Detection of 2004 Leonid meteor shower by observing its effects on VLF transmission

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Results of the detection of 2004 Leonid meteor shower over Kolkata (22°34´ N, 88°30´ E), India is presented in this paper, by using a VLF amplifier tuned at one of the transmission frequencies of Indian Navy Traffic stations at Vijayananarayanam (8º25´59.88´´ N, 77º48´ E) at 16.3 kHz. The shower was predicted to exhibit a peak activity on 19 Nov. 2004. In spite of low ZHR predicted, the peak activity had been observed earlier than the predicted times, which confirms the nongravitational 'A2 effect' on meteoroid trails. The observation also suggests that electromagnetic detection of meteor shower is better than the visual observation, as any time of the day and night its effect on VLF transmission can be recorded.

Keywords: Meteor shower, VLF radio wave, ionospheric disturbances.

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1 Introduction

Meteors produce audible sound along with optical signature during their entry through the earth’s atmosphere1,2. These sounds are generated by shockwaves or other audio signals produced by the meteorite itself. The explanation of these sounds was not so clear because of the time delay between optical signals and audio signals coming from a meteor due to the difference in their propagation velocities.

Also, meteors entering the earth’s atmosphere produce electromagnetic waves in the VLF range due to interaction with the medium, which propagate and reach the ground at the same instance as the optical signals3. The low frequency waves generate electrophonic phenomena inducing perceptible sound vibrations at electrically conducting objects near the observer.

The present work envisages the detection of Leonid Meteor shower by recording its effects on a transmitted VLF signal VTX1 at 16.3 kHz from one of the Indian Navy stations.

The Leonids emanate from the trail of comet Tempel-Tuttle swings past the Sun approximately every 33 years, and during each close approach it emits a dense stream of dust and small particles. With time, these dust trails extend along the whole length of the comet's orbit, but the trails remain very narrow and concentrated in space taking hundreds of years to spread out. Comet Tempel-Tuttle revolves around the Sun in the opposite direction to the Earth, so when the Earth encounters the trails of particles, they enter the atmosphere at very high speeds, about 257,495 kmph. Most of the dust grains are very small, like grains of sand, and vaporize on entry within the first few seconds at heights around 96.5 km. Every year roughly between 14 and 20 Nov. 2004, the Earth meets a stream of ancient debris, leading to the annual meteor shower visible in the early morning hours, high in the north-east sky after midnight during those dates. The cometary dust particles move in very similar orbits and the resulting meteor shower appears to radiate from a point in the constellation Leo, hence the term Leonids.

It was thought that the Leonid period was over after 2002 but there was a fair activity4 in 2003. For 2004, another activity was predicted. Not a storm level, but the Earth was predicted to pass close to two streams: the 1333 and the 1733. The 1733 stream was already encountered in 2002 and the 1333 stream was thought to be responsible from the 1998 storm, but not all models agree about that. Nevertheless, the three current models5-7 all agreed to have some Leonid activity on 2004.

It was predicted that any outburst from the 1333 trail will peak at 0642 hrs UT, on 19 Nov 2004. Rates would not be high, ZHR = 10 at best. The second
1733 trail would arrive at 2149 hrs UT, when the rates could go up as high as ZHR = 65. Even though predicted rates were not as high as in past Leonid storms, it was important to continue observing these showers to learn how dust is distributed by the parent comet 55P/Tempel-Tuttle.

Many workers reported the detection of Leonid showers by recording VLF signals emitted by the meteors during their passage through ionosphere. VLF signals at 19 kHz produced by 2002 Leonid meteor shower has been recorded from Kolkata. Generation of electrophonics was also confirmed to be the results of VLF emission during a meteor shower.

The authors are able to continuously record a VLF signal at 16.3 kHz, which is transmitted by VTX1 Indian Navy station located at Vijayanarayananam (8°25′59.88″ N, 77°48′ E), at a distance of about 2000 km from Kolkata. Continuous recording at this frequency enables us to monitor ionospheric disturbances due to lightning activity, solar flare, etc. Recently, the authors observed the effect of recent Leonid meteor shower on the propagation of VLF signals. Regarding the effects of meteor propagation, choice of VLF frequency is immaterial. In spite of that, the transmitted signal chosen was at a frequency where the influence of atmospherics is relatively low compared to the atmospherics at 12 kHz and lower frequencies. Moreover, suitable signal strength of 16.3 kHz at the receiving station led to its choice. Interestingly, not only the shower could be detected, but also the non-gravitational ‘A2 effect’ on Leonid meteor trails could be confirmed.

2 Experimental set-up
To receive the VLF signal a horizontal 8 SWG straight copper wire of length 120 m was installed as an antenna at a height of 20 m from ground. The antenna is sensitive to the vertical electric field of the electromagnetic signal. To record the signal, a Gyrator-II VLF receiver was fabricated. A block diagram of the recording system is given in Fig. 1. The VLF receiver was tuned at 16.3 kHz with a quality factor around 250. The overall gain of the amplifier is around 40 dB. The rms value of the signal was recorded using a Pentium IV computer sound card at a sample rate of 10/s. The recorded data were analysed later using Origin 5.0.

3 Observational results
Two types of perturbation at the receiving signal strength of VLF signal can happen due to the passage of meteor through the ionosphere. Figure 2(a) depicts the condition of normal one-hop VLF propagation in a very simple manner. In normal condition and in a given time frame, “signal 1” can reach the receiver but “signal 2” cannot. Figure 2(b) shows how the integrated VLF signal strength can increase due to passage of meteor. The ionized column produced by the meteor path reflects “signal 2” and it can easily reach the receiving station increasing the effective signal strength when both “signal 1” and “signal 2” are in phase. On the other hand, the effective signal strength at the receiving station can decrease due to reflection of “signal 1” from the ionized path produced by the meteor. The situation is shown in Fig. 2 (c).

The days from 14 to 20 Nov. 2004 had very clear sky and no serious ‘thunder-bolt’ related events were reported at Kolkata. So apart from the solar-terrestrial influences on the ionosphere, the period was ideal for observing meteor shower. Moreover, the predicted peak activity periods on 19 Nov. 2004 were around 0642 hrs UT and 2149 hrs UT, respectively and no solar flare events were reported around that time by GOES 10 and GOES 12 satellites that continuously monitor solar activity. At the predicted peak activity period, there were no local lightning or flare generated perturbations in the ionosphere that could alter the average signal received at Kolkata.

A total of three occurrences of meteor shower were detected. Two of these meteor showers were on 19 Nov. 2004 and one was on 22 Nov. 2004. The variation of 16.3 kHz signal strength at the same durations of the recorded meteor showers one day before and one day after has been shown in Fig. 3 [(a)-(f)]. It is clear from the plots that in normal condition, there is no noticeable variation in the signal strength received at Kolkata.

Figures 4 and 5 show the effect of Leonid meteor shower on VLF signal on 19th November. In both the
cases, the signal level increased six to seven times the normal value. The authors believe that the extra ionization produced by the supersonic meteoroids during their passage through lower ionosphere was the cause of this enhancement. The ionized column produced by the meteors reflected some signals from the VLF transmitter, which could otherwise miss the receiving station in undisturbed conditions. The first occurrence of Leonid meteor shower on 19 Nov. 2004 has been analyzed event-wise and the result is shown in Table 1. On the second occurrence of the shower on 19 Nov. 2004, the successive events were so dense that individual events could not be resolved as the resolution of the measurement system was not sufficient.

Figure 6 shows the Leonid meteor shower on 22nd November, 2004. The shower was not as strong as on 19th November. The individual events have been analyzed and the results are presented in Table 2. One interesting observation was that, both the increments and decrements of signal level have been found during the entry of the meteor into the atmosphere.

There was another interesting feature of the observation. The peak activity was noticed earlier
than the predicted times. The first peak activity on 19 Nov. 2004 was predicted at 0642 hrs UT, but the peak activity started at 0605 hrs UT. This is 37 min earlier than the predicted time. The second activity started at 1842 hrs UT, which is 3 h 07 min earlier than the scheduled time at 2149 hrs UT. Based on the reports of International Meteor Organization\textsuperscript{13}, Vaubaillon et al.\textsuperscript{14} estimated that the times of peak activities would be earlier than the predicted values due to non-gravitational ‘A2 effect’ on 1333 and 1733 meteor trails. Using some model calculations they showed that the peak activity from 1333 trail would be earlier by as much as five hours, from the predicted time and peak activity from 1733 trail would be earlier by as much as two to three hours, from the scheduled time. Although the authors noticed 1333 trail effect to be only 37 min earlier than the predicted time, taking into account the ‘A2 effect’, the activation of peak activity for 1733 trail matched closely with their observation. Here they observed the peak activity to start at 3 h 7 min earlier than the predicted time.

### 4 Possible explanation of the ionized path

During the entry of the Leonid into the earth’s atmosphere, there will be strong fluctuations of charge distribution in the medium, which enhances the rate at which the energy gets randomized. As a result, instability is produced. For this, the relative electron-ion drift velocity may exceed the value for the onset of Kelvin-Helmoltz instability. The compressible ionospheric plasma driven by velocity
shear and earth’s magnetic field at the frontal path of the meteor increases the growth rate of Kelvin-Helmoltz instability. Strong turbulence is developed, in which non-linear perturbation at the particle trajectories towards the rear zone of the meteor acts to stabilize the turbulent flow leaving a strongly ionized trail. The station signal at 16.3 kHz frequency gets depleted at this ionized zone during its travel towards the ionospheric layer for reflection and for this, the effective reception of the reflected signals at the ground will be weak. Such ionized trail can also contribute to the process of reflection of station signals at the ground receiver along with the reflected wave from the ionosphere and consequently higher signal strength will be pronounced.

5 Discussion
The detection of meteor shower by electromagnetic signals is very effective, since the presence of a shower can also be detected during daytime unless there is severe thunderstorm activity. If the system is properly designed, it is also useful in detecting very weak or low ZHR meteor showers, which are not detectable with visual observation even at night. It was daytime at 1212 hrs LT, when the first shower occurred on 19 Nov. 2004. Nevertheless, it was successfully observed using electromagnetic waves from standard sources. To confirm non-gravitational ‘A2 effect’, it is presumed that simultaneous observations are necessary, which will be possible by synchronizing time at different places.

Acknowledgements
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References
1 Keay C S L, Anomalous sounds from the entry of meteor fireballs, Science (USA), 210 (1980) 11.
2 Keay C S L, Progress in explaining the mysterious sounds produced by very large meteor fireballs of large meteoroids in Earth's atmosphere, J Sci Explor (USA), 7 (1993) 337.
5 McNaught R & Asher D, Leonid dust trails and meteor storms, WGN (Belgium), 27 (1999) 85.
10 www.aavso.org.
11 www.imd.ernet.in.
12 www.sel.noaa.gov.
13 www.imo.net.

Table 2— Leonid shower data on 22 Nov. 2004

<table>
<thead>
<tr>
<th>Events</th>
<th>Event property</th>
</tr>
</thead>
<tbody>
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<tr>
<td>Event 10</td>
<td>30.8</td>
</tr>
</tbody>
</table>

Total Period of the Shower (from 05:30:00 UT to 07:23:59 UT) ≈ 114 min
Observed Zenithal Hourly Rate from the variation of E.M. signal ≈ 5