ESTIMATED LEONID METEOROID FLUENCES UNDER STORM CONDITIONS

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ABSTRACT

The Leonid meteor shower is expected to undergo enhanced activity, possibly to storm levels, in mid-November of both 1999 and 2000. There are already clear signs that Leonid stream activity, measured according to the greatest hourly rate of meteors on the night of shower maximum, is on the increase. The meteoroid fluence at the top of the Earth's atmosphere during past meteor storms is described by a Gaussian function parameterized by the maximum hourly meteor rate and the time for which the hourly meteor rate exceeds the background level by a factor of ten. Under extreme Leonid storm conditions the meteoroid impact probability upon space platforms in Earth orbit may rise to ~ 10^{-2} percent per square meter.

1. METEOROID FLUX ESTIMATES

The cumulative meteoroid flux for the Leonid stream can be derived from annual visual meteor observations (Ref. 1). Table 1 is a comparison between the non-storm cumulative Leonid meteoroid flux, derived on the night of shower maximum, and the cumulative sporadic background meteoroid flux, over the same mass range, as presented by Grün *et. al.,* (Ref. 2).

To a first approximation the meteoroid flux that will be experienced at the top of the Earth's atmosphere during a meteor storm is the annual, non-storm meteoroid flux multiplied by an appropriate storm enhancement factor, F_{storm}. The storm enhancement factor can be defined as the ratio $(ZHR_{storm}/ZHR_{non-storm})_{max}$. Where the Zenithal hourly rate (ZHR) is defined as the number of meteors of magnitude +6.5 and brighter that an observer would see directly overhead, under ideal observing conditions if the shower radiant was at the zenith. The limiting mass for a Leonid meteoroid to produce a meteor of visual magnitude +6.5, in the observer's zenith, is $m_{+6.5} = 10^{-5}$ g. During past Leonid storms the enhancement factor has varied between ~500 and 10^4.

Log_{10} [m(g)]	Cumulative non-storm Leonid flux	Cumulative sporadic meteoroid flux
-8	1.9×10^{-9}	1.2×10^{-6}
-7	1.9×10^{-10}	3.0×10^{-7}
-6	1.9×10^{-11}	4.7×10^{-8}
-5	1.9×10^{-12}	4.6×10^{-9}
-4	1.9×10^{-13}	3.3×10^{-10}
-3	1.9×10^{-14}	1.9×10^{-11}
-2	1.9×10^{-15}	9.7×10^{-13}
-1	1.9×10^{-16}	4.7×10^{-14}
0	1.9×10^{-17}	2.2×10^{-15}

Table 1. Cumulative fluxes (meteoroids/m^2/s) for Leonid and sporadic meteoroids. The Leonid flux is based upon an assumed ZHR of 15 hr^{-1} and a stream mass index of s = 2.

There is some evidence to suggest that the mass index increases during a meteor storm, indicating a greater relative number of smaller mass meteoroids (Ref. 1). Table 2 gives a set of multiplication factors, F_S, to be applied against F(6.5), the cumulative flux at 10^{-5} g, in the case that the mass index varies.

s	1.5	1.75	2.0	2.25	2.5	2.75
F_S	0.1	0.4	1.0	2.0	3.8	6.5

Table 2. Multiplication factors, F_S, to be applied against the cumulative flux at 10^{-5}g.

In general, the cumulative meteoroid flux during a Leonid storm, to a limiting mass m_O, is:

$$F(s, m_O) = F_{storm} F_S (m_O/m_{+6.5})^{1-s} F(6.5)$$

Where F_{storm} accounts for the increased ZHR at storm maximum and F_S accounts for any variation in the mass index. This relationship holds provided F(6.5) is known.

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2. METEOROID FLUENCES

An analysis of the observed ZHRs, as a function of time, for historically observed meteor storms indicates that, to first order, the variations can be approximated as a Gaussian function parameterized by Δt and ZHR_{max}, where Δt is the time that the observed ZHR is greater than ten times the visual sporadic background rate. The Gaussian function is described by the relationship:

$$ZHR(t) = ZHR_{max} \exp\{-(t - t_{max})^2 / \sigma^2\}$$

where t is the time, t_{max} is the time at which ZHR_{max} is realized and where σ is given by:

$$\sigma = \Delta t / [2\,(-2\,\mathrm{Ln}(100 / ZHR_{max}))^{1/2}]$$

If we integrate the expression for ZHR(t) over the interval 12 hours before t_{max} and 12 hours after t_{max}, the meteoroid fluence during a storm can be derived. In order to determine the fluence, we need to first convert the ZHR to a genuine flux in units of meteoroids per square meter per second. Koschack and Rendtel (Ref. 3) give expressions for this conversion.

Table 3 shows a representative set of potential Leonid storm fluences. The parameter space in the table allows for variations in the peak ZHR, and the length of time that the activity is ten times greater than the background. If the stream's mass index is different from s = 2 during a storm, the fluences in table 3 should be multiplied by the appropriate F_S value from table 2. By way of example, the 1966 Leonid storm had a peak ZHR ~ 100,000 hr^{-1}, a duration of some five hours, and a mass index of 2.2 (Refs. 1, 4). From table 3 we obtain a fluence of 4×10^{-5}, and from table 2 we find $F_S \approx 2.0$. Hence, the derived meteoroid fluence, to a limiting meteoroid mass of 10^{-5} g, during the 1966 Leonid meteor storm was $\sim 2 \times 4 \times 10^{-5} \sim 10^{-4}$ meteoroids/m^2.

3. IMPACT ENERGETICS

Leonid meteoroids encounter the Earth with a velocity of 71 kms^{-1}. Clearly, under these conditions the kinetic energy of impact will be large for even small mass meteoroids.

Space debris has a characteristic impact velocity of 10 kms^{-1}. At the same mass, a Leonid meteoroid has seven times the momentum of space debris, and nearly fifty times the kinetic energy. If we make a comparison according to impact plasma generation, which varies as $v^{3.5}$, then the ratio of Leonid to space debris plasma generation is of order 1000.

ZHR	$\Delta t = 1$	2	3	5
10^3	$1x10^{-7}$	$3x10^{-7}$	$4x10^{-7}$	$7x10^{-7}$
10^4	$1x10^{-6}$	$2x10^{-6}$	$3x10^{-6}$	$5x10^{-6}$
10^5	$9x10^{-6}$	$2x10^{-5}$	$3x10^{-5}$	$4x10^{-5}$

Table 3. Meteoroid fluences (meteoroids/m^2) under parameterized Leonid storm conditions (s = 2).

4. SPACE DEBRIS

We use the model of Kessler (Ref. 5) to derive representative space debris fluxes. The fluxes are calculated for fragments of space debris having the same mass, momentum, kinetic energy and plasma generation capability as a Leonid meteoroid of mass 10^{-5} g. We assume an orbital altitude of 1000 km, an orbital inclination of 60 degrees, and a 10.7 cm solar radiation flux of 100. The results are given in table 4.

Comparison	Mass (g)	Flux (/m^2/sec)
Mass	1×10^{-5}	1×10^{-8}
Momentum	7×10^{-5}	2×10^{-9}
Kinetic energy	5×10^{-4}	4×10^{-10}
Plasma generation	9×10^{-3}	3×10^{-11}

Table 4. Space debris fluxes. The comparison is made according to a Leonid meteoroid mass of 10^{-5} g.

5. DISCUSSION

We can compare Leonid storm and space debris impact probabilities per square meter with the aid of tables 3 and 4. For a Leonid storm of duration 5 hour, maximum ZHR of 10^5, and mass index of 2.5, the meteoroid impact probability per square meter is 2×10^{-2}, at a limiting mass of 10^{-5} g. The corresponding impact probabilities per square meter for space debris (at 1000 km altitude and with an orbital inclination of 60 degrees) are given in table 5.

Mass (g)	Impact probability/m^2 (%)
1×10^{-5}	2×10^{-2}
7×10^{-5}	4×10^{-3}
5×10^{-4}	7×10^{-4}
9×10^{-3}	5×10^{-5}

Table 5. Space debris impact probabilities.

We find from table 5 that at 10^{-5} g the impact probabilities for a Leonid meteoroid and a fragment of space debris are equal, and of order 10^{-2} (%) per square meter (under the storm conditions adopted and the orbit selected). The impact probabilities for fragments of space debris delivering the same momentum, kinetic energy and plasma generation as a 10^{-5} g Leonid are one to three orders of magnitude smaller than that derived for equal mass.

6. LEONID SHOWER ACTIVITY

The Leonid shower is active between November 14 to November 21 each year, with a maximum being observed at a solar longitude of 235.2° (epoch 2000). During the time that the shower is active, the radiant position of the stream will move on the celestial sphere as a result of the Earth's motion through the stream. Linear least square fits to the drift in radiant Right Ascension and Declination are as follows (data is from the IAU Meteor Data Center at Lund Observatory, Ref. 7).

$$\text{RA (deg.)} = 0.7176\,\lambda_{\odot} - 16.211$$

$$\text{Dec (deg.)} = -0.3160\,\lambda_{\odot} + 96.509$$

Recent observations indicate that the Leonid rates have begun to increase during the past few years (Ref. 6). In 1994 the maximum meteor rate was about 60 per hour (this is a factor of three higher than normal), in 1995 the meteor rates fell to about 30 per hour while in 1996 they rose slightly to about 45 per hour. In 1995 the Leonids were observed to peak at a solar longitude of 235.5 ± 0.1 (about six hours after the nodal crossing time), significantly, however, there was some evidence to suggest an earlier maximum at a solar longitude of 235.0 (about six hours before the nodal crossing time). In 1996 a double maximum was distinctly observed (Ref. 6), the first maxima occurred at a solar longitude of 235.15 (about 2.5 hours before the nodal crossing time) and the second at a solar longitude of 235.37 (about three hours after the nodal crossing time). Interestingly, the first maximum was associated with mainly faint meteors, that is, low mass meteoroids, while the second maxima was characterized by many bright meteors, that is, higher mass meteoroids. The first of the 1996 maxima occurred at the same location (that is, solar longitude) as the 1966 Leonid storm maximum, and it is suggested that we are now beginning to sample meteoroids that were ejected from 55P/Tempel - Tuttle in 1932 and 1965.

7. REFERENCES

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