The Leonids

Bulletin 18 of the International Leonid Watch: Preliminary Analysis of the 2002 Leonid Meteor Shower

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An analysis of visual observations covering 528 observing hours with 57 045 Leonids logged by 207 observers from 37 countries is presented. The activity peak time of the 7-revolution-old dust trail of Comet 55P/Tempel/Tuttle is found at $4^{\rm h}10^{\rm m} \pm 1$ min UT on November 19, 2002. The peak time of the 4-revolution-old dust trail is found at $10^{\rm h}47^{\rm m} \pm 1$ min UT on November 19, 2002. Visual activity reached ZHRs of 2510 ± 60 and 2940 ± 210 respectively. The full widths at half maximum are found to be 40 minutes for the 7-revolution trail and 25 minutes for the 4-revolution trail.

1. Introduction

The fifth year of impressive activity of the Leonid meteor shower in a row has again seen a large number of observers reporting their results to the global database of the *IMO*. Two major peaks of activity were predicted by several researchers. We compile the predictions as they were known right before the maxima at the end of this Paper and compare them with the observations. Predicted times varied between November 19, $03^{\rm h}48^{\rm m}$–$04^{\rm h}04^{\rm m}$ UT for the first peak and $10^{\rm h}23^{\rm m}$–$10^{\rm h}47^{\rm m}$ UT for the second peak. The first maximum was derived from the evolution of the dust trail of 1767, ejected by the parent comet 55P/Tempel-Tuttle near its perihelion passage seven revolutions ago. The second maximum originates in the 4-revolution-old dust trail of 1866. While most of the predicted timings are results of numerical integrations of meteoroids, the predicted meteor numbers are chiefly phenomenological.

The present analysis is based on the visual meteor data reported by 207 observers from

> Algeria, Austria, Belgium, Brazil, Bulgaria, Canada, China, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, India, Iran, Israel, Italy, Japan, Jordan, Luxembourg, Macedonia, Malta, the Netherlands, Norway, Poland, Romania, Russia, Slovakia, Slovenia, Spain, the UK, Ukraine, the USA, and Yugoslavia.

The input of observing reports into the *Visual Meteor Database* is far from complete. Nevertheless, we would like to present a preliminary analysis of the population index and activity of the 2002 Leonid meteor shower from the current data set.

2. Analysis

We performed a first computation of the population index profile. The usual algorithm with an adaptive bin size is applied. The optimum meteor number for the algorithm was set to 1000 and the minimum step size was set to 15 minutes. We derived the profile shown in Figure 1. Low population indices, i.e. a large fraction of bright meteors, were recorded from Asian geographical longitudes before the first predicted peak. A very steep increase of r was observed until a highest value of $r = 2.53 \pm 0.06$ (7-revolution dust trail).

The population index tends to decrease, although the Atlantic data gap does not provide a conclusive value between $\lambda_\odot = 236\overset{\circ}{.}7$ and $236\overset{\circ}{.}8$. A very high r-value is reached near the predicted American peak with $r = 3.0 \pm 0.1$ (4-revolution trail). The number of observers providing magnitude estimates for the meteors is much smaller than in Europe. The maximum r-values for the same dust trails as observed in 2001 were $r \approx 2.2$ for both peaks (Arlt et al. 2001).

The bad influence of the Moon may have increased the population indices. We checked a similar profile obtained from observations with limiting magnitudes (lm) better than or equal to +5.0. The two peaks in r near the predicted maximum times indeed decreased, but by less than 0.1. We will thus adopt the original r-profile of Figure 1 and postpone a more thorough study of perception effects under moonlight to a later analysis.

The activity of the 2002 Leonids is measured by Zenithal Hourly Rates (ZHR). This is a meteor number extrapolated to one hour duration which a single observer would see under a sky with a limiting magnitude of +6.5 and with the radiant exactly overhead. The scaling to +6.5 involves an enormous extrapolation of observations under the bright Moon, because limiting magnitudes are significantly lower than +6.5 in all observations submitted. A huge fraction of 40% of the observing periods have lm $< +5.0$. A mere 3% of the intervals have lm $> +6.0$.

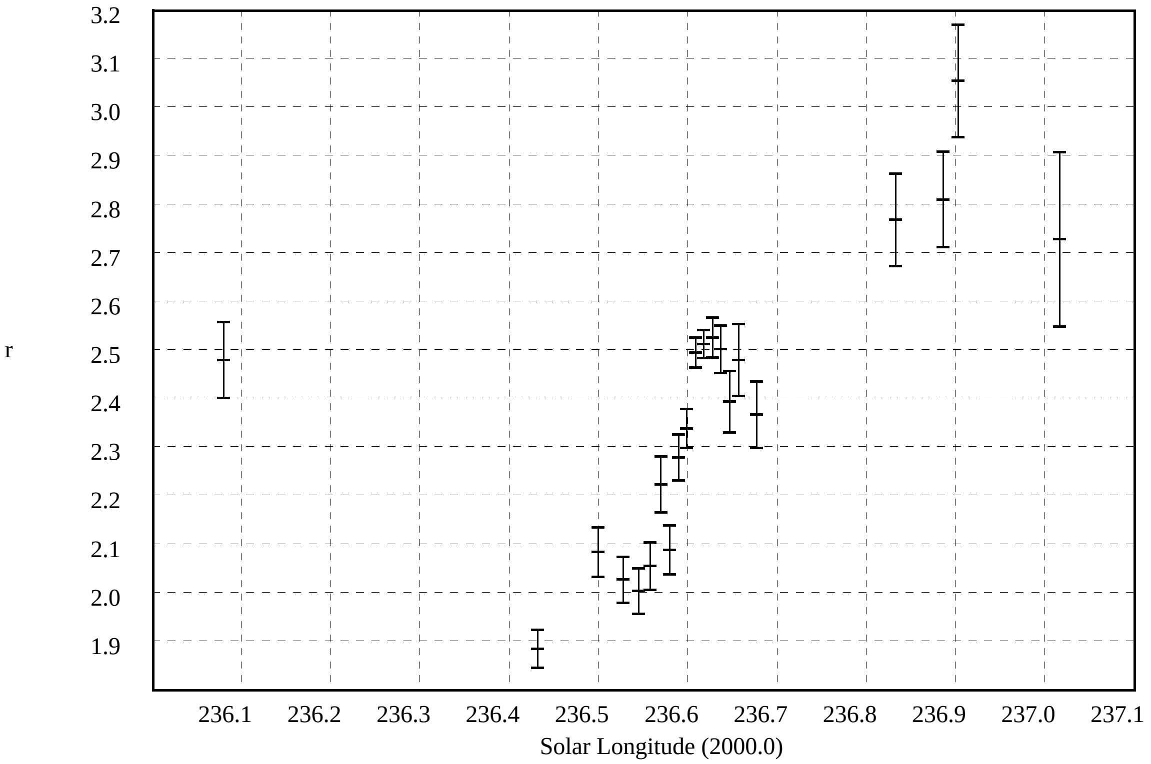

Figure 1 – Population index profile of the 2002 Leonids. Low values denote large fractions of bright meteors; large values represent large fractions of faint meteors.

The low limiting magnitudes make the absolute activity level of the 2002 Leonids in terms of a ZHR virtually inaccessible. A comparison of ZHR profiles from all observations and from those with limiting magnitudes better than or equal to +5.0 is shown in Figures 2 and 3. The graphs are found by an adaptive-bin-size averaging. The adaptiveness is, however, limited to a minimum bin size of $0^\circ\!.0025$ or 3.6 minutes. During the two peaks, this minimum is generally reached. Meteor numbers in each average exceed 1000 near the European peak and were above 100 near the American peak. As already mentioned, the European peak (7-revolution trail) is covered by more observations than the American (4-revolution trail), and still the pile of European data waiting for utilization is the largest.

Comparing Figures 2 and 3 immediately reveals the uncertainties caused by the low limiting magnitudes. Since low lm tend to provide higher ZHRs, we may suppose that

(i) the low lm are a result of underestimating the sky quality, or

(ii) the population index is not constant from +4 to +6.

Table 1 – Numerical listing of the 2002 Leonid results. The population indices are interpolated from Figure 1. The ZHRs are taken from Figure 3. Note that *this sample is limited* to observing periods with limiting magnitudes better than +5.0. Solar longitudes refer to equinox J2000.0.

Solar Long.	Date	r	Intervals	Leonids	ZHR	$\overline{\mathrm{lm}}$
236.°5052	Nov 19, 01 : 32	2.07 ± 0.05	29	197	114.6 ± 8.1	+5.48
236.°5145	Nov 19, 01 : 45	2.05 ± 0.05	22	194	199.0 ± 14.3	+5.50
236.°5239	Nov 19, 01 : 58	2.03 ± 0.05	35	189	110.5 ± 8.0	+5.51
236.°5326	Nov 19, 02 : 11	2.02 ± 0.05	26	184	138.1 ± 10.2	+5.44
236.°5381	Nov 19, 02 : 19	2.01 ± 0.05	23	196	206.6 ± 14.7	+5.42
236.°5430	Nov 19, 02 : 26	2.01 ± 0.05	23	192	225.0 ± 16.2	+5.33
236.°5482	Nov 19, 02 : 33	2.02 ± 0.05	23	189	264.8 ± 19.2	+5.36
236.°5532	Nov 19, 02 : 40	2.04 ± 0.05	24	181	215.7 ± 16.0	+5.55
236.°5571	Nov 19, 02 : 46	2.06 ± 0.05	21	150	320.4 ± 26.1	+5.28
236.°5611	Nov 19, 02 : 51	2.12 ± 0.05	22	190	301.7 ± 21.8	+5.33
236.°5651	Nov 19, 02 : 57	2.18 ± 0.06	24	189	315.8 ± 22.9	+5.41
236.°5693	Nov 19, 03 : 03	2.20 ± 0.06	21	144	285.9 ± 23.7	+5.43
236.°5730	Nov 19, 03 : 08	2.16 ± 0.05	22	198	308.0 ± 21.8	+5.39
236.°5766	Nov 19, 03 : 14	2.11 ± 0.05	20	180	376.0 ± 27.9	+5.36
236.°5801	Nov 19, 03 : 19	2.13 ± 0.05	21	175	342.5 ± 25.8	+5.38
236.°5835	Nov 19, 03 : 23	2.18 ± 0.05	22	199	404.3 ± 28.6	+5.38
236.°5864	Nov 19, 03 : 28	2.23 ± 0.05	20	163	467.6 ± 36.5	+5.37
236.°5891	Nov 19, 03 : 31	2.28 ± 0.05	34	321	543.9 ± 30.3	+5.43
236.°5914	Nov 19, 03 : 35	2.30 ± 0.04	33	311	720.9 ± 40.8	+5.40
236.°5940	Nov 19, 03 : 38	2.32 ± 0.04	55	547	815.0 ± 34.8	+5.39
236.°5969	Nov 19, 03 : 43	2.34 ± 0.04	63	689	798.8 ± 30.4	+5.42
236.°5993	Nov 19, 03 : 46	2.37 ± 0.04	50	656	1156.0 ± 45.1	+5.41
236.°6019	Nov 19, 03 : 50	2.41 ± 0.04	65	895	1125.7 ± 37.6	+5.49
236.°6043	Nov 19, 03 : 53	2.45 ± 0.03	71	1187	1447.6 ± 42.0	+5.44
236.°6069	Nov 19, 03 : 57	2.48 ± 0.03	99	1296	1609.0 ± 44.7	+5.46
236.°6099	Nov 19, 04 : 01	2.50 ± 0.03	108	1948	2145.3 ± 48.6	+5.46
236.°6124	Nov 19, 04 : 05	2.51 ± 0.03	87	1849	2324.3 ± 54.0	+5.48
236.°6149	Nov 19, 04 : 08	2.51 ± 0.03	98	1990	2506.0 ± 56.2	+5.45
236.°6178	Nov 19, 04 : 12	2.52 ± 0.03	97	1756	2284.6 ± 54.5	+5.46
236.°6203	Nov 19, 04 : 16	2.52 ± 0.03	78	1128	1966.8 ± 58.5	+5.46
236.°6227	Nov 19, 04 : 19	2.52 ± 0.04	76	1098	1803.8 ± 54.4	+5.43
236.°6257	Nov 19, 04 : 24	2.52 ± 0.04	84	1175	1577.5 ± 46.0	+5.43
236.°6287	Nov 19, 04 : 28	2.52 ± 0.04	71	843	1332.0 ± 45.8	+5.43
236.°6318	Nov 19, 04 : 32	2.51 ± 0.05	61	625	1169.3 ± 46.7	+5.44
236.°6343	Nov 19, 04 : 36	2.50 ± 0.05	32	321	987.1 ± 55.0	+5.39
236.°6366	Nov 19, 04 : 39	2.49 ± 0.05	43	417	947.1 ± 46.3	+5.43
236.°6395	Nov 19, 04 : 43	2.46 ± 0.05	44	430	929.6 ± 44.8	+5.41
236.°6425	Nov 19, 04 : 48	2.43 ± 0.06	35	235	585.2 ± 38.1	+5.53
236.°6453	Nov 19, 04 : 52	2.40 ± 0.06	32	339	711.1 ± 38.6	+5.64
236.°6480	Nov 19, 04 : 56	2.41 ± 0.07	26	197	581.1 ± 41.3	+5.62
236.°6506	Nov 19, 04 : 59	2.44 ± 0.07	23	199	588.9 ± 41.6	+5.58
236.°6535	Nov 19, 05 : 03	2.46 ± 0.07	29	222	502.3 ± 33.6	+5.63
236.°6561	Nov 19, 05 : 07	2.47 ± 0.07	28	190	522.4 ± 37.8	+5.65
236.°6591	Nov 19, 05 : 11	2.46 ± 0.07	31	183	407.2 ± 30.0	+5.66
236.°6621	Nov 19, 05 : 16	2.44 ± 0.07	31	196	471.8 ± 33.6	+5.57
236.°6658	Nov 19, 05 : 21	2.43 ± 0.07	36	190	352.3 ± 25.5	+5.58
236.°6708	Nov 19, 05 : 28	2.40 ± 0.07	35	174	316.1 ± 23.9	+5.74
236.°6782	Nov 19, 05 : 39	2.38 ± 0.07	32	175	251.9 ± 19.0	+5.94
236.°6920	Nov 19, 05 : 58	2.41 ± 0.07	45	174	159.1 ± 12.0	+6.06
236.°7139	Nov 19, 06 : 30	2.46 ± 0.07	17	85	141.9 ± 15.3	+5.97
236.°7502	Nov 19, 07 : 21	2.56 ± 0.08	2	18	243.0 ± 55.7	+5.10
236.°7776	Nov 19, 08 : 01	2.62 ± 0.08	2	12	149.9 ± 41.6	+5.11
236.°8125	Nov 19, 08 : 50	2.72 ± 0.09	8	49	283.4 ± 40.1	+5.34
236.°8297	Nov 19, 09 : 15	2.76 ± 0.09	18	109	313.2 ± 29.9	+5.35
236.°8510	Nov 19, 09 : 45	2.78 ± 0.10	22	143	315.7 ± 26.3	+5.35
236.°8675	Nov 19, 10 : 09	2.80 ± 0.10	25	193	615.6 ± 44.2	+5.34
236.°8753	Nov 19, 10 : 20	2.80 ± 0.10	30	182	802.2 ± 59.3	+5.36
236.°8819	Nov 19, 10 : 29	2.81 ± 0.10	27	188	957.5 ± 69.6	+5.44
236.°8864	Nov 19, 10 : 36	2.82 ± 0.10	19	133	1742.1 ± 150.5	+5.46
236.°8899	Nov 19, 10 : 41	2.86 ± 0.10	16	175	1615.9 ± 121.8	+5.57
236.°8933	Nov 19, 10 : 46	2.92 ± 0.11	18	199	2941.3 ± 208.0	+5.42
236.°8963	Nov 19, 10 : 50	2.95 ± 0.11	18	196	2252.2 ± 160.5	+5.49
236.°8994	Nov 19, 10 : 54	3.00 ± 0.11	19	159	1740.2 ± 137.6	+5.52
236.°9062	Nov 19, 11 : 04	3.04 ± 0.12	28	187	1136.7 ± 82.9	+5.54
236.°9188	Nov 19, 11 : 22	3.00 ± 0.12	14	190	507.4 ± 36.7	+5.43
236.°9422	Nov 19, 11 : 56	2.94 ± 0.14	9	89	293.9 ± 31.0	+5.59
236.°9613	Nov 19, 12 : 23	2.89 ± 0.15	7	62	199.7 ± 25.2	+5.60
236.°9841	Nov 19, 12 : 55	2.82 ± 0.16	3	22	150.7 ± 31.4	+5.40

The value of r may have been high for relatively bright magnitudes (say magnitudes 0 to +4) and decrease for magnitudes +4 to +6, as was observed in 1999 (Arlt et al. 1999). We should not forget that the highest limiting magnitudes reported may also be inapplicable, because it is definitely possible that observers, especially inexperienced ones, unconsciously try to reach their usual lm despite the Moon. A good lm does not always mean a more reliable lm!

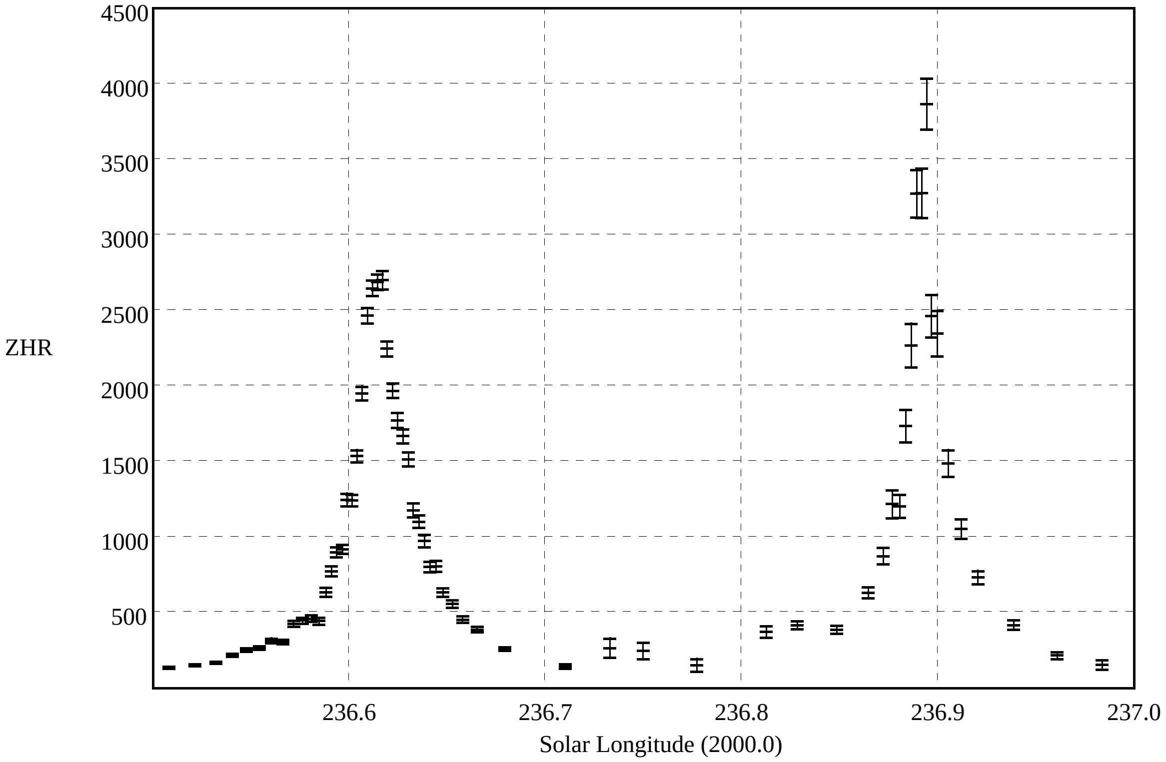

Figure 2 – Activity profile of the 2002 Leonids in terms of the Zenithal Hourly Rate. All observing periods with a maximum correction factor of 10 and a minimum radiant elevation of 20° were used. Implicitly, lm $\geq$ +4.0 because the *Visual Meteor Database* does not store observing periods logged under poorer conditions. The minimum size of averaging windows is 3.6 minutes, but may be larger for periods in which data are less abundant.

The scrutiny of this problem goes beyond the scope of this first analysis; *we suggest assuming the peak values of Figure 3 to be the most reliable ZHR estimates.* These are 2510 ± 60 for the 7-revolution dust trail and 2940 ± 210 for the 4-revolution dust trail. These values are somewhat higher than reported in the first Leonid Circular (Krumov et al. 2002), because smaller averaging bins could be used here.

Because of the size of the Earth, different locations encounter the center of the meteoroid stream at different times. A correction for the topocentric stream encounter must be applied. For the Leonid meteoroid stream, these corrections are of the order of a few minutes—typically shifting the observer's clock time to an earlier topocentric moment. For example, observers in Norway saw the European peak about 5 minutes after colleagues in southern Spain or on Malta. The large fraction of observers in southern France saw the peak 1.6 to 2 minutes later, while the group in Algeria encountered the peak 0.7 min before topocentric encounter. We applied the correction for topocentric encounter to all individual observing periods according to the equations given by McNaught & Asher (1999).

Although we chose a minimum step size of 3.6 minutes, we permitted periods of up to 6 minutes to be involved in the average. This clearly smears out small-scale structures, but ensures that enough data are used in constructing the profile, thus defining the times of maxima very precisely.

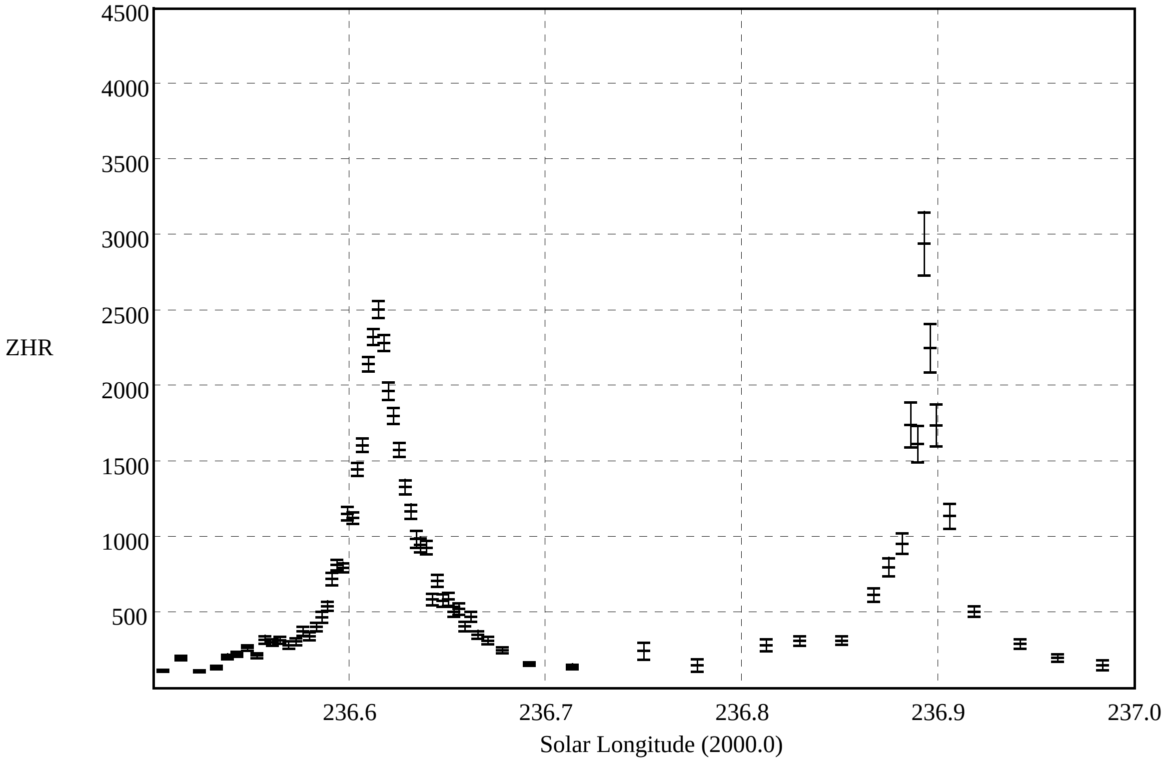

Figure 3 – ZHR profile of the 2002 Leonids as in Figure 2 but based only on observations with a limiting magnitude of +5 or better. We consider this profile more reliable with respect to the determination of the maximum ZHR level of the 2002 Leonids. Numerical data are given in Table 1.

Functions of Lorentz type were applied to the two peaks in order to find their most probable moment of maximum activity and the full width at half maximum (FWHM). The graphs indicate good applicability of Lorentz shapes, although they need not necessarily provide a good fit for a relatively old dust trail like the 7-revolution one.

The first peak in Figure 2 leads to $\lambda_\odot = 236\overset{\circ}{.}6157 \pm 0\overset{\circ}{.}0004$ corresponding to November 19, $04^{\mathrm{h}}10^{\mathrm{m}} \pm 1$ min UT and a FWHM of 39 ± 3 minutes. The fit of the second maximum delivers $\lambda_\odot = 236\overset{\circ}{.}8933 \pm 0\overset{\circ}{.}0004$ corresponding to November 19, $10^{\mathrm{h}}47^{\mathrm{m}} \pm 1$ min UT. The FWHM is significantly shorter with 25 ± 3 minutes. Widths and peak times are the same for fits to the graphs in Figure 2 and 3. The fitting implied a background constant of about $\mathrm{ZHR}_{\mathrm{bg}} = 100$ (which is also a result of the fits). The FWHMs thus refer to the peak functions above this background level.

A first attempt to look into the fine structure of the two Leonid peaks is shown in Figures 4 and 5. Now all observations are used with the limitations that the total correction factor should not exceed 10 and the radiant elevation should be larger than 20°. The maximum of the 7-revolution dust trail encounter is averaged with a minimum bin size of $0\overset{\circ}{.}001$ corresponding to about 1.4 minutes. Again we permitted larger periods of up to 3 minutes duration to be involved in the averages. Each observing period, however, is used only for one average. The 7-revolution trail in Figure 4 reveals a smooth rise in activity and a ragged decline of activity.

The profile of the 4-revolution trail in Figure 5 is very smooth. The minimum bin size of $0\overset{\circ}{.}001$ is not always reached, because of the smaller number of observing periods available. Reporting no shorter periods than 5-minute bins is a particular drawback in North American observations.

Fits of Lorentz profiles again delivered the same peak centers and FWHMs for both maxima. The results are apparently independent of the data sampling applied. This fact is particularly satisfying as we have attempted to achieve sub-bin accuracy for the peak times by applying reasonable fit functions. Choosing the highest ZHR value for the peak time from Figure 4 or 5 would certainly not be wise. Table 2 finally summarizes the predictions of Leonid maxima in 2002 and the observed peak times and ZHRs obtained in this preliminary analysis.

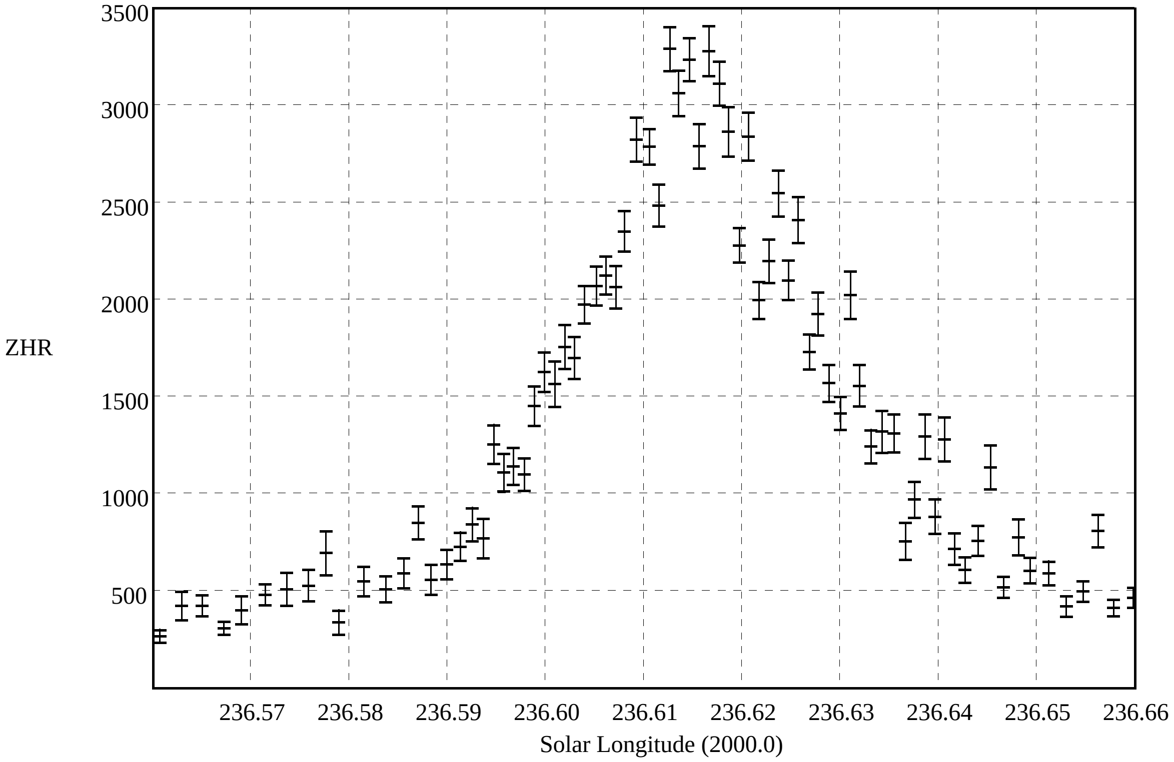

Figure 4 – ZHR profile of the 2002 Leonids near the time of encounter of the 7-revolution dust trail. The bins for averaging are about 1.4 minutes wide near the peak and are about 3 minutes wide in the wings of the graph. The ZHRs may be overestimated due to the low limiting magnitudes involved in the graph (lm $\geq +4.0$). The maximum total correction permitted is 10, the minimum radiant elevation is 20°.

Table 2 – Comparison of predicted Leonid maxima with the preliminary, observed peak times and activity levels in 2002. The observed times are the topocentric stream encounters.

Source	7-revolution dust trail		4-revolution dust trail	
	Time	ZHR	Time	ZHR
Numerical integrations				
Lyytinen & van Flandern (2000)	04 : 02	4500	10 : 44	7400
Lyytinen et al. (2002)	04 : 03	3500	10 : 40	2600
McNaught & Asher (2002)	03 : 56 ± 5	1000 (810–2000)	10 : 34 ± 5	6000 (2900–6000)
Vaubaillon (2002)	04 : 04	3600	10 : 47	3200
Phenomenological models				
Jenniskens (2002)	03 : 48	5900	10 : 23	5400
Langbroek (2002)	–	2000+ (2000–5700)	–	2400+ (2400–5200)
Observed	04 : 10 ± 1	2510 ± 60	10 : 47 ± 1	2940 ± 210

Acknowledgments

The present analysis is based on a part of the observations submitted to the *IMO*. A name list of observers would be confusing, since reports not yet included are not worse than others. We would therefore like to emphasize our gratitude here to all the observers contributing to the global picture of the 2002 Leonid storms. We would also like to thank Jürgen Rendtel and Orlando Benitez Sanchez for their help in data input.

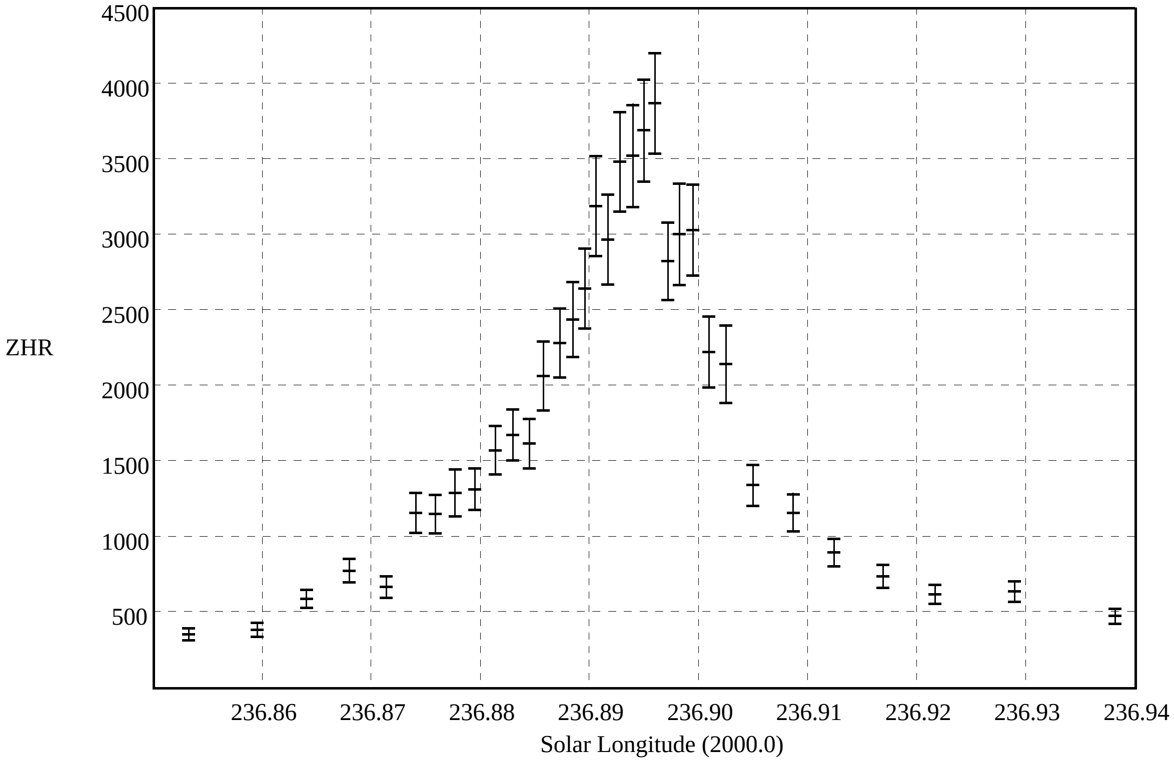

Figure 5 – ZHR profile of the 2002 Leonids near the time of encounter of the 4-revolution dust trail. The length of the averaging bins reduces to about 2 minutes near the peak. As in Figure 4, the ZHRs may be overestimated due to the low limiting magnitudes; the same constraints hold here, too.

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