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The 1997 Leonids outburst

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Abstract. In November 1997 a shower of bright Leonid meteors was observed from Spain. The visual and photographic measurements of the Zenital Hourly Rates (ZHRs) and the respective spatial number densities together with the meteor distribution characteristics indicate the existence of a broad component rich in large grains prior to the perihelion passage of P/Tempel-Tuttle comet. This dust component may be responsible for similar outbursts in previous appearances. However, the Lunar conditions impeded in 1997 obtaining conclusive evidence of the presence of a component of small meteoroids from more recent ejecta, really responsible for past meteor storms. After comparing 1997 peak data with 1965 data, a very close pattern is detected that supports the presence of future storms.

Key words: meteors, meteoroids – comets: individual: 55P/Tempel-Tuttle

1. Introduction

The Leonids is a meteor stream of special interest in astronomy because, among other aspects, of the impressive meteor storms that appear with a periodicity of approximately 33 years. This activity is caused by a dense cloud of meteoroids from a relatively recent ejecta from comet P/Tempel-Tuttle. The mean orbit of the meteoroids possesses a high inclination that allows high orbital stability and a low magnitude of the dispersion processes (Kresak, 1993). During the years before return of the parent comet a young meteoroid cloud appears that produces the strongest meteor storm ever recorded (Jenniskens, 1995). In consequence during several years around perihelia the spatial distribution of the meteoroids in the stream changes greatly and two different populations are responsible for the meteor activity from year to year. The older population dispersed along the full orbit produces an approximately constant rate of 20 meteors per hour at the maximum known as the annual Leonid shower. Besides that, the appearance of a dense cloud of younger Leonid population coincides with the years of the comet's return. A specially dense component distributed as a "sheet" close to the comet node is the part of the Leonids stream responsible for the intense meteor storms detected from at least back to 902 A.D. (Jenniskens 1996).

Members of the Sociedad de Meteoros y Cometas de España (SOMYCE) have been covering the Leonids activity since 1987. During the 1990 return, an important campaign was organized in the east of Spain, reporting an important sample of faint meteors (Simmons 1991). In 1994 the appearance of an intense peak, in addition to the traditional peak, in the Leonids' activity profile was detected by several observers, among them some members of our group (Jenniskens 1996; Trigo-Rodriguez 1994). This more extended feature of large meteoroids distributed as a "blanket" along the comet node also appeared during the years previous to the 1966 meteor storm when the Zenithal Hourly Rates (ZHRs) were higher than average, showing a succession of meteor outbursts rich in fireballs.

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2. Visual observations and methodology

2.1. Visual results

The Leonids activity during November 1997 was affected by the full Moon as in 1994. Despite this, the SOMYCE campaign had a good participation, and the angular distance between the Moon and the radiant was sufficient to allow reliable observations. The generalized cloudy weather over Spain during the campaign prevented a higher coverage of the event, and only the observing stations on the Canary Islands and the Mediterranean coast (Castellón and Murcia) were able to contribute useful observational data.

Observations were analysed by using the standard International Meteor Organization (IMO) methods. The final ZHR calculations are presented in Fig. 1 and were obtained from international data provided by Rainer Arlt (IMO, 1997). The data sample covers the entire activity period very well. Fig. 1 covers the stream behaviour around the comet node, between λ_0 =234.8-236.0°

2.2. Spatial structure

Once all the ZHR data obtained during the whole observational period are plotted, two components appear: a narrow main peak (the Leonid outburst) and a broad background (annual component). A detailed graph of the maximum plotted on a logarithmic

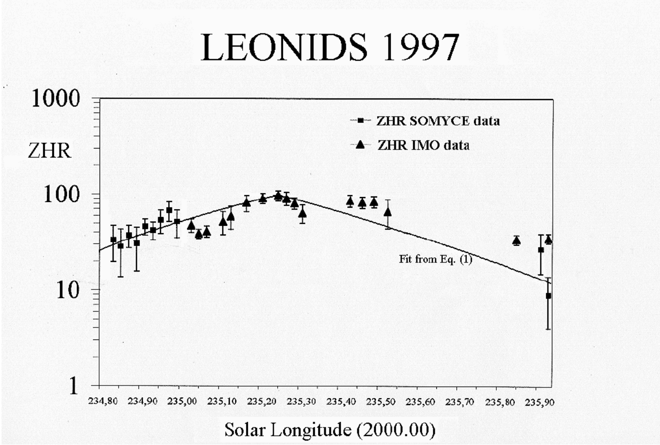

Fig. 1. A detailed graph of the maximum where individual observations were binned in solar longitude intervals of 0.025°. The data reveal an increase of activity observed from Spain when the Earth begins to cross the denser component. After this increase, the mean peak was observed by US observers at λ_0 =235.22°. All the ZHR displayed (except some additional Spanish observations) were calculated from observational data published in IMO (1997). A comparison with previous return values could be seen in Jenniskens (1996)

scale (Fig. 1) shows the shape of the narrow component. It appears that, between λ_0 =234.8–235.6° (2000.00), the activity surpasses the mean level of the annual Leonids shower. In this period the Earth crosses a broad meteoroid cloud of high density; the visual activity exceeds ZHR=30 and is accompanied by bright fireballs. The Zenith Hourly Rate profile of two components can be described with an exponential form according to Jenniskens (1994):

$$ZHR = ZHR_{max} \cdot 10^{-B|\lambda_0 - \lambda_0^{max}|} \quad (1)$$

where a small number of parameters allows for activity to be described and to be compared with other profiles. The parameters ZHR$_{max}$, B and λ_0^{max} are free.

In the preceding formula, the ZHR maximum is modulated with the B parameter and with the solar longitude difference from the peak. The best fit value obtained to the mean observed peak in λ_0 =235.25° was of B= 1.3 ± 0.1, very similar to that obtained in other years by Jenniskens (1995). With this data it is possible to construct a model of the activity during the maximum. For example, in the latest observations obtained from Spain at 6h in the morning of November 17th, the activity was close to the ZHR=75 obtained in Eq. (1). It is also possible to conclude that the Earth crossed this cloud in approximately 30 hours. Its spatial cross section, deduced from the duration of the outburst, is approximately 3 million km. or 0.02 A.U. The denser zone exhibits activity higher than 50 meteors per hour during a short interval of 15 hours between λ_0=234.9–235.5° (2000.00), which is similar to the activity observed during the years just before the 1966 outbust and during the 1994 maximum (Jenniskens 1996).

At maximum activity there was no clearly defined peak, with the ZHR higher than 75 meteors per hour during, at least, four hours. In this way, the spatial structure around the comet node reveals a "blanket" structure rich in large meteoroids with a top maximum of ZHR=100, practically in the same solar longitude as in 1996 (λ_0 =235.25°). This peak is closer to the nodal longitude of 55P/Tempel-Tuttle located in (λ_0 =235.26°). The observations obtained from Spain between λ_0 =234.80–235.00° reveal important activity of bright meteors and a possible secondary maximum of 70 meteors per hour in λ_0 =234.95°. Another secondary maximum was seen at λ_0 =235.4°, with around ZHR=80. This apparent secondary peak appeared between λ_0 =235.4-235.5°, and was possibly due to the underestimation of limiting magnitudes under moonlit sky conditions, as was deduced from sporadic rates in this interval by Arlt & Brown (1998). The consequence of this complex structure in the broad component is an apparent activity plateau at the top of the visual profile of Fig. 1, as also reported by Arlt & Brown (1998).

2.3. Characteristics of the two components

The increase of activity near the maximum was accompanied by a clear change in the intrinsic characteristics and spatial distribution of the meteoroid cloud. This change indicates the presence of a dense cloud of large meteoroids superposed to the other annual members of the stream. Analyzing the magnitude distribution data during λ_0 =234.80–235.00° leads to a value of the population index r =1.8 ± 0.3, with a correlation coefficient of 0.995. In the next interval between λ_0 =235.00–235.30° a new value of r =2.2 ± 0.2 reveals an increase in small meteoroids during the mean peak.

As was reported by Langbroek (1996), the magnitude distributions obtained during 1996 contain an interesting feature. The range in magnitude appears split in two components, one for brighter Leonids and one for a fainter population. This data was supported by a different population index for each component and by the simultaneous presence of a great number of fireballs, together with many faint Leonids seen by Langbroek (1996) in λ_0 =235.16° (2000.00). To find the presence of this component of faint meteors in 1997, the magnitude distributions in IMO Report Series (IMO, 1997) have been analyzed. In comparison to 1996 observations with very good sky conditions, during 1997 the Moon severely affected the mean limiting magnitude. Only experienced observers with the best skies for limiting magnitude (near +5.5) were able to report magnitude distributions with a large sample of faint meteors. In consequence, although some magnitude distributions reveal a possibly split structure, it is not possible to reach any conclusion about the presence of the faint meteors, especially because of the small sample of data obtained in good skies.

With all the IMO data the spatial number densities of the 1997 Leonids stream were obtained between λ_0=234.85–235.85° in 0.05° solar longitude steps (Table 1). The visual meteor observations let us obtain the ZHR and the population index directly, and determine the spatial number density of meteoroids causing meteors of magnitude at least +6.5, by means of the IMO method (Koschack & Rendtel 1990). These authors

Table 1. Spatial number densities in particles per billion km^3 obtained from IMO visual data and from our photographic data during the night of Nov. 17th and 18th. F is the usual cloud correction, according to the percentage of camera field covered by clouds.

Interval (UT)	Mean solar longitude	Photographic effective time	F	Photographied leonids	$\varrho_{-0.5}$	Error $\varrho_{-0.5}$	$\varrho_{6.5}$	Error $\varrho_{6.5}$
17th Nov. 03h-04h	234.85	0.83	1.33	1	0.9	0.9	26	8
04h-05h	234.90	0.80	1.05	2	1.4	1.0	35	14
05h-06h	234.95	0.66	1.00	6	4.5	1.8	58	14
06h-07h	235.00	-	-	-	-	-	38	10
07h-08h	235.05	-	-	-	-	-	32	7
08h-09h	235.10	-	-	-	-	-	48	30
09h-10h	235.15	-	-	-	-	-	71	11
10h-11h	235.20	-	-	-	-	-	83	12
11h-12h	235.25	-	-	-	-	-	77	15
12h-13h	235.30	-	-	-	-	-	57	11
15h-16h	235.45	-	-	-	-	-	74	12
16h-18h	235.50	-	-	-	-	-	58	5
18th Nov. 01h-05h	235.85	-	-	-	-	-	30	4

standardize the number of meteoroids in a cube of 1000 km of edge using

$$\rho_{6.5} = \frac{ZHR_0 \cdot C(r)}{3600 \cdot A_{red}(r) \cdot v_g} \quad (2)$$

where ZHR_0 is the observed Zenith Hourly Rate, corrected by a function C(r) that depends on the population index and the probability of perception p of each meteor of magnitude M. A_{red} represents the projected geometric area at meteor level corrected to population index as was obtained by Koschack & Rendtel (1990).

The last column of Table 1 shows the spatial number density of meteoroids causing meteors of at least +6.5 ($\varrho_{6.5}$). Starting from the mean geocentric velocity of Leonids meteoroids (approximately 70 km/s), this magnitude corresponds to a mass of $5 \cdot 10^{-5}$ grams according to the formula of Hughes (1995):

$$\log m(g) = 25.7 - 4logV(cm \cdot s^{-1}) - 0.4M_v \quad (3)$$

which relates meteor mass to magnitude (M_v) and geocentric velocity (V). In particular, the meteoroids responsible for the Leonids meteors have a mean geocentric velocity of 71km/s. The preceding equation can be rewritten as

$$m(g) = 10^{-1.7-0.4M_v} \quad (4)$$

During the 1997 Leonids maximum the spatial density of particles above a mass of $5 \cdot 10^{-5}$ was approximately 90 meteoroids/$10^9 \cdot$km^3. For example, this spatial density is close to recent observations in the Perseids new peak associated with the return of the Swift-Tuttle comet.

During the 1966 storm, the spatial number density was close to one million meteoroids with a volume of 10^9 km^3 (Williams, 1998). Other shower maxima have no more than 50 meteoroids in the same volume, as for Alpha Capricornids, Delta Aquarids or Eta Aquarids, according Trigo-Rodriguez (1991).

Fig. 2. A -8 mag. impressive fireball appeared in Perseus at 3h38m24s UT. The film used was a Kodak Panther Professional 1600. The digitalized images allow one to obtain the meteor trail astrometry and to determine the Leonids radiant

3. Photographic results

3.1. Spatial number densities obtained from photography

From the photographic data from Spain the spatial number density was also obtained. The 20mm lens covers a field of $62° \times 84°$ that was centered in the Leonids radiant. The effective area projected in the atmosphere was calculated according Bellot (1994) using a meteor level of 100 km and a population index of r=1.8. Table 1 shows the spatial number density ($\varrho_{-0.5}$) in the photographic magnitude range]-∞, -1] compared to that obtained from visual data ($\varrho_{6.5}$).

3.2. Radiant determination from train astrometry

The astrometry of the meteor trails recorded in 35mm plates leads to determining the position of the Leonids radiant during the maximum with more precision than visual observations. Between λ_0=234.86–234.94° (2000.00) at November 17th, 9 Leonids were recorded apparently originating in a small radiant of approximately 1 degree at $\alpha = 151.5° \pm 0.3°$ and $\delta = +21.8° \pm 0.5°$.

Another Leonid meteor, captured on November 23rd, shows the radiant derivation to $\alpha = 156°$, due to the Earth's movement. The photographic astrometry of the meteor trails was obtained with software developed by Steyaert (1990). The standard deviations of the beginning and ending points of the trails were between 1 and 5 arc minutes. A similar methodology was used to determine the Quadrantids 1993 radiant by Trigo-Rodriguez (1996).

4. Conclusion: The future years of Leonids

The 1994-1997 analysis of the Leonids activity is part of the general study of density and position of Tempel-Tuttle dust clouds. As Leonid storms are caused by a swarm of young meteoroids distributed in a narrow "sheet" in the vicinity of the 55P/Tempel-Tuttle, several authors assume that the previously observed activity patterns will be repeated (Jenniskens 1996; Yeomans, 1981). The visual and photographic observations obtained in 1997 help determine the presence and structure of the broad component, although it apparently does not show the presence of the faint component responsible for meteor storms.

According to Jenniskens (1996), this broad dust component rich in bright meteors dominated the encounters before and after the 1966 maximum. By comparing the returns of 1962-1965, he predicted an unusually strong activity in the population of larger meteoroids (brighter than magnitude 0) during 1997, as which is confirmed in our analysis. This young Leonid population will encounter the Earth at λ_0=234.85° (2000.00), approximately the same position that was observed in 1965 (λ_0=234.9°). That the encounter was characterized by very bright meteors, confirms the existence of a broad component in a P/Tempel-Tuttle dust distribution rich in great meteoroids. Other confirmation of the beginning of the Leonid outburst in this solar longitude was obtained by the radar of Ondrejov according to data analyzed by Brown et al.(1997). In 1994 and 1995 these radar data showed the activity increasing at λ_0=234.9°. After our 1997 observations a peak of 100 meteors per hour was seen from the USA in (λ_0=235.22°), also reported by Arlt & Brown (1998). As in the previous years 1995-1996 the peaks appear to be shifting closer to the nodal longitude of the parent comet. This is expected from general dynamic grounds, so any meteor storm in the next years will occur near the time of the comet's nodal passage (Yeomans, 1996).

In past years several authors have performed numerical modeling of the spatial structure of the Leonids stream that explains some of its basic features (Brown & Jones 1993; Brown et al. 1997; Wu & Williams 1996; McNaught & Asher 1998). Other authors have used the patern of past storms to understand the distribution of meteoroids in relation to orbital changes in the parent comet (Yeomans, 1981). Despite these advances, the first step in understanding the spatial structure of the Leonids stream is to obtain accurate observational information about the shower with any technique possible. Discrepancies found in the ZHR estimations obtained during Leonids storms (see f.e. Jenniskens, 1995) are the result of the intrinsic difficulty to visually estimate very high meteor rates, so that in future meteor storms, more reliable estimations of meteor flux densities require combining visual, photographic and video techniques.

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