Pergamon

Adv. Space Res. Vol. 20, No. 8, pp. 1509–1512, 1997
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Printed in Great Britain
0273-1177/97 $17.00 + 0.00

PII: S0273-1177(97)00427-4

THE DANGER TO SATELLITES FROM METEOR STORMS

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ABSTRACT

During past meteor storms impact probabilities of between 1 and 0.01 percent have be realized per $50m^2$ of exposed surface area at altitudes corresponding to both GEO and LEO. The most likely meteoroid stream to yield a storm in the near future is that of the Leonids. Numerical simulations of the orbital evolution of hypothetical Leonid stream meteoroids suggest that storms may occur in the years 1999 and 2000.

INTRODUCTION

Meteor storms do not occur very often, there typically being 2 to 4 such events per century (Beech *et al.*, 1995). During a meteor storm the hourly rate of visual stream meteors increases by a factor of at least 100 above the nominal background rate. Since 1799 at total of 11 meteor storms have been observed and the essential characteristics of these storms are summarized in table 1.

Table 1. Basic characteristics of meteor storms since 1799 (see text for details)

Stream	Year	Δt (hrs)	ZHR_{max}	Parent comet	δt/P
Leonids	1799	4.8	>10,000	55P/Tempel-Tuttle	- 0.010
"	1832	9.6	>20,000	"	- 0.005
"	1833	4.8	100,000	"	+0.026
"	1866	4.8	10,000	"	+0.025
"	1867	4.8	>1,500	"	+0.055
"	1965	16.8	>5,000	"	+0.016
"	1966	4.8	150,000	"	+0.046
Draconids	1933	2.5	10,000	21P/Giacobini-Zinner	+0.033
"	1946	2.6	20,000	"	+0.007
Andromedids	1872	9.6	15,000	3D/Biela	+0.036
"	1885	8.4	8,000	"	- 0.012

The first two columns of table 1 identify the meteoroid stream and the year of the storm, the third column gives the time during which the hourly flux of visual meteors was greater than 10 times background activity. Column 4 gives the estimated peak zenithal hourly rate (ZHR) of visual meteors. Column 5 identifies the parent comet to the stream and the last column gives the time between the passage of the comet through its descending node and the time at which the storm occurred - the time is expressed in units of the comet's orbital period and the '-' or '+' sign indicates whether the storm occurred before or after the comet passed through the node. Given the poor quality of most of the historical data we estimate that prior to 1900 the peak ZHRs may be in error by a factor of ~5 and the durations in error by a factor ~2. After 1900 the errors are probably of order a factor of two smaller.

An estimate of the meteoroid fluence at the top of the Earth's atmosphere during a storm can be obtained by assuming a Gaussian activity profile parameterized by Δt and ZHR_{max}. Figure 1 shows the activity profiles, as deduced by Jenniskens (1995), for the 1872 Andromedid, the 1946 Draconid and the 1966 Leonid meteor storms.

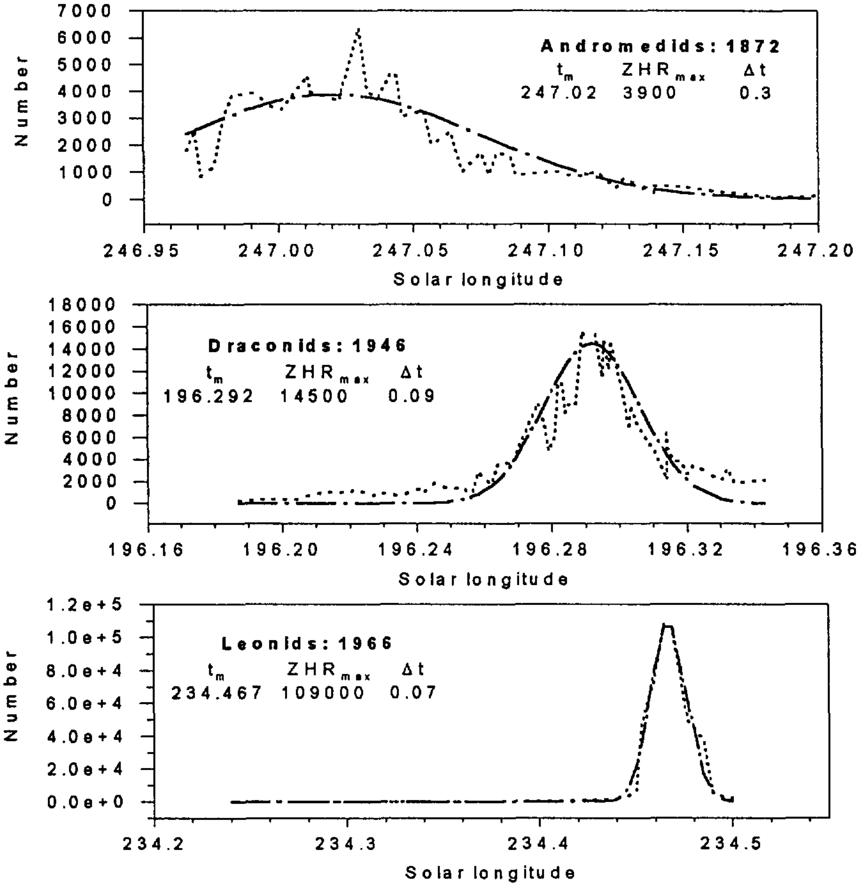

Fig. 1. Meteor storm activity profiles. The dotted line traces the visual data points (Jenniskens, 1995), while the solid line is a Gaussian approximation to the visual data. The Gaussian is parameterized by the maximum hourly rate of meteors and the time Δt for which the hourly meteor rate is greater than 100. Note, in this figure Δt is in fractions of a day and t_m is the solar longitude at the time of maximum.

Impact probabilities can be calculated from the storm activity profiles by first integrating the area under the Gaussian to derive the meteoroid fluence. The limiting meteoroid mass for visual observations is determined by the condition that a meteor of visual magnitude +6.5, or brighter, is produced during the meteoroid ablation process. The limiting masses for the Leonid, Draconid and Andromedid streams are, 10^{-5}, 10^{-3} and 2.10^{-3}g respectively. The meteoroid fluence at masses different to that of the limiting mass can be derived from the cumulative flux relationship: flux($m \geq m_o$) ~ m_o^{1-s}, where s is the stream's mass index. There is some evidence to suggest that the mass index increases during a meteor storm, indicating a relative enhancement in the number of smaller mass meteoroids (see e.g., Beech and Brown, 1994). Table 2 gives the meteoroid impact probabilities for the storms listed in table 1.

Table 2. Meteor storm impact probabilities. The calculations assume an exposed surface area of $1 m^2$. The impact probability for sporadic meteoroids assumes the storm Δt.

Stream	Date	Ip(%) stream, s = 2.0	Ip(%) stream, s = 2.5	Ip(%) Sporadic, ($m \geq 10^{-3}$ g)
Leonid	1799	0.0004	0.0016	$3.8\ 10^{-6}$
	1832	0.0018	0.0067	$7.6\ 10^{-6}$
	1833	0.0031	0.0144	$3.8\ 10^{-6}$
	1866	0.0004	0.0016	$3.8\ 10^{-6}$
	1867	0.0001	0.0003	$3.8\ 10^{-6}$
	1965	0.0009	0.0033	$1.3\ 10^{-5}$
	1966	0.0053	0.0198	$3.8\ 10^{-6}$
Draconid	1933	0.0002	0.0008	$2.0\ 10^{-6}$
	1946	0.0003	0.0011	$2.1\ 10^{-6}$
Andromedid	1872	0.0015	0.0056	$7.6\ 10^{-6}$
	1885	0.0007	0.0026	$6.6\ 10^{-6}$

Table 2 indicates that for a typical space platform, with a surface area ~50 m^2, an impact probability of between 1 to 0.01 percent can be realized during a meteor storm. The equivalent time to realize the same 'storm' impact probability from sporadic background meteoroids can be calculated from the interplanetary flux model of Grün *et. al.*, (1985). At a sporadic meteoroid mass of 10^{-3}g (i.e., the limiting sporadic meteoroid mass to produce a visible meteor) the equivalent time is typically of order 10 to 100 days, but at a sporadic meteoroid mass of 10^{-5}g the equivalent time is of order 1 to 10 hours.

Meteoroid impact damage can be either of a mechanical nature (e.g., resulting in cratering and surface erosion) or of a plasma discharge nature. The latter mechanism may be particularly important in the case of Leonids since the typical encounter velocities will be of order 70 km/s and charge production scales as $Q/m \sim v^{3.5}$. The plasma cloud produced from multiple Leonid meteoroid impacts may trigger electrostatic discharge events, and may possibly allow surface charge to enter otherwise insulated electronic sub-systems. It has been suggested, for example, that the demise of the OLYMPUS telecommunications satellite was the result of a plasma discharge event triggered by a Perseid meteoroid impact (see e.g., Beech *et al.*, 1995, Caswell *et al.*, 1995).

THE LEONID METEOROID STREAM

It is clear from table 1 that the Leonid meteoroid stream has dominated the contemporary meteor storm record. Leonid storms tend to occur when the Earth samples meteoroids that are situated spatially outside of the orbit and temporally behind the stream's parent comet, Comet 55P/Tempel-Tuttle (Yeomans, 1981). The time between perihelion passages is ~33.3 years for Comet Tempel-Tuttle and the possibility of observing Leonid storms repeats on this time-scale. Extensive numerical modeling of the Leonid stream (Brown and Jones, 1996) has revealed that the observed Leonid storms are comprised of material ejected during several previous perihelion passages of 55P/Tempel-Tuttle.

The present Leonid model suggests that strong shower activity will commence in 1998 and continue until at least 2002, with the returns between 1999 and 2000 being the strongest. The material causing these storms is densely concentrated at a nodal longitude of $235^\circ.16 \pm 0.04^\circ$ (epoch 2000). Table 3 summarizes the anticipated peak activity times.

Table 3. Predicted Leonid maxima times to 2002.

Year	Centroid of peak activity (UT)	Optimum location (visual observers)	$\delta t/P$
1997	Nov. 17.32	North Pacific	-0.009
1998	Nov. 17.71	Central Asia	+0.021
1999	Nov. 17.96	Central Europe	+0.051
2000	Nov. 17.22	Canada & USA	+0.081
2001	Nov. 17.47	North Pacific	+0.112

ACKNOWLEDGMENTS

Travel funds for MB to attend the 1996 COSPAR conference have been provided by the Institute of Space and Terrestrial Sciences, The Department of Defence, the Defence Research Agency Ottawa, TMI Communications and the Canadian Space Agency.

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