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Video and radar observations of the 2000 Leonids: evidence for a strong flux peak associated with 1932 ejecta?

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ABSTRACT

Video and radar observations of the 2000 Leonid shower are presented. We find strong evidence that the first peak in the shower on 2000 November 17 near 8 UT resulting from 1932 ejecta is much stronger than previously recognized and larger than the broader peak on November 18 resulting from 1866 and 1733 ejecta. In particular, we find a TV–radar average peak flux value on November 17 at solar longitude $235\overset{\circ}{.}29 \pm 0\overset{\circ}{.}02$ near 0.15 ± 0.02 meteoroid km^{-2} h^{-1} ($M_v > +6.5$), which corresponds to a zenithal hourly rate (ZHR) $\sim$900 assuming a mass index of 1.7. Similarly, we find the second peak on November 18 to be located at $236\overset{\circ}{.}26 \pm 0\overset{\circ}{.}02$ with a maximum flux value of 0.11 ± 0.02 meteoroid km^{-2} h^{-1} corresponding to a ZHR of 600. Evidence for this narrower and stronger early peak on November 17 is present in several other observations by radar/radio, although only for data smoothed over 15-min intervals or less. The implications of this higher early peak for the 2000 Leonids associated with 1932 ejecta for predictions and visual observations of the shower in 2002 are briefly discussed.

Key words: techniques: radar astronomy – meteors, meteoroids.

1 INTRODUCTION

The Leonid shower has produced two meteor storms and several strong showers over the last four years. While much attention has been paid to the meteor storms of 1999 and 2001 (cf. Gural & Jenniskens 2000; Arlt 2002), the lesser activity in 1998 and 2000 is also noteworthy. In particular, models of the Leonid stream have reached previously unparalleled levels of predictive capabilities (e.g. Asher 1999), and thus precise measurements of the flux and mass distribution throughout each Leonid return are valuable in refining these models. In addition, weaker activity in non-storm years offers another means to assess the full spread in nodal positions for young stream meteoroids, providing constraints on Leonid ejection speeds (Brown & Arlt 2000).

The Leonid return on 2000 November 17–18 was perhaps the least monitored shower of the last four Leonid returns. In particular, a Moon situated near the radiant as well as poor weather produced significant interference to visual observations (Arlt & Gyssens 2000). Global visual data analysed by Arlt & Gyssens (2000) revealed three distinct maxima associated with the shower: one near 8 UT on November 17 ($\lambda = 235\overset{\circ}{.}28 \pm 0\overset{\circ}{.}01$) with a maximum zenithal hourly rate (ZHR) of 130 ± 20, another near 3:30 UT on November 18 ($\lambda = 236\overset{\circ}{.}09 \pm 0\overset{\circ}{.}01$) with a peak ZHR of 290 ± 20, and finally a primary peak near 7 UT on November 18 ($\lambda = 236\overset{\circ}{.}25 \pm 0\overset{\circ}{.}01$) where the ZHR reached 480 ± 20. The timings of these observed maxima were in general accordance with predictions made by several groups (Lyytinen & Van Flandern 2000; McNaught & Asher 1999) who also associate these peaks with material ejected in 1932, 1733 and 1866 respectively. While the timing for these peaks was well constrained by these models, the associated peak activity was not. Lyytinen & Van Flandern (2000) suggest that the earlier of these peaks would produce a peak ZHR of approximately 215 and would be dominated by faint meteors, while the latter two peaks would both have ZHRs near 700. Asher & McNaught (2000) suggest ZHRs of the order of 100 for the last two peaks but emphasize the uncertainty in this prediction; they do not attempt to estimate the magnitude of the even more uncertain activity associated with 1932 ejecta in the earliest peak.

In addition to these global visual data, Jenniskens & Gustafson (2000) present results from airborne observations employing video systems. They note that their results in connection with the early peak (at solar longitude $235\overset{\circ}{.}27$) are preliminary and scale their peak count rates to a visual ZHR of 170, and so do not provide an

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independent estimate for the peak ZHR. They do provide a relative measure for the width of this early peak as fit to a Lorentzian distribution which they report as 0°.049.

Here we present video, radar and forward-scatter data collected from Europe and North America in the interval 2000 November 17–18 (UT). We compute the absolute Leonid flux (referenced to an equivalent limiting absolute magnitude of +6.5) and mass distribution indices, and estimate the relative magnitude of the early peak on November 17.

2 EQUIPMENT AND DATA REDUCTION TECHNIQUES

2.1 Electro-optical data

The TV data summarized here were collected from Calar Alto, Spain (37°.2 N, 2°.5 W, altitude 2200 m), from the Massachusetts Institute of Technology Experimental Test Site (MIT–ETS), New Mexico, USA (106°.7 W, 33°.7 N) and from Pinson Mounds State Park, Tennessee, USA (35°.6 N, 88°.8 W). The cameras for Spain and New Mexico employed generation III image intensifiers coupled to video rate monochrome CCD devices. The total spectral response for these systems extends from about 340 to 870 nm. Different focal length lenses were used at each site, resulting in different fields of view and limiting sensitivities, in order to extend the mass regime for determination of the mass distribution index. C-mount objective lenses with focal lengths from 25 to 75 mm were used, producing fields of view ranging from 35° to 9°, and a maximum limiting stellar magnitude on the most sensitive systems of nearly +9 mag. The limiting meteoroid mass for the most sensitive cameras was approximately 2×10^{-8} kg for Leonid meteors. All CCD cameras used in the campaign were Cohu[1] model 4910 scientific monochrome units operated at National Television System Committee (NTSC) video frame rates (30 frames per second, with two interlaced video fields per frame). The generation III systems consisted of both NiteMate model microchannel-plated, lens-coupled intensifier tubes manufactured by Litton,[2] and NiteMate generation III systems manufactured by ITT.[3] The video output from each camera was recorded directly to VHS tape and later digitized directly from the same tape.

At the Tennessee site, a single camera was used with a 25-mm microchannel plated generation II intensifier (Litton P/N 510-3808-327). This device uses an S-20 spectral response photocathode and a P7 output phosphor. The resolution of the device is 28–40 lp mm^{-1} (line pairs per mm) with a luminous gain of about 40 000×. A Tamron[4] 90 mm/f2.8 macro-lens was used for optical coupling between the intensifier and the Cohu CCD. These lenses have excellent low distortion and field uniformity characteristics, and can produce the range of reproduction ratios needed to image the microchannel plated (MCP) output to the CCD input. They achieve this by a relatively long object to lens distance, but the high luminous gain of the image intensifier means that additional gain is available.

The sensitivity, deployment location, pointing direction, field of view and geometric collecting area for each of the cameras are shown in Table 1. The meteor limiting magnitude (LM) measures the equivalent limiting magnitude for Leonids for each camera and its pointing direction relative to the radiant. The Leonid TV LM was found using the relation (Hawkes 1998)

$$\Delta_m = 2.5 \log\left(\frac{180 r_1 V \tau \sin\xi}{\pi F_{\mathrm{ov}} R}\right). \tag{1}$$

Here Δ_m is the difference in magnitude between the stellar limiting magnitude and the meteor limiting magnitude, r_1 is the resolution of the detector in number of video lines (which for most of our systems is ∼300), V is the geocentric velocity in km s^{-1} (71 km s^{-1} for the Leonids), τ is the effective CCD integration time (0.033 s at NTSC frame rates), ξ is the solid angle between the radiant and the pointing direction of the camera, F_{ov} is the field of view (taken as the average of vertical and horizontal fields of view) and R is the range to meteors in the centre of the field, which we compute assuming a mean altitude of ablation of 110 km as was measured for an ensemble of two-station TV Leonid meteors in 1999 (Brown et al. 2002).

Using this relation, it is possible to determine the effective limiting magnitude of detection for Leonid meteors – these are shown for each camera in Table 1. Note that as the angle ξ varies throughout the night as the radiant drifts across the sky, we have chosen the average value for ξ to be representative of the data from the entire night. In general, the extreme variations in ξ found throughout the night for a given camera produced less than $0.5M_v$ variation in meteor LM (with the majority of the data later in the night within $0.2M_v$ of our nominal value), which we take to be negligible compared with the counting statistics. The stellar limiting magnitude is computed by counting the number of stars in several selected regions from each camera/tape and comparing the number of visible stars within these regions with the numbers available from standard computer planetarium programs. The resulting values have been found to be accurate to better than $0.2M_v$.

The method for measuring each meteor in the video frame and then computing begin and end angles relative to the radiant is given in Campbell et al. (2000). We accepted meteors as Leonids if their backward projections passed within 5° of the radiant. The procedure for computing the physical collecting area of each camera projected on to the meteor zone in the atmosphere can be found in Brown et al. (2002). By correcting the Leonid rates for radiant altitude for each camera together with the physical collecting area, we may calculate the flux directly by dividing the total observed shower rate by the

Table 1. Summary of camera locations, designations and pointing characteristics. All cameras were generation III (except camera G which was a generation II system). The field of view is given in degrees, the pointing direction is in degrees with azimuth north equal to 0°, and the collecting area is in units of square kilometres. The limiting Leonid magnitude is relative to the centre of each field and the measured limiting stellar magnitude is determined as described in the text.

Camera designation/ location	Field of view horizontal × vertical	Pointing direction (altitude, azimuth)	Collecting area (km^2)	Limiting Leonid (mag)	Limiting stellar (mag)
H/Spain	26° × 20°	53, 8	5400	+4.9	+8.2
K/Spain	26° × 20°	46, 43	8400	+4.8	+8.4
R/Spain	28° × 21°	55, 19	5500	+4.6	+8.1
P/Spain	14° × 10°	48, 20	1940	+5.4	+9.4
S/New Mexico	34° × 26°	57, 33	7600	+4.4	+8.1
T/New Mexico	15° × 11°	53, 358	1800	+6.4	+9.0
U/New Mexico	29° × 22°	54, 255	6200	+4.6	+7.6
G/Tennessee	34° × 25°	51, 259	10 430	+3.1	+6.4

[1] Cohu, Inc., Electronics Division, PO Box 85623, San Diego.
[2] Litton Poly Scientific, Security Systems, 1213 North Main Street, Blackburg, VA 24060-3100, USA.
[3] ITT Industries Night Vision, Subsidiary of ITT Industries, Inc., 7635 Plantation Road, Roanoke, VA 24019, USA.
[4] Tamron USA, Inc., 10 Austin Boulevard, Commack, NY 11725, UAS.

collecting area. The resulting values for each camera are referenced to an equivalent limiting magnitude of +6.5 for ease of comparison with visual data through the formula

$$\Phi_{6.5} = \Phi_{\mathrm{MLM}} \times 10^{(6.5-\mathrm{MLM})\log r}, \quad (2)$$

where $\Phi_{6.5}$ represents the flux at an equivalent limiting magnitude of +6.5, MLM is the meteor limiting magnitude and r is the population index defined to be $r = N(M+1)/N(M)$, i.e. the ratio of the numbers of true shower meteors of magnitude $M + 1$ and those of magnitude M. The population index and mass index are found directly from the TV data (see later).

2.2 Radar data

The radar performing these observations was the commercial SkiYmet HF/VHF meteor radar jointly manufactured by Genesis Software Pty[5] and MARDOC[6] Inc. The particular system used was designed specifically for the real-time detection, recording and analysis of meteor echoes, and this particular unit was constructed to make simultaneous observations at frequencies of 17.450, 29.850 and 38.150 MHz. The radar is located near Tavistock, Ontario, Canada at 43°.2 N, 80°.9 W. Owing to severe interference at the time of the 2000 Leonids on 17.450 MHz, only 29.850- and 38.150-MHz data were analysed. More details of the detection algorithms employed can be found in Hocking, Fuller & Vandepeer (2001).

The system design allows measurement of the direction and range to each meteor echo. Each of the seven receiving antennas are laid out in a 'cross-shaped' configuration to perform interferometry on received echoes, establishing the arrival direction of the scattered radio waves. The phase difference between the echoes permits measurement of the altitude and azimuth from which the echo was received. This echo direction, in conjunction with the specular scattering condition (which implies that echo directions are perpendicular to the radiant), is then used to distinguish Leonids from non-Leonids. Details of the interferometry procedure and methods for selecting shower echoes can be found in Brown et al. (1998).

Using the final data collected in this way, we selected all echoes that were within 5° of perpendicular to the Leonid radiant for the time period 2000 November 14–20 for both 29.850 and 38.150 MHz. Owing to a system error, no data were recorded on 2000 November 14–16 at 38.150 MHz.

Taking Leonid echoes in this manner establishes the observed shower rate for each radar system. We then compute the effective collecting area for the radar as given in Brown & Jones (1995). From this collecting area, the apparent flux to the limiting sensitivity of the radars (equivalent to an absolute visual magnitude of +7.8) can then be calculated.

However, this is not the true out-of-atmosphere Leonid flux. As the Leonids form at high altitudes they have initial trail radii comparable to the radar wavelengths being used, and as a result these high-altitude echoes are severely attenuated and effectively 'missed' when counting the total flux [cf. Ceplecha et al. (1998) for a discussion of this effect]. Greenhow & Hall (1960) derived approximate formulae for correcting observed sporadic flux for this effect, and when we apply their formalism to our radar wavelengths we find that 10 and 15 per cent of all Leonid echoes are measured at 38.150 and 29.850 MHz respectively.

We have also re-examined these correction values by making use of simultaneous, multi-frequency observations of the 2001 Geminids, scaled to the de-biased heights of ablation for the Leonids found from the 1999 Leonid video observations (Brown et al. 2002) and modelled to match the relative amplitude differences for each Geminid echo observed on 29 and 38 MHz (Campbell 2002). The result for the Leonids using this procedure is identical to that from Greenhow & Hall (1960) to within a few per cent. We note that a more accurate description of this correction factor needs to account for the more fragile nature of the Leonids relative to the Geminids (Koten & Borovicka 2001) in modelling their fragmentation behaviour, which appears to be the determining physical mechanism in connection with the initial trail radius (Campbell 2002).

This final correction allows us to estimate the 'absolute' values of flux. It should be noted that this is a very large correction and the final numbers are still quite uncertain – as a result, the absolute levels of radar Leonid flux could easily be in error by a factor of ∼2 given our poor characterization of this effect for fragile Leonids.

3 RESULTS

3.1 Electro-optical Leonid results

The final flux values found for the cameras for November 17 and 18 are shown in Fig. 1. Note that this final flux curve is the average of all cameras for a given site weighted according to the magnitude of the error associated with each measured flux measurement. Note also that some of the scatter (and hence larger error margins) associated with some flux values is due to interference from the Moon at the time of the observations. We have used a mass index value of 1.7 (equivalent to a population index of 1.9) for all flux calculations, which is consistent with the available radar and video data (see later).

It is important to note that the New Mexico site experienced clear weather on November 17, but suffered from cloud interference beginning at 7:15 UT on November 18 with conditions becoming overcast 1 h later. Spain was clouded out on the night of November 17 (UT) and Tennessee had only a short interval of partial clearing from 235°.2 to 235°.3 (November 17 from 5 to 8.5 UT). Corrections for cloud obscuration were performed for each camera, but where conditions were rapidly changing (as with the Tennessee camera data and the last two points of the New Mexico data on November 18), some underestimate of the true correction is probable.

The flux profile is binned at 15-min intervals and shows two primary peaks. One at 235°.27 ± 0°.01 is reasonably well defined both in the New Mexico data and to a lesser degree in the Tennessee camera data, while a second peak near 236°.23 ± 0°.01 is also visible. The Gaussian width of the first peak is 0°.031 ± 0°.006 while that for the second peak is 0°.038 ± 0°.019.

To calculate the population index the linear portion of the cumulative number of Leonids as a function of peak magnitude is measured for each camera. The magnitude distribution for Leonids from camera R for the entire night of November 18 (UT) is shown as an example in Fig. 2. Statistically significant values of the population index can only be obtained for binned samples with at least ∼100 shower meteors. This limits our temporal resolution and provides for only a single measure of the population index on each camera per night. Taking the average of these estimates for all cameras, we derive a population index of 1.60 ± 0.07 from New Mexico data for the night of November 17 and 1.88 ± 0.04 for the night of November 18 from Spain data.

For comparison, flux values of 0.05 and 0.10 correspond to ZHRs of ∼300 and 600 respectively using a mass index of 1.7.

[5] Genesis Software Pty Ltd., 10 Marian St, North Adelaide, SA 5006, Australia.
[6] MARDOC Inc., 18 Pitcairne Cres., London, Ontario, N6G 4N4, Canada.

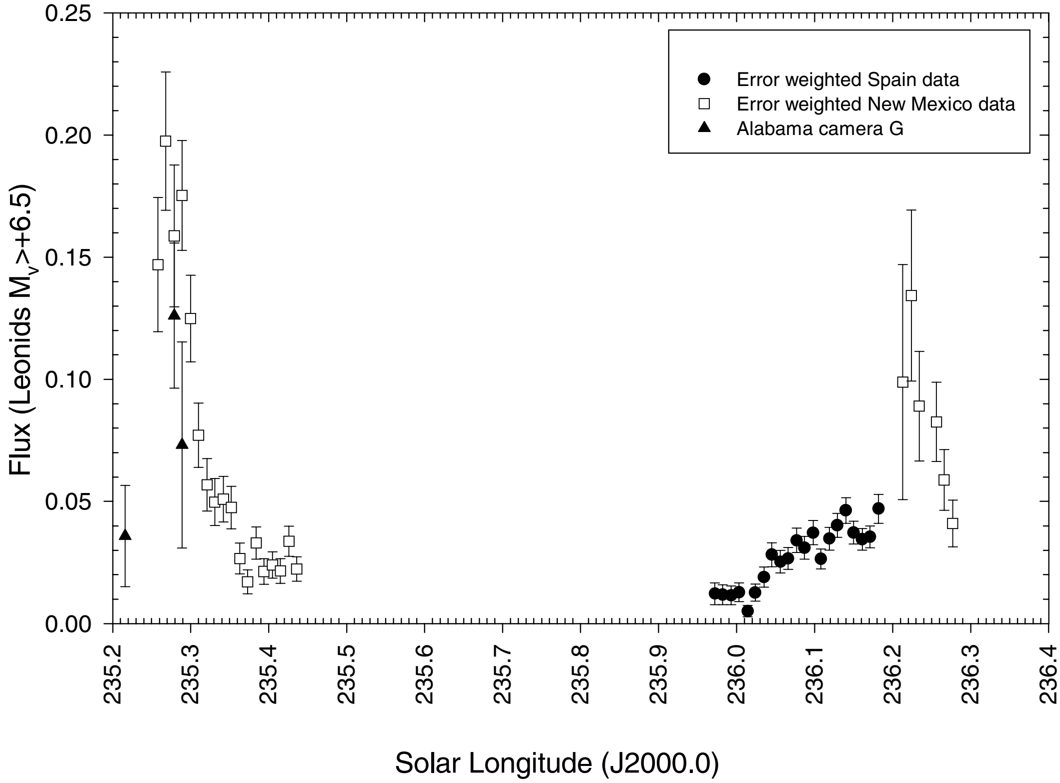

Figure 1. TV flux measurements of the Leonids.

3.2 Radar results

Using the techniques described earlier, Leonid radar fluxes were computed for both 29.850- and 38.150-MHz radar systems. We have used the rates on November 14 as a measure of the sporadic contamination for the 29-MHz results and subtracted these values for each day from November 15–20 to determine 'true' Leonid rates. Similarly, the rates for November 20 were taken to represent the sporadic background for 38-MHz data.

Final corrected fluxes for both 29- and 38-MHz radar systems as a function of solar longitude are shown in Figs 3 and 4 respectively. There are two clear features visible at both frequencies, namely an early peak at $235\overset{\circ}{.}29 \pm 0\overset{\circ}{.}02$ as well as a second peak some 24 h

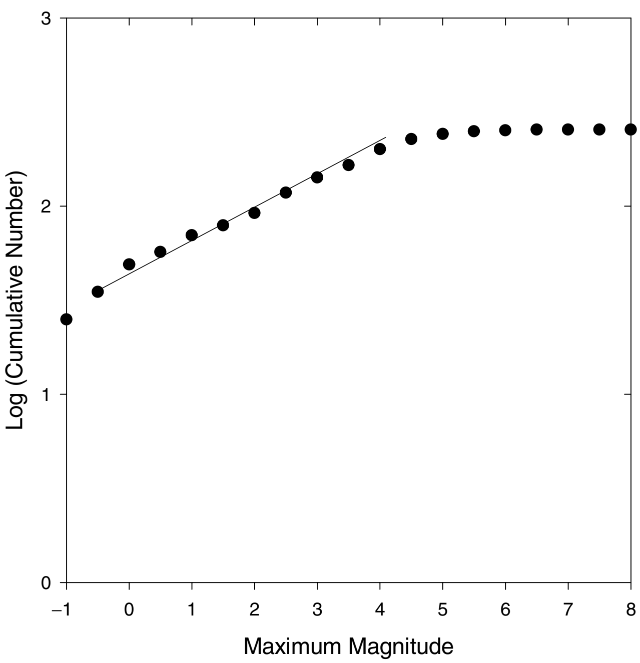

Figure 2. Magnitude distribution of Leonids on the night of 2000 November 18, from Spain as measured by Camera R. The straight line shows the assumed 'linear' portion of the curve used to compute the population index.

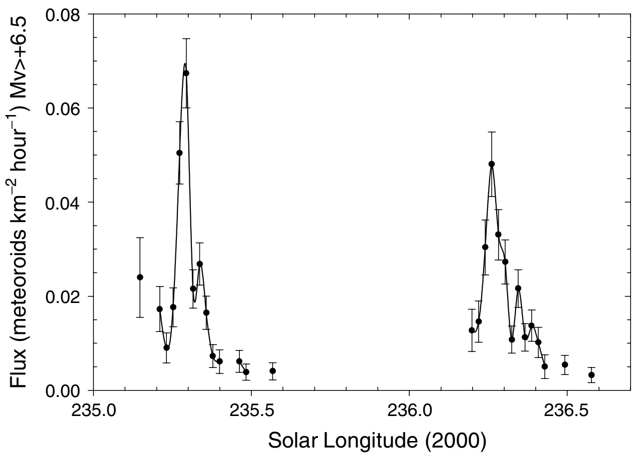

Figure 3. Radar Leonid flux as measured at 29 MHz and corrected for initial trail radius (see text). The two major Leonid peaks on November 17 and 18 are clearly visible near the mid-point of each day's data. Only Leonid activity is measured here – the blank time intervals represent times when the radiant is below the horizon and/or when the Leonid rate is at or near the sporadic rate level from the same radiant area.

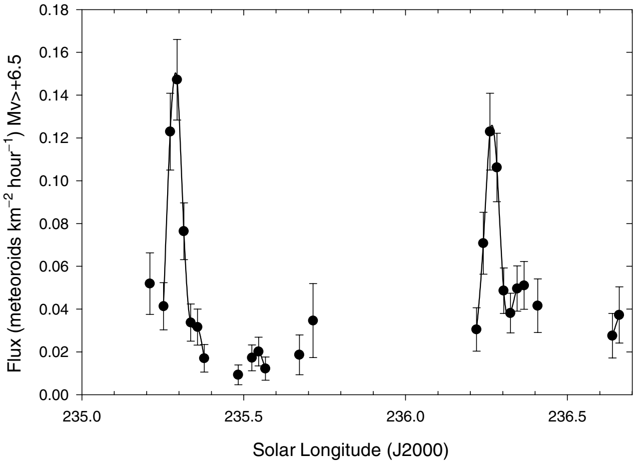

Figure 4. Radar Leonid flux as measured at 38 MHz and corrected for initial trail radius (see text).

later at $236\overset{\circ}{.}26 \pm 0\overset{\circ}{.}02$, both at exactly the same time from 29- and 38-MHz observations and very similar in shape. The Gaussian half-widths for the first peak are $0\overset{\circ}{.}020 \pm 0\overset{\circ}{.}003$ and $0\overset{\circ}{.}014 \pm 0\overset{\circ}{.}002$ for 29 and 38 MHz respectively. Similarly, the second peak has Gaussian half-widths of $0\overset{\circ}{.}020 \pm 0\overset{\circ}{.}002$ and $0\overset{\circ}{.}025 \pm 0\overset{\circ}{.}006$ for 29 and 38 MHz respectively.

However, while the locations of the peaks are the same, the absolute magnitudes are different at the two frequencies, with the magnitude systematically ~2 times higher at 38 MHz as compared with 29-MHz data. This is probably due to the uncertainty in the initial radius correction at these high frequencies.

Also notable is the fact that the first of the two peaks is relatively stronger at both frequencies than the later peak. This is not a result of changing correction factors, as the observations are almost exactly 24 h apart. It can be seen that the Leonid radiant response function for each radar for the first peak on November 17 is identical to the second peak on November 18. Fig. 5 shows the collecting area for the Leonid radiant as a function of Universal Time for November 17 and 18. The power output for each radar system was monitored at 1-min intervals over this entire time period and showed no appreciable change. That there is a clear difference in the observed Leonid peak rates on these two dates at identical local times is directly attributable to substantial changes in the relative intensity and/or mass distribution between the two peaks.

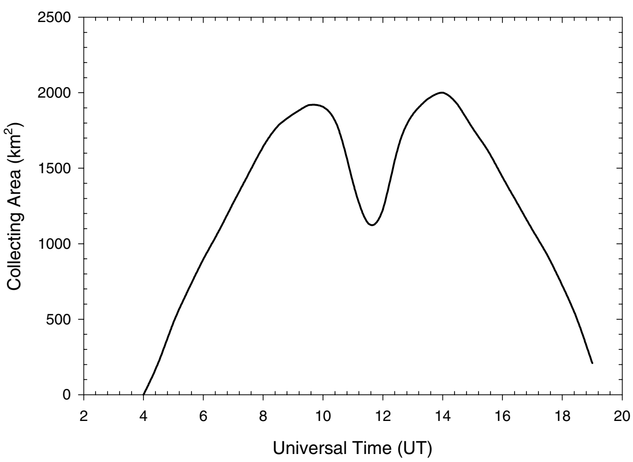

Figure 5. Radar collecting area for the 2000 Leonids from Tavistock, Ontario, for 2000 November 17 and 18.

Table 2. Summary of peak flux values observed by radar for two major peaks on November 17 (UT) and November 18 (UT) respectively. Note that the flux is in units of meteoroid km^{-2} h^{-1} brighter than +6.5 astronomical magnitude. The peak times correspond to November 17 7:22 for peak 1 and November 18 7:13 (UT).

Frequency	$\Phi_{\text{peak1}(235.29\pm0.02)}$	$\Phi_{\text{peak2}(236.25\pm0.02)}$
29.850 MHz	0.067 ± 0.008	0.048 ± 0.007
38.150 MHz	0.147 ± 0.019	0.123 ± 0.018

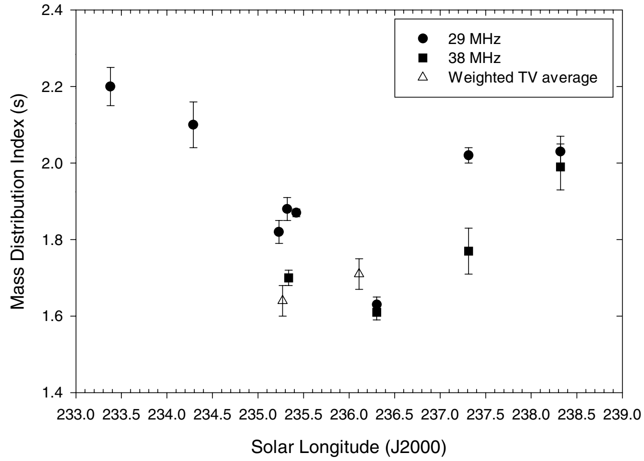

Figure 6. Mass distribution indices for the 2000 Leonids measured by TV and radar.

Table 2 summarizes the observed peak magnitudes at both frequencies. It is clear that the first peak is relatively larger than the second for both radars. In both cases, activity also decreases monotonically after the peak, while also showing a sharp rise.

In addition to these radar flux data, using the cumulative amplitude distribution for selected Leonids permits an independent determination of the mass distribution index, much as was done for TV data (cf. Brown et al. 1998, for details of this technique). However, with more temporal sampling in the radar results, it is possible to construct a coarse mass distribution profile across the stream. This is shown in Fig. 6, together with the weighted average TV mass index measurements. A clear decrease in the mass index is apparent at the time of the two peaks, indicating that a proportionately greater number of large echoes occurred near the time of maximum. In general, in the radar mass distribution indices are relatively close in magnitude to that determined from the TV data, although the spread on November 17 ranges from $s = 1.6$ to 1.9 across both data sets. We note that our choice of $s = 1.7$ for computing both the TV and radar fluxes represents an approximate average across observed values for November 17–18. For comparison, the results of the visual analysis (Arlt & Gyssens 2000) suggested mass index values between 1.7 and 1.75 as most appropriate over the same interval, consistent with our results.

4 DISCUSSION AND CONCLUSIONS

The combined TV and radar flux results are shown in Fig. 7 for November 17–18 (UT). It is clear that the TV and 38-MHz radar data are in general agreement regarding the magnitude and time of the first maximum, while the timing with 29 MHz agrees but the magnitude is lower, which we attribute to the uncertainty in initial

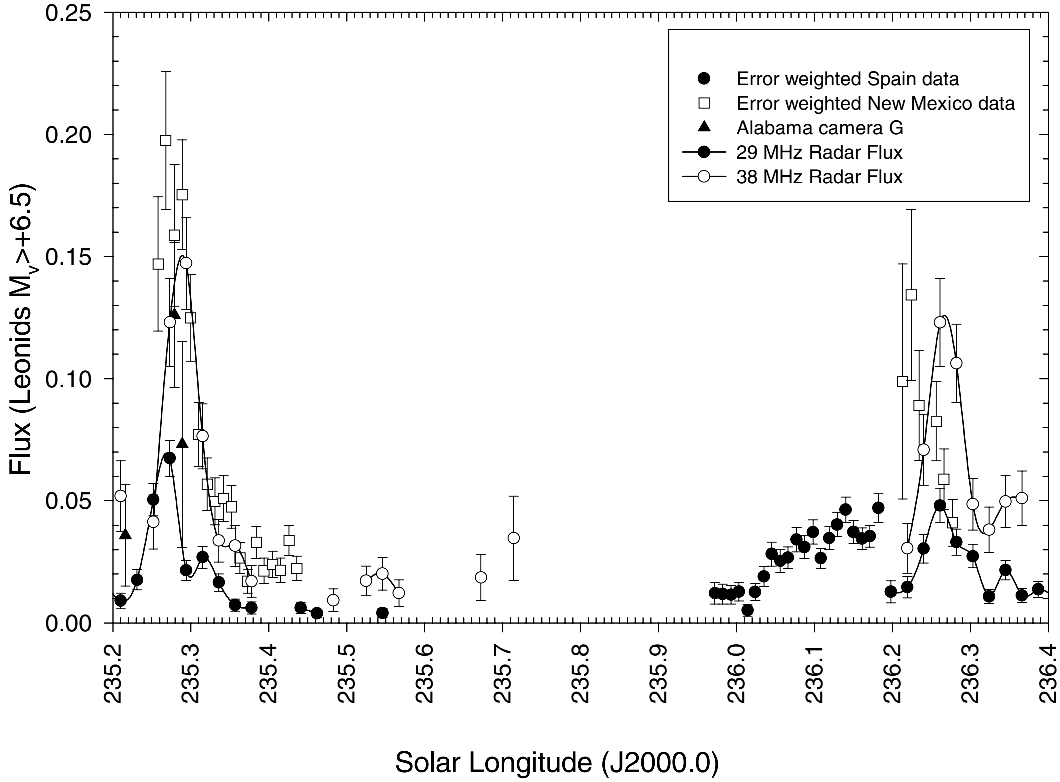

Figure 7. Combined TV and visual flux profiles for 2000 November 17 and 18.

trail radius correction. The camera data from Tennessee and New Mexico and the 38-MHz radar data all suggest that this early peak is near $\sim$0.15 $\pm$ 0.02 meteoroid km^{-2} h^{-1}, which corresponds to a ZHR $\sim$900 with $s \sim 1.7$. We also note that choosing a different value for s will not change this ZHR result substantially.

The second peak is not as well defined, although 38-MHz and TV data suggest a peak flux value near 0.11 $\pm$ 0.02 meteoroid km^{-2} h^{-1}, which corresponds to a ZHR $\sim$600 with $s \sim 1.7$. This peak level and location are the same, within error, as reported in the visual study (Arlt & Gyssens 2000) where a maximum ZHR $\sim$500 was recorded at 236°.25. The visual profile also shows strongly decreasing activity returning to ZHRs <100 by 236°.35, qualitatively similar to the radar results. Arlt & Gyssens also report a less pronounced third peak at 236°.09 with ZHR = 290 as part of the rise in activity to the major final peak, but if this is a real feature it is not particularly evident in our Spain TV results (and is too early for our radar observations).

The most puzzling difference between the Arlt & Gyssens (2000) result and our own is the extreme prominence in our data of the early peak relative to the second in both radar and TV data. This difference also exists between our data and the TV data of Jenniskens & Gustafson (2000), although we note that these authors simply scaled their ZHR values to match visual observations and thus do not provide an independent measure of the absolute level of activity.

In visual data, the first peak is much smaller than we find relative to the second peak. The population index is larger at the time of the first peak according to the visual results, but only by about 10 per cent; not nearly enough to account for the huge disparity in the relative peak fluxes. One obvious possibility is that the earlier peak is in fact stronger than indicated by visual observations – higher in either ZHR or population index (or both) to account for our higher flux values. We note that the visual results were severely hampered by lunar interference in 2000 and had a large scatter (owing to the quite small observer base) at the time of the first maximum. Furthermore, the first maximum in visual data as analysed by Arlt & Gyssens (2000) is almost entirely confined to a single datum, where the average stellar LM was only 5.46 based on 10 visual observers. Indeed, Arlt & Gyssens (2000) comment that the individual visual reports associated with the first peak (on November 17) are composed of very high and very low ZHR values, attesting to the wide scatter present as a result of small numbers of contributing observers and lunar interference.

Given that the radar and TV data indicate very strong activity confined to less than an hour total for the first peak, this could be consistent (within the binning used by Arlt & Gyssens 2000) to a strong, narrow maximum which might be easily missed by visual observers if the maximum were rich in fainter Leonids. Indeed, an unusually high value for the population index could explain the very large radar flux, and could easily result (from systematic bias in lunar-affected visual magnitude estimates) in an underestimate of r in visual data. In addition, it is possible that some visual observers were not expecting high activity because of the well-distributed predictions associated with the 1932 peak, and this might have served to influence results subjectively in this time interval. A similar psychological effect is discussed in detail by Arlt & Gyssens (2000) in connection with differing peak ZHR values arrived at with different observer subsets associated with the November 18 peak.

We consider the relative strength of the first peak compared with the second to be the most secure result from our data, as well as the most compelling evidence in favour of this interpretation. The TV data on November 18 nearest the time of the peak from New Mexico have problems of both lower radiant elevation and interfering cloud for the last few data, making the absolute levels from the TV data alone suspect. The radar data are also suspect in terms of absolute activity because of uncertain correction factors; again the relative strengths of the two radar peaks are the most convincing evidence that the early peak is much stronger than noted in visual data, particularly since the radar response function is identical for the two peaks.

Other radio/radar observations further support this interpretation. A forward-scatter receiver operated at the Marshall Space Flight Center near Huntsville, Alabama, was tuned to channel 4 television broadcast carriers at 67.25 MHz. The signals from several transmitters in the south-eastern USA are scattered by the ionization trails and the signals are counted using an automated system. A maximum equivalent hourly rate was counted on November 17 of 516 underdense-type echoes centred about $\lambda = 235\overset{\circ}{.}275$ (8 UT) in a single 15-min interval. Similarly, on November 18 UT with an identical forward-scatter response geometry relative to the Leonid radiant, the same system recorded a peak 15-min equivalent hourly rate of 319 underdense echoes at $236\overset{\circ}{.}27$ (7.7 UT). For comparison, the echo rate on November 14 at the same local time (8 UT) using the same settings was 114.

Similarly, backscatter radar observations at the Ondrejov Observatory (cf. Simek & Pecina 2001) show a similar effect. These radar data are appropriate to a limiting equivalent magnitude of +9. The peak 10-min raw echo count on November 17 was an equivalent hourly count of 648 echoes (http://www.asu.cas.cz/~koten/radar.html) near $235\overset{\circ}{.}28$, while the peak hourly count on November 18 was 420 at $236\overset{\circ}{.}26$. Again, the radar response function is identical for the two peaks and we infer the former peak to be significantly (almost 50 per cent) higher from these data. Sporadic rates on November 15 at the same local time were 180.

Further support for the higher strength of the November 17 peak is presented by Singer, Mitchell & Weiß (2001). They show high-time-resolution echo rates from 2000 November with the Julisruh meteor radar in Germany where a peak observed rate of high-altitude (mostly Leonid) echoes of 175 is noted in the 10-min interval near 8 UT on November 17. In contrast, the highest rate peak on November 18 associated with material from 1866 is just after 7 UT with a 10-min rate of under 150. It is instructive to note that longer time binning of these data strongly suppresses the early peak, emphasizing its very small width. We encourage those with radio/radar data from the 2000 Leonid return to re-examine their data (particularly for November 17) using higher temporal resolution.

The implications of this revised magnitude for the first early peak, if found to be correct, both apply to predictions for future activity and serve to highlight pitfalls in the interpretation of visual results for forthcoming Leonid displays. The model predictions of Goeckel & Jehn (2000) suggested that this early peak should be of the order of 900 near the observed time, while the second peak on November 18 should be of the order of 300. This may, in fact, be nearly correct. Their predictions for 2001, however, are much lower than observed. Similarly, iterative models using the lower ZHR values for the 1932 peak in 2000 (such as Lyytinen & Van Flandern 2000) may find better agreement for peak ZHR values in 2001 and more precise predictions in 2002 using this revised ZHR value for the 1932 peak in 2000.

In 2002, the Leonid shower is expected once again to produce very strong activity, potentially approaching storm levels (cf. McNaught & Asher 1999). As in 2000, a nearly full Moon will interfere greatly with the display for visual observers. The visual observations conducted in 2002 should be compared closely with other techniques that do not suffer as greatly from the effects of moonlight. Indeed, the generation III intensified systems used primarily in this work are very red-sensitive and thus much less affected by the scattered moonlight than visual observers whose peak sensitivity is more toward the blue.

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