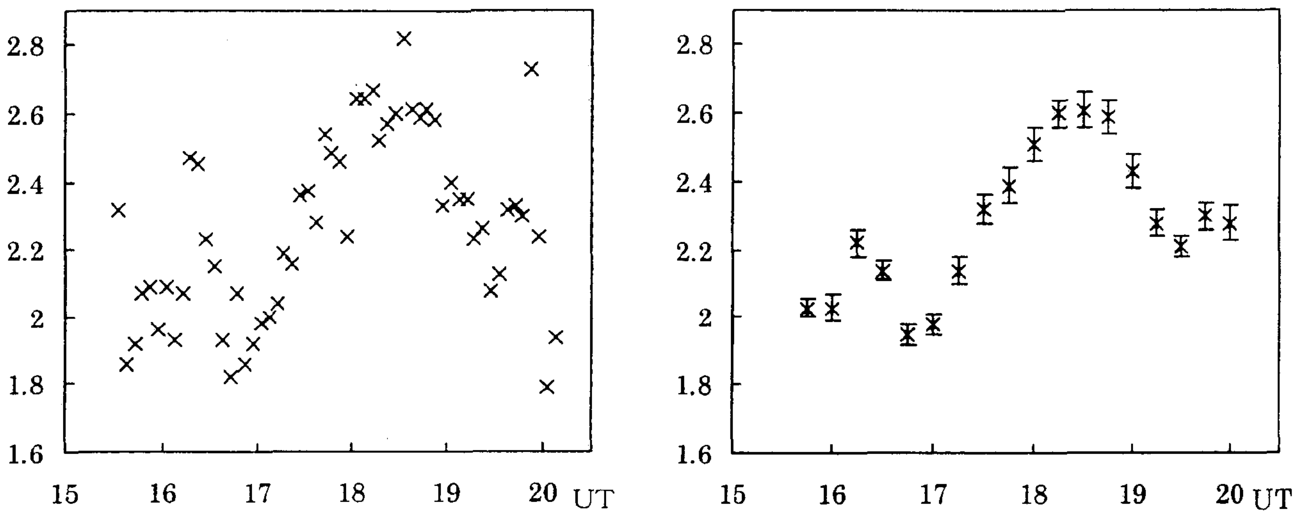

Figure 3 – Population index profile derived by the regression method applied to the magnitude range 0 – +4. Left: Binned in 5-minute intervals. Right: Binned in 30-minute intervals shifted by 15 minutes.

Figure 3 shows that the population index for the magnitude range 0 – +4 goes up with the rise of the ZHR, but the r-values after the ZHR peak time are larger than before. Thus, it is supposed that the population index of the 4-rev trail r_4 is larger than the population index of the 9-rev trail r_9. The peak value of the population index for the magnitude range 0 – +4 is 2.61 ± 0.05 at $18^{\mathrm{h}}5$ UT as obtained from the data binned in 30 minutes. This value is derived from magnitude data including the 9-rev trail that is expected to have a smaller r-value. Therefore, r_4 must be larger than 2.61. It is supposed that r_4 is 2.8 or larger.

Now, how large is r_9 here? Since the ZHR profile shows already a large number and a rise in the period between $15^{\mathrm{h}}5$ and $17^{\mathrm{h}}0$ UT (Figure 1), it is probable that many meteors from the 9-rev trail appeared in that period. While the r-values in that period show a scatter due to the low elevation of the radiant, they are almost constant with a value of around 2.0 (Figure 3). If meteors from the 4-rev trail already appeared in that period, r_9 is smaller than 2.0. However, too small an r-value contradicts the absence of a rise of bright meteors. Therefore, it is supposed that r_9 is 1.8–2.0.

4. Estimation of ZHR profiles of the 4-rev and 9-rev trails

In order to calculate ZHR profiles of the individual trails, r_4 and r_9 must be assumed to be 3.0 and 2.0 respectively, for example, and it must be assumed that the r-values were constant in the observing period.

It is thought that population index r is constant in the visual magnitude range. Then, we can write:

$$N_{4,m} = N_{4,0} r_4^m.$$

where $N_{4,m}$ and $N_{4,0}$ are the true meteor numbers of the 4-rev trail of magnitude m and 0, respectively.

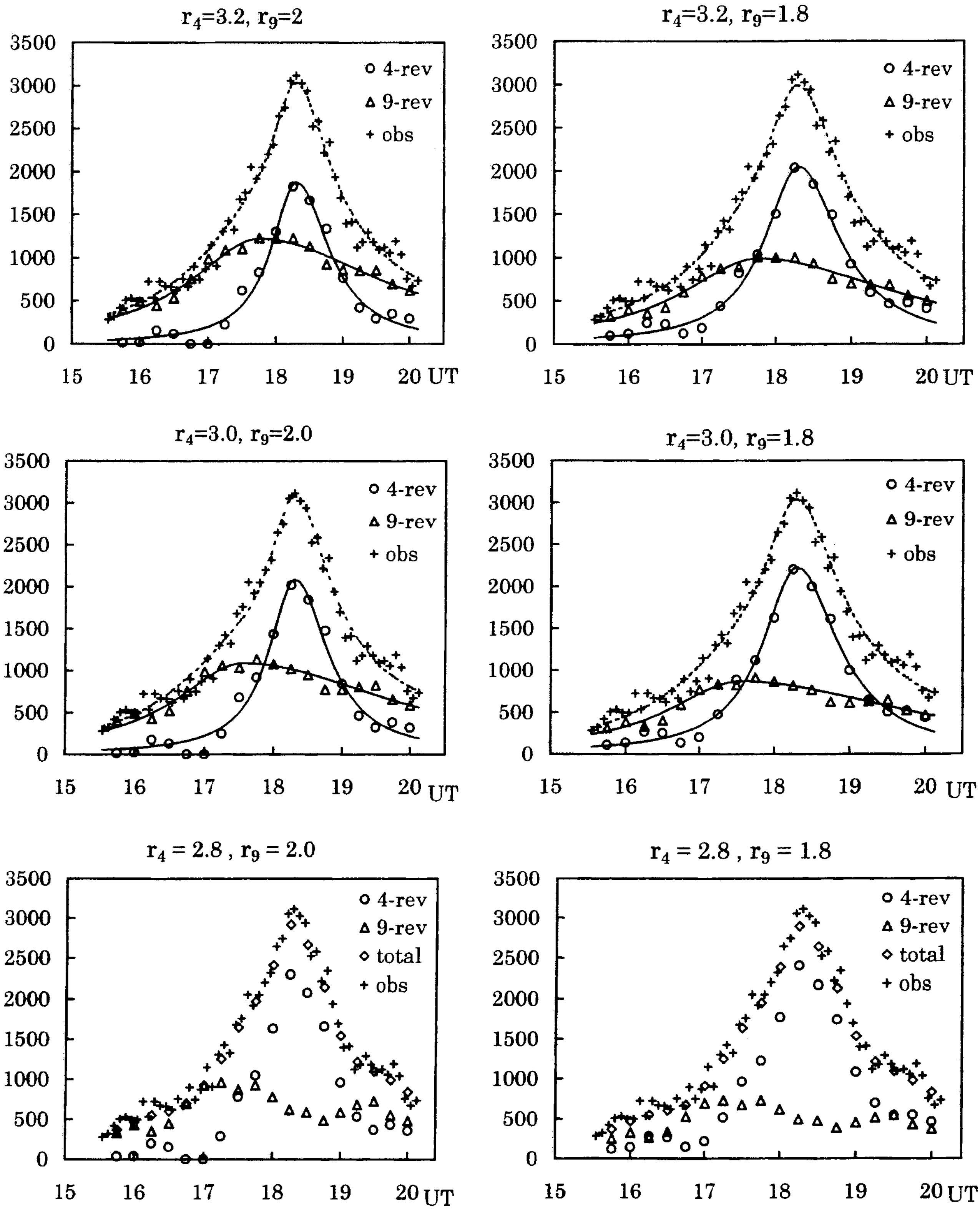

Figure 4 – Estimated ZHR profiles of the 4-rev trail and the 9-rev trail with fitting Lorentz profile lines. Since we cannot determine r_4 and r_9 correctly, I show the case that r_4 is 2.8–3.2 and r_9 is 1.8–2.0. In the case of $r_4 = 2.8$, the ZHR profile of the 9-rev trail has a dip between 18^{h} and 19^{h} UT. Since the dip is unusual, I guess that the value of 2.8 is improper for r_4, and I did not draw the Lorentz profile in the case. Dotted lines are for the sum of the values of the Lorentz profiles of the 4- and 9-rev trails. In the case of $r_4 = 2.8$, "total" means the sum of the ZHRs of these trails. The estimated ZHR of the 9-rev trail includes ZHRs of the 10- and 11-rev trails, since these trails are difficult to separate from the 9-rev trail.

The temporary $N_{4,0}$ determines the temporary $N_{4,m}$ and we can derive a temporary $N_{9,m}$ from:

$$N_{9,m} = \mathrm{ZHR}_{\mathrm{t},m} - N_{4,m}$$

And the temporary r_9 is calculated from temporary the $N_{9,m}$ of the magnitude range $0 - +4$. If the true r_9 is not the value assumed for r_9 at first such as 2.0, for example, $N_{4,0}$ is changed, and the calculation is repeated to get the r_9 value assumed. With such calculations, $N_{4,0}$ and $N_{9,0}$ are derived for each period, and we can calculate each magnitude $N_{4,m}$ and $N_{9,m}$ from $N_{4,0}$, $N_{9,0}$, r_4, and r_9. Then the ZHRs of the individual trails can be derived by the correction of perception probability and summing up the numbers of each magnitude class. However, I could not find out how to estimate the errors of the ZHRs of individual trails.

For the 2001 Leonid storm, it was predicted that the Earth should encounter the 10- and 11-rev trails in our observing period and the activity of these trails were lower than that of the 9-rev trail [1,2,3]. Since their r-values are expected to be close to r_9, we can hardly distinguish these trails from the 9-rev trail. Therefore, the estimated ZHR of the 9-rev trail includes ZHRs of the 10- and 11-rev trails in this article.

The results are shown in Figure 4. Since we cannot determine r_4 and r_9 correctly, we must assume their values. I show the case that r_4 is 2.8–3.2 and r_9 is 1.8–2.0. In the case of $r_4 = 2.8$, the ZHR profile of the 9-rev trail has a dip between 18^{h} and 19^{h} UT. I find that the dip is unusual and the proper value of r_4 should be 3.0–3.2. While the estimated ZHR profiles of individual trails vary with the assumed r_4 and r_9, the ZHR profiles are not so sensitive to changing r_4 and r_9.

Jenniskens et al. found that the ZHR profile of the 1999 Leonid storm fits to a Lorentz profile described by the following formula [8]:

$$\mathrm{ZHR} = \frac{\mathrm{ZHR}_{\mathrm{max}} W_{\mathrm{h}}^2}{(T - T_{\mathrm{max}})^2 + W_{\mathrm{h}}^2}$$

W_{h} is the half width of the profile at half the peak intensity. I drew Lorentz profile lines fitted to the ZHR profiles of individual trails in Figure 4 except for the cases of $r_4 = 2.8$. However, the profiles of these trails, especially of the 9-rev trail, are not symmetric, thus the ascending branches from half-maximum level are applied to the half width W_{h} before the peak time, and the descending branches to half-maximum level are applied to W_{h} after the peak time.

By finding the Lorentz profiles being good fits to the ZHR profiles of individual trails with the method of least squares, I estimated the values of peak time, maximum ZHR, full width at half maximum (FWHM), ascending and descending branches from/to half-maximum level for the individual trails. I show the results in Table 1 together with the predictions by Lyytinen et al. and McNaught & Asher.

The estimated peak time of the 4-rev trail is consistent with the predictions by these authors. The estimated ZHR profiles of the 9-rev trail show a broad peak, and the peak time is between the predicted times. The estimated FWHM of the 4-rev trail is close to the prediction by Lyytinen et al., while the estimated FWHM of the 9-rev trail is longer than the prediction, the FWHM, especially from the descending branch, may be affected by the 10- and 11-rev trails because the estimated ZHR of the 9-rev trail includes ZHRs of these trails. The maximum ZHRs of these trails are at about half the prediction by Lyytinen et al.

5. Discussion

Leonid meteors have very large geocentric velocities. Exceptionally many meteors appeared during the Leonid storm. And I found a fatigue effect for some observers who continued to observe for a long period, as was found in [8]. Therefore, the perception for faint meteors during the Leonid storm might be lower than in [7]. Indeed, numbers of magnitude +4 meteors are slightly smaller than the values on the regression line (Figure 2). The true population indices, especially r_4, may be larger than the value assumed. While values of 3.0–3.2 that I estimated to be proper for r_4 are large for major showers, a possibly larger r_4 is surprising. If the perception probability for faint meteors was lower, and the true r_4 is larger, how do ZHR profiles of the 4- and 9-rev trails change? Since I thought that the reduction of the perception probability for faint meteors causes a similar effect such as a reduction of the limiting magnitude, I re-calculated with a tentative correction by reducing the limiting magnitude. The result is close enough to the result shown in Figure 4, but a larger value is favored for r_4, such as 3.5 for example, and the ZHR values increase by reducing the limiting magnitude.

Table 1 – Estimated values and predicted values. The estimated values are derived from Lorentz profiles fitted to estimated ZHR profiles of individual trails in Figure 4 with the method of least squares. However, the profiles of these trails, especially that of the 9-rev trail, are not symmetric, thus ascending and descending branches from/to half-maximum level are applied to the half width W_h before/after the peak time. Since the 10- and 11-rev trails could not be separated from the 9-rev trail in this work, it is thought that the 10- and 11-rev trails affect the values of the 9-rev trail, especially the FWHM and the descending branches.

	Trail	Assumed r-value	Peak Time UT	Maximum ZHR	FWHM	Asc. branch	Desc. branch
Estimated result in this work	4-rev	$r_4 = 3.2$	18h18m	1880	62m	27m	35m
	9-rev	$r_9 = 2.0$	17h45m	1220	212m	75m	137m
	4-rev	$r_4 = 3.2$	18h18m	2050	73m	33m	40m
	9-rev	$r_9 = 1.8$	17h46m	990	216m	78m	138m
	4-rev	$r_4 = 3.0$	18h18m	2090	62m	27m	35m
	9-rev	$r_9 = 2.0$	17h33m	1090	231m	71m	160m
	4-rev	$r_4 = 3.0$	18h18m	2230	73m	33m	40m
	9-rev	$r_9 = 1.8$	17h33m	870	236m	73m	163m
Lyytinen et al. [1]	4-rev		18h20m	5000	86m		
	9-rev		18h03m	2600	123m	58m	65m
	10-rev		19h10m	150	280+m		
	11-rev		19h10m	150	180+m		
McNaught and Asher [2]	4-rev		18h13m	8000			
	9-rev		17h24m	2000			
	10-rev		18h43m	40			
	11-rev		17h36m	40			

Here, we can derive ZHRs per magnitude class of individual trails from $N_{4,0}$, $N_{9,0}$, r_4, r_9, and the perception probabilities. Now, I show the result derived with the assumption of $r_4 = 3.0$ and $r_9 = 2.0$ in Figure 5. Dotted lines are the sum of the values of Lorentz profiles of the 4- and 9-rev trails. At magnitude +4, the observed ZHRs are slightly below the estimated line of the sum. That indicates lower perception for faint meteors during the Leonid storm. At magnitude +2, the observed ZHRs are above the estimated line. It is possible that the perception for meteors of magnitude +2 is higher than the value in [7], because many Leonid meteors of magnitude +2 produced persistent trains. At magnitude 0, the observed ZHRs are lower than the estimated line, while they are close to the estimated line at magnitude −1. And at magnitude −2, the estimated line of the sum is not consistent with the observed ZHR profile. While the peak ZHR of magnitude class −2 is close to the peak of that line, the observed ZHR profile shows no rise,

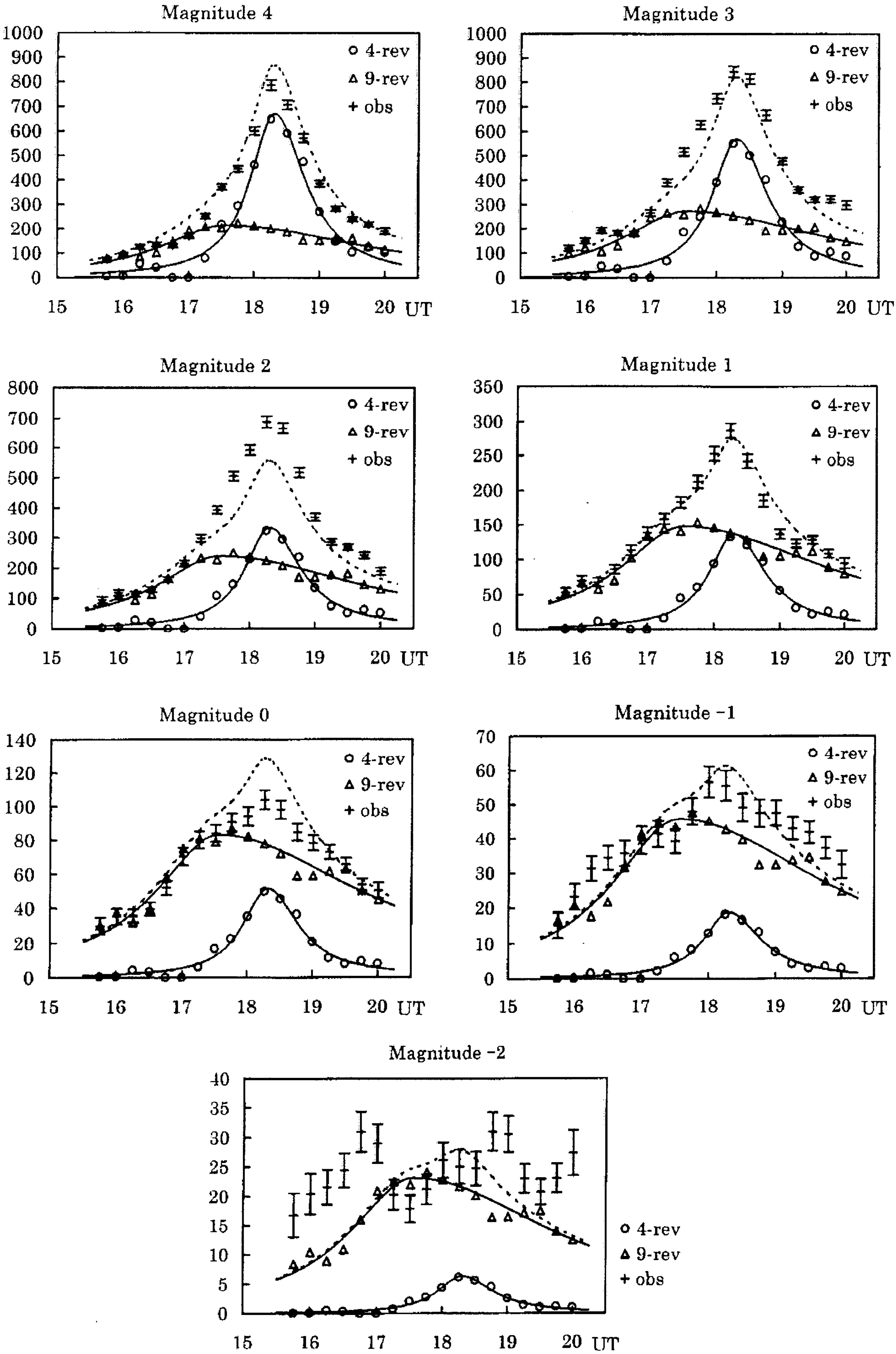

Figure 5 – Estimated ZHR profiles per magnitude class of the 4- and 9-rev trails and the observed ZHR profiles per magnitude class. The results shown here are derived with the assumption that $r_4 = 3.0$ and $r_9 = 2.0$. Dotted lines are the sum of the values of Lorentz profiles for the 4- and 9-rev trails.

although there must be effectively a rise according to the estimated value. This is an open issue here. It is possible that r_4 and r_9 are larger than the values assumed. If r_4 and r_9 are larger, we had to observe more faint meteors and less bright meteors.

It is possible that the perception provability for faint meteors was lower than the value in [7] during the Leonid storm. Then, we can explain that the observed ZHRs of magnitude +3 to +4 are close to the estimated line of the sum, and that the observed ZHRs of magnitude 0 are lower than the estimated value. Although the observed ZHRs of magnitude −1 are close to the estimated line, the shape of the ZHR profile is slightly different. If r_4 and r_9 are larger, meteors of magnitude −1 and −2 from the 4- and 9-rev trails are less than the estimated line. But it is thought that there was a source of bright meteors (Section 3).

Strictly speaking, the population indices of the 10- and 11-rev trails are expected to be slightly smaller than that of the 9-rev trail [3]. It is possible that the 10- and 11-rev trails have small population indices and that they were the source of bright meteors, though it is uncertain. It is expected to be studied in future work.

Some readers may think that one can assume a proper r-value for the 10- and 11-rev trails and calculate the ZHRs of the individual trails separating them from the 9-rev trail. However, this method has a problem. When there are two trails to be consiedered, assuming r_4 and r_9 determine only one solution with a set of $N_{4,0}$ and $N_{9,0}$. But, when we want to calculate ZHRs of three or more trails, there are many solutions with sets of $N_{4,0}$, $N_{9,0}$, $N_{10,0}$ and $N_{11,0}$, and one cannot determine a unique solution.

Figure 5 shows that the 4-rev trail supplied many faint meteors, and most of the meteors of magnitude −1 were by the 9-rev trail. If r_4 and r_9 were larger and there was a source of bright meteors, the numbers of bright meteors from the trails were smaller than the estimated values. While it is predicted that storm level activity will be caused by the 4-rev trail in 2002 again [2,3], it is possible that an abundance of faint meteors and a few bright meteors will appear in the sky with a full Moon.

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Outburst of Faint Piscids in 2001

Yoshihiko Shigeno and Hiroyuki Shioi

Data of double-station TV meteor observations and radiants determined by visual meteor observations were compared. We find a difference between the results based on TV observations with a large portion of faint meteors on the one hand and visual observations with a preference of brighter meteors on the other hand. The observational data show an activity of the Piscids. While successful visual observation of the Piscids yielded a rate of less than one per hour, we recorded many meteors on TV.

1. Comparing double-station TV meteors and visual meteor radiants

The double-station TV meteor observation was conducted on September 22, 2001. In total we recorded 67 meteors. The observational results are all open to the public [1]. We used $f/1.2$, $f = 85$ mm lenses and achieved a limiting stellar magnitude of about +9.5 and a field of view of 10°.5 by 8°.5. The average measuring error was 105 arc seconds, and the average radiant error was 0°.55.

The radiants found during the observation are indicated by crosses in Figure 1. The results of radiant determinations from visual meteor observations by H. Shioi, T. Hashimoto, and K. Osada of the *Nippon Meteor Society* of September 22, 2001, to September 24, 2001, are indicated by circles in order to compare them with the TV data. Scattered radiants were found near Perseus, Auriga, and Taurus, but there is no exact correspondence between radiants derived by the two techniques. This is probably because the visual observations contained mostly bright meteors with relatively concentrated radiants while the radiants of the faint TV meteors obviously appear to be diffuse.

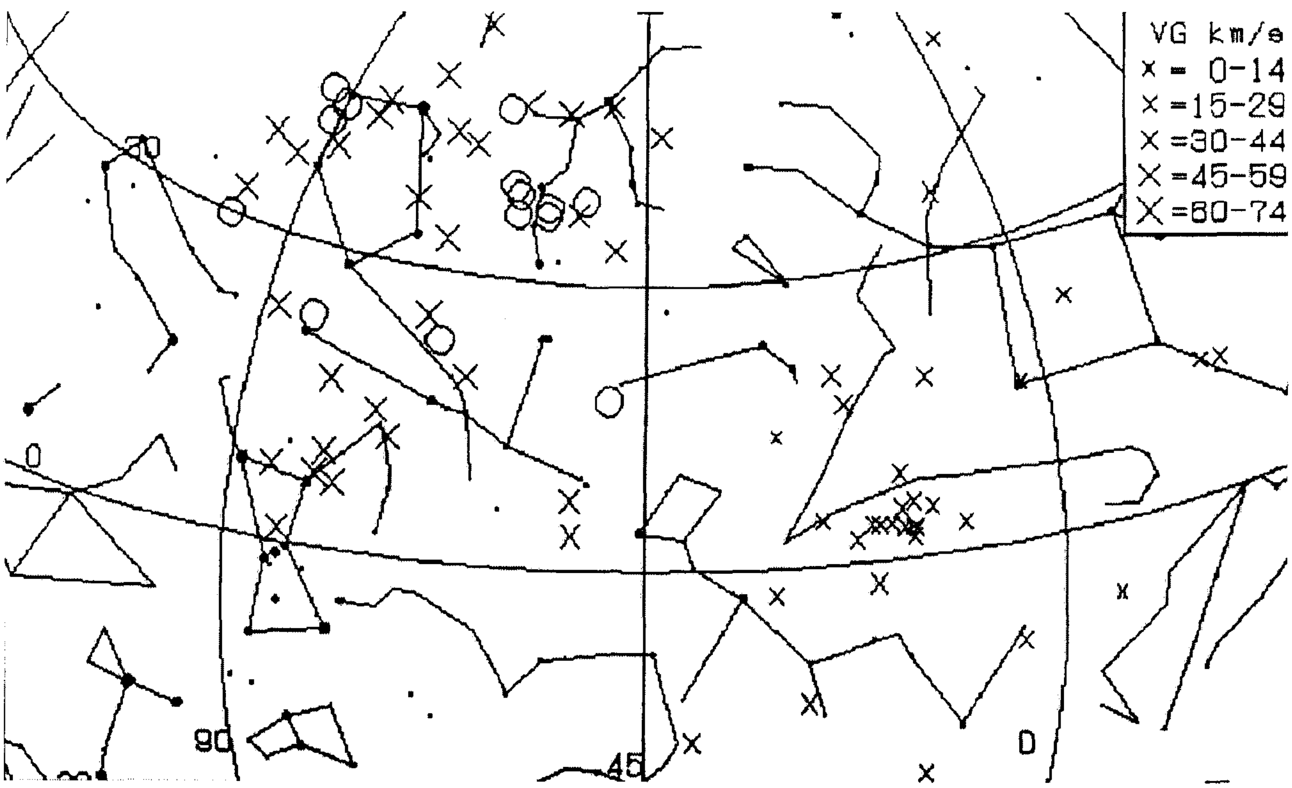

Figure 1 – Map of the corrected radiant positions. Crosses are TV meteors, circles are visual radiant observations (H. Shioi, T. Hashimoto and K. Osada).

Table 1 – Data of observed Piscid meteors. All data are given for Equinox 2000.0.

ID	Y	M	D	UT			Radiant		S.D.	V_g	S.D.	a	e	q	Peri	Node	i	Abs.	H_b	H_e
				h	m	s	α	δ	deg	km/s	km/s	AU			deg	deg	deg	mag	km	km
MSSJ62	2001	9	22	13	18	56	20.33	3.67	0.40	28.2	1.2	1.36	0.819	0.248	132.4	359.6	6.5	4.9	101.1	92.8
MSSJ6H	2001	9	22	15	03	02	16.58	2.20	0.22	29.8	1.2	1.89	0.852	0.280	124.6	359.7	6.3	4.8	104.6	92.6
MSSJ6R	2001	9	22	15	48	54	20.33	3.70	0.70	27.7	2.0	1.33	0.808	0.255	132.0	359.7	6.2	5.6	102.6	93.9
MSSJ6T	2001	9	22	16	00	15	19.03	3.69	1.23	27.2	1.9	1.36	0.799	0.274	129.7	359.7	5.3	5.6	106.8	96.9
MSSJ6j	2001	9	22	16	52	01	17.56	3.23	0.30	26.2	0.8	1.37	0.779	0.304	126.4	359.7	4.7	4.4	102.5	90.2
MSSJ6u	2001	9	22	17	24	09	16.32	3.02	1.17	26.6	0.8	1.48	0.788	0.314	124.0	359.7	4.3	4.0	100.4	91
MSSJ6y	2001	9	22	17	42	52	20.97	3.79	0.77	29.1	2.4	1.41	0.834	0.233	133.4	359.8	7.0	5.2	100.1	94
MSSJ6z	2001	9	22	17	45	45	16.64	3.19	0.32	28.5	0.5	1.66	0.826	0.288	125.1	359.8	4.8	3.6	101.3	89.0

Table 2 – Averages and standard deviations of the Piscids. The upper line gives the averages, the lower line gives the scatter in the data in standard deviation and does not indicate the errors in the averages.

Date (UT)	S.Long	Radiant (J2000)		S.D.	V_g	S.D.	a	e	q	Peri	Node	i	Abs.	H_b	H_e
Y M D	deg	α	δ	deg	km/s	km/s	AU		AU	deg	deg	deg	mag	km	km
20010922.668	179.699	18.01	3.11	0.64	27.8	1.4	1.55	0.817	0.284	126.6	359.7	5.3	4.8	102.4	92.6
SD(+/-)0.067	0.065	1.82	0.62	0.40	1.3	0.7	–	0.028	0.021	3.0	0.1	0.9	0.7	2.3	2.8

2. The Piscids

A concentration of radiants can be seen in the southern part of Pisces. Data for the concentrated part of the radiants and orbits are given in Tables 1 and 2. The visual observations conducted by H. Shioi, T. Hashimoto, and K. Osada yielded 0.2 to 0.5 possible shower meteors per hour as there were only a few bright meteors. There are some radiants reported from past visual meteor radiant observation [2]. R.E. McCrosky and A. Posen's photographic observations [3] show scattered radiants. These radiants are classified as the Piscids in G.W. Kronk's list [4]. However, enhanced rates like this time were neither mentioned nor predicted.

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SPA Meteor Section Results: 2001 Leonids

Alastair McBeath

Details extracted from visual and radio reports submitted to the SPA Meteor Section over the Leonid epoch in 2001 November are given. The two storm-strength maxima on November 18 were well-observed by radio and visual methods. A possible, though poorly-observed, peak near the nodal crossing time on November 17, 13^h–14^h UT ($\lambda_\odot \approx 235.^\circ27$; eq. J2000.0), with ZHR = 35 ± 9, can be inferred too. Other interesting facets included a brief resurgence to storm level suggested by visual data around November 18, $12^h10^m \pm 5$ m UT ($\lambda_\odot = 236.^\circ2 \pm 0.^\circ004$), after the North American storm peak, and a $\approx$ 50-minute-long "plateau" of almost storm-level rates (mean EZHR = 940 ± 170) after the Far Eastern peak on November 18, between 18^h45^m–19^h35^m UT ($\lambda_\odot = 236.^\circ48$–$236.^\circ51$). Radio data indicated a further peak at 6^h–7^h UT on November 18 ($\lambda_\odot = 235.^\circ94$–$235.^\circ98$), but this was unconfirmed by the visual results. Some discussion of these events in regard to the main dust filament theoretical peaks is given, along with a selection of personal recollections by Section correspondents.

1. Introduction

With a plethora of peaks of varying strength and duration up to storm level predicted for the 2001 Leonids by different authors, it was always going to be fascinating to see just what happened. As we now know from the IMO reports soon after the event on *IMO-News* and in this journal, observers in 2/3 of the world enjoyed a superb return of the shower, with two storm-strength maxima visible on November 18. Europe was unfortunately in the unlucky 1/3 of the globe where storm rates were not visible, although this was some relief for British meteor watchers, as here, clouds persisted across the entire country between November 16-17 to 18-19, and scarcely a Leonid was seen! Fortunately, thanks to the splendid efforts by British Section members who had travelled overseas, plus excellent reports from other individuals and groups, 2001 was our most successful Leonid campaign to date.

2. The Observers

The most important part of any article like this is the contribution made by the many observers and casual witnesses who watched the sky and then submitted their results. A great debt of gratitude is owed to the following list of people for their efforts during the 2001 Leonids. In addition many thanks also go to: Bob Lunsford of the *American Meteor Society* (*AMS*) for forwarding extremely extensive data summaries from November 18 in the *AMS*'s journal *Meteor Trails* 13 (December 2001; observers whose detailed reports were extracted chiefly from this source are credited below with "AMS". This issue of *Meteor Trails* also contained a splendid overview of the Leonid storm over the USA, complete with observers' comments); Enrico Stomeo of the Meteor Section of the *Unione Astrofili Italiani* ("UAI" below) for summaries of their successful Leonid campaign; and Chris Steyaert who provided copies of virtually all the radio data (except that from Dirk Artoos, and the Belarus observers, which latter was forwarded by Rainer Arlt) as *Radio Meteor Observation Bulletins* (*RMOB*s) 100–102, November 2001 to January 2002 inclusive. In the listing, "R"—radio observations, "Vi"—video data and "+V"—"and visual results". Those not noted provided visual reports.

Enric Fraile Algeciras (Spain; R), Rainer Arlt (South Korea), Dirk Artoos (Belgium; R), Jim Bedient (Hawaii, USA; AMS), Belarus observers (Ivan Bryukhanov, Aleksei Gain, Roman Grabovski, Aleksei Kosinski, Sachar Lapizki, Timur Radyuk, Stanislav Schikun, Vladislav Syrtsev, Valentina Tamello; Belarus; R), Lance Benner (California, USA; AMS), Sushrut Bhanushali (India; AMS), Antonio Blanco (Spain; AMS), Mike Boschat (Canada; R), Brenda Branchett (Florida, USA; AMS), David Branchett (Florida, USA; AMS), Jay Brausch (North Dakota, USA), Matthew Collier (Texas, USA; AMS), Luigi D'Argliano (Italy; UAI), Maurice de Meyere (Belgium; R), Michael Doyle (Virginia, USA; AMS), Gavin D Edwards (Colorado, USA), Andrew Elliott (Arizona, USA: Vi), Steve Evans (Arizona, USA; Vi), Erzsébet Farkas (Hungary; AMS), Didier Favre (France; R), MarLou Gaudet (California, USA; AMS), Joseph Gerver (New Jersey, USA; AMS), Vladimir Getman (Pennsylvania, USA; AMS), Ghent University (Belgium; R), Antonio Gioiosa (Italy; UAI), George Gliba (West Virginia, USA; AMS), W T Goodart (Arizona, USA; AMS), Roberto Gorelli (Italy; UAI), Patrice

Guérin (France; R), Rafael Haag (Brazil; R), Walter Haas (New Mexico, USA; AMS), Chaz Hafey (Mississippi, USA; AMS), Roberto Haver (Italy; UAI), Edwin Jones (Arkansas, USA; AMS), Javor Kac (Arizona, USA; AMS), Ákos Kereszturi (Hungary; AMS), Yoko Kikuta (Japan), Gene Kispert (Maine, USA; AMS), Girish Kulkarni (India; AMS), Marco Langbroek (Arizona, USA), Trevor Law (Western Australia), Ken Legal (Pennsylvania, USA; AMS), Bob Lunsford (Arizona, USA), Alan MacRobert (Massachussetts, USA; AMS), Pierre Martin (West Virginia, USA; AMS), Felix Martinez (Virginia, USA; AMS), Paul Martsching (Illinois, USA; AMS), Norman McLeod III (Florida, USA; AMS), David Meisel (New York, USA; AMS), Frank Melillo (New York, USA; AMS), Amruta Modani (India; AMS), Sirko Molau (South Korea; AMS), Stan Nelson (New Mexico, USA; R), Gyula Nyerges (Hungary; AMS), Hiroshi Ogawa (Japan; R), TianJing Ouyang (China; R), Steve Page (Georgia, USA; AMS), Carles Pineda Ferre (Spain; AMS), Szaniszló Prohászka (Hungary; AMS), Francisco Ramirez (Canary Islands; AMS), Paulo Raymundo (Brazil), Ina Rendtel (Germany; AMS), Jean Richard (France; R), Marion Rudolph (Germany; AMS), John Sabia (Pennsylvania, USA; AMS), Richard Schmude (Georgia, USA; AMS), Ton Schoenmaker (Netherlands; R), Jonathan Shanklin (Palau, Caroline Islands), Daniel Simmons (Florida, USA; AMS), Karl Simmons (Florida, USA; AMS), Matthew Simmons (Florida, USA; AMS), Stephan Simmons (Florida, USA; AMS), Wanda Simmons (Florida, USA; AMS), George Spalding (England), Enrico Stomeo (Italy; UAI), Dave Swan (England; R), Rich Taibi (Maryland, USA), István Tepliczky (Hungary; R + V (AMS)), Pierre Terrier (France; R), Jurkic Tomislav (Croatia; AMS), Garfield Tsao (Taiwan; R), Diego Valeri (Italy; UAI), Gabriele Vanin (Italy; UAI), Kim Youmans (Georgia, USA; AMS), Bruce Young (Queensland, Australia; R).

3. Visual Results

The very high observed Leonid rates meant most observers were often unable to give accurate meteor magnitude estimates during the stronger phases of the shower, so the r-value of 2.6 used for computing the ZHRs was based on the magnitude distributions obtained away from the storm peaks. Obviously a different r-value would influence the ZHRs, especially those during the storm maxima, but this was felt a suitable compromise, as most comments suggested a similar magnitude distribution to the typical Perseids and Geminids (r for both ≈ 2.6) was seen during the storms themselves. Figure 1 gives magnitude distribution graphs and corrected mean magnitudes for the Leonids and November sporadics (based on 932 Leonids and 339 sporadics).

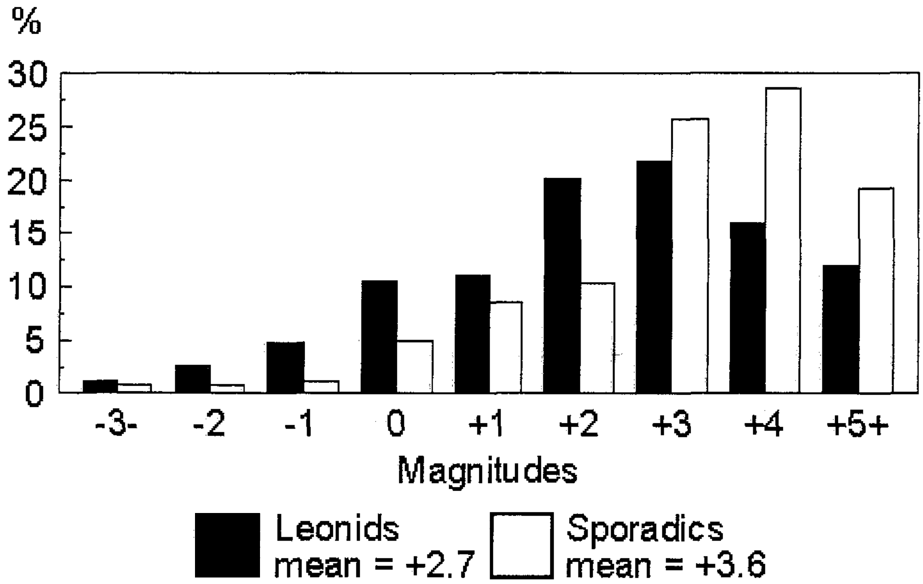

Figure 1 – Percentage magnitude distributions for the Leonids and November sporadics.

Away from the storm maxima, mean ZHRs were computed using the standard IMO formula, as given in the *Visual Handbook* and elsewhere, based on hourly meteor counts. Near the storm peaks, mean estimated ZHRs (EZHRs) were computed using 5-minute to 15-minute intervals instead to define any possible short-term variations in the stream, and to help better indicate the main peak times. For North America, often up to eight observers contributed to each short-interval datapoint, while fewer observers for the Pacific to Asia peak meant at best only four observers contributed to some of the datapoints here, so this peak was less ideally defined.

Normally, SPA Meteor Section ZHRs are taken from observations made with a radiant elevation of $\geq 20°$ to $\geq 30°$, LM +5.5 or better, and $< 30\%$ cloud cover. In order to give maximum detailed coverage for the 2001 Leonids, the radiant elevation and LM constraints were relaxed somewhat, in extreme cases using data with a radiant elevation of only about 10°–15° or where the LM was just +4.0. However, very few data of this kind were employed, and only in cases where no serious contradiction was apparent with data from nearby times either by the same observer or others, except where no other data was available.

Despite these provisos, the Leonid ZHR graphs here (Figures 2–5) seem to be generally reliable and accurate estimates for what occurred. This is particularly so as the radio results, detailed later, tend to support the general character of the visual findings.

With regard to the magnitude distribution in Figure 1, while the Leonids were typically bright (50% of the Leonids were of magnitude +2 or brighter, compared to about 25% of the sporadics for instance), relatively few fireballs were seen, and hardly any meteors of magnitude −6 or brighter were reported, those that were, often spotted during the storm maxima, when almost nobody was recording complete sets of magnitude estimates, or by casual witnesses who were not recording details accurately anyway!

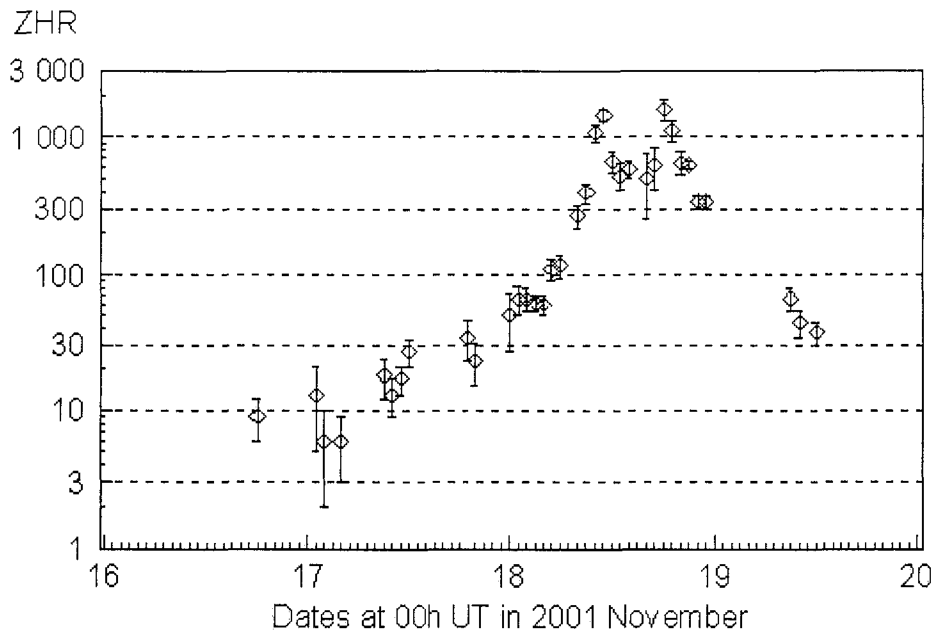

Figure 2 – Leonid ZHRs from November 16 to 19, using hourly datapoints and a logarithmic y-axis.

Figure 2 gives an overview of Leonid activity. The twin storm maxima on November 18 are very clear, with a distinct dip between lasting several hours. There is a hint of the normal near-nodal maximum recurring roughly two to three times stronger than usual on November 17, when ZHRs were 35 ± 9 around $12^{h}30^{m}$ UT ($\lambda_{\odot} = 235\overset{\circ}{.}21$), and again at $19^{h}00^{m}$ UT ($\lambda_{\odot} = 235\overset{\circ}{.}48$), but the gap in data between these times was most unfortunate. If it kept to its normal time, this peak should have happened at about 13^{h}–14^{h} UT ($\lambda_{\odot} \approx 235\overset{\circ}{.}27$ [1]).

Figure 3 closes-in on both storm peaks. ZHRs were picking up by the end of the European night on November 17-18, just off to the left of this graph, and had climbed to 100+ before dawn twilight set in from Spain and the Canary Isles. Rates jumped to 300+ by 8^{h} UT over eastern North America, as the radiant pulled higher into the eastern sky there, and climbed steadily after that towards the first storm maximum.

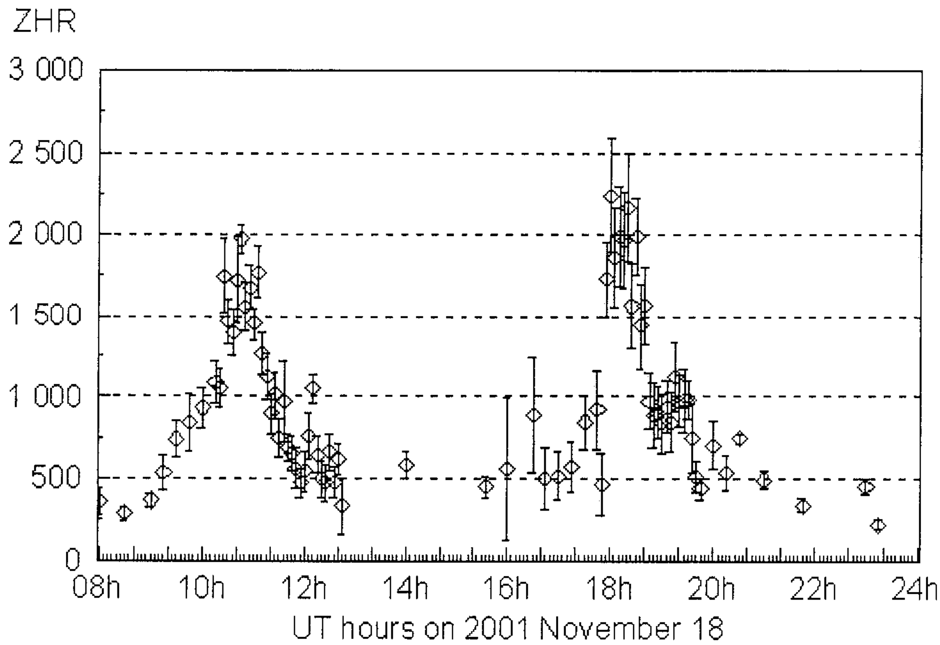

Figure 3 – The two November 18 storm maxima, using short-interval (5 min–15 min) EZHRs and a linear y-axis.

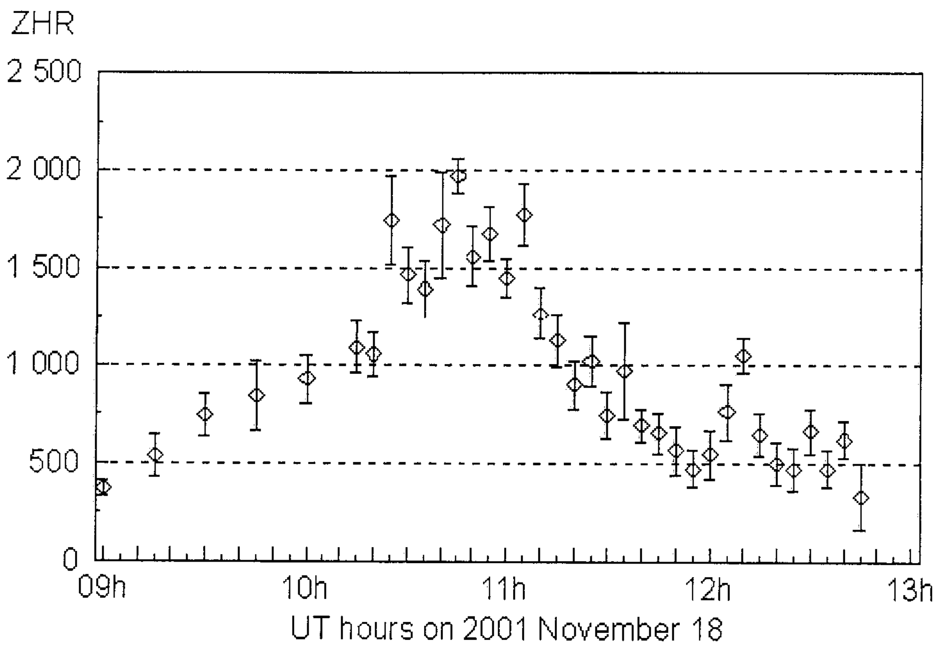

Figure 4 – Detail from Figure 3, showing the first (North American) storm peak.

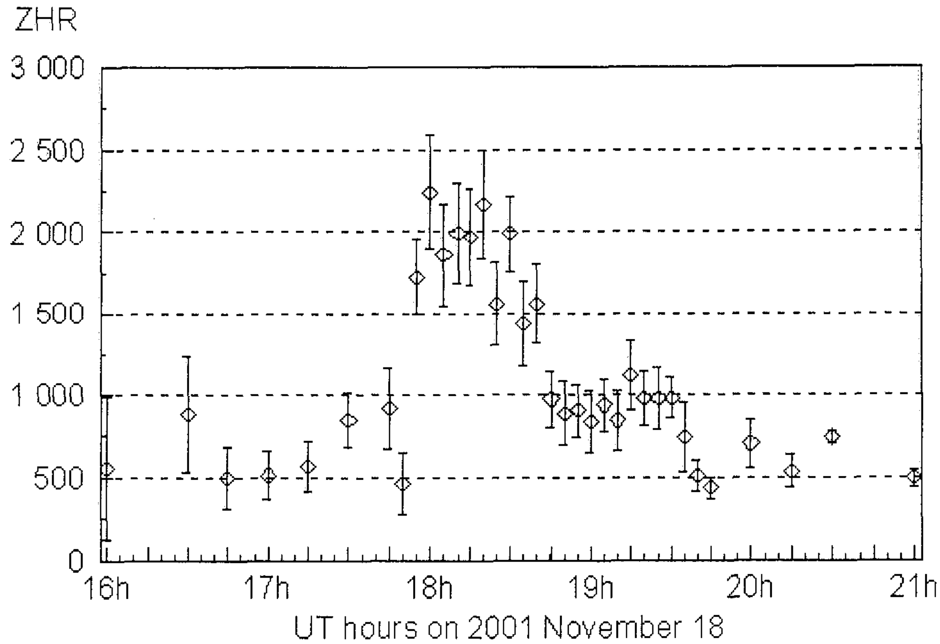

Figure 5 – Detail from Figure3, showing the second (Far Eastern) storm peak.

Consequently, this initial peak was seen well across North America, and was centred around $10^{\rm h}45^{\rm m}$ UT ($\lambda_\odot \approx 236.^\circ14$) when EZHRs reached 1970±90. This maximum is shown more clearly in Figure 4. The approaching and receding activity curves were relatively gentle, giving the graph quite an open shape, with a Full-Width-Half-Maximum, FWHM, time of 1.38 h, so observers had plenty of time to enjoy the show. After rates dropped back below storm level, a short-lived revival to storm proportions happened again at $12^{\rm h}10^{\rm m} \pm 5$ min UT ($\lambda_\odot = 236.^\circ2 \pm 0.^\circ004$), EZHR $= 1050 \pm 90$, which was spotted from the western USA near dawn, and on Hawaii. The small number of observations by this time means this facet is not definitely confirmed however.

Despite gaps in the data over the Pacific Ocean, ZHRs apparently dropped to 300–500 for several hours after $12^{\rm h}30^{\rm m}$ UT, until things picked up again over Australia, the Far East and Asia. As Figure 5 demonstrates, the second storm burst very rapidly after $17^{\rm h}30^{\rm m}$ UT, peaking between $18^{\rm h}00^{\rm m}$–$18^{\rm h}20^{\rm m}$ UT ($\lambda_\odot = 236.^\circ446$–$236.^\circ46$) when EZHRs reached 2200 ± 330. Rising rates almost quadrupled from a dip to 450 ± 200 to 1700 ± 230 in the five minute interval between $17^{\rm h}50^{\rm m}$–$17^{\rm h}55^{\rm m}$ UT in our data! This peak was significantly sharper than the North American one (FWHM only 50m), but the fascinating aspect of this second maximum was a plateau-like "shoulder" on the declining branch of the storm's activity curve. For about 50m from $18^{\rm h}45^{\rm m}$–$19^{\rm h}35^{\rm m}$ UT ($\lambda_\odot$ about $236.^\circ48$ to $236.^\circ51$), rates stayed nearly constant, hovering around storm level (EZHR $= 940 \pm 170$). This was great for the observers of course, who wanted the spectacle to continue for as long as possible! After this, rates dropped slowly, until by radiant-rise over Europe, ZHRs were back below the 500 mark once more, although even by the time North America was back under night-time skies on November 19, ZHRs were still well up on normal, at 70 ± 15.

One final aspect of the visual data concerns persistent trains. While many observers continued trying to record meteor magnitudes until the storms were upon them, train data were an earlier casualty as rates began rising, so the number of trained meteors overall was very small. Some 38% of Leonids away from the storm maxima left persistent ionization trains, compared to 5% of November sporadics, but barely 10% of the Leonids in the magnitude distribution sample had the presence or absence of trains noted for them, while for the sporadics, this figure was nearer 20%, so these details should be treated with caution.

4. Radio Results

The graphs in Figure 6 give a representative sample of the radio observations received, with two each from Europe, the Americas and the Australian/Far Eastern regions, including two datasets from the southern hemisphere. The effect of the Leonids is very obvious in these, and drawing on all the available results, it is possible to clearly pick out the two main storm maxima on November 18, circa 10^{h}–12^{h} and 17^{h}–19^{h} UT (remembering that as the radio data is given only in hourly bins by most observers, it is not possible to give the timings of any peaks more precisely than to the nearest hour). However, only Stan Nelson in New Mexico was located to catch both the North American and Far Eastern storms. There are definite signs that radio rates dropped only very slowly after the second peak (as shown by Bruce Young's and Hiroshi Ogawa's data here), helping to support the "plateau" in rates around 19^{h} UT found by the visual results. The visual storm resurgence at $\approx 12^{h}10^{m}$ UT does not appear in the radio data, though few observers were active then anyway. It may have been too short-lived to be clearly found in the hourly counts in any case, against the general backdrop of declining rates. There are though definite signs in the North and South American data of a small peak for several hours close to 12^{h} UT on November 17, which gives some, though inconclusive, support for the possible visual peak around the expected "normal" maximum time.

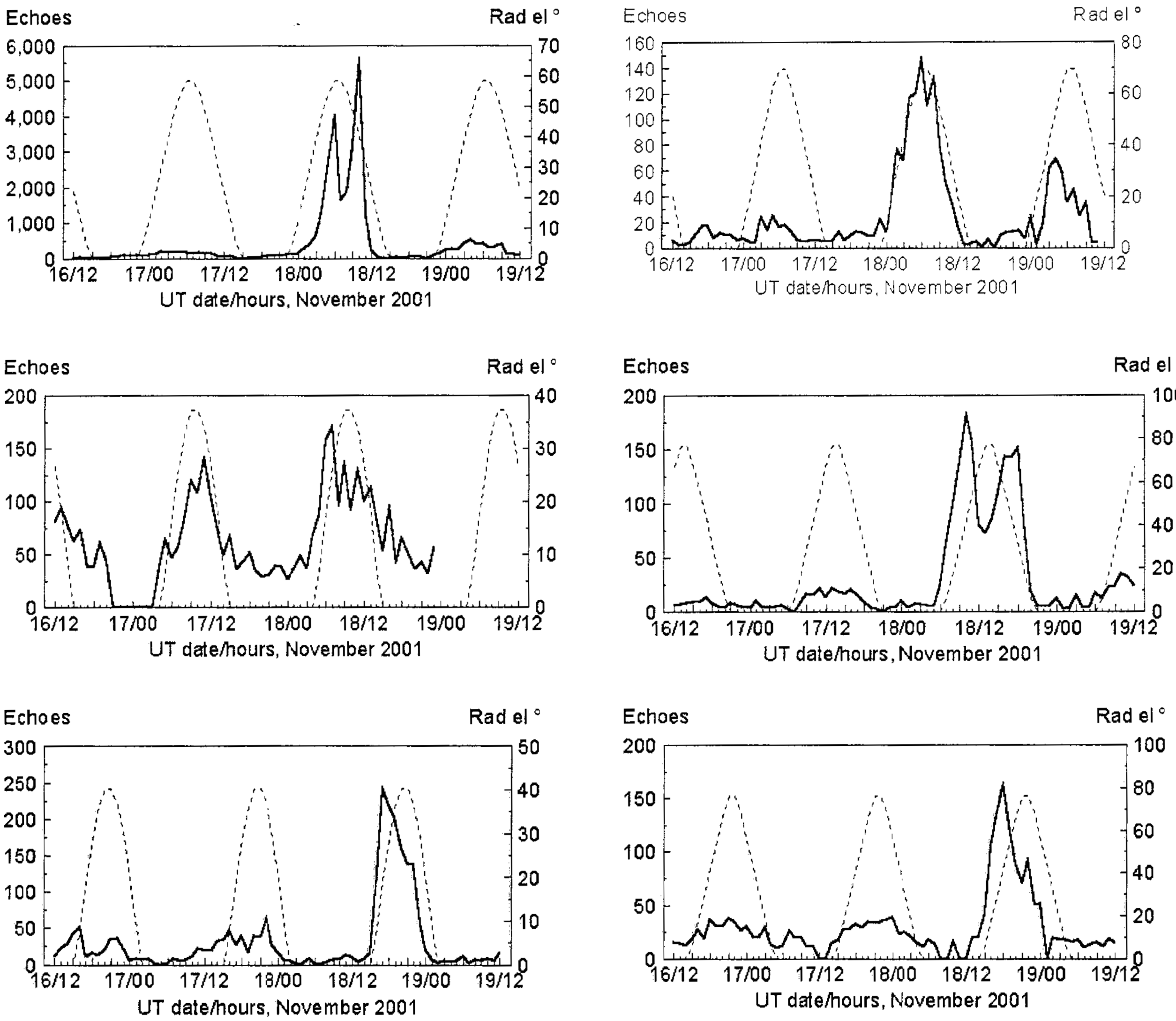

Figure 6 – Six graphs showing raw radio meteor echo counts, as collected by the stated observers, from midday UT on November 16 to midday UT on November 19 (thicker, irregular lines, keyed to the left-hand y-axes). The finer, symmetrical lines, keyed to the right-hand y-axes, give the Leonid radiant elevation in degrees for each observer's site. Ton Schoenmaker's data is corrected for dead time due to his system being saturated by meteor echoes where more than 10to this cause.

Another peak at 6^h–7^h UT on November 18 ($\lambda_\odot = 235.^\circ94$ to $235.^\circ98$) occurred in 60% of the available datasets. Although this coincided with the highest radiant elevation over Europe—and thus could simply be related to that fact—the North American data also shows clear signs of this. Unfortunately, too few visual data were available from this time in the SPA results for confirmation of it. There is a hint of an additional radio peak towards around 22^h UT on November 18 ($\lambda_\odot \approx 236.^\circ62$), which coincided with another gap in the visual data, though there were some indications that visual rates may have picked up again near this time.

5. Discussion

With around 25 Leonid maximum times of different strengths predicted well in advance for November 17 or 18, 2001, by various authors (some differing from one another by only a few minutes), it would be helpful to see which, if any, were the more useful guides to the above detected events. Here, details are considered from the two main groups who made to-the-minute predictions for the 2001 Leonids based on theoretical dust trail encounter times, Rob McNaught and David Asher (M&A [2]), and Esko Lyytinen, Marku Nissinen and Tom Van Flandern (LNV [3]). Additional peaks suggested by Peter Brown and Ignacio Ferrin as noted in [1] are also taken into account in the following, and some notes on the late-appearing McNaught and Asher revisions [4], and predictions by Jenniskens [5], are given at the end. We should recall that M&A never claimed any great accuracy for their ZHR estimates, and that all of the dust trail ideas can only ever be as accurate as previous observations and computer models can achieve.

November 17, 13^h24^m UT and 14^h17^m UT (M&A): Due to the 2- and 1-revolution dust trails respectively, possible ZHRs for both = 0. These timings were roughly coincidental with the Earth's closest passage to the comet's node, around 13^h–14^h UT. Our radio and visual data suggested a possible peak near this time, but with an unfortunate gap in visual data between 12^h30^m UT and 19^h00^m UT (visual ZHRs of 35 ± 9 at both times). The radio data indicated somewhat enhanced Leonid rates were probably present at a fairly uniform level right over this period. Ferrin's prediction of a peak with ZHR ≈ 350 at 16^h30^m UT was not found at anything like this strength in the radio results.

November 18, 10^h01^m UT (M&A) **and 10^h04^m UT** (LNV; corrected to 10^h28^m UT): Due to the 7-revolution trail, possible ZHR = 2500 (M&A) or 2000 (LNV—lasting about 2 h). The first storm peak over the USA was centred at $\approx 10^h45^m$ UT in our results, with EZHR = 1970 ± 90, and a FWHM of 1.38 h, so the LNV prediction was closer to the mark in all respects. Peter Brown predicted a possible bright meteor peak at 11^h UT, and although there was no confirmation of more bright Leonids near this time, it did fall close to the first storm peak, and there were plenty of bright meteors during the whole storm. No prediction of enhanced activity towards 6^h–7^h UT, as implied by the radio data, was made.

November 18, 12^h00^m UT (LNV) **and 12^h08^m UT** (M&A): Due to the 6-revolution trail, with possible ZHR = 110 (LNV—lasting about 1 h?) or 0–10? (M&A). Very interesting, because this coincided with the possible visual storm resurgence at around 12^h10^m UT, even though this was unconfirmed by the radio reports. Visual EZHRs were much more significantly boosted than the predictions suggested.

November 18, 14^h10^m UT (LNV) **and 14^h18^m UT** (M&A): Due to the 5-revolution trail, with possible ZHR = 60 (LNV—lasting about 1 h?) or 0 (M&A). This fell during a poorly-observed period in the SPA data, but it is intriguing that the three ZHR datapoints over this spell were 330 ± 170 (12^h45^m UT, $\lambda_\odot = 236.^\circ23$), 580 ± 80 (14^h00^m UT, $\lambda_\odot = 236.^\circ28$) and 450 ± 60 (15^h35^m UT, $\lambda_\odot = 236.^\circ34$), which implies a possible small peak near 14^h UT at least. The radio data are inconclusive about a possible maximum near this time, but this could have been subsumed into the generally active radio Leonid rates anyway.

November 18, 17^h38^m UT (LNV; corrected to 18^h03^m UT): Due to the 9-revolution trail, possible ZHR = 2600, lasting about 2 hours. The later revised time coincided more or less exactly with the beginning of the second storm maximum in our visual and radio data, which lasted from 18^h00^m–18^h20^m UT, when EZHRs reached 2200 ± 330, somewhat lower than predicted, while the FWHM time was only ≈ 50 m. The very steep increase in rates just before this peak began visually could indicate quite a sharply-defined edge to this trail's boundary. No very high visual activity was noted around 17^h20^m–17^h40^m UT however, and only one of five radio datasets showed a marginally stronger peak in the 17^h–18^h UT interval than in the following hour. Peter Brown proposed the main Leonid peak might happen near 16^h54^m UT, which was clearly well off the actual maximum, though visual EZHRs did seem somewhat (if uncertainly) stronger at around 16^h30^m UT for a time (890 ± 350; $\lambda_\odot = 236\overset{\circ}{.}38$).

November 18, 18^h19^m UT (M&A) **and 18^h26^m UT** (LNV; corrected to 18^h20^m UT): Due to the 4-revolution trail, possible ZHR of 13 000–35 000 or below 10 000 (M&A, the latter a late revision), or 5000 (LNV; lasting about 1 h 20 min). Coincident with the end of the second storm's peak visually, none of the rate predictions were at all close to the reality as witnessed by our observers, and again the FWHM of the observed storm was shorter than predicted. We should note though the $19^h10^m \pm 25$ m UT "shoulder" after the main maximum had passed may have been partly produced by activity from either the 9- or 4-revolution dust trails—or indeed both.

November 18, 17^h23^m UT (corrected to 19^h10^m UT) **and** 17^h26^m **UT** (corrected to 19^h10^m UT; both LNV): Due to the 10- and 11-revolution trails respectively, possible ZHRs of 150 for both, lasting more than ~ 5 h and more than ~ 3 h. The corrected times picked out the centre of the post-maximum "shoulder" pretty exactly, as defined by our watchers (and approximately confirmed by the radio observers), though rates were boosted well beyond the expected ZHR levels. As ZHRs persisted at over 200 until approaching midnight UT on November 18-19, contributions from these sources do seem plausible in helping give the declining activity as a whole a far gentler slope than that in advance of the Far Eastern maximum.

Overall, the modified LNV dust trail model seems to have been the better guide to when the main events occurred within the near-storm Leonid activity, and roughly how long and how strong that activity was, though these parameters were not especially close at times. Hopefully, the 2001 data will help refine the model better for future use. Although the earlier dust trail model developed by Rob McNaught and David Asher was in general less useful for the precise storm peak timings, it was a much more important piece of work, for drawing wider attention to the dust filament model. Without it, we might have been much more unprepared for the events in 2001.

The revised trail encounter times by McNaught and Asher in [4] are not considered in detail here, as most did not coincide with any observed Leonid peaks (UT times on November 18 included: 9^h10^m (ZHR ≈ 2), 9^h55^m (≈ 800), 17^h24^m (≈ 2000), 17^h36^m (≈ 40), 18^h43^m (≈ 40)), though the 9^h55^m and 18^h43^m predictions were during times of near-storm rates. Other peaks suggested for November 18 at 11^h00^m (ZHR ≈ 70) and 18^h13^m (ZHR ≈ 8000) UT fell in parts of the two main storm maxima.

For the Jenniskens trail encounter predictions [5], the 13^h14^m and 16^h20^m UT ones on November 17 (both with probable ZHRs near 0) were tolerably coincident with what may have been the near-nodal "bulge" in our data, but nothing unusual was found at the 20^h22^m UT (near 0) prediction. On November 18 UT, the 10^h09^m and 10^h10^m events (ZHRs respectively ≈ 4200—FWHM ~ 40 min—and near 0) were not close to any of the observed parameters for the first storm maxmum, but the 12^h07^m one was at the time of the brief storm resurgence (expected ZHR only ≈ 40 however, and FWHM ~ 1 h 15 min). The next peak at 13^h57^m (≈ 14, ~ 6 h 50 min) was at the possible 14^h UT weak peak. Three peaks at 17^h01^m (≈ 170, ~ 2 h 05 m), 17^h08^m (≈ 1800, ~ 1 h 15 min) and 17^h21^m (≈ 510, ~ 1 h 15 min) were not apparent, coinciding with just the generally rising Leonid rates before the second storm happened. The final prediction for 17^h55^m (≈ 2700, ~ 50 min) was good regarding timing, moderate concerning possible ZHRs, but most accurate for the main FWHM time.

6. Personal Recollections

The 2001 Leonids drew a lot of comments, as those with access to the electronic media especially will know. Newsgroups were flooded with notes from lucky and not-so-lucky observers, and e-mail lists including *IMO-News* and *Meteorobs* also featured recollections, initial thoughts and data summaries. SPA member John Lambert provided a representative selection of 65 newsgroup reports from individuals that he spotted, 58 from the USA, 5 from Australia and 2 from Hong Kong. It was impossible to find anyone in that set who was unimpressed by the display, even though several battled with unhelpful conditions. A few people commented on seeing rare Leonid trains of 5m-15m duration. Most who saw any commented on their brightest Leonid fireball. Many noted that the meteors were bright, but not especially brilliant, which echoed the thoughts of the more experienced observers. Personal recollections, photos and other results are now posted on a number of websites for those interested. Here, we will look at some of the comments that reached the SPA Meteor Section directly.

In Britain, as I commented earlier, conditions were hopeless during the Leonids' best, though people here seemed to have been well-warned that even clear skies were unlikely to produce good meteor rates. A notice to this effect appeared in some of the broadsheet newspapers at least, and *The Independent* for 2001 November 17 featured again the infamous "star-trails" photo taken in the Jordanian desert before the 1999 Leonid storm. This was originally captioned in 1999 as showing the Leonid storm, which of course it did not, as there were no meteor trails on it! The message had got through—partly at least—as this time's caption read: "Stars outnumber Leonid meteors lighting up the night sky of the al-Azraq desert last year," suggesting the *Independent* caption-writer had slipped through a time-warp, or perhaps had had a slight spell of forgetfulness!

George Spalding in Oxfordshire, England, a veteran observer who saw the 1966 Leonids from Scotland, was the only observer in Britain to report any Leonids to us from 2001—two in 25 min shortly before dawn on November 14-15! George commented on November 19: "This was just a brief check to see if there was any significant early activity. I was a bit late in rising; I had intended to start around $4^{h}00^{m}$. So I did not get even half an hour before dawn had begun. It was a pleasure to see at least a couple of Leonids—the only two I was to see. Needless to say, I have not had a chink of clear sky since, so have nothing else to report. I wonder if there are any UK reports!"

SPA Website Editor Paul Sutherland was able to provide details from the one place in Britain to get a good view of the Leonids—the fictional village of Ambridge in the BBC's long-running radio soap opera *The Archers*. Paul notes: "David Archer was describing the display as Spielberg-like. It was amusing to hear *Feedback* on Radio 4 a few days later when various listeners wrote in to ask if the Archers were on hallucinogenic drugs!"

Elsewhere, things were not always ideal. Jay Brausch in North Dakota was able to watch on both November 17 and 19, but was clouded-out due to, as he put it, "the 'well-timed' front" which ruined his skies on November 18. Even so, he remained philosophical despite missing the storm.

Rich Taibi in southern Maryland decided to prepare for whatever the Leonids produced by sensibly carrying out a test run with his observing equipment on November 13, to make sure everything worked. He said: "I concluded that trying to simultaneously call out meteor magnitudes and announce WWV (UTC) time markers for the tape recorder (at 1 minute intervals), for approximately one hour, will be quite a feat of endurance and coordination! And especially when the temperature is likely to be $-6°$ C/21° F! Who said meteor observing is relaxing?" The great night itself was marred by fog, but even so he enjoyed an excellent time, with plenty of bright Leonids.

In South America, Paulo Raymundo had a wonderful night on November 18: "Very bright and fast meteors of all colors were seen dropping everywhere across the sky above Reaiche

Observatory in Salvador, Brazil from 1^h30^m to 5^h30^m a.m. local time (UT −2 h). The show started at 3^h28^m UT when we saw a magnitude −6 Earth-grazer that extended from horizon to horizon. Half of the Leonids were magnitude zero or brighter and most of them left afterglows, lasting no longer than a second or two at most. Many meteors occurred within seconds of each other and fireballs also appeared to come in clusters frequently. The fireballs were the best since 1998's display, but this time there was a much greater number of red fireballs. The highest concentration of bright meteors occurred within 8 minutes: I counted eleven Leonids of negative magnitude from 5^h48^m to 5^h56^m UT. We saw so many meteors and fireballs during the four-hour period under +4.9 LM skies that we could not take pictures and count Leonids at the same time. Although astronomical twilight had started at 4^h40^m a.m. local time, we kept seeing fireballs until 26 minutes before sunrise, three hours before the predicted peak of the 1767 dust trail over the USA."

In the south-western USA, the dry desert and mountain areas of New Mexico, Colorado and especially Arizona must have been groaning under the weight of all the meteor observers and their equipment! Marco Langbroek had gone to Arizona with DMS teams to operate multi-station camera networks at different sites during the Leonids. They were not disappointed with rates well over a Leonid per minute all night after the radiant reached a useful elevation: "The meteors were quite bright (with fireballs up to magnitude −5), much brighter than the 1999 storm, and unlike 1999 the peak was broad, taking several hours... My highest counts (with LM +6.7) were 40-45 Leonids per minute. I found this outburst visually more attractive than the 1999 storm!!! This was definitely the best Leonid show I ever observed!" However: "Murphy struck again: ... my personal dataset has a gap of about 10 minutes right at the peak! My tape recorder jammed right at that point... :-("

Steve Evans had also travelled to Arizona for the storm, and observed with one of a number of Czech and Dutch teams using video and still cameras there. At a beautifully dark-sky site where the zodiacal light seemed dazzlingly bright before dawn, his team had two excellently successful nights on November 17 and 18: "The maximum night itself exceeded my expectations in that the rates were higher, activity lasted longer and bright meteors were numerous, certainly more so than in 1999...my impression was that at peak activity (somewhere between 10^h00^m–10^h30^m UT) rates were almost as high as those seen from Portugal in 1999... The meteors seemed to come in bursts and at times were difficult to count. I saw 7 meteors within $\sim$ 1 second on one occasion." One of Steve's video trails is shown in Figure 7. Other images, plus a video clip of this meteor, can be found in the SPAMS webpages (`http://www.popastro.com/sections/meteor.htm`).

Bob Lunsford was another observer in Arizona. After visiting Marco Langbroek's team from November 15–17, Bob met up with some other AMS watchers and a group from Europe at Mount Lemmon for the November 18 event. Skies were very poor in mid evening, but the clouds started to thin by midnight, and a series of very long-pathed atmosphere-grazing Leonids began to appear as the radiant came up, despite the cirrus. Bob started watching around 12^h45^m a.m. local time (7^h45^m UT): "Rates and the brightness of the Leonids were impressive from the start. The long Leonids continued for at least another hour." Following minor problems with his tape recorder because of the cold (1° C/33° F) after 10^h UT, Bob commented that observed rates seemed to peak around 10^h45^m UT at $\sim$ 30 per minute, then dropped somewhat, but: "The show climaxed near 11^h05^m when 6 near simultaneous Leonids shot in different directions creating 'the spokes of a wheel' effect." Even after this, rates remained strong, and failed to drop as fast as in 1999 in Bob's estimation. Indeed he felt the show overall surpassed 1999's both for activity and bright meteors. With a magnitude −8 fireball as the wonderful dawn twilight colours were strengthening, it had been quite a night, perfectly rounded off in the mountain's observatory dome with a magnum of champagne shared between the observers before heading off to bed!

In Colorado, Gavin Edwards had a splendid night too: "It was glorious here in Boulder, easily saw around 200 per hour with several bright fireballs. Peak activity was around 3^h30^m a.m. [local time; = 10^h30^m UT] I would have said, but there were numbers around 50 per hour or greater from around 1^h a.m. until 5^h a.m. our time." Gavin wasn't seriously observing, but enjoyed the show visually and with 20x80 binoculars, and kept enough of a record to show observed rates in a LM +5 sky were easily 3-5 a minute at the peak.

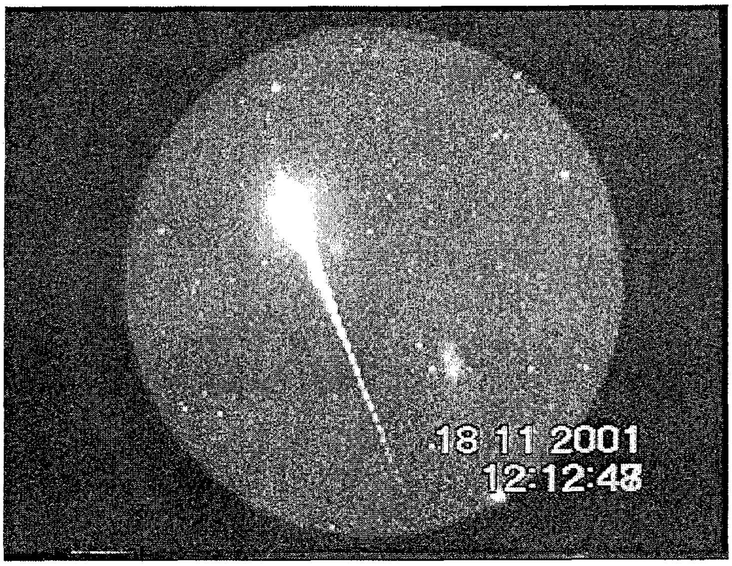

Figure 7 – A spectacular Leonid fireball caught on video by Steve Evans at Keams Canyon, Arizona, USA on November 18. This is a composite image taken with an $f/1.8$, 28-mm lens, giving a 37° field of view. Jupiter is just above the end of the meteor, with Orion and Betelgeuse to the right. The misty patch to lower centre-right is a flare on the camera lens due to the meteor's brilliance!

Across the Pacific Ocean in Western Australia, Trevor Law had selected a site near Meekatharra, about 600 km north-west of Perth, and had a good night's observing there on November 17. Unfortunately, on November 18, the area was in the midst of a series of terrific thunderstorms: "Mostly cloudy with some spectacular lightning and the first time I've been rained on *whilst still conducting the watch—and still recording meteors!*" When the lightning started striking too close, Trevor darted into his car for shelter temporarily! Despite all this, in 2 h 17 m between 17^h20^m–19^h37^m UT, he picked up almost 300 Leonids, and unlike most other observers who endured uncomfortable cold, he found "that it was pleasantly, indeed almost oppressively, warm, probably 21°–22° C, real T-shirt weather!" Of course, as meteor observers know only too well, nothing is ever easy. On the flight to Australia, the aircraft Trevor was on had to climb to 12.8 km to overtop some more cumulonimbus storm clouds over Indonesia, which reduced the cabin pressure, bursting a carton of orange juice in the bag with Trevor's all-important tape recorder. Cleaning and drying the machine had no positive effect, and he was forced to use his camcorder as an audio recorder instead! This was not an ideal solution, as the camcorder used up its batteries very quickly, hence he had to abandon his concentrated watching prematurely, but it was better than not being able to properly record any of his data at all. Typical of the ingenuity observers must often employ under such unexpected circumstances certainly!

Yoko Kikuta in Japan enjoyed the Leonids on November 18 from a most evocative setting, partway up Mount Fuji, where she had gone with six astronomical friends specially to observe. Skies were marvellously clear and dark, and although Yoko commented that her eyesight is not especially keen, she still noted nearly 900 meteors in the peak hour from 2^h30^m–3^h30^m a.m. local time (17^h30^m–18^h30^m UT), and her group enjoyed a wonderful night. Yoko also commented on how the local media reported the event, which had caught everyone's attention—well almost everyone: "Newspapers reported the fantastic night. Among many reports, there was one about a car thief. He made preparations for stealing a car, and implemented his plan at 3^h a.m. on November 19th [local time; November 18 UT]. However, so many people were out looking up at the night sky, that he was caught quite easily. He would have been successful if he had done it on a different day. Those who caught him said, 'Stupid thief who didn't know about the Leonids!' "

The last word goes to Rainer Arlt, who was observing with Sirko Molau. On November 23, just after getting home to discover around 500 Leonid e-mailed reports awaiting his attention, he wrote: "I was in South Korea during the last five days and was able to see a magnificent show! Activity was similar to 1999, but the high numbers lasted into the very morning." All in all, November 18 had been quite a night for all these observers, and many more.

Acknowledgments

Grateful thanks are once more extended to all the SPAMS contributors to what was a truly fascinating and successful Leonid observing campaign in 2001. Good luck and clear skies for your next observing, whether that is for the 2002 Leonids or sooner!

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The Leonid Meteor Shower of November 18, 2001

R.B. Minton

Experiences with visual, photographic, and video observing techniques of the 2001 Leonid maximum are reported.

For those of you who do not know me, I am an amateur astronomer with experience during the 1960s as a Photo Tech at New Mexico State University, Las Cruces; and 1970s as a Research Assistant at the Lunar & Planetary Laboratory, Tucson, Arizona. In the 1980s, I was a Software Engineer at the Denver Martin-Marietta facility (now Lockheed-Martin) writing defense-oriented simulation software. In the 90s I was also a computer programmer working at the Denver VA Medical Center. I retired in 1995 to pursue my primary interest—astronomy. I am a technology-savvy person who enjoys building instruments, and using them to study astronomical objects and phenomena. I am a member of several meteor observing groups, and the acting Coordinator for the Instruments Section of the Association of Lunar and Planetary Observers (ALPO). My wife and I moved to northern New Mexico in 1995 attracted by the mountain climate, clear and dark skies, and very inexpensive retirement living conditions. However, we are occasional part-time substitutes in the Raton schools.

I was fortunate to observe the 1966 Leonid meteor shower when perhaps 100 000 meteors fell over Las Cruces, NM, in about 4 hours. This sparked an interest in meteors and the Leonids in particular; and I make a special effort to observe this shower. Visual observations and photography were a simpler way of observing during the 1960s, but nowadays one can bring more powerful tools to bear. I observed the Leonids both visually and photographically, but also with an intensified video camera, and two forward-scatter radio receivers. Other optical instruments were not used due to weather.

1. Leonid photographs taken between 3^h51^m UT and 4^h01^m UT

Figures 1 to 4 show four photographs of Leonid meteors and two persistent trains [*color photos in original—Ed.*]. Twenty-seven Leonids were captured on 24 frames. I used a Pentax SLR 35-mm camera with an $f/2$ lens with a focal length of 50 mm, and Polaroid high-definition print film ISO 200. I have tested four types of color print films for meteor photography and prefer this type for its superior color saturation, low-light sensitivity, and fine grain. The original 4×6-inch prints were scanned at 300 dpi and the contrast (gamma) increased by 2, thus emphasizing the vignetting.

Color photographs of Leonids by myself and others show they are green at high altitudes and reddish-white at lowest altitudes. The green color is from atmospheric oxygen and the ruddy hue from nitrogen and metals in the meteor. Medium-brightness meteors show the colors best, because overexposure from high-brightness washes out the color in photographs. Visually, the trails appeared turquoise (blue-green) in color, and the latter path was mostly white. The trains recorded a ruddy-yellow in color photographs taken this night (and in other photos by myself).

There is a physical-instrumental effect not appreciated when looking at a color Leonid photo. The green portion of the trail is usually about the same brightness as the rest of the trail—which appears yellow, white, and red. Depending on the magnitude of the Leonid, the green afterglow will persist motionless for a few (1–3) seconds, whereas the head of the meteor trails very rapidly across the film surface. Assuming the meteor is brighter than magnitude 0 for 0.25 s, the instantaneous exposure is 1/10 of this if there are 10 resolution elements in the image. (Here, a resolution element would be the diameter of a star image near the meteor—not the lines-per-millimeter resolution of the emulsion.) The *relative* film exposure time is the ratio of 3 s to 0.25×0.1, or about 120! Thus, although the green appears about as bright as the rest of the trail, it is actually a hundred times fainter! Note that the fainter Leonids *only appear green* in my color photos.

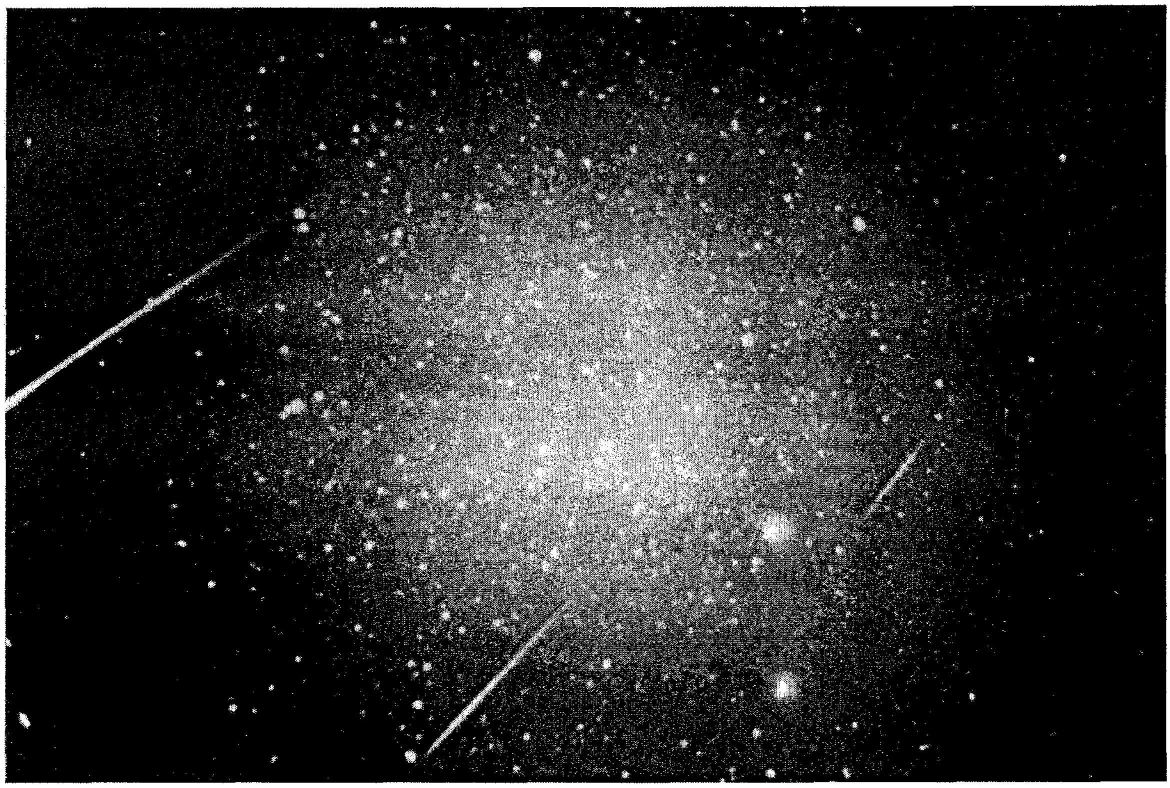

Figure 1 – Photo 1 of $3^h51^m50^s$–$3^h54^m20^s$ MST showing 3 Leonids. The brightest at left was the brightest of the night at magnitude −4. I immediately closed the shutter and moved the camera to the left to photograph it's persistent train. The train lasted about 10 minutes. Two other old faint trains can be seen; one near the top of the brightest trail, the other near the top center.

Figure 2 – Photo 2 of $3^h54^m25^s$–$3^h56^m20^s$ MST. The train and another Leonid to the right. A flare at the end of the trajectory is visible as a small (reddish in original) triangular patch. The photo shows the greatest east–west shear which is near the top of the train. The brightest part is moving east.

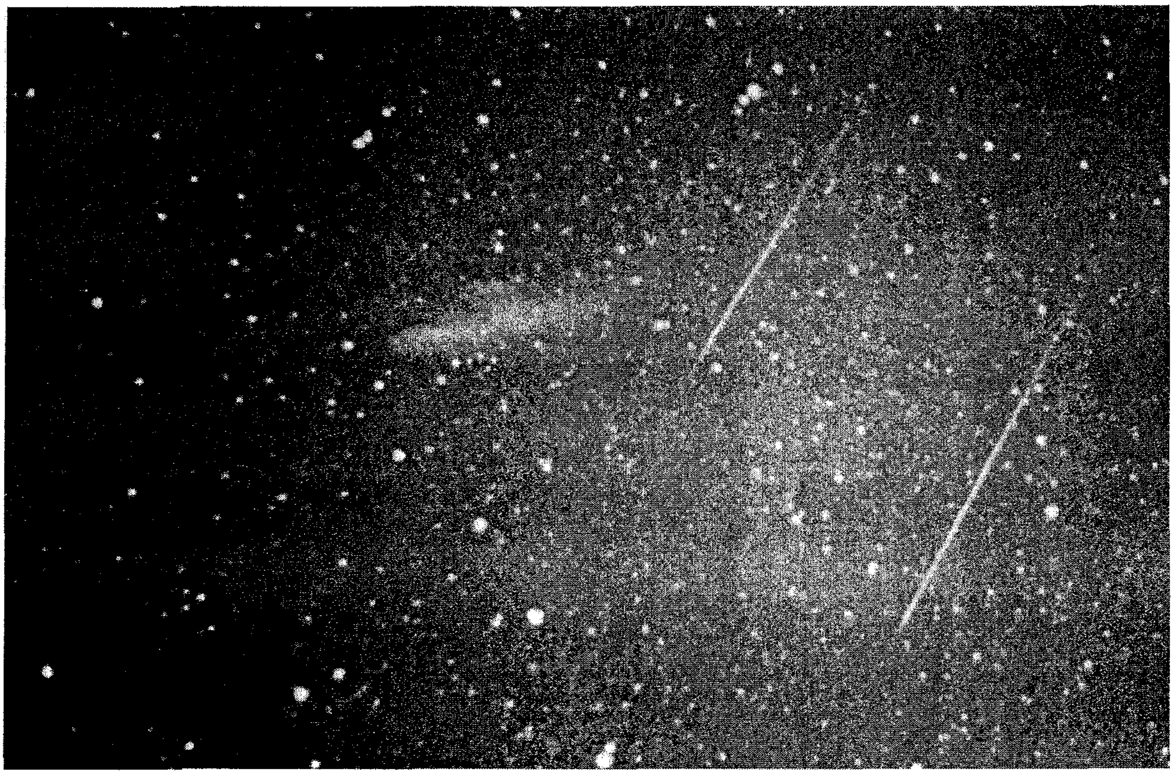

Figure 3 – Photo 3 of $3^h56^m25^s$–$3^h58^m20^s$ MST. Train is fainter and more elongated; flare at bottom still visible as small (ruddy in original) spot. Two more Leonid meteors visible at right.

Figure 4 – Photo 4 of $3^h58^m25^s$–$4^h01^m35^s$ MST. Camera was moved half a field of view to the right to include a new train covering γ Ursae Majoris (Alcor and Mizar below). The first train and a faint Leonid are at the left.

2. Radio meteor observations of the 2001 Leonids

There are many different types of receivers utilizing different wavelengths. A good reference source concerning radio-meteor receivers is the monthly publication Radio Meteor Observer's Bulletin (*RMOB*) which can be found on the internet. Good primer material about the forward scattering of radio waves can be found at the American Meteor Society web location. I will describe my radio, the antenna, finding suitable FM station, the recorder, and a few software programs in minimal detail; so that the interested parties (such as teachers and amateurs) will have a fair idea of what hardware is required (and the software is available free of charge to all experimenters—no commercial inquiries please) to build a system. Write me for details if you are interested in building a simple recording/non-recording radio-meteor receiver. Note that this is a receiver—no transmissions are necessary, and no amateur (ham) radio operator license is required.

FM radio and antenna

My receiver is the fourth model I have assembled—learning from my mistakes with each model. My choice of receiver is still an FM car radio with digital tuning. Recent models of these radios have excellent sensitivity, selectivity, and impulse noise rejection. Digital tuning is a "must have" feature because analog tuners will drift with temperature. Since it also runs on 12 V DC it can be used in the field, or a 1-ampere 12 V DC power supply can be built (my choice). Recent models use large-scale ICs, older models use discrete transistors.

My antenna is a 1/4 wavelength ground-plane type. This type of antenna has a reception pattern like a doughnut laying flat—it is well suited to "see" 360° of the horizon (the zenith gets minimum reception, but this is ok). The vertical element is cut to receive 92.9 MHz; this cut length is 77.09 cm long. The four ground-plane radials are cut to 74.60 cm, are spaced every 90°, and droop down at 45°. See the AARL Antenna Book for ground-plane antenna construction details. The impedance of this antenna is 50 Ω, so it matches any coax cable near 50 Ω very well. These FM receivers are also fed with coax to shield the active element (the center conductor) from noise. The coax braid is normally at electrical ground (−) which is also usually the metal radio chassis. My coax is always soldered to the case as it enters the case. My FM radios have all come from thrift stores and cost $2 to $5.

A problem is identifying the leads. These are for 12 V DC power (red is +, black is −), speakers (usually four), ignition switch (power on/off), display lights (high, low, off), and more. If one uses a benchtop power supply with short-circuit protection, locate the power leads, then search for the display lights—sometimes you cannot tell the frequency in use without these lights. When it looks like it is powered up correctly, and drawing 300 mA, hook an old speaker up to the remaining lines taping each one quickly. (since it may have 12 V DC on it and not 1 or 2 V of audio). You might also find a power connector at an auto-discount store, but it might cost another $5 or $10 for the convenience. If you lack experience and tools, it would be best to buy the connector.

I usually cut the coax line and install a BNC connector—female on the radio and male on the antenna. If your chassis has a push-plug coax connector, bypass it by opening the chassis and installing a "chassis type" female BNC connector. This way you can disconnect the antenna when it is time to move the radio, or store it, or try out a different antenna. My masts are usually a wood dowel or broomstick 1–2 m long with the elements on top. Three-foot length brass brazing rod about 1/8" (about 3 mm) or so in diameter is excellent stock material for antenna elements. Aluminum is the choice of amateur radio operators, but this antenna is fairly small so weight is not a problem and you can solder to brass. The wood mast slides into a hole in a block of wood which has been epoxied to the top of the chassis. A lockscrew holds the mast to the block, and a coax line runs down the mast. A 1- to 2-meter mast is fine for a portable "survey receiver", but my "27/4" receiver antenna is on a metal non-movable 4-meter mast.

FM transmitting stations

Assuming all has gone well so far, and you have at least one channel (left or right, stereo not needed) of audio; it is time to spend a week listening to every frequency on the dial for stations that are suitable for FM radio-meteor reception. If you live in a large city, there may be no suitable stations due to many sources of interference. Start at the high end (107.9 MHz) and work towards the low end (88.1 MHz). Listen to each frequency for 30 s and then go to the next one working up and down the dial. Rapidly skip over strong stations (or interference from a strong station) on any frequency. If you hear a brief burst of music or voice then you are receiving an FM station normally "out of range", but "in range" because a meteor created an ionized trail (at an altitude of about 100 km). The best time to listen is 6 am in the morning since meteors are most abundant at this time—listening from 6 am to 9 am is convenient. Write down those frequencies that have any bursts and add the number of bursts and their loudness. The best one will probably be those that have multiple stations at the same frequency, not just one. It is important to continue this for days, because you might have a dense fall of meteors and thus pick a poor frequency based on one cluster of many meteors. The following is the list of stations I get at 92.9 MHz:

Table 1 – Stations received at 92.9 MHz.

Call sign	Location	Range (km)	Bearing (°)
KTZA	Artesia, NM	444	178
KSPZ	Colorado Springs, CO	217	352
KYBR	Espanola, NM	180	236
KWFM	Tucson, NM	798	233
?	Juarez, Mexico	579	198

Recorder

I used to record the date, time, and duration of the audio signal received; but found that this consumed a lot of computer disk space. Now I count how many times a meteor burst occured during a 6-minute interval, and write these 10 numbers to a disk file once an hour, providing easily numbers of meteors observed per hour. (The quantity "meteors per hour" is the most common way of defining the activity or strength of a meteor shower. Note, however, that this term originated from visual observations and cannot be compared with radio observations.) Any old computer is fast enough to do this job. If you do not have an old computer, go to a thrift store and you will probably find a 386 or 486 for $10 or less—this will do just fine! My current "27/4" 486DX/40 computer can record 100 days worth of data on a single high-density (HD) 3.″5 floppy disk. If the computer has a minimal-capacity hard drive (such as 20 MB), you will be able to record for years.

The audio signal must be "conditioned" in order to feed it into the computer via its mouse port—also called the DB-9 connector or RS232 Serial Port. A computer only recognizes and manipulates digital signals (data), and the radio only puts out audio or analog signals. What is needed is called an "analog-to-digital" or A/D converter. There are several ways to find and use an A/D converter. The simplest is to buy one of the newer digital multimeters which have a PC interface feature. These meteors take the analog voltage, current, or resistance at the tips of two probes, convert it to a digital string of data, and transfer (upload at regular intervals) along a RS232 line to the back of your computer—what could be simpler? Table 2 lists two suitable and inexpensive Radio Shack digital multimeters (DMMs).

Both are suitable for recording meteor events—I have both meters on FM radios. The first is used on my "24/7" (i.e., continuous-operation) receiver. The second sits in my den next to my

386SX/33 computer and is used as a "live signal feed" so I can develop and test my BASIC software for collecting, reducing, and plotting meteor events.

Table 2 – Digital Multimeters (DMM) for computer upload.

Name of DMM in catalog	Catalog No.	Upload frequency	Cost/Sale Cost
38-Range LCD Digital Multimeter	22-168A	3 times per second	\$100/\$80
24-Range Digital Multimeter	22-805	1.5 times per second	\$60/\$40

The meter is connected directly to the audio line of the FM radio. It is necessary to isolate the radio from the meter for electrical safety, system reliability (avoid "ground loops"), and to stretch the meter's event duration in time (to do DMM program logic testing on the signal). I recall this vital bit of circuitry the "signal conditioner". If the audio line voltage or current were measured, the majority of meteors would not be counted—or they would be counted twice. Most meteor signal reflections usually last from 0.1 s to several (1–10) seconds. The shorter reflection time would not be seen by the meter since it only looks at the input every 0.33 to 0.67 s (average 0.5 s). The ratio of $0.5/0.1 = 5$ indicates that only 1 out of 5 meteors would be measured. The longer reflection time would register as many meteors. Taking 5 s as the average reflection time, and 0.5 s as the upload frequency, this would register as $5/0.5 = 10$ meteors. A fine line exists between missing counts and multiple counts. The simplest solution I have found is to only measure the very strongest *change* in signal level—and to also avoid doing this twice for the same event.

This is solved fairly well (in my experience) by using a mix of hardware and software. The hardware solution is to connect a green light-emitting diode (LED) to the audio output line and monitor its brightness with a cadmium sulphide (CdS) photoresistive cell. Both can be purchased for a few dollars total. Insert one in each end of a non-reflective black plastic tube and separate the two so that the meter resistance (to the faint LED glow) is about one half of the highest resistance that can be measured on the DMM. In other words, if this top-scale value is 40 MΩ, set the distance to get 20 MΩ. Set the tone controls to maximize treble and adjust the volume control so that the LED just flashes when you hear a meteor-reflected signal.

When the LED briefly flashes from the passage of a meteor, the resistance of the green-sensitive CdS cell will go from a value of many MΩ to a few kΩ. The LED may flash for only 0.1 s, but the CdS cell will change more slowly taking perhaps 0.2 s to 0.5 s to reach its minimum resistance. The DMM software programs (described in the next Section) will detect this sudden drop in resistance and count it as a meteor. Meanwhile, the CdS cell is now in darkness or in some light-level between darkness and the initial intensity. Fortunately, the majority of meteor events produce a brighter initial flash than any secondary flashes; and this helps discriminate against multiple counts of one event. Also helping to discriminate against this is the fact that a CdS cell has a pronounced "dark memory". It takes from 1 s to 5 s to return to full resistance—depending on your cell and the initial flash intensity. The net effect of the signal conditioner is to send a signal to the computer that rapidly drops, and then recovers more slowly. *The user monitors the drop and recovery rates to find the best discrimination level between missed and multiple counts.*

Software

A short BASIC program appears in the owner's manual for both DMMs. It is only seven lines long, but allows the user to write a simple BASIC computer program to read one value from the DMM. This input is a long string variable, and the measurement must be "parsed" out of the string and converted to a numerical value for subsequent use. I have written many BASIC programs of two main types: (1) collect meteor counts and (2) process, dump, and plot meteor counts. Collect means take data from the DMM and write to a file. Process means read the file and optionally reformat it to use less disk space. Dump means print the file to look at individual 6-minute intervals, 1-hour totals, and 1-day totals. Plot means create a screen pixel plot or histogram of 2 or 9 days' data. These programs are free (including the BASIC source code) to any amateur experimenters who wish to use them; and are listed below:

- DMM168.BAS: Collects meteor counts using the 168 model DMM.
- DMM805.BAS: Collects meteor counts using the 805 model DMM.
- PDP_9D_P.BAS: Process/Dump/Plot 9 days of data, a 24-min sample-integration pixel plot.
- PDP_2D_P.BAS: Process/Dump/Plot 2 days of data, a 6-min sample-integration pixel plot.
- PDP_2D_H.BAS: Process/Dump/Plot 2 days of data, a 1-hour sample-integration histogram.

I will now discuss discrimination—the most important dynamic function in the DMM programs. This discrimination level (program variable "lvl") is set to 10 when the software program begins running. This means that if the CdS cell resistance drops by more than 10 MΩ from one measurement cycle to the next, it will be counted as a meteor event. It would be hard to drop any further if a second event occurred in the next measurement cycle, because the CdS cell is near its minimum resistance. On the other hand, after one or two seconds, it can drop 10 MΩ from a second event. *Whether or not this second event is measured as the same meteor (or a second meteor) depends on the discrimination of the operator.* The user can press the "+" key to increase "lvl" by 1 MΩ (per key press), or press the "−" key to decrease it by 1 MΩ. The program displays the current value of "lvl" in the upper-right corner of the screen. *I cannot overstate the wisdom of testing your system on real meteor events to find the optimum level settings before running the system unattended for 24 hours a day, 7 days a week (24/7) operation.* A great aid in deciding whether the second event is really part of the first event is just listening carefully to the FM signal. If you hear a burst of music followed by a burst of voice, it was probably two events. If you hear a burst of audio (vioce or music) followed by oscillations in audio volume, it was most probably one event—the ear becomes trained. Finally, use the same "lvl", volume, and treble settings to collect data—consistency is very important.

Results:

Four graphs are enclosed. The first labeled "Plot of Leonid Meteor Rates..." is a 9-day pixel plot where one pixel is 24 minutes (an integration of 4 six-minute intervals). This runs from November 14 at 0^h UT to November 23 at 12^h UT (9.5 days).

Note the pronounced diurnal effect where the Earth faces toward its orbital motion, and where the Earth faces away. When the meteor contribution is primarily sporadic (from many directions), this is a minimum value near sunset (0^h UT for my longitude); and is maximum near sunrise (12^h UT for me). When the meteor contribution is primarily from a single radiant, the value rises more quickly and then drops more quickly as the radiant rises from the horizon and sets.

The first plot shows the Leonid shower with a double maximum peak around 40 radio counts during a 6-minute interval. (Although as x-axis pixel corresponds to 24 minutes.) Thus, a count of 40 is 400 per hour; but we cannot compare radio counts per hour with visual counts per hour because of very different measurement parameters.

The second two-day plot (2 d 9 h) shows the double peaked maximum near the center and runs from November 17, 12^h to November 19, 21^h UT. This plots six-minute intervals at the highest resolution available (six minutes per pixel of screen resolution). It shows the first maximum commencing at 6^h42^m–6^h48^m at 14 counts, and the second maximum ending at 20^h18^m–20^h24^m at 15 counts. I assume the diurnal variation is about 10 counts (per six minutes) at these times.

For those interested in the counts around commencement and end times (and illustrating the dump program feature), the 0.1-hour counts before and after my choices for these times (choose your own if you wish) can be found in Table 3.

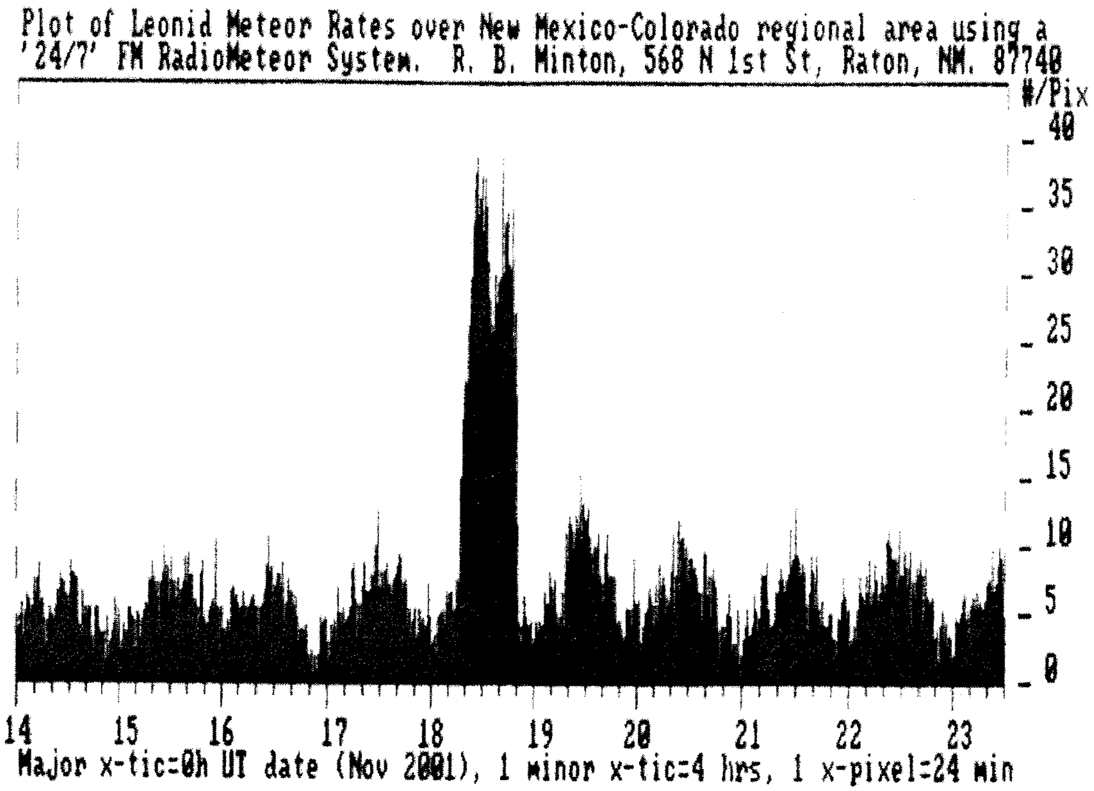

Figure 5 – Plot of Leonid meteor rates over New Mexico–Colorado regional area using a 24-hours-7-days-a-week FM radio meteor system.

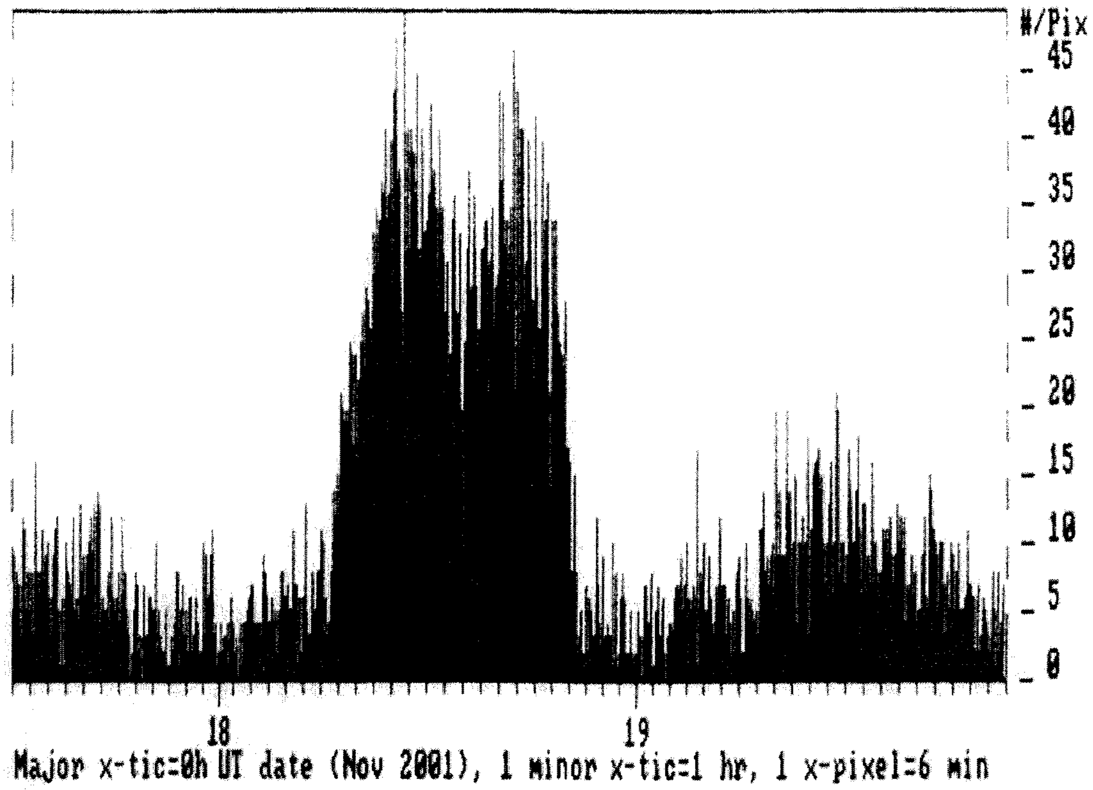

Figure 6 – Same as in Figure 5, but with 6 minutes resolution.

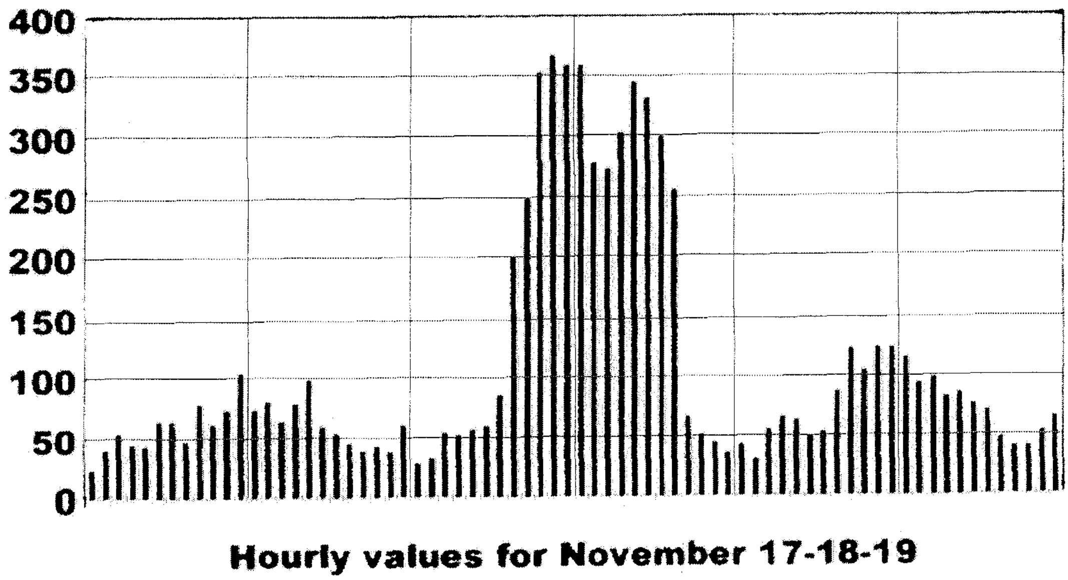

Figure 7 – Hourly rates from the radio meteor system.

These times indicate that the Leonids began being counted when the radiant was 2° below the eastern horizon, and ended being counted when the radiant was 11° above the western horizon. Midway between these two maxima, there is a deep minimum at 14^h00^m–14^h06^m UT where the count is only 9. This suggests that the Leonid meteor contribution was zero, and that perhaps rather than one meteor shower with two maxima, there were two showers.

Table 3 – Leonid counts by forward scatter radio observations. See text for details.

Hour	00^m–06^m	06^m–12^m	12^m–18^m	18^m–24^m	24^m–30^m	30^m–36^m	36^m–42^m	42^m–48^m	48^m–54^m	54^m–00^m
6^h	11	10	3	6	3	4	8	14	12	15
7^h	12	21	20	19	20	19	25	24	17	24
19^h	34	27	34	27	25	24	23	28	17	17
20^h	16	8	8	15	8	2	3	5	2	0

These commencement and end times strongly suggest that the Earth was already in the Leonid meteoroid stream when the radiant was rising (near 6^h45^m UT), but that the Earth left the stream boundary (near 20^h21^m UT) before the radiant had set in the west—it was still 11° high.

The third plot shows the average of 10 six-minute intervals—thus each minor x-tick represents the sum of 1 hour. At this resolution, the two maxima are November 18, 10^h–11^h; and November 18, 16^h–17^h UT. The plot includes a full three days of meteor counts and was created with a word-processor by manually typing in the hourly values from a dump.

The time of the first predicted maximum for the United States was November 18, near 10^h UT. A second predicted maximum was near 18^h UT. In my opinion, given the uncertainties and difficulties in making predictions, these are excellent predictions.

These results illustrate how a home-made continuously operating radiometeor system made from parts found locally, and costing less than \$100 can contribute to our understanding of meteor showers.

3. Intensified-video observations

Only a small percentage of this audience may be familiar with the observational prowness of the modern image intensifier tube when coupled to a video camera. This imagery is usually seen on the news of nighttime warfare—a grainy green circle of light showing soldiers, aircraft fire, and exploding ordinance—all occurring in near or total darkness.

These tubes are now available from various sources at a price comparable to the video camera coupled to it. Inexpensive night-vision devices (containing image intensifier tubes) are available at major sporting goods stores, "big-box" consumer discount stores, military surplus distributors, gun shows, electronic distributors, scientific supply stores, video camera suppliers, advertisers in astronomy/bird/military magazines, mail-catalogs, and "trendy-image" walk-in gift stores—the list is almost endless.

These night-vision viewers contain a small objective lens on the front, an image tube in the middle, and an eyelens on the back. The front lens focusses an image on the light-sensitive cathode of the tube, which then emits a cascade of electrons, which then are accelerated to the rear of the tube, and finally impact a phosphor screen. The screen glows (usually greeen) with an image of the object. The screen is viewed with the aid of the rear eyelens. This process within the tube amplifies the brightness of the field by a few hundred to a few thousand times. (Beware of claims that light is amplified hundreds of thousands of times—this is most probably not true.) Even a light amplification of a hundred times is sufficient to videotape the night-sky. Videocameras with a 1-Lux sensitivity rating can record stars of magnitude +2 with no supplementary optics—so amplify the light 100 times and this increases to magnitude +7. A detailed description of assembling a scope/intensifier/video system is beyond the scope of this explanatory supplement, but it can be as simple as removing the front lens to use a larger lens or telescope, and videotaping through the back eyelens! Two versions exist of this two-hour unedited tape—one has audio, and the other is silent. If the tape label indicates "no audio", skip to the image intensifier section.

Audio on the video

If your version has audio you will hear commentary about the nature of the meteor shower, trains, animals, and other unprintable comments when cameras are dropped, orheads are bumped. Most importantly, however, you will hear a digital FM car radio (about 6 feet from the video camera) tuned to 92.9 MHz. There are no stations at this frequency near Raton, New Mexico; but when a meteor ionizes the atmosphere, it reflects this radio signal back to Earth, and stations can be heared for a split-second to many seconds. If you hear a type of music listed in Table 1, you can assume that a meteor has fallen somewhere in the general area between Raton and that station. At other times, a single large meteor nearly overhead will cause 2–4 stations to be heared at the same time. It may sound like someone is tuning the radio constantly—but it is always on one frequency!

This radio coverage volume is many thousands of times larger than the sky visible from Raton (or any other single location), therefore, the first indication that many meteors are starting to fall (or stopping) will be heared on the FM radio—not from what can be seen in the sky. On a few occasions, you will see video of a bright meteor and hear the radio reflection at the same time. This is noted on the video summary list at the end.

Image intensifier

The image intensifier is a Litton second-generation micro-channel plate (MCP) type, with circular 18-millimeter diameter input and output faces. The faces are fiber-optic bundles to increase light transmission and reduce geometric distortion. The cathode has an S-20R spectral response. This means the tube responds similar to the eye, but has an extended red and infrared response. There is no transfer lens between the MCP and the 8-mm Sony video camera because my camera "macro" focuses to 1 inch. A 50-mm focal length $f/1.4$ Pentax camera lens focuses the sky on the front surface of the MCP. The MCP is powered by two 1.5-volt batteries (this powers a high-voltage-low-current power supply built into the collar surrounding the MCP.) I purchased this

MCP in 1992 from an Australian electronics surplus distributor who advertised in an electronic magazine. It probably cost \$5000 brand-new, but only cost \$350 some 10–15 years later.

The field of view with this system is 20°.6, and the instantaneous limiting magnitude is +8 based on imagery of the bowl of the Big Dipper (during the last 60 minutes of the tape). Earlier there were low-altitude cumulus, fog, and some high-altitude cirrus—all contributed to 1 to perhaps 8 magnitudes of absorption. During the worst times, the camera was stopped. The 2-hour videotape runs from 1^h46^m to 5^h36^m a.m. with these interruptions. A few minutes are lost on the copies due to the 8-mm tape running 10 minutes longer than two hours, but no meteors were seen this late.

In the video summary, I list the location, time, and meteor activity. Some meteors fell nearby and lit the sky a small amount, one fell far to the south and lit the horizon. Some were only seen when they flashed (or exploded) near the end of their path. At two times, 3 or 4 meteors very low to the north (at an altitude of 5°) were seen simultaneously for a few seconds—but only through the viewfinder of the intensified videocamera. There were probably as many overhead, but the increase in air path length and perspective emphasized their numbers.

Table 4 – Video summary with meteor list and observing fields.

Meteor (UT)	Time and Field	Meteor (UT)	Time and Field	Meteor (UT)	Time and Field
	10:43:16 UMi	11:00:00		11:31:30	several meteors
10:43:25		11:00:25			11:32:35 low north
10:44:25		11:00:45		11:32:55	
10:45:10		11:01:09		11:35:15	
10:46:00		11:01:36		11:36:13	
10:46:27		11:04:45			11:36:35 UMi
10:46:40		11:05:10		11:37:10	
10:47:45		11:05:58			11:37:20 UMa
10:48:08			11:10:50 Aur	11:39:25	
10:48:25		11:11:20			11:40:20 UMa
10:48:39			11:11:40 UMa	11:42:10	
10:49:25		11:15:12			11:42:30 end
10:49:51			11:17:25 UMa		(smoke moved
10:50:00		11:18:10			through field)
10:50:30		11:19:30			
10:51:10		11:20:30			
10:52:30		11:20:45			
10:54:43		11:21:50			
10:55:25		11:26:30			
10:57:10		11:27:20			
10:57:40		11:28:40			
	10:57:55 UMa				

One can also see the sky light up and darken in a fraction of a second. This is caused by a meteor flare (or explosion) somewhere not in the camera's field of view. On six occasions, the meteor is bright enough (magnitude 0 to −4) to leave a visible glow in the sky for 15 seconds to 10 minutes. This persistent train initially appears as a bright and thin straight line, but rapidly expands to become shaped like a pencil, snake, corkscrew, fan, and when last visible—a diffuse cloud. They are distorted by upper winds and diffuse with time. On the subject of Leonid meteor altitudes, they are first visible (as well as photographed with common film cameras) near an altitude of 110 km and generally burn out by 85 km. The initial detection altitude depends on how sensitive one can observe them. A sensitive video intensifier should begin to record a 1-g Leonid at an altitude of 170 km (see meteor simulation in Figure 8).

Anyone wishing further information about the tape, meteors, or astronomical instruments is encouraged to write to me. I do not have Internet access or a fax number.

Author's address

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Figure 8 – Simulation of Leonid meteor with the BASIC program in J.A. Kennewell, "The Flight of a Meteor", *Sky & Telescope* 1987, p. 83.

INITIAL MASS (G)	1
DENSITY (G/CM^3)	1
SPEED AT ENTRY (KM/SEC)	71
ANGLE BETWEEN ZENITH & RADIANT (DEG)	30
92.9 MHZ UNDERDENSE ECHO CEILING (KM)	103.8
92.9 MHZ UNDERDENSE ECHO DURATION (SEC)	.023

'90KM ALTITUDE @ D=1 & @1/2D' ARE THE ALTITUDES OF A 90KM HIGH LAYER OVER THE TRANSMITTER AND A POINT 1/2 WAY TO THE TRANSMITTER. TOV IS OVERDENSE ECHO DURATION & DEPENDS ON Q (ELECTRONS PER METER OF PATH LENGTH), AND IS COMPUTED FROM THE RATE OF ABLATION.

CALL SIGN	POWER (KW)	TRANSMITTER LOCATIONS: FROM RATON, NEW MEXICO	RANGE (KM)	BEARING	90KM ALTITUDE @ D=1	@1/2D
KSPZ	53	COLORADO SPRINGS, CO.	217	352	27.0	32.8
KTZA	100	ARTESIA, NEW MEXICO	444	178	14.7	26.7
KWFM	??	TUCSON, ARIZONA	798	233	-4.4	17.2
KYBR	??	ESPANOLA, NEW MEXICO	180	236	29.0	33.8
????	-	CIUDAD JUAREZ, MEXICO	579	198	7.4	23.1

ENTER <CR> TO CONTINUE ?

TIME SEC	ALT. KM	SPEED KM/S	MASS (%)	MAG. (V)	E/M (Q)	TOV SEC	SCALE HEIGHTS: BEST FIT S/H	KING HELE SH	RATIO B/K
0.00	173.0	71.00	99.99	8.0	4.8E+12	0.0E+00	1.9E-14	4.1E-10	0.00005
0.11	166.5	71.00	99.99	7.7	5.6E+12	0.0E+00	2.1E-14	4.8E-10	0.00004
0.21	160.1	71.00	99.99	7.5	6.5E+12	0.0E+00	2.5E-14	5.6E-10	0.00004
0.32	153.6	71.00	99.98	7.3	7.5E+12	0.0E+00	2.9E-14	6.6E-10	0.00004
0.42	147.2	71.00	99.98	7.0	8.7E+12	0.0E+00	3.4E-14	7.8E-10	0.00004
0.53	140.7	71.00	99.97	6.7	1.0E+13	0.0E+00	3.9E-14	9.1E-10	0.00004
0.63	134.2	71.00	99.97	6.3	1.3E+13	1.0E-03	5.1E-14	1.1E-09	0.00005
0.74	127.8	71.00	99.96	5.7	2.1E+13	3.0E-03	8.2E-14	1.3E-09	0.00007
0.84	121.3	71.00	99.95	4.8	4.5E+13	1.0E-02	1.7E-13	1.5E-09	0.00012
0.95	114.9	71.00	99.88	2.2	4.3E+14	1.6E-01	1.6E-12	1.7E-09	0.00095
1.05	108.4	70.99	98.55	-1.2	8.7E+15	5.8E+00	3.4E-11	2.0E-09	0.01662
METEOR IS NEAR THE UNDERDENSE ECHO CEILING									
1.07	107.2	70.99	97.55	-1.8	1.4E+16	1.1E+01	5.7E-11	2.1E-09	0.02683
1.09	106.0	70.98	95.90	-2.3	2.4E+16	1.9E+01	9.4E-11	2.2E-09	0.04330
1.11	104.7	70.97	93.19	-2.9	3.9E+16	3.5E+01	1.6E-10	2.2E-09	0.06990
1.13	103.5	70.95	88.95	-3.4	6.0E+16	6.0E+01	2.5E-10	2.3E-09	0.10676
METEOR HAS REACHED UNDERDENSE ECHO CEILING									
1.15	102.3	70.92	82.53	-3.8	9.0E+16	1.0E+02	3.9E-10	2.4E-09	0.16280
1.17	101.0	70.87	73.06	-4.3	1.3E+17	1.6E+02	6.1E-10	2.5E-09	0.24823
1.19	99.8	70.79	59.63	-4.7	1.8E+17	2.5E+02	9.6E-10	2.5E-09	0.37835
1.21	98.6	70.66	43.37	-4.8	2.0E+17	3.0E+02	1.3E-09	2.6E-09	0.49441
1.23	97.4	70.46	26.69	-4.8	2.0E+17	3.3E+02	1.7E-09	2.7E-09	0.63553
1.25	96.1	70.15	11.87	-4.6	1.6E+17	3.0E+02	2.3E-09	2.8E-09	0.81635
1.27	94.9	69.56	2.17	-3.9	8.2E+16	1.7E+02	3.0E-09	2.9E-09	1.04734

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