# The Leonids
# Bulletin 10 of the International Leonid Watch: Final Results of the 1996 Leonid Maximum

*Peter Brown and Rainer Arlt*

The activity profile for the 1996 Leonids from 434 observations made by 109 observers and comprising 4449 shower meteors is presented. Two peaks in the ZHR profile are found, one very distinct at $\lambda_\odot = 235.^\circ17 \pm 0.^\circ07$ (eq. 2000.0) and a less well-defined peak at $\lambda_\odot = 235.^\circ4 \pm 0.^\circ1$. The former peak has a ZHR of $86 \pm 22$ and the latter a maximum of $45 \pm 4$. There is a statistically significant increase in the population index near the first peak, from a pre-outburst value near $r = 1.7$ to $r = 1.9$ at the early maximum and falling again to $r = 1.6$ in the period $\lambda_\odot = 235.^\circ30$–$235.^\circ40$. The maximum flux at the early peak corresponds to $0.012 \pm 0.004$ meteoroids per square kilometer and per hour with absolute magnitudes greater than 6.5, and $0.003 \pm 0.001$ meteoroids per square kilometer and per hour for the later peak. We associate the early peak with material of very recent ejection from Comet 55P/Tempel-Tuttle and the broader, less visible maximum, with the more traditional peak comprising older material.

## 1. Introduction

For the third year in a row, the Leonid shower has shown significantly enhanced activity over its usual annual performance. The increased activity observed in 1994–1995 and recorded again in 1996 is related to the impending return of the parent comet, 55P/Tempel-Tuttle, which is due to reach perihelion on February 28, 1998.

The parent comet was recovered on March 4, 1997 [1], very close to the predicted location based on the work of Yeomans et al. [2]. Pre-discovery observations of Tempel-Tuttle have also been found from as early as May of 1996 taken with the ESO 2.2 m telescope [3]. Current estimates of the nuclear radius of the comet based on its brightness at discovery suggest a value of 1.9 km, assuming an albedo of 0.04. This estimate is very similar to an earlier estimate by Sekanina [4] of 2 km based on the brightness of the comet at its 1965 passage. The refinement of this estimate along with further confirmation of the size of the comet using observations at other than visual wavelengths should provide some of the needed information for modelers to begin constructing more precise models of the dynamics of the stream in preparation for the strong Leonid returns expected from 1998 to 2000.

The 1996 return marks the first occasion when the narrow outburst component of the shower was unambiguously detected during the current Leonid epoch [5]. Though significant scatter does exist amongst the 10 or so observers reporting rate data during the outburst period, there appears to be enough information from these visual data to conclude that this component was observed in 1996. It would be most interesting to determine if other observational techniques detected this increase or not, but the time of occurrence of the central portion of the outburst ($5^h$ UT on November 18) falls between the European and North American observing windows and makes independent confirmation less likely. Calibrated radio observations from 1996 could be particularly useful in this regard.

In addition to the outburst component, a broad level of activity consisting of larger particles, very similar to the profile seen in 1994 and 1995 was also detected.

## 2. The ZHR activity profile

Figure 1 shows the ZHR profile for the 1996 shower over a one day interval centered about $\lambda_\odot = 235.^\circ5$. Also shown is the level of sporadic activity recorded over the same interval. A nearly monotonic increase in shower activity from $\lambda_\odot \approx 235.^\circ0$ to $\lambda_\odot = 235.^\circ17$ is apparent, where the peak ZHR of $86 \pm 22$ is reached. Note that the higher-than-average sporadic rates in the early portion of this interval suggests that some of the early activity in the rising portions of the curve may be overestimated. At the peak, however, the sporadic HR is very near the normal value of 10–15. The scatter in individual ZHR estimates is apparent during the peak period and is manifested by the large error margins. The activity associated with this first peak has a half-width to half-maximum (HWHM) of 0°07 ± 0°02 (1.7 ± 0.3 hours).

A second, weaker peak is also visible in this profile near $\lambda_\odot = 235^\circ\!.4 \pm 0^\circ\!.1$. This peak is ill-defined within the error margins and is likely associated with the normal annual peak which has shown a maximum near $\lambda_\odot = 235^\circ\!.5$ in past years [6]. The 1995 ZHR profile showed a very similar structure at this location [7]. The peak ZHR associated with this maximum is 45 ± 4, which is more than 4 times the normal annual maximum and is 10 above the 1995 level. This peak is an order of magnitude broader than the early maximum having a HWHM of 0°6 ± 0°2. This HWHM is for the broad profile, ignoring the sharp early maximum. It is instructive to note from the sporadic and shower ZHR profiles that Leonid activity in 1996 climbed above the sporadic background only over the interval $\lambda_\odot = 234^\circ\!.0$–$236^\circ\!.0$.

## 3. The population index

From the quiet-time activity compiled between 1988 and 1993, the mean $r$-value for the Leonid stream was found to be 2.0 [6]. Figure 2 shows the $r$-profile over the same interval of solar longitude as given in Figure 1. Outside this interval, there was only enough magnitude data reported to accurately measure the $r$-value once (at $\lambda_\odot = 234^\circ\!.3$) pre-maximum and three times post-maximum ($\lambda_\odot = 236^\circ\!.26$, $\lambda_\odot = 236^\circ\!.31$, and $\lambda_\odot = 237^\circ\!.0$). The pre-maximum and extreme post-maximum measurements of $r$ all suggest values in the 2.0–2.2 range as being most appropriate.

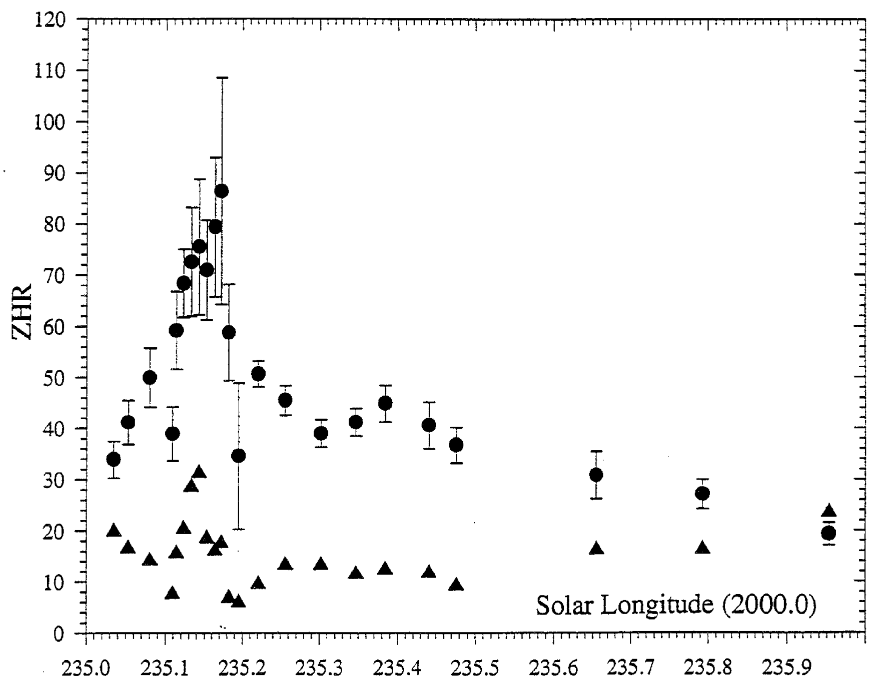


Figure 1 – ZHR versus solar longitude for the 1996 Leonid return. This profile was constructed using 0°1 smoothing intervals shifted by 0°05 before $\lambda_\odot = 235^\circ\!.1$ and 0°02 intervals shifted by 0°01 during the period $\lambda_\odot = 235^\circ\!.1$–$235^\circ\!.2$. The remainder of the profile was found using 0°1 increments shifted by 0°05 during the period $\lambda_\odot = 235^\circ\!.2$–$235^\circ\!.5$ and 0°5 increments shifted by 0°25 thereafter. The solid circles are shower ZHRs while the solid triangles are the sporadic HR in the corresponding intervals.

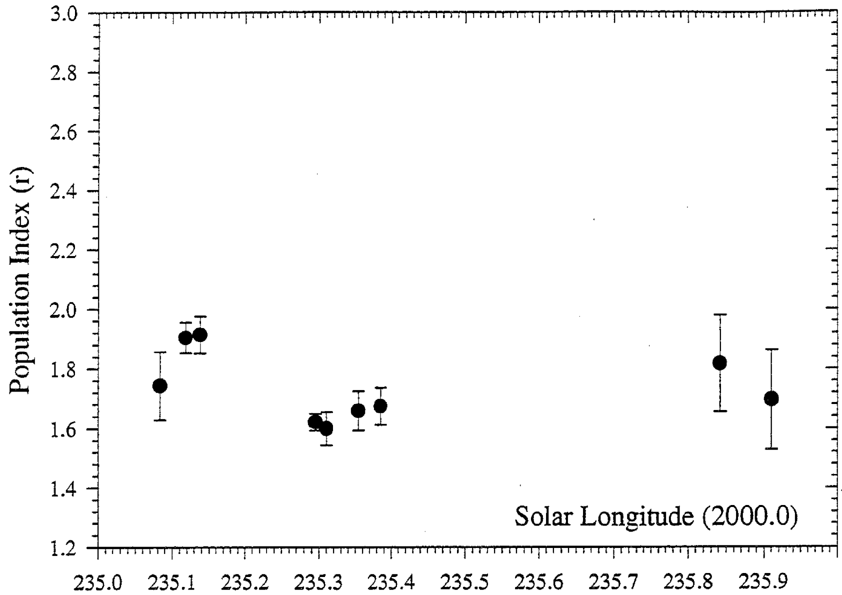


Figure 2 – The $r$-profile for the 1996 Leonids as derived from magnitude data comprising 3220 Leonid meteors. Each datum was derived from a group of between 25 and 688 Leonid meteors.

From Figure 2, there is an increase in $r$ near the time of the early ZHR peak relative to the intervals immediately before and following. The extreme minimum in $r$ is reached at about $\lambda_\odot = 235\overset{\circ}{.}31$ when it attains a value of 1.6. This low value for $r$ remains until at least $\lambda_\odot = 236\overset{\circ}{.}0$ with values constant near 1.7–1.8. This is very much lower than the $r = 2$ normally associated with the central portion of the stream and if true would indicate an abundance of brighter Leonids over the roughly day-long period centered about the normal peak as compared to quiet-time activity during the 1996 display. However, the abundance of bright meteors in this interval may be due to reduced observer attention to the fainter meteors as fewer experienced observers contributed data at the time of the minimum in the $r$-profile.

From the $r$-profile and the ZHR-activity it is possible to derive a flux profile for the 1996 Leonids and this is shown in Figure 3. The peak flux at the early peak corresponds to $0.012 \pm 0.004$ meteoroids per square kilometer and per hour with absolute magnitudes brighter than 6.5. The later, broad peak is roughly 4 times lower than this value, in large part due to the very low values for $r$ in this interval.

## 4. Discussion

The high ZHRs associated with the early outburst peak, combined with its short duration and increase in numbers of fainter meteors as compared to adjacent observational periods is consistent with the interpretation that it is composed of very young material (only 2–3 revolutions old) and potentially associated with the storm-producing segment of the stream (the Ortho-Leonids). Very similar characteristics are associated with the 1966 and 1969 showers [8]. The broader activity which peaks later near the time of the normal maximum is composed of larger meteoroids than either the outburst peak or the normal annual shower. The total duration of this section of the stream is roughly 2 days—this is the length of time the shower is above the sporadic background. From the quiet-time analysis of the stream [6] it is known that the normal annual peak is just barely at the level of sporadic activity. This suggests that material in this portion of the stream is significantly older, probably of the order of 10 revolutions, which is enough time to allow for the degree of nodal spread observed as well as allow a noticeable enhancement in the proportion of larger meteoroids (cfr. Arlt et al. [9] for more discussion on these points).

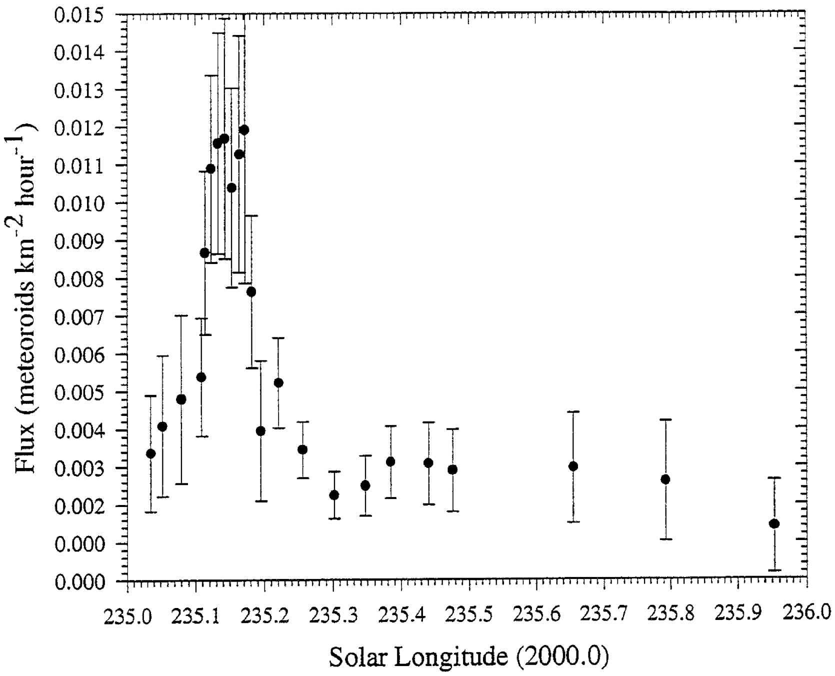


Figure 3 – Flux profile for the 1996 Leonids.

A similar peak was observed in 1995, but with far less confidence. It is still not clear if this is a genuine feature of the stream or simply an artifact of the reductions and poor observer coverage in that year. The peak location for the possible outburst in 1995 is 4 hours earlier than in 1996, though the two just barely agree within the (large) errors for the location in 1995.

The location of the outburst peak is almost precisely the same as the location of the 1966 storm and an enhancement recorded by radar in 1965 [10]. This might imply that the material we are currently encountering has suffered virtually no perturbations in the intervening years and thus has not significantly changed its nodal longitude. Kazimircak-Polonskaja et al. [11] were among the first to explicitly point out that the mean secular advance of the nodes of the stream (amounting to some 29′ per revolution) is actually achieved through a number of punctuated advances associated with perturbations from Jupiter, Saturn, and Uranus. Thus the actual rate of change for any one Leonid meteoroid from one revolution to the next may be anywhere from nearly 0 to several times the average rate. According to Kazimircak-Polonskaja et al. [11], the portions of the stream likely to be nearest to the Earth in 1999 shows virtually no change in nodal longitude between 1950 and 2000. In particular this section of the stream maintains essentially identical nodal longitudes from 1966 to 2000. If this is in fact the case, then the activity we have first seen in 1996 presages the probable location of the shower peaks over the years 1997–2001. Similar results were also found by Brown and Jones [12] on the basis of numerical modeling of the stream who suggested shower peaks during the current Leonid epoch would be most probably near $\lambda_\odot = 235^\circ\!.16$. Further detailed modeling needs to be done in light of the recovery of the parent comet and a key observation during the 1997 Leonid return will be the presence or absence of a strong component of the shower near these solar longitudes.

## 5. Seventh ILW period: November 5–25, 1997

The seventh *International Leonid Watch* (*ILW*) period is almost certain to reveal further heightened activity from the stream. With the parent comet little more than three months away from perihelion, 1997 is the first year in which the possibility of a very strong Leonid shower/storm can be taken seriously.

Unfortunately, the rather promising shower activity is hindered to a large degree by an 18-day old Moon on the night of maximum. The Moon will rise well before the radiant and will not set until after sunrise thus eliminating any possibility for dark-sky viewing of the shower. Nevertheless, careful observations at the time of maximum and magnitude estimates may help to roughly define the peak ZHR (as in 1994) as well as provide some reference as to any relative changes in the particle make-up across the stream.

If the patterns from the last few years persist, it seems probable that there will be an extended level of activity lasting perhaps 2 days centered around the peak with a peak ZHR of 50–60 in 1997 composed of larger Leonids. The visibility of the outburst maximum will be heavily compromised by the Moon, but some TV observations as well as careful radio/radar measurements of activity of the stream may be able to detect the expected flurry of fainter meteoroids from the Ortho-Leonids. The position of the outburst maximum detected in 1996 will recur at $11^{h}$ UT on November 17 in 1997 and will be best seen from the Central and Western United States. The time of nodal crossing in 1997 is $13^{h}_{.}5$ UT, which places best viewing on the extreme West Coast of North America and Hawaii. The "normal" maximum at $\lambda_{\odot} = 235^{\circ}_{.}5$ occurs at $19^{h}$ UT, and will be best seen from Eastern Asia.

As activity associated with the first maximum in 1996 had a higher $r$-value than adjacent periods, particular attention is drawn to the possibility of numerous faint meteors (which will certainly be difficult to see due to the moonlight) in addition to the probable large number of brighter events.

## References

[1] O.R. Hainaut, K.J. Meech, J. Bauer, P. Martin, K. Mueller, G. Van De Steene, N. Hurtado, J. Miranda, J. Schubart, S. Nakano, I. Hasegawa, D.K. Yeomans, "Comet 55P/1997 E1 (Tempel-Tuttle)", *IAUC* 6579, 1997.

[2] D.K. Yeomans, K.K. Yau, P.R. Weissman, "The Impending Appearance of Comet Tempel-Tuttle and the Leonid Meteors", *Icarus* 124, 1996, pp. 407–413.

[3] O.R. Hainaut, K.J. Meech, J. Bauer, R.M. West, "Recovery of 55P/Tempel–Tuttle", *Meteoritics and Planetary Science* 32, 1997, pp. A53–A54.

[4] Z. Sekanina, "Meteoric Storms and the Formation of Meteor Streams", in *Asteroids, Comets, and Meteoric Matter*, C. Cristescu, W.J. Klepczynski, and B. Milet, eds., Scholium International, New York, 1974, pp. 239–267.

[5] M. Langbroek, "Observation of a Narrow Component of Faint Leonids in 1996", *WGN* 24:6, 1996, pp. 207–208.

[6] P. Brown, "Significantly Enhanced Leonid Activity in 1994: Bulletin 5 of the International Leonid Watch", *WGN* 22:6, 1994, pp. 190–193.

[7] P. Brown, "Bulletin 8 of the International Leonid Watch", *WGN* 24:5, 1996, pp. 139–141.

[8] B.A. McIntosh, P.M. Millman, "The Leonids by radar—1957 to 1968", *Meteoritics* 5, 1970, pp. 1–18.

[9] R. Arlt, J. Rendtel, P. Brown, "ILW Bulletin 9: Results of the 1996 Leonid Maximum", *WGN* 24:6, 1996, pp. 203–206.

[10] P. Brown, Šimek, J. Jones, "Radar Observations of the Leonids: 1964–1995", *Astronomy and Astrophysics* 322, 1997, pp. 687–695.

[11] E.I. Kazimircak-Polonskaja, N.A. Beljaev, I.S. Astapovich, A.K. Terentjeva, "Investigation of the Perturbed Motion of the Leonid Meteor Stream", in *Physics and Dynamics of Meteors*, L. Kresak and P.M. Millman, eds., 1968, pp. 449–476.

[12] P. Brown, J. Jones, "Dynamics of the Leonid Meteoroid Stream: A Numerical Approach", in *Physics, Chemistry, and Dynamics of Interplanetary Dust*, B.A.S. Gustafson, M.S. Hanner, eds., 1996, pp. 113–117.