THE LEONID OUTBURST OF 1996

Does It Improve Prospects of Leonid Storm in 1998?

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Abstract. There is strong anticipation that the Leonid meteor shower could produce storm-level activity in 1998 and/or 1999. The well-documented Leonid outburst in 1996 and the more poorly observed one in 1994 have been taken by many observers to imply that a storm is imminent, This article explores the possible relationship between the 1996 outburst in activity and possible Leonid storms. The curve of activity is found to be much closer to that of normal activity, although with greater hourly rates, than it is to the very brief, steeply rising activity curve of a storm. It is probable that the 1996 outburst is thus completely unrelated to any future storm which may appear.

Key words: Meteor streams.

1. Introduction

The appearance of the great Leonid meteor storm of 1833 was one of the events which acted as a detonator of public and scientific activity in meteors. In the light of the observation of the Leonids, various studies were made which led, first to identification of many other past major Leonid showers and then to the identification of a number of different meteor showers as annual events. By the time that the following Leonid storm was observed in 1866, the link between comets and meteor showers had been firmly established. It is now assumed that almost all meteor showers are due to comets, although the precursor of the stream is not always known, however there is increasing evidence that some meteor streams are related to Earth-crossing asteroids of the Apollo group.

The recent study by Jenniskens (1995) has shown that, whilst meteor storms are infrequent, and only seen from a very few meteor streams, outbursts to major shower and sub-storm level are relatively common phenomena. Jenniskens estimates that as many as two per year may occur, but are usually very brief and poorly observed because of their very unexpectedness. Meteor storm activity, although less common, is easier to study because it is usually widely observed and may be predicted, although the data available is often qualitative rather than being rigorously quantitative.

As the Leonid stream is the most reliable of the meteor storm-generating showers, public and scientific interest in its activity is unusually high, especially as the predictions for the 1998 maximum suggest that it will be visible from North America, placing it within view, once again, of the world's largest concentration of professional and amateur astronomers. However, as meteor storm prediction is not a precise science, observations taken in the years prior to a possible storm are still a critical diagnostic tool. Given that 55P/Tempel-Tuttle, the Leonid progenitor, is little more than one year from perihelion, it is reasonable to expect an important increase in shower activity ahead of the comet.

2. Recent History of the Leonid Shower

The last three cycles of the Leonids' 33 year period have shown very different behaviour patterns.

In 1899, the Earth passed 0.0112AU outside the orbit of the comet. Despite prior predictions that a major storm would occur, the discovery that perturbations to the orbit of the material in the orbit would increase greatly the distance between the Earth and the core of the stream caused a dampening of optimism which, unfortunately, was not successfully communicated to the general public. However, minor storms (Zenithal Hourly Rate, ZHR = 1100 and 1400) were seen in 1898 and 1903 and a storm (ZHR = 7000) in 1901. This appears to be the greatest sustained level of Leonid activity in recent centuries, although it has been generally very little mentioned in the literature.

In 1932, the miss distance was rather higher. No storm activity was expected, largely due to the 1899 "failure". However, higher than normal activity was registered in several years, culminating in a return at sub-storm level (ZHR = 240) in 1932. A strong return (ZHR $\sim$ 50) was seen in 1928 and even stronger ones were detected in 1930 (ZHR $\sim$ 120) and 1931 (ZHR $\sim$ 190), showing that high levels of activity a few years before the return of Comet Tempel-Tuttle do no necessarily predict storm activity.

In 1966, a great Leonid storm was observed from the western United States. In many works this is cited as being the greatest storm ever observed, although Jenniskens (1995) has recently cast doubt on this, suggesting that the commonly cited value of ZHR = 144 000 at maximum is exaggerated by a factor of more than 10 with respect to the true activity. Whilst a strong return of the Leonids was observed in 1961, the level of activity was much lower in the succeeding years until the sudden storm was observed in 1966. The miss distance was only 0.0031AU with, once again, the stream passing inside the Earth's orbit. This separation is particularly small: for the great 1866 shower it had been more than double (0.0065AU) the 1966 value.

Leonid activity since the 1966 storm has been generally modest. The last of the storm-related activity died out at the start of the 1970s. A study of shower activity over the interval 1981–1991 suggested a peak ZHR of 22 (Jenniskens, 1994), but the International Meteor Organization (IMO) favours rather lower hourly rates of around 15 for this interval (McBeath, 1995, 1996). A strong Leonid return was observed in 1994 (ZHR $\sim$ 60), but activity was little above normal in 1995 (ZHR =

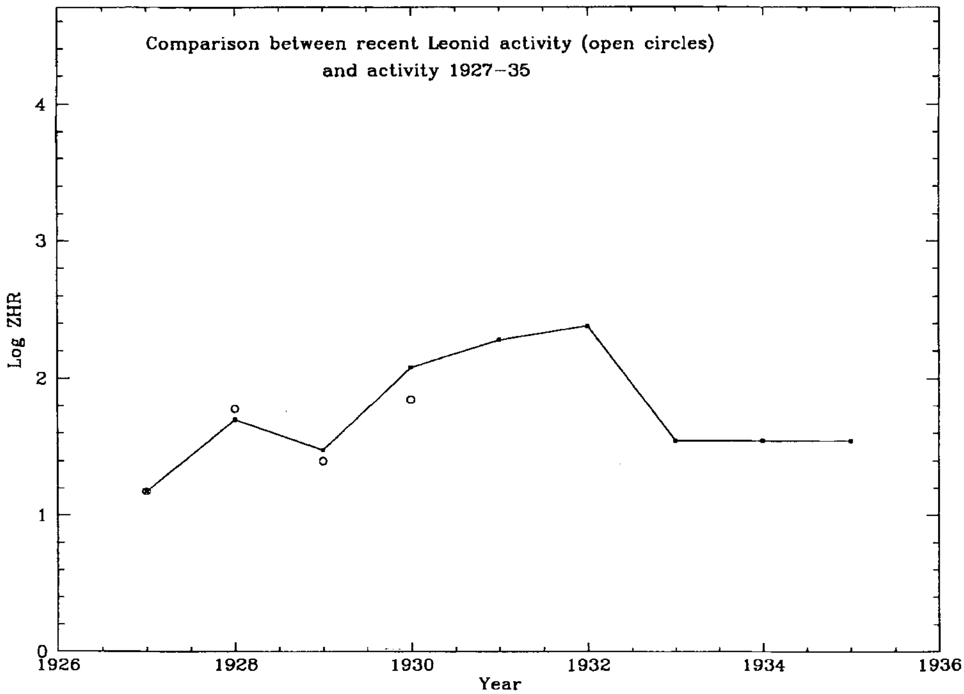

Figure 1. Comparison of Leonid activity over the years 1927–35 (filled squares) with activity 1993–96 (open circles). The recent data are plotted such that 1998 corresponds in position in the x-axis to the 1932 maximum. We see how the activity up to 2 years before the 1932 peak corresponds closely to that observed at the same phase in the 1990s.

20 – 25), although the IMO accepts a slightly higher peak ZHR ($\sim$ 35). However, the historical precedents for previous Leonid returns are equally ambiguous, with no strong correlation between Leonid activity in the years around a possible storm and the maximum level of observed activity (see Figures 1 and 2). The best fit of recent Leonid activity to previous patterns is to that of 1927–32, when no storm was observed. The recent Leonid activity is actually rather higher at present than it was at a similar stage prior to the 1966 storm. Prior to 1961 the level of ZHR was steady at around 10–15 and only the strong 1961 and 1965 activity stand out as being clearly well above average before the 1966 storm.

3. Observations Made in 1996

A large number of observational results have been reported for the 1996 Leonid maximum. Many of these results have been published on the Internet, although a significant proportion have been communicated directly to the author by the observers and are, as yet, unpublished in the literature. A summary of Leonid observations has also been compiled by Arlt et al. (1996).

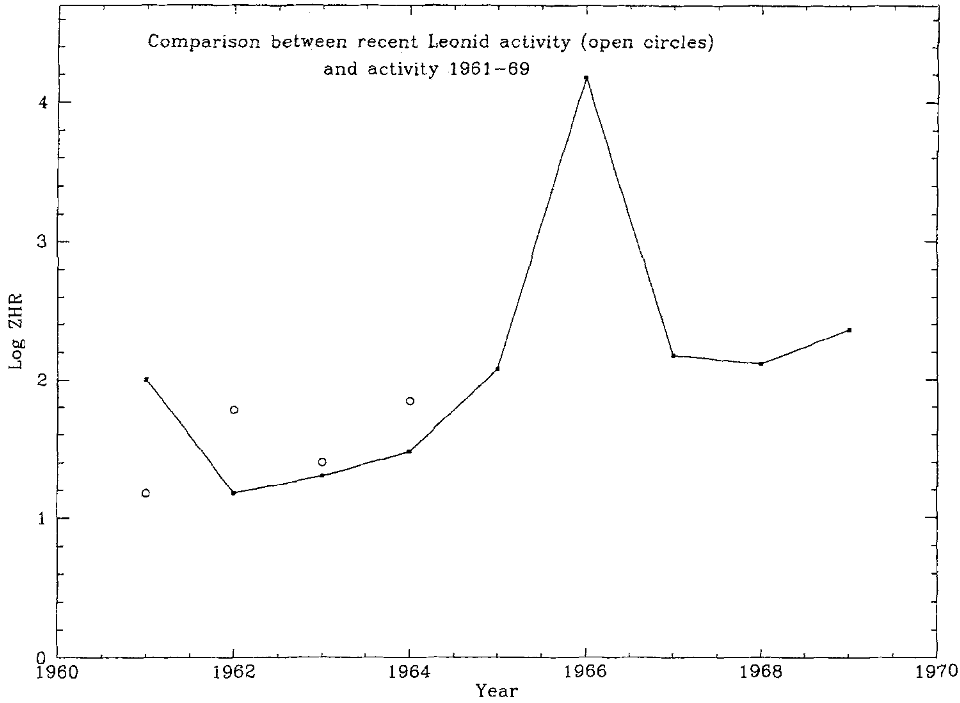

Figure 2. Comparison of Leonid activity over the years 1961–69 (filled squares) with activity 1993–96 (open circles). The recent data are plotted such that 1998 corresponds in position in the x-axis to the 1966 maximum. Recent activity is seen to be significantly greater than the activity which was registered at a similar phase before the 1966 storm, apart from the possibly anomalous peak in 1961.

4. Results

The ZHR curve from the observations is shown in Figure 3. Error bars are not included because of the confusion that these would cause in such a dense plot. It is obvious from Figure 3 that the rise time to maximum is very much slower than the post-maximum fall. Jenniskens (1994) found that such behaviour is typical of several annual meteor showers (e.g. the Quadrantids, Perseids and Geminids), but found that an identical rate of rise to maximum to rate of fall after maximum provided the best fit to the Leonid activity, with a gradient, defined by the relation:

$$\log ZHR = ZHR_{\max} 10^{-b|L_{\odot} - L_{\odot\max}|} \quad (1)$$

where, ZHR_{max} is the maximum Zeithal Hourly Rate of the shower and $L_{\odot}$ is the solar longitude. This result was based on a sufficiently well-sampled curve of activity that a significant asymmetry would have been easily detectable.

Jenniskens finds that the slope before maximum ($b-$) is equal to the slope after maximum ($b+$) and that:

$$b- = b+ = 0.39 \pm 0.08 \quad (2)$$

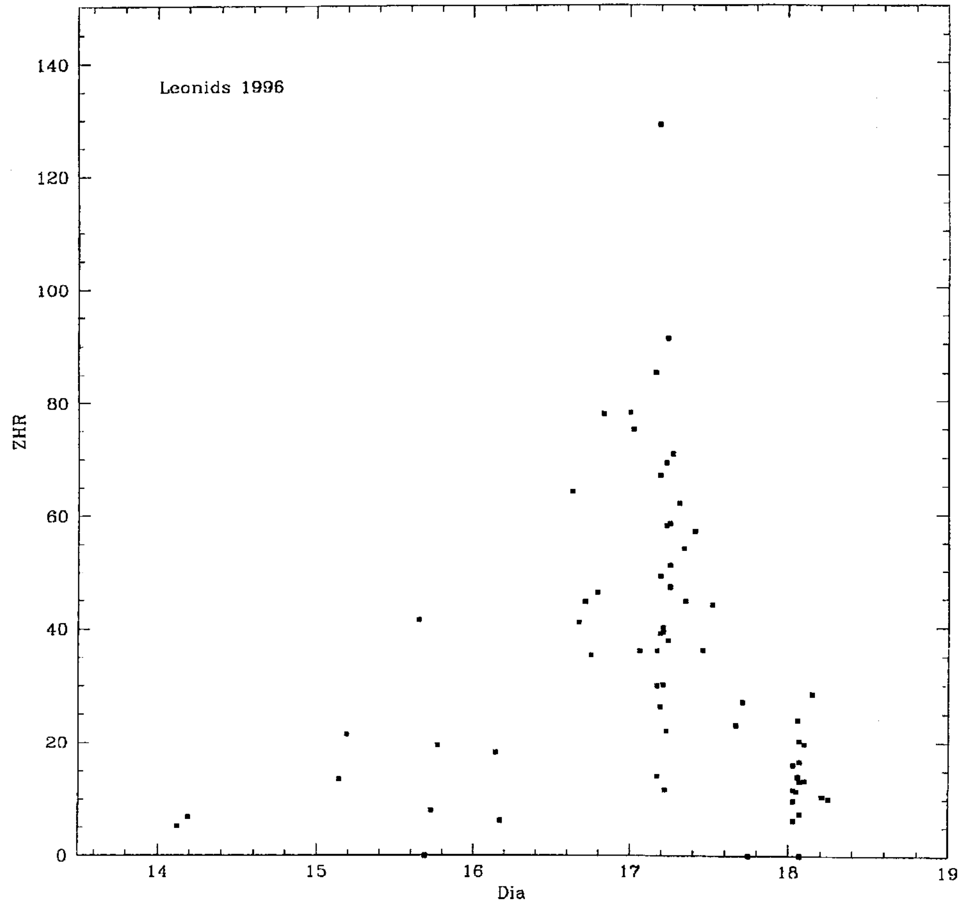

Figure 3. Raw activity curve for the 1996 Leonid meteor shower. Error bars are not shown because of the large number of points which are plotted.

Taking averages of the data in bins of 0.2° in $L_\odot$ and ignoring outlying points (mainly due to inexperienced observers or to inexact application of the correction terms to obtain the Zeithal Hourly Rate, we find the average activity curve shown in Figure 4 for the 4 days around maximum. In the log–log axis we see that both the rise and fall appear to be good straight lines, i.e. there is no evidence for a significant change of slope around maximum. The rise time is also seen to be much slower than the fall from maximum. A least squares fit finds:

$$b- = 0.374; \qquad b+ = 0.694 \tag{3}$$

As we can see, the slope of the rising branch of the activity curve is almost identical to that found by Jenniskens for the annual shower. The maximum ZHR of 70 derived from the fit is rather higher than that found by Arlt et al. (1996)

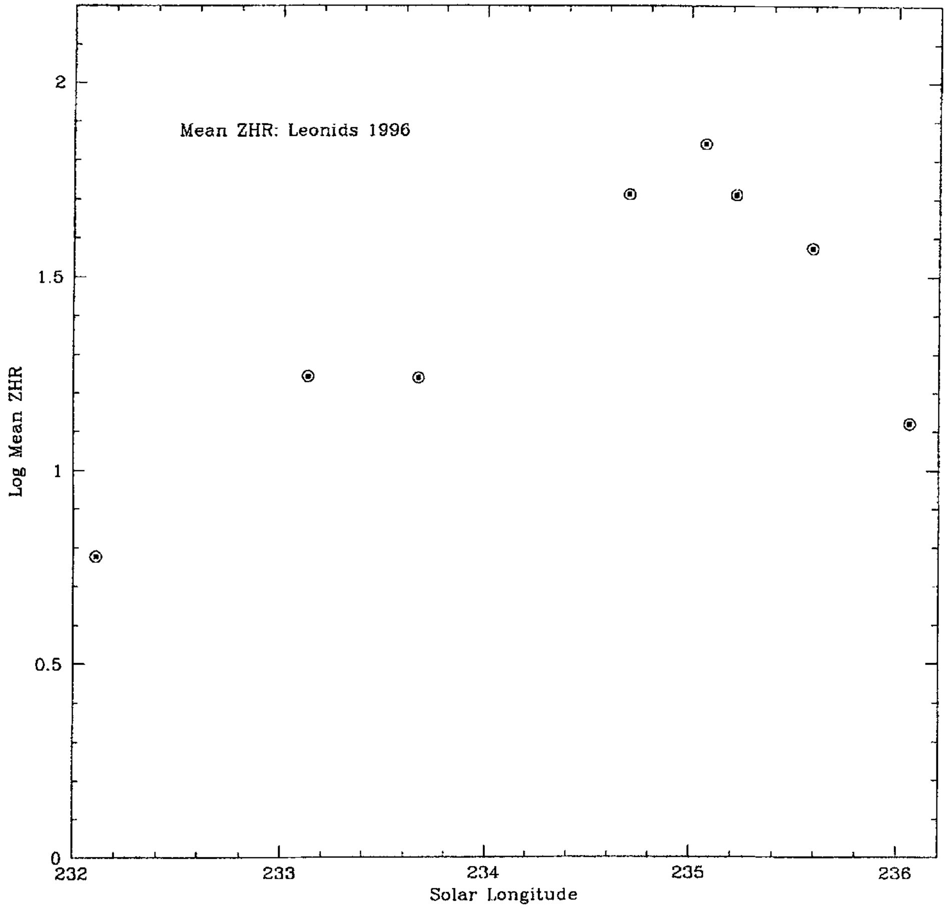

Figure 4. Raw activity curve for the maximum of the 1996 Leonid meteor shower. Only limited evidence can be seen for a flat maximum, especially if the observations from less experienced observers are neglected.

($ZHR_{\mathrm{max}} = 46 \pm 4$). As can be seen in Figure 5, the fit of the model curve to the raw data plotted in Figure 1 is very good. Arlt et al. suggest that there is a double peaked maximum in the activity curve, with maxima at $L_{\odot}$ = 235.15 and at $L_{\odot}$ = 235.37. The evidence for this is very limited (see their Figure 3) as the profile of activity profile which they present is constant to considerably less than one sigma and the dip suggested at the nodal crossing is well below one sigma in depth.

The lack of a two-component ZHR curve suggests that the activity was not due to the normal, annual shower plus an incipient storm component. This conclusion appears to be confirmed by a comparison with previous Leonid storm activity

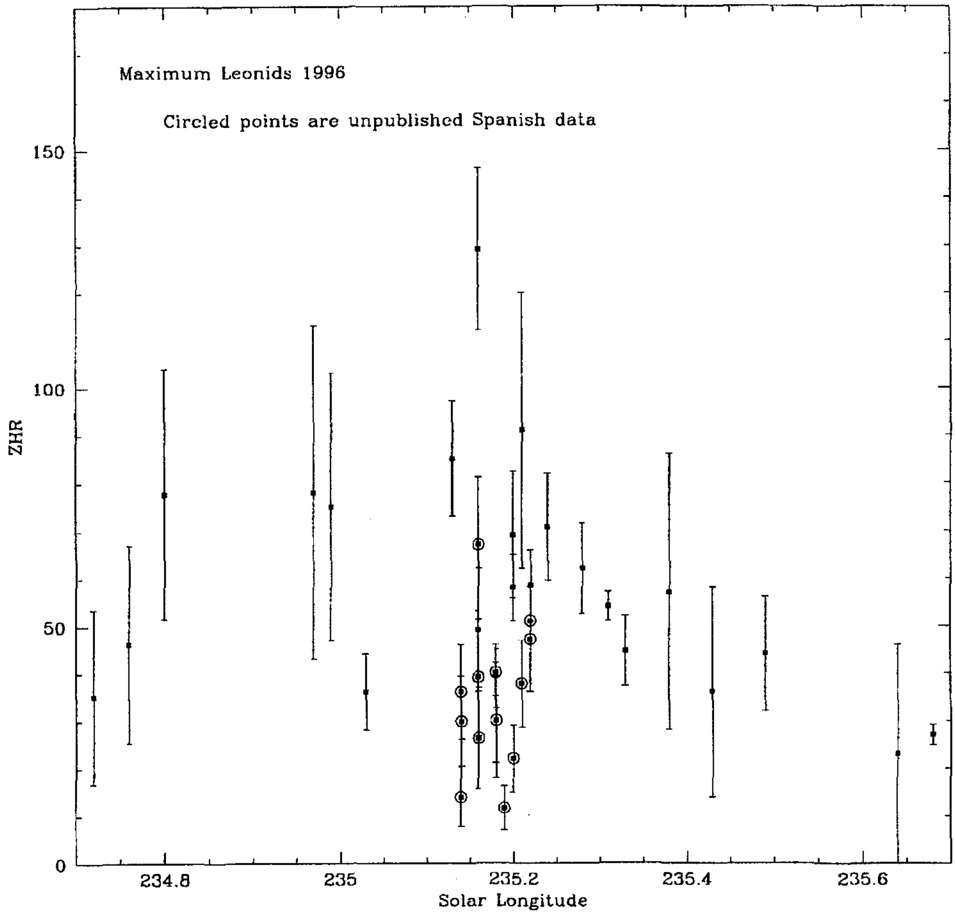

Figure 5. Average ZHR for the 1996 Leonid maximum in bins of 0.2° in $L_{\odot}$. The data is presented as log ZHR against $l_{\odot}$.

curves. For the 1866, 1867 and 1966 storms and the 1969 sub-storm, Jenniskens finds

$$b- = b+ = 30 \tag{4}$$

In other words, the storm component of the Leonid stream has a rise and fall approximately two orders of magnitude faster than the annual stream. Whilst the 1996 shower was above half of its maximum activity for 2 days, the storm activity is usually only above half maximum for about one hour.

Superimposed on the storm component there is a background component in storm years which is broader and also well above annual stream rates. The details of this broad component for various years of storm and sub-storm activity are shown in Table 1 where they are compared with the activity curve for 1996.

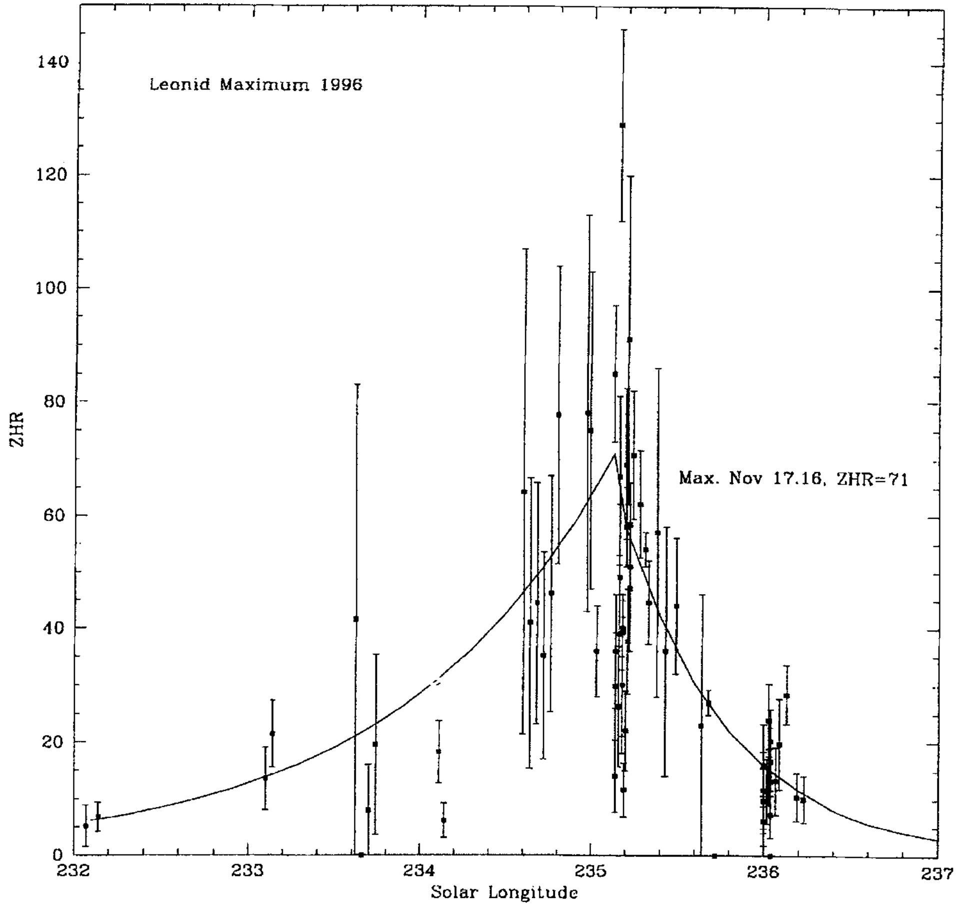

Figure 6. The fit of the model activity curve derived in the text to the observational data plotted in Figure 1. The fit, which uses a single gradient for the rise and steeper one for the fall is seen to give a very good fit to the data.

We see, however, that even the broad component is an order of magnitude faster in rise and decline than the 1996 maximum. This strongly suggests that the 1996 outburst is unrelated to storm activity and may simply reflect an increase in the density of material in the stream ahead of the comet.

From the position of maximum defined in Table 1 the rate of drift of the node is $+0.020° \text{ yr}^{-1}$. The 1996 maximum occurs 1.1 hours earlier than would be expected by the nodal drift seen over the last century. Thus, although the characteristics of the activity profile are completely different to those of the broad component of previous maxima, the position is in close agreement, although about 0.1° ahead of the nodal crossing.

Table I

Parameters of the activity curve for the broad component of the Leonid meteor stream for various years of high or storm activity. The table presents the year that the activity was observed, the solar longitude at maximum and the slopes of the rising branch ($b-$) and declining branch ($b+$). This table is adapted from Jenniskens (1995)

Year	$L_{\odot max}$	$b-$ (deg^{-1})	$b+$ (deg^{-1})
1866	232.625		6 ± 0.5
1867	232.713	6 ± 2	
1868	232.122		4.5 ± 0.5
1898	233.46?	4.1 ± 1.0	
1901	233.46?	3.2 ± 0.6	3.8 ± 0.6
1903	233.46?	3.5 ± 0.4	
1966	234.468	6?	6?
1996	235.13	0.37	0.69

5. Conclusions

The case for stating that the strong Leonid display in 1996 is intimately related to a possible Leonid storm in 1998 is not proven. The profile of activity is much broader than for even the background component of past meteor storms and substorms. There is strong evidence however that some change in shower properties is seen with the approach of 55P/Tempel-Tuttle as, although the rise time to maximum was normal for the annual shower, the decline was very much faster than usual, although still a factor of 5 slower than for the broad component of storm activity. It is suggested that the activity of the Leonids since 1990 is more similar to that before the weak 1932 return than a pre-storm pattern.

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