Publ. Astron. Obs. Belgrade No. 80 (2006), 179 - 184 *Contributed paper*

FORWARD SCATTERING OF METEORS AT MULTIPLE FREQUENCIES

SAŠA NEDELJKOVIĆ[1] and CALVIN BARTH NETTERFIELD[2]
Department of Physics, University of Toronto, 60 St. George St, Toronto M5S 1A7, Canada
E–mail: [1]*sasa@physics.utoronto.ca*
E–mail: [2]*netterfield@astro.utoronto.ca*

Abstract. Forward scattering of meteors is a method of meteor detection using a radio receiver to detect signals coming from the transmitters not in line-of-sight. When a meteoroid enters the atmosphere an ionized trail which can reflect radio waves is created. If the meteor, the transmitter and the receiver are in "good" geometrical alignment such that coherent scattering is possible, the receiver will be able to detect a signal reflected from the meteor. A digital radio spectrometer working between 50 and 150MHz and connected to a small wide-frequency, wide-beam antenna can be used as a detector. Its spectral resolution is better than 50kHz and able to resolve individual FM radio and TV stations. In this paper we shall give an overview of the apparatus used to detect meteors at FM frequencies. We will also explain how we can extract the kinetic parameters of the meteoroid. Some preliminary results will be presented.

1. INTRODUCTION

Meteoroids entering the earth's atmosphere form ionized trails. At a height of approximately 120km above the earth's surface, the atmosphere is dense enough to start the process of creation of a meteor trail. Atoms from the meteoroid's surface evaporate due to collisional heating, and collide with atmospheric particles producing light, heat and ions. Behind the meteoroid an ionized trail is formed. The characteristics of the trail depend primarily on the velocity, the mass and the shape of the meteoric body as well as on the atmospheric density at a given altitude. The trail's charged particles start disintegrating in the surrounding media immediately after the trail is formed. The usual approximation is to consider a cylindrically symmetric trail with the maximal electron density in the center of the cylinder. A good overview of disintegration processes is given in the classical meteor textbook written by Bronshten (1983).

The ionized trail reflects radio waves. Free electrons in the meteor trail re-radiate an incident radio wave. Reflected signal can be picked up by a receiver located at the same place where a transmitter is (backward-scattering), or in the more general case by a receiver separated from the transmitter (forward-scattering).

Figure 1: The map of 45570 North American FM transmitters (2005).

The maximal intensity of the reflected signal is obtained in the case of a coherent scattering: the transmitter, the trail and the receiver are aligned in such a way that the transmitter and the receiver are foci of an ellipsoid, while the meteor trail is tangent to this ellipsoid. In most cases the trail can be approximated as a straight line, but for meteors with a long duration (∼10s) the trail becomes deformed due to wind. Ionization useful for meteor forward-scattering occurs between 80 and 120km above the earth's surface, hence the maximum distance where reflected signal can be received is 2400km. In the case of the radar observations, the ellipsoid becomes a sphere which makes data analysis much simpler than in the case of forward-scattering.

The meteor scatter propagation is a very complex process due to a number of parameters affecting the ionized trail. With the use of several approximations (infinite cylindrical trail with Gaussian electron distribution in radial direction, and an electron density low enough so that individual electrons behave like Hertzian dipoles) a model for the received signal power P_R as a function of time is given by

$$P_R = \frac{P_T G_T G_R \lambda^3 \sigma_e}{64\pi^3} \frac{q^2 S}{R_T R_R (R_T + R_R)(1 - \sin^2\phi \cos^2\beta)} e^{\frac{-32\pi^2 D t \cos^2\phi}{\lambda^2}} e^{\frac{-8\pi^2 r_0^2 \cos^2\phi}{\lambda^2}}, \tag{1}$$

where P_T is the transmitter's power, G_T and G_R are the transmitter and the receiver gains, R_T and R_R are the distances from the transmitter and the receiver to the trail, λ is the wavelength, σ_e is the scattering cross section of a free electron, q is the electron density, D the diffusion constant, S the polarization coupling factor, β the angle of the trail relative to the plane formed by R_T and R_R, ϕ the propagation angle, and r_0 is the initial radius of the train (McKinley, 1961).

2. DETECTION OF METEORS AT MULTIPLE FREQUENCIES

A common setup used for the forward scattering meteor detection uses a receiver tuned at a fixed frequency, receiving the signal from a known distant transmitter at this particular frequency. Currently there are no methods which can successfully extract all kinetic parameters of a meteoroid based on a single frequency forward-scattering (Foschini, 1999).

Advances in digital electronics enable us to construct a spectrometer capable of obtaining VHF spectra with resolutions of 10kHz covering a large portion of the sky. In general such a system is composed of a wide beam broadband antenna, amplifiers, filters, an analog/digital converter and a computer. By comparing with the traditional setup, our digital receiver does not use a mixer for tuning to a specific frequency. Our digital system can receive at a range of frequencies, thus being able to receive signals from a variety of transmitters, making it possible to do meteor astronomy with only one antenna.

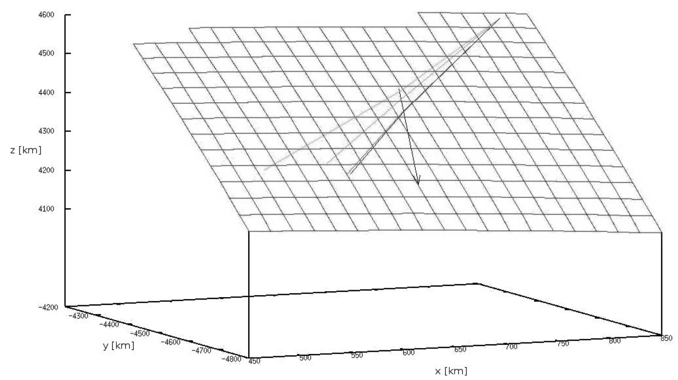

Figure 2: The meteor forward scattering at multiple frequencies. Radio signals coming from the four transmitters are scattered off the meteor trail and observed in the receiver point. The center of the coordinate system is in the center of the earth. The earth's surface is represented by red colored grid.

An example of four reflections from a meteor trail is given in Fig. 2.

Commercial FM (87.9 - 107.9MHz) stations can be used as the transmitters for the forward-scattering observations. Data extracted from Canadian Broadcast Database (Industry Canada, Spectrum Management and Telecommunication) and USA FM Radio Database Query (Audio Division of the Media Bureau, USA federal government) are plotted in Fig. 1 in order to give a full North American map of FM transmitters. In total there are 45570 FM transmitters. Knowing that in the whole FM band there is enough space for only 100 stations we are forced to numerically determine the locations of the observed transmitters.

The coherent scattering in the general case occurs when a meteor trail is tangent to an ellipsoid with foci in a transmitter (x_T, y_T, z_T) and a receiver (x_R, y_R, z_R).

Since the ellipsoid has only two foci and the projection of a meteor trail is a line then c must be equal to b. The meteor line in 3D is defined by using two points $\mathrm{M}_1(x_1, y_1, z_1)$ and $\mathrm{M}_2(x_2, y_2, z_2)$ lying on the line as

$$\frac{x - x_2}{x_1 - x_2} = \frac{y - y_2}{y_1 - y_2} = \frac{z - z_2}{z_1 - z_2}. \tag{2}$$

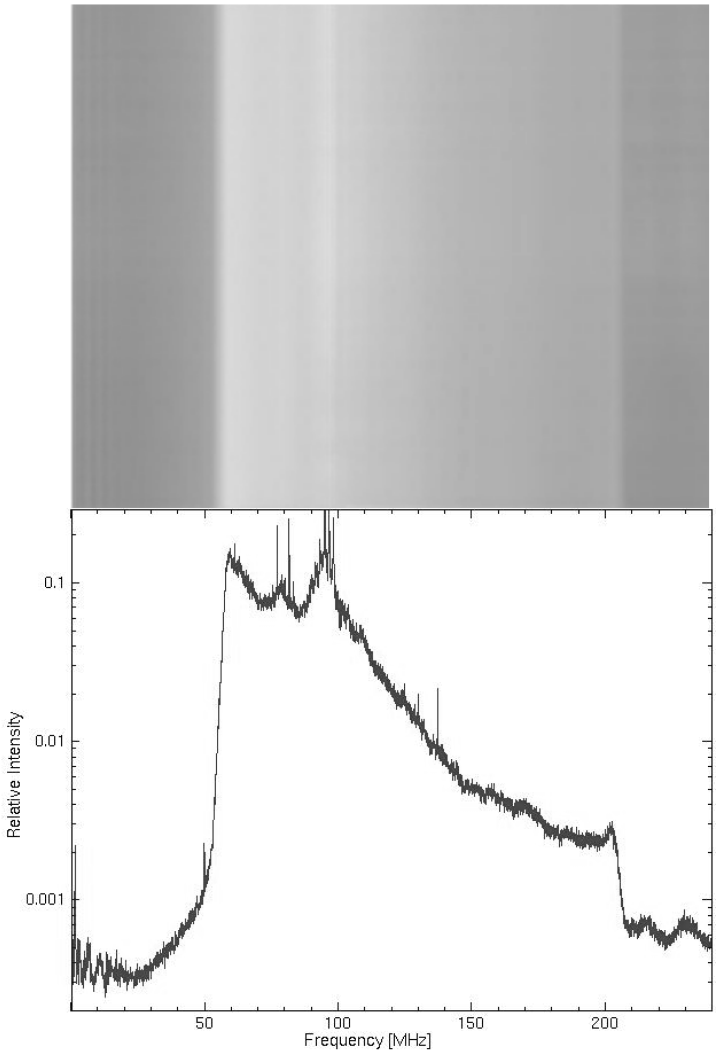

Figure 3: The spectrum obtained at Algonquin Park in Aug 2005. The intensity is normalized to the highest peak for the given data set. The exponential growth of the Galactic "noise" toward the lower frequencies is clearly present. Top: the time evolution of the spectrum, with the time resolution of one data set per second.

We have developed an analythic method to determine whether there is a coherent scattering for a given meteor, a transmitter and a receiver (Nedeljković, 2005). Our approach is strictly geometrical and assumes that the ionized trail is a straight line, thus neglecting the deformations due to wind. Such an approximation is valid for the meteors with the duration of less than 10 seconds.

Looping trough all transmitters in the range of 300-1700km, we check whether the coherent scattering exists and we find where on the meteor line the center of the 1st Fresnel zone is.

Any meteor detected at 4 different frequencies from the transmitters at 4 different locations can be uniquely identified if the location of all 4 transmitters is known. However, the computational time is still far from being the real time. There is ongoing work to improve the computational efficiency of the algorithm.

The first author of this paper performed a set of measurements using the rectangular approximation of a conical spiral antenna and the 8bit 500MHz PCI ADC in the central part of Algonquin Park, Ontario, Canada at Pretty Lake, in the period 12-16th of August, 2005. The obtained spectrum is shown in Fig. 3.

The FM part of the spectrum is dominated by three weak radio stations only, proving that the site is almost completely radio quiet in the given frequency range.

For the purposes of the meteor astronomy, the measurements of the FM band of the spectrum have been taken with the frequency resolution of 60kHz and the time resolution of 30 samples per second. The reflections at the multiple frequencies have been detected. A more detailed analysis is currently under way.

3. CONCLUSION

The forward-scattering detection of meteors has not been fully explored because of the complicated geometry associated with the detection. With the advances in digital electronics we are capable to receive the reflected signals from multiple transmitters at multiple frequencies scattered from the same meteor trail.

The commercial FM stations can be used as the transmitters for the forward-scattering observations. Knowing that in the whole FM band there is enough space for only 100 radio stations, a problem of identifying the detected transmitter appears. It makes the numerical simulation more complex than in a case when the transmitters are unique and well known.

Having four or more detections of the same meteor we can determine the meteor kinetic parameters without making any assumptions about physical properties of the trails.

Acknowledgements. The authors would like to thank Alicja Koprianiuk for the help during the Algonquin 2005 observations and Vjera Miović for useful discussions and helpful comments.

References

Bronshten, V.A.: 1983, Physics of meteoric phenomena, D. Reidel Pub. Co, Holland.
Foschini, L.: 1999, *Astron. Astrophys.*, **341**, 634.
McKinley, D.W.R.: 1961, Meteor Science and Engineering, McGraw-Hill Book Company.
Nedeljković, S.: 2005, IMC 2005 Proceedings, Oostmalle, Belgium (in press).
Web page: Canadian Government Broadcasting Database: 2005, http://strategis.ic.gc.ca/epic/internet/insmt-gst.nsf/en/h_sf01842e.html.
Web page: USA FM Radio Database: 2005, http://www.fcc.gov/mb/audio/fmq.html.