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POWER FLUCTUATIONS IN METEOR HEAD ECHOES OBSERVED WITH THE EISCAT VHF RADAR

JOHAN KERO, CSILLA SZASZ and ASTA PELLINEN-WANNBERG
Swedish Institute of Space Physics, Kiruna, Sweden
GUDMUND WANNBERG and ASSAR WESTMAN
EISCAT Scientific Association, Kiruna, Sweden

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Abstract. We present observations and preliminary results from a meteor experiment carried out with the 224 MHz EISCAT VHF radar in Tromsø, Norway, which was run for 6 h on November 26, 2003. The data set contains echoes with peculiar pulsations in received power in the frequency range 20–200 Hz, limited by instrumental parameters. The process causing the echo power pulsations has not yet been identified. Plasma effects are the most likely cause, a possible mechanism is for instance asymmetrical dust grains in rotation causing a modulation of the ionization rate.

Keywords: HPLA radar, meteor head echo, meteoroid rotation, plasma effects

Abbreviations: EISCAT: European incoherent scatter; HPLA: high power large aperture; SNR: signal-to-noise ratio

1. Introduction

Several authors, e.g. Beech and Brown (2000), have reported optical intensity fluctuations in fireball observations and have suggested that these arise from rotational modulation of ablation processes. These fluctuations have shown up in the frequency range from a few to as high as 500 Hz.

Hawkes and Jones (1978) have made theoretical estimations of the rotation rates of small meteoroids, and obtained plausible frequencies of the order 50–13,000 Hz for 10^{-3} g meteoroids considering rotational bursting the only spin-limiting mechanism. Jones (1990) has since presented a mechanism of damping caused by absorption and re-emission of solar radiation. This kind of damping would lead to an equilibrium spin distribution for small interplanetary particles with a lower upper limit than Hawkes and Jones presented.

This report presents the first observations of pulsations in received power of faint radio-meteors, which could possibly be caused by spinning meteoroids.

2. Experiment overview

The 224 MHz EISCAT VHF radar located at a latitude of 69.58° N in Tromsø, Norway, was run with a dedicated meteor experiment for 6 h 02.00–08.00 UT (03.00–09.00 LT) on November 26, 2003. The time span of the experiment was chosen to admit the highest possible meteor rates and is too short to discern any diurnal variations. The beam was directed toward magnetic north with a 30° elevation providing a geometry as far from geomagnetic field-parallel as possible, approximately 17° from perpendicular. A sketch of the beam geometry is shown in Figure 1. The transmitted and received waves were left- and right-hand circular.

A 32-bit pseudo-random coded pulse sequence with a baud length of 2.4 μs was used in the experiment, giving a total pulse length of 76.8 μs. The received signal was oversampled by a factor of four, which means a 0.6 μs sampling period providing 90 m range resolution. The transmission/reception was alternated between two different frequency channels, 223.6 and 224.4 MHz, to lower the risk of range aliasing and to permit a high pulse repetition frequency. The channel-to-channel interpulse period was set to 2167 μs, enabling parameters such as meteor line-of-sight velocity and echo power to be monitored with a frequency of 461 Hz.

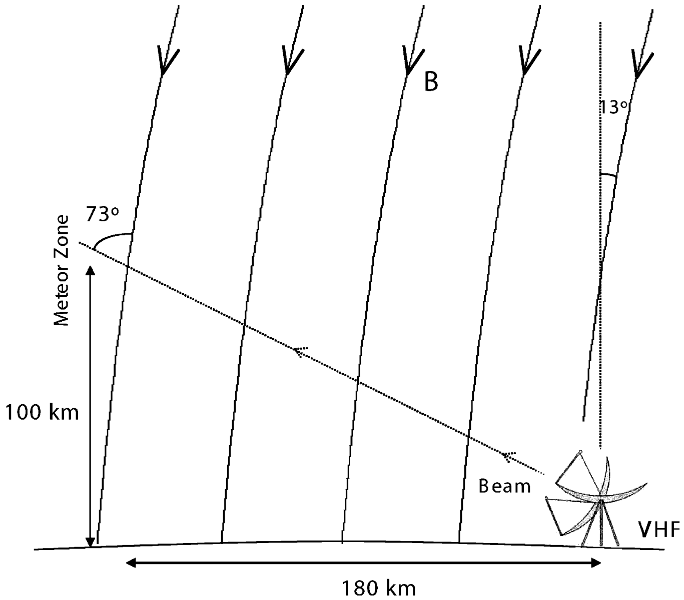

Figure 1. Sketch of the beam geometry of the experiment under consideration, 30° elevation and azimuth collocated with magnetic north.

The antenna of the EISCAT VHF radar is a parabolic cylinder. The beam is roughly elliptical and its cross-sectional power profile is Gaussian. The main lobe has a one-way half-power beam width of 1.2° × 1.7°. This is equivalent to 4 × 6 km at a range of 200 km, which corresponds to an altitude of 100 km with the given beam geometry.

The whole altitude interval illuminated by radio waves during reception reached from 86 to 123 km, chosen to include most of the EISCAT VHF meteor altitude distribution (Westman et al. 2004). The altitude interval illuminated by all 32 bits of the pulse sequence, in which full decoding is possible, was 92–117 km.

Previous EISCAT meteor experiments and results are described in a review by Pellinen–Wannberg (2004) and references therein.

3. Observations

About 2500 meteors were observed during the 6 h experiment. Many meteoroids have line-of-sight velocities lower than the minimum geocentric velocity of 11 km s^{-1} as they travel across the beam. No range-spread trail echoes have been found in the data set.

If a meteoroid passes through the radar beam at a large angle from the pointing direction, one can expect the received power of the meteor head echo to smoothly rise and disappear as the meteoroid traverses the Gaussian-shaped main lobe of the antenna in a time frame of the order of a tenth of a second. Approximately 10% of the detected meteors have a transient behavior of this kind. An example is shown in Figure 2. Remaining events do not have such smooth profiles, and are probably manifestations of non-uniform ionization and/or fragmentation during the meteors' observability within the beam.

As the EISCAT VHF radar is monostatic and does not have interferometric capabilities, it is not possible to deduce in an unambiguous way how far from the centre of the beam a specific meteoroid passed. The figures in this first report from the experiment show plots of SNR versus time of individual observations, leaving out radar cross-section and meteoroid mass estimations for the time being.

Approximately 13% of the detected events show intensity pulsations in the frequency range 20–200 Hz in their power-versus-time profiles. Figure 3 shows an example of a pulsating event with a fluctuation frequency increasing from about 25 to 200 Hz throughout its detectable duration of 0.16 s in the radar beam. The power of some events pulsates with more regular rates. One example shown in Figure 4 has an almost constant fluctuation frequency of 50 Hz. Very few events have decreasing pulsation

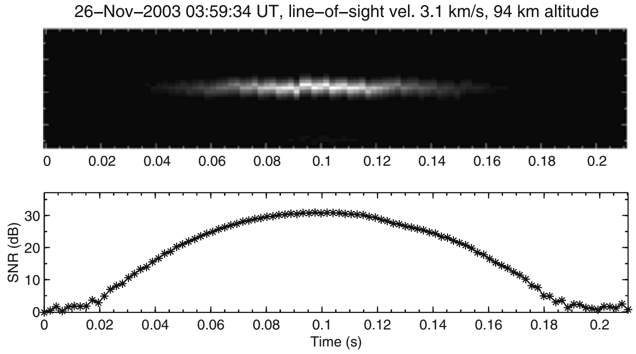

Figure 2. A meteoroid passing through the Gaussian-shaped antenna main lobe. The upper and lower panels show the meteor-aligned range-time intensity plot (upper) and the SNR (lower).

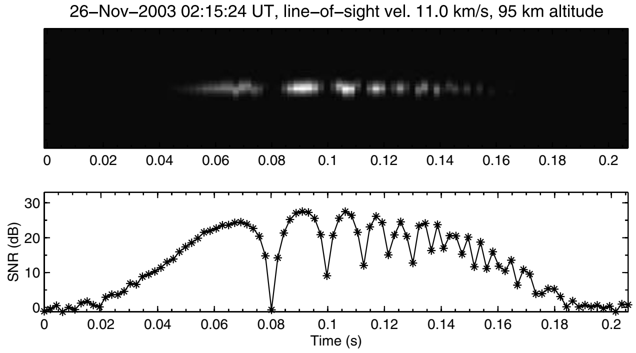

Figure 3. A pulsating event with a fluctuation frequency increasing from about 25 to 200 Hz throughout its duration of about 0.16 s. The upper and lower panels show the meteor-aligned range-time intensity plot (upper) and the SNR (lower).

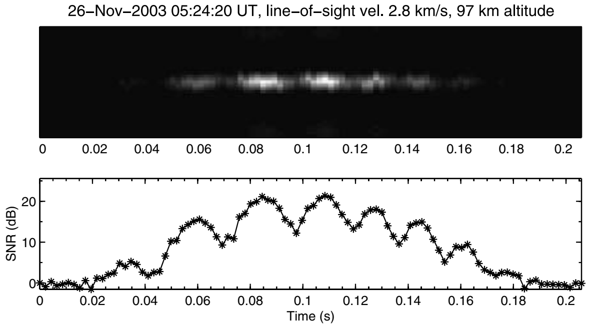

Figure 4. A pulsating event with a fluctuation frequency of about 50 Hz. The upper and lower panels show the meteor-aligned range-time intensity plot (upper) and the SNR (lower).

frequencies. The highest reconstructible power modulation of a detected signal in the experiment is 230 Hz.

Pulsating events have similar altitude distribution, line-of-sight velocity distribution and maximum SNR distribution as non-pulsating events. The received power fluctuates down to the noise floor for about 30% of the pulsating events.

4. Discussion

Recent investigations by Novikov et al. (2004) consider the influence of meteoroid rotation on the diffraction characteristics of underdense radio-meteors. They assumed $5 \cdot 10^{-4}$ g meteoroids rotating at 0–400 Hz. The investigations involved calculations of how much the electron volume density production inside a meteor trail would vary along the trail axis due to the varying cross-sectional area of a rotating cubic shaped meteoroid. In their results the electron volume density fluctuates with an amplitude of about 25% of the average density, but they conclude that the simulated fluctuations would be practically undetectable with meteor radars. The Fresnel diffraction patterns of echoes reflected from trails with fluctuating densities would be indistinguishable from patterns of echoes reflected from uniform meteor trails.

HPLA radars have a much higher sensitivity than meteor radars and can detect the small transient volume of dense ionization produced in the immediate vicinity of the meteoroid itself. Even a modest fluctuation of the ionization production should therefore be detectable provided its modulation frequency is suitable. For the EISCAT VHF experiment under consideration, the detectable frequency range is 10–230 Hz. The upper and lower limitations stem from the sampling frequency of 461 Hz and from the typical duration of an event, which is one tenth to a few tenths of a second.

The observed periodic power fluctuations cannot be explained by polarization fading or Faraday rotation as circular polarization was used. Multipath fading due to, e.g. aurorae is not likely, especially as the geomagnetic conditions were very quiet during the campaign (deflections of the order of 10 nT).

The head echo target size is smaller than or equal to one atmospheric mean-free path (~0.1 m at 100 km) according to several different present scattering models (Close, 2004). The target is therefore much smaller than the radar wavelength ($\lambda = 1.34$ m) in the part of the measurement interval where most meteors are detected. The altitude distribution of pulsating events is not up-shifted compared to non-pulsating events. Thus, target-wavelength resonance effects are unlikely to be the cause of the pulsations.

5. Conclusions

The fluctuations of received power in echoes from the faint meteors observed with the EISCAT VHF radar are the first of their kind to be presented. Several authors have reported similar pulsations in optical observations of fireballs. The process causing the radar echo power pulsations has not yet been identified. Plasma effects are the most likely cause, a possible mechanism is for instance asymmetrical dust grains in rotation causing a modulation of the ionization rate. Future work includes analysis of tristatic UHF data and a more exhaustive investigation of possible mechanisms of the phenomenon.

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