Risk assessment and operations strategy for ISRO satellites during Leonid storm encounter

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The comet 55P/Tempel-Tuttle crossed the perihelion on 28 February 1998. As the earth ploughs through the path of the debris-cloud left behind by the comet, any of the 500 operational satellites currently in space may get sand-blasted. The Leonid storm impact probabilities and risks involved for ISRO operational satellites serving remote sensing, scientific and communication fronts are assessed. The earth-shielding analysis reveals that all the Indian satellites will be exposed to the storm for near full duration. The sun-tracking solar panels of the spacecraft are less probable to get affected as the meteor storm approach is edge-on to the panels. ISTRAC has evolved an operations strategy for all ISRO satellites to counter the potential threat of the Leonid storm, which is discussed in detail.

Leonids

Leonid meteoroids are associated with Comet 55P/Tempel-Tuttle whose orbital period is 33.3 years. The meteors are named Leonids as they appear to emanate from the constellation of Leo due to perspective. The comet spews low density debris on and around its track like a wheel barrow due to sublimation of ice and dust, when the comet is in close proximity to the sun. The dissipation of the comet forms the annulus of meteoroids called 'stream' with the genes of orbital characteristics inherited from the parent comet. The distribution of these cosmic spherules in the stream is governed by the 'Poynting–Robertson Effect' by which the smaller particles sort themselves closer to the sun, whereas the larger ones keep away, provided all are of equal density. The earth on its annual journey on the ecliptic around the sun, encounters this stream during 14–20 November every year (Figure 1). In the case of Leonid, the shower takes the shape of storm once in 33.3 years, when the earth stirs the hornet's nest of debris swarm, just left behind by the perihelion passage of Tempel-Tuttle with the concomitant increase in deposit of debris[1] (Table 1).

The Leonid storm of current interest has dominated the contemporary storm record, with seven of them since 1799 (ref. 2) (Table 2). In 1965, Tempel-Tuttle passed the perihelion but the earth experienced a Leonid storm on 17 November 1966, the most intense storm ever recorded. The 1966 storm did not evoke much interest to space industry as there were only a few spacecraft and hence there is no historical data about the extent of damage on the satellites. The Leonid storm is forecast for November 14–20, 1998 when the earth along with about 500 operational satellites (6% of the total of 8000 orbiting) in its gravitational cradle, plough head-on through the swarm of dust particles precipitated by the comet 55P/Tempel-Tuttle, which slid through the perihelion on 28 February 1998. While we predict the Leonid storm to peak on 17 November 1998 at 20:40 UT, there is historical precedent for the storm to peak a year later on 18 November 1999. The Leonid storm is more severe for a couple of hours on either side of the peak[3] (Table 3).

It was clear even before the launch of Sputnik in 1957 that the satellites would be subjected to hypervelocity impacts from meteoroids and the main thrust of the early space research was on how to safeguard the space assets from these rubbles. The extent of damage inflicted on the satellites depends upon the combined effect of several factors such as the impact probabilities, relative velocity of the meteoroids,

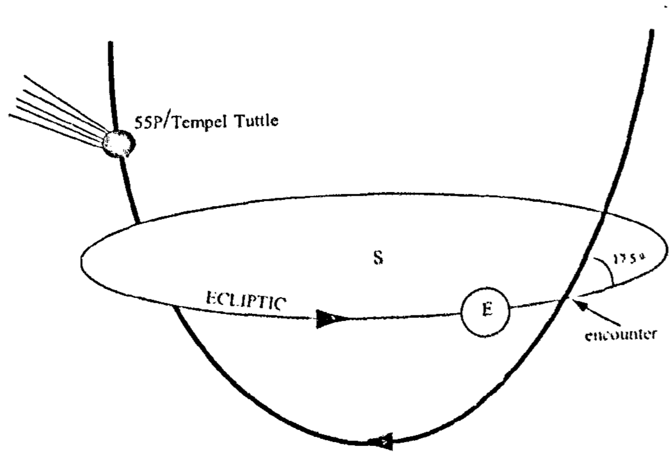

Figure 1. Earth–Leonid encounter.

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vulnerability of the satellite subsystems, the area of cross section, sensitivity of instruments on-board, orientation of the spacecraft to the storm, fluence, mass distribution of meteoroids, angle of incidence, etc. The present study is to assess the impact probabilities and then arrive at an idea on how best the preventive/ protective mechanisms can be developed.

ISRO satellites and the risks involved

Remote sensing satellites (IRS) are in near circular, near polar, sun synchronous orbits at about 820 km with 3 axis stabilization and the scientific satellite (SROSS-C2) at 430 km × 588 km elliptical orbit with spin stabilization. Communication satellites (INSAT) are in geostationary orbits. The satellites are state of the art in nature and have several microprocessors on board. The surface area of these satellites exposed to the storm are considerably small (12–24 m^2) compared to space station-MIR (500 m^2). Many of these satellites with miniaturized, processor-based electronic and sensitive electro-optical devices on board are vulnerable to physical assault and plasma-oriented spacecraft-charging. The damage could be a catastrophic rupture, secondary fracture, leakage, vapourific flash, deflagration, deformation, reduced residual strength, fluid contamination, thermal insulation damage, erosion and plasma-caused microprocessor upsets, glitches, etc. The analysis of the Leonid storm effect using the available data shows that all Indian satellites serving scientific, communication and remote sensing missions are certain to undergo this ordeal with Leonid storm for the near full duration and earth will not protect the satellites as the orbital planes will be exposed to the storm. The locations of IRS and INSAT satellites on the equator at the time of leonid storm peak are given in Figures 2 and 3.

What makes this ribbon of debris stand out high is their hyper-velocity encounter. At 71 km/s, they can play havoc with the life of the spacecraft. The risk due to the storm on satellites could be of both physical/ mechanical and electrical. Impact damages may be due to direct mechanical cratering, plasma and ESD creation, leading to electronic noise, sudden current and voltage spikes and software anomalies[4].

Table 1. Leonid meteoroids storm data

Radiant (in Leo Constellation)	
Right ascension	153.45°
Declination	21.87°
Radiant dia	4°
Magnitude of relative velocity w.r.t. earth	71.0 km/s
Closest approach between Earth and centre of meteoroid storm	0.0085 AU (1271590.18 km)
Angle between Earth–Sun line and meteoroid approach vector	92.46° (1998), 92.44° (1999)
Time of storm	17 November 20:40 UT
Duration of storm to be watched	± 7 h
Storm intensity	200–10000 ZHR
Storm duration	1–3 h
Meteoroid composition	Silicate and carbonaceous grains
Size of dominant particles	0.5 to 1 mm weighing about 10^{-5} to 10^{-7} g
Width of the stream	18×10^6 km
Thickness of the stream	35×10^3 km
Orbital elements	
Perihelion distance	0.9765849 AU
Longitude of ascending node	235.25883°
Eccentricity	0.9055036
Argument of perihelion	172.49731°
Inclination	162.48614°
Time of perihelion	28 February 1998 02 h 20 m

Table 2. 200 years of Leonids (based on observations)

Year of storm	Duration (h)	ZHR
12 Nov. 1799	5	> 10000
13 Nov. 1832	10	> 20000
13 Nov. 1833	5	~ 100000
13 Nov. 1866	5	~ 10000
13 Nov. 1867	5	> 1500
17 Nov. 1965	17	> 5000
17 Nov. 1966	5	~ 150000

ZHR: Zenithal hourly rate.

Physical damage

The meteors could cause physical damage to the satellite structures or components, pitting of optical surfaces and mirrors, degrading the performance of critical sensors, etc. However, the studies undertaken show that the probability of impact on our satellites ranges between 0.01% and 0.03%. Physical damage to the solar panels is very unlikely as the meteor storm approach is edge-on to the sun tracking solar panels[5].

Table 3. Time of storm peak

Year	Month/ date	Nodal crossing time UT	Solar longitude (deg.)	Moon's age
1966	November/17	12 h 00 m	235.20	–
1998	November/17	20 h 40 m	235.29	28 days
1999	November/18	01 h 50 m	235.28	9 days
2000	November/17	08 h 00 m	235.28	21 days

The time difference between the nodal crossing time and the storm peak could be anywhere within ± 7 h as the Leonid particles for a given year are shifted slightly above or below the orbital plane of the comet.

Electrical damage

Meteors disintegrating upon impact with the spacecraft could generate electrically charged plasma cloud as a result of ionization. This could lead to electro-static discharge (ESD) on adjacent surfaces, induce electrical shorts and failures in sensitive components. The plasma can cause sudden electrical pulse (SEP) which can upset sensitive microprocessors.

The probability of impact

The probability of impact is a function of surface area exposed and fluence of the storm. Though the probability number is low, the consequences of the impact, if occurred, could be catastrophic and hence an in depth study is warranted. The nominal Zenithal Hourly Rate (ZHR) observed is about 15 to 20 particles, whereas it peaks to about 40 particles per second, as was witnessed during the 1966 storm.

The impact probability (IP%) of Indian satellites is calculated and given in Table 4. But the uncertainty in the estimation is due to the fluence, as the mass distribution index and the flux as a function of mass are not accurately known and can vary by an order of magnitude. For the purpose of computation of impact probability, storm duration of 5 h and a limiting mass of 10^{-5} g is considered[2].

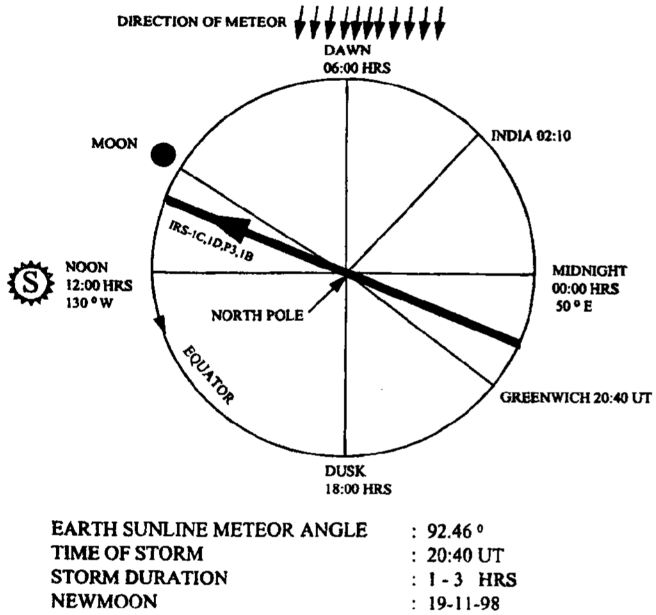

Figure 2. IRS satellites vs storm peak

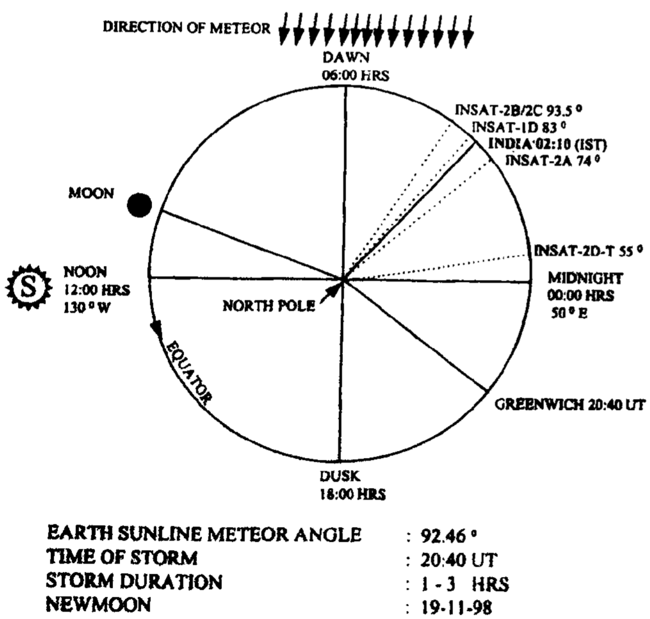

Figure 3. INSAT sattellites vs storm peak.

Operational strategy to safeguard the satellites

Operation teams

The entire team of satellite controllers involved in the satellite operation are to be made aware of this event and its impact. The presence of senior spacecraft controllers and sub-system specialists should be ensured at the spacecraft control centre during the storm period. The operation team should have the support of the sub-system designers for a period of seven hours on either side of the storm peak. Discussions should be held with designers, mission and project teams so that the experts will be available on the day of storm to overcome any contingencies. Controllers should check the health of the satellites frequently, looking primarily for electrical anomalies and glitches, regulator voltage and currents, etc. during 14–20 November 1998 in a count-down mode.

Spacecraft health monitoring

Vigilant and frequent health-monitoring prior to, during and post-storm phase is mandatory. Intensive monitoring of critical and additional important satellite parameters is to be carried out during the storm period. As IRS-1C, 1D and P3 are processor-based satellites, these satellites need to be monitored with a bit of extra care[6].

Table 4. Impact probabilities of Indian satellites

Spacecraft	Cross sectional area (m^2)	Impact probability (%)
IRS-1B	11.67	0.012
IRS-1C	12.78	0.013
IRS-1D	12.78	0.013
IRS-P3	11.20	0.011
SROSS-C2	0.64	0.001
INSAT-1D	24.0	0.024
INSAT-2A	29.0	0.029
INSAT-2B	29.0	0.029
INSAT-2C	32.0	0.032

Limiting mass: 10^{-5} g; Fluence (5 h): 10^{-5} Leonids.

Payload operations

Pan camera steering for IRS-1C/1D in positive direction may be avoided during the storm period. It is preferable that Pan operations be carried out with nadir viewing or with negative tilt angle. X-ray payload operations of IRS-P3 and Gamma Ray Burst Detector payload operations of SROSS-C2 which involve high voltage, may be suspended for the period of storm. Remote sensing payload operations may be stopped during the storm period. If payloads are to be serviced on priority, such operations may be conducted without inhibiting the solar panels. On-Board Tape Recorder operations need not be scheduled for the orbits during the peak of the storm, as the instrument has a built in processor.

Configuration changes for the satellites

It is suggested to power off sensitive instruments and prefer to be in AOCE Hardware, wherever the option exists. It should be ensured that the satellites are configured for 'safe mode'. In case of IRS-P3, favourable X-ray source should be selected in stellar-pointing mode to suit the safe orientation of the star sensor and X-ray detectors against the meteor storm. It will be expedient to operate the satellite in the earth-pointing mode. As the equipment panels of our satellites are generally of uniform area, re-orientation may not help in reducing the exposed surface area to the storm. In case of INSAT satellites gyros will be switched on, if not 'ON' already to provide rate information.

Scheduling efforts

It would be prudent to plan only the essential operations and not to schedule any special or critical operation during this period. Scheduling efforts should be made to allocate more TTC stations for processor-based and important missions. Scheduling priorities are to be assigned such that minimum visibility gap exists for IRS-1C, 1D and P3 satellites.

General guidelines

It is also essential that alternative communication links are at hand in case of any communication blackout from the connected GEO satellites. In case of any planned launch, the simple solution is to wait for the storm to blow over. NASA has also cancelled the space shuttle launch during the storm period. 14–20 November may be declared as Leonid campaign week for intensive health monitoring of satellites.

Conclusions

All Indian satellites are certain to undergo this ordeal with Leonid storm. The earth will not shield the satellites and most of the orbital plane will be exposed to the storm for full duration. The studies made show that the probability of impact on our satellites falls in the range of 0.01% to 0.03%. Physical damage to the solar panels is very unlikely as the meteor storm approach is edge-on to the sun-tracking solar panels. Though the probability number is low and our satellites are designed to be rugged with in-built fault-tolerant features, the consequences of the impact, if occurred, could be catastrophic and therefore the Leonid storm event cannot be taken lightly. As a measure of abundant caution, a strategy has been worked out to take adequate steps to safeguard the satellite fleet with minimal interruption in the routine operational services. As most of the satellites can switch over to 'safe mode' in the event of any serious anomaly, loss of satellite is unlikely. Even if the satellites are found to be unaffected after the event, the Leonid storm of 1999 and 2000 can not be neglected as the intensity of the storm can be high in the subsequent years, as is evident from the precedence set by the previous storms.

Will our satellites come out unscathed ? An affirmative answer is hard to be made now. But, the heavenly experience and the challenges courageously faced will be the positive aspect of this great event. The experience gained will stand as in good stead in facing future situations. We await the rare spectacle of this century with a repeat next year too, which may drive the event of comet Shoemaker–Levy's impact on Jupiter into the back-seat. Let the flamboyant Leonid illuminate the winter sky without any sparkle on our inflammable space assets.

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