1997 LEONID SHOWER FROM SPACE

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Abstract. In November 1997, the Midcourse Space Experiment satellite (MSX) was deployed to observe the Leonid shower from space. The shower lived up to expectations, with abundant bright fireballs. Twenty-nine meteors were detected by a wide-angle, visible wavelength, camera near the limb of the Earth in a 48-minute interval, and three meteors by the narrow field camera. This amounts to a meteoroid influx of 5.5 ± 0.6 10^{-5} km^{-2} hr^{-1} for masses > 0.3 gram. The limiting magnitude for limb observations of Leonid meteors was measured at M_v = –1.5 magn. The Leonid shower magnitude population index was 1.6 ± 0.2 down to M_v = –7 magn., with no sign of an upper mass cut-off.

Keywords: Flux, Leonids 1999, meteors, meteor shower, MSX, population index, space

1. Introduction

Space based observations of meteors are at a disadvantage in being further away from the meteors than ground-based observers and instrumentation being more expensive to operate, so less observing time is available to catch an elusive phenomenon. However, the larger effective surface area that is covered from such a distant vantage point does make space based observations potentially a suitable technique for measuring the influx and population index of the rare bright fireballs. Occasionally, bright < –17 magn. sporadic meteor fireballs are reported from the routine monitoring of rocket launches by the USA Department of Defense satellites (Reynolds, 1992; Tagliaferri *et al.*, 1994).

Space based observations are also uniquely suited for UV spectroscopy of meteors, at wavelengths that are inaccessible from the ground. The Midcourse Space Experiment (MSX) has unique capability for both imaging of meteors from space and for UV spectroscopy over a wide spectral range (Mill *et al.*, 1994). MSX is a Ballistic Missile Defense Organization project. The satellite was launched on April 24, 1996 by a delta rocket from Vandenberg Air Force Base, CA into a nominal circular orbit with an altitude of 908 km and an inclination of 99.6 degrees. The Johns Hopkins University Applied Physics Laboratory developed, integrated, and operated MSX. The Ultraviolet and Visible Imagers and Spectrographic Imagers (UVISI) instrument houses 11 optical sensors that are precisely aligned so target activity can be viewed simultaneously by multiple sensors covering a wide wavelength range.

The sensors were first deployed to study a meteor shower on November 17, 1997, when the Leonid shower showed a broad maximum in activity centered at 14 ± 2h UT (Arlt and Brown, 1998). The shower is thought to have been a recurrence of the "Leonid Filament", a broad structure of old debris causing abundant bright fireballs and also responsible for the fireball outburst of Nov. 1998 (Asher *et al.*, 1999; Jenniskens and Betlem, 2000). Indeed, the UVISI imagers detected numerous Leonid meteors. These images are unique in being the first record of a meteor shower from space. The results of UV spectroscopy will be discussed elsewhere.

2. Methods.

Two of the UVISI imagers were used during these observations. The UVISI Wide Field Visible Imager is sensitive over the spectral range of 440–695 nm and has a field of view of 13.1 x 10.5 degrees. The Narrow Field UV and Visible Imager covers the spectral range from 300 to 723 nm and has a field of view of 1.6 x 1.3 degrees. The UVISI cameras were run at high gain and gate and provided a white-light (open filters) record of meteors near the slit of the spectrograph. Each image was integrated for 0.5 seconds, with alternating images for each camera every second.

The viewing geometry was chosen to have the spectrographs look to the nighttime limb of the Earth in fixed anti-Sun direction, with the slit parallel to the Earth's surface. Bright Leonid fireballs have the brightest point at about 95 km altitude, while fainter Leonids tend to peak near 100 km altitude. In order to increase our chances of detecting a persistent train and capture different parts of the meteor track, we covered the altitude range between 120 and 80 km in 10 mirror steps perpendicular to the Earth's surface, taking into account the curvature of the Earth. As a result, the cameras are oriented parallel to the Earth's limb and centered in a direction corresponding to 100-km altitude at the limb.

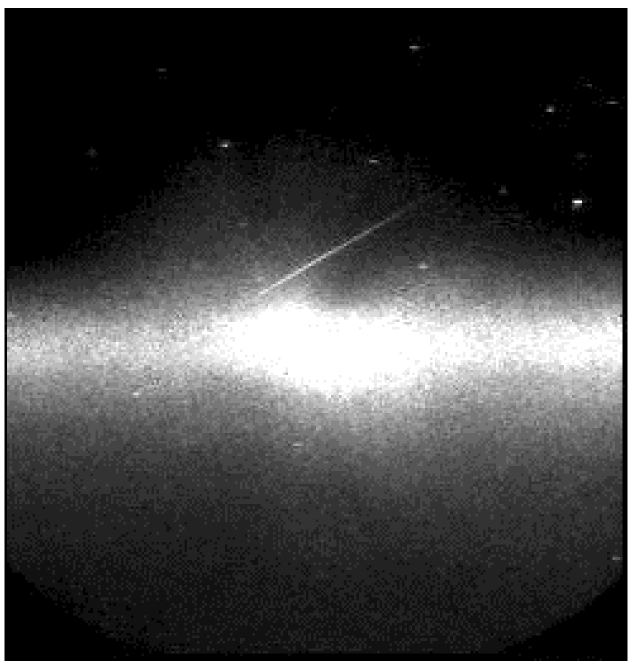

Figure 1 Leonid meteor ablating above the airglow layer in a UVISI Narrow Field UV and Visible Image.

The optimum observing period was chosen to be the 1–2 hour interval centered on 13:34 UT on November 17, when the Earth passed the orbital plane of comet 55P/Tempel-Tuttle (Yeomans *et al.*, 1996). This time was close to the actual peak of the shower (Arlt and Brown, 1998). Specifically, the observations were timed to coincide with the satellite being between +0 and +40 degree northern latitude, while moving in a south to north orbit over the apex (morning) side of the Earth, the part which was exposed to the Leonid meteors. To avoid twilight at the 120 km altitude layer and resulting increase in the airglow emission, the solar zenith angle at the tangent point had to be greater than about 102 degrees. In fact, the higher the better in order to get away from any off axis internal scattering due to the bright limb or sunlit Earth. The full Moon was not expected to interfere with the observations other than causing a bright cloud deck at low viewing elevations.

3. Results

Two target of opportunity events were allotted to this program on 17 November. The first run started with sampling the evening sky at 14:28:16 UT, gradually turning towards the morning sky until about 15:12 UT. Problems with data transmission caused a loss of many video frames and the cameras did not detect meteors during this period. During the second run as many as 29 meteors were observed in the wide field imager and 3 meteors in the narrow field imager. These were all Leonids that appeared between 15:12:16 and 15:58:00 UT.

Figure 1, for example, shows a Leonid meteor detected at 15:31:12 UT in the narrow field imager. The meteor is seen in a direction $\alpha = 36^{o}$, $\delta = 17^{o}$, and is positioned mostly above the airglow layer. The brightness distribution in the airglow layer peaks at about 89 km altitude and much reflects the distribution of ablated meteoric metals from mainly smaller and slower meteoroids that make up the sporadic meteor background. This illustrates that the fast Leonid meteors tend to ablate at higher altitudes than the meteoroids that dominate the mass influx. The meteor light curve is characteristic for many Leonids: an exponential increase, followed by a broad maximum, a rapid decline and a brief end flare.

The meteors move in parallel paths from a direction $\alpha = 153.6^{o}$, $\delta = +22^{o}$ which is the radiant of the shower (Jenniskens and Betlem, 2000).

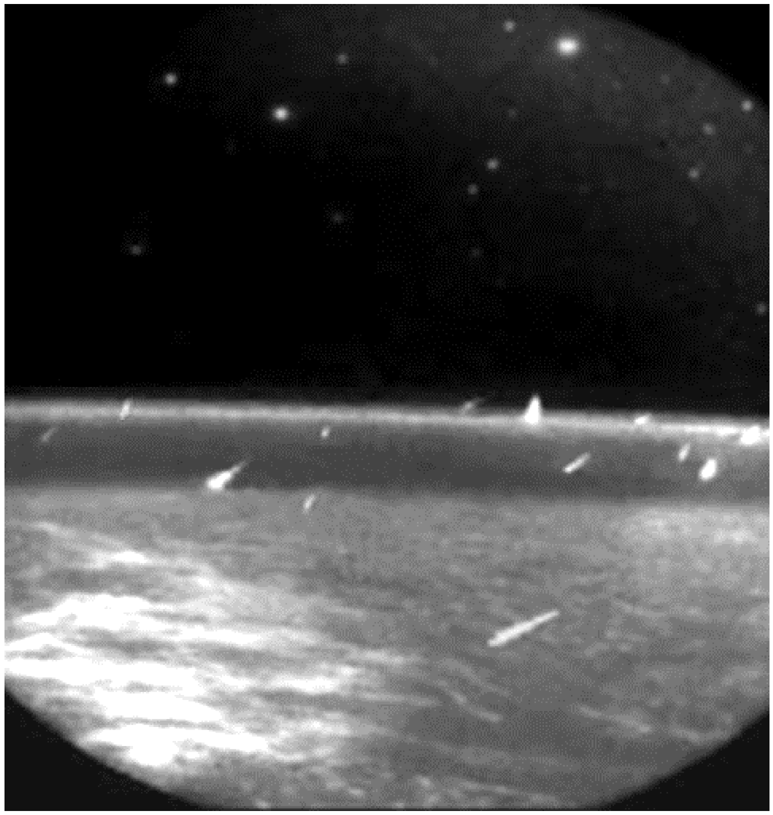

Figure 2a Composite of Leonid meteors in wide-angle camera. We chose the most striking star background and cloud pattern observed between 15:20 and 15:59 UT. Full Moon glare is visible on the clouds in the lower left of the image.

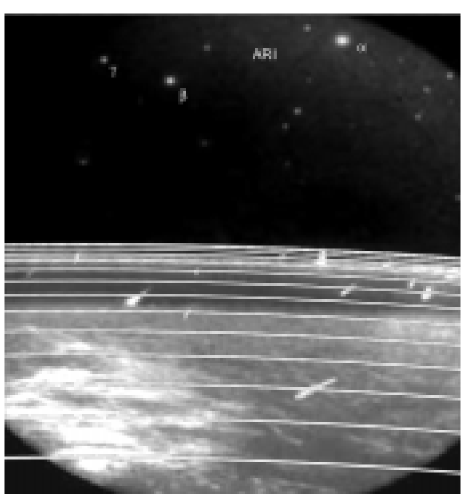

Figure 2b Equidistant lines from the satellite to a layer at altitude 100 km. Stars serve as magnitude calibration. Stars in the constellation of Aries are marked.

However, the relative viewing direction changes when the satellite scans along the limb of the Earth in each revolution. At the time of first detection, the meteors appear to come from the left in projection to the horizon, while later they appear to come from the right. To give a sense of how the Leonid shower is seen from space, a composite image of meteors detected in the wide field imager between 15:20 and 15:59 UT is shown in Figure 2a.

To uniquely determine the meteor flux and size distribution in the Leonid shower, the distance to each meteor is determined. Figure 2b shows equidistant lines from the satellite to a layer at 100 km altitude. Distances range from 1,900 km at the bottom in Figure 2b to 3,300 km at the limb. Beyond the limb, meteors are detected as far away as 4,700 km between airglow layers and the cloud deck. As a result of these large distances, relatively bright meteors appear faint enough to not cause problems with non-linear effects of blooming, and their intensity can be directly compared to that of background stars. Individual magnitudes were determined by comparing the integrated intensity of the meteors with the integrated intensity of the stars. A good correlation between visual magnitude and the log of integrated intensity of comparison stars was found in the range +2 to +7 magnitude, with the expected slope, which implies that the system is linear over this regime. Apparent magnitudes of meteors covered about the same range: +1 to +6 magnitude. Meteors located between cloud top and airglow layers can be at one of two distances, depending on whether they are on the near side or the far side. We find that five out of ten meteors in between the airglow layers and the horizon lack a recognizable exponential increase in brightness and show the bright central part of the light curve more compressed. They are likely on the far side. Thus, the light curve of each meteor can discriminate between near and far meteors, especially in cases close to the Earth's cloud deck where the difference in distance is largest, and offers a unique measure of distance for all meteors.

The resulting magnitude distribution is shown in Figure 3. The wide field visible imager detects nearly all Leonid meteors of magnitude -2 and brighter. The exponential slope implies a magnitude distribution index of $r = 1.6 \pm 0.2$, with a most likely value of $r = 1.7$. The light of a full Moon hampered ground-based observations in 1997. Brown and Arlt (1998) stated "It is almost certain that any attempt to use magnitude data from the peak night will be heavily biased and produce artificially low values for the population index r". Nevertheless, Arlt and Brown (1998) found a low value of $r = 2.0 \pm 0.2$ from apparent visual meteor magnitudes in the range +0 to +5 magn. A general dominance of bright meteors was observed by forward meteor scatter radar (Foschini *et al.*, 1998). From ground-based video observations, Hawkes *et al.* (1998) found, $s = 1.71 \pm 0.07$, which corresponds to $r = 1.92 \pm 0.13$. Hence, we can confirm that the trend for meteor magnitudes between +0 and +5 continued until at least -7 magnitude, without any sign of an upper mass cut-off.

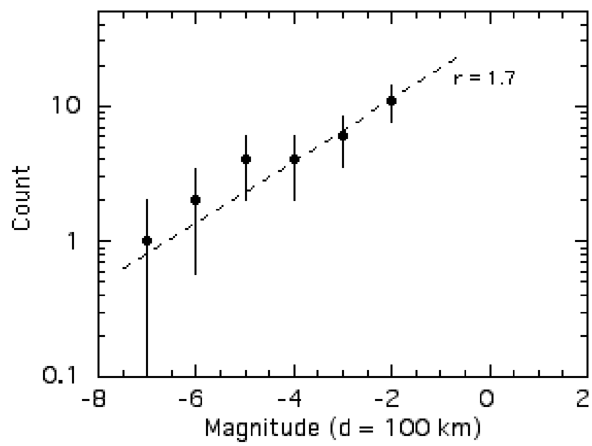

Figure 3 Meteor count in intervals of absolute magnitude distribution.

With this information, it is possible to calculate the influx of meteoroids of magnitudes less than –1.5, or masses larger than about 0.3 gram (Jacchia *et al.*, 1967). For, $r = 1.7$, we count 40 meteors below the integral dashed line in Figure 1. The observing interval covers a period of 48 minutes. The wide field imagers were recording data during about 40% of that time. The effective surface area perpendicular to the shower is about 1.1×10^6 km^2. The radiant of the shower is about 36 degrees out of the zenith on average over the spatial and temporal interval. Hence, the influx of meteoroids > 0.2 gram (< –1.5 magn.) was $5.5 \pm 0.9 \times 10^{-5}$ km^{-2} hr^{-1} at the peak of the 1997 Leonid shower between 15:12 and 15:59 UT. Arlt and Brown (1998) reported ZHR = 96 ± 13 at the peak at 12:15 UT, which translates to about 1–5 x 10^{-2} Leonids km^{-2} hr^{-1} of limiting absolute magnitude +6.5 and brighter. Extrapolation of our magnitude distribution, $r = 1.7$, gives $1.6 \pm 0.3 \times 10^{-2}$ km^{-2} hr^{-1} at 15.6 UT, in general agreement with the results reported by Arlt and Brown (1998).

The good agreement is encouraging for future applications of space based observations in meteor shower research.

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