THE TRISTATIC 930 MHz EISCAT RADAR SYSTEM: A UNIQUE TOOL FOR METEOR/DUST STUDIES

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ABSTRACT

We report results from meteor head-echo observations utilizing the tristatic EISCAT 930 MHz radar system located in northern Scandinavia. The 930 MHz tristatic configuration provides meteor absolute geocentric Doppler speeds as well as very precise radiant information for those meteors that are detected by the three receivers. An overview of the methodology and a summary of the results obtained so far as well as orbital calculations are presented. These observations prove EISCAT to be a crucial instrument for the study of extraterrestrial particles entering the earth's upper atmosphere, in particular at very high geocentric latitudes.

INTRODUCTION

Over the last decade, high power large aperture (HPLA) VHF/UHF radars have played a major role in radar meteor studies. Although, the first use of these radars for meteor studies was performed by [1] who observed meteors with the 440 MHz Millstone-Hill radar, no further work was reported for nearly 4 decades. The re-introduction of HPLA radars to the field is marked by the work of [2] who utilized for the first time the European Incoherent Scatter (EISCAT) UHF/VHF (930/224 MHz) radar system for the observation of dust particles entering the earth upper atmosphere. Since then, observations with almost all the HPLA around the world have been reported.

Unlike the classical meteor radars, which based their studies on the detection of Fresnel diffraction patterns from the developing trail, HPLA radars detect the signal scattered back from a cloud of electrons traveling at the speed of the meteoroid known as the meteor head-echo [3], [4]. This is crucial, since the classical use of the developing trail as a method for determining the meteor speed has a few shortcomings. It provides time-integrated velocities instead of instantaneous velocities, preventing the measurement of any physical process occurring to the meteoroid during the time it is observed by the radar. In addition, the classical method has two radar sensitivity effects. The first effect is that the Fresnel diffraction intensity is sensitive to angular departure from the meteor perpendicular path with respect the radar beam axis. The second effect is introduced by the dependency of the atmospheric diffusion coefficient with altitude resulting on a rapid diffusion of the trails that form at higher altitudes. A review of this method can be found in [5].

The consistent detection of the meteor head-echo by HPLA radars allows the measurement of the instantaneous meteor Doppler velocity that is essential to address a number of aeronomical, astronomical and radio science issues [4]. In this paper we report results from meteor observations utilizing the EISCAT 930 MHz tristatic radar system, located in northern Scandinavia. This system consists of three antennas located in Tromso, Norway (69.6 N; 19.2 E), Kiruna, Sweden (67.9 N; 20.4 E) and Sodankylä, Finland (67.4 N; 26.6 E). The EISCAT tristatic geographical configuration is diplayed in Fig. 1. Because of its location at high geocentric latitudes, it is possible to observe portions of the sky that are not accessible for most HPLA radars, allowing the investigation of high orbital inclination meteors. In addition, the 930 MHz tristatic configuration provides meteor absolute geocentric speeds as well as very precise radiant information for those meteors that are detected by the three receivers. We report results from the first tristatic measurements of radar meteors obtained during November 17-18, 1997 and 1998. An overview of the methodology and a summary of the results obtained so far as well as preliminary orbital calculations are presented. Other HPLA meteor radar work is also discussed. To the best of our knowledge, these observations represent the first of their kind and prove EISCAT to be a crucial instrument for the study of extraterrestrial particles entering the earth's atmosphere, in particular at very high geocentric latitudes.

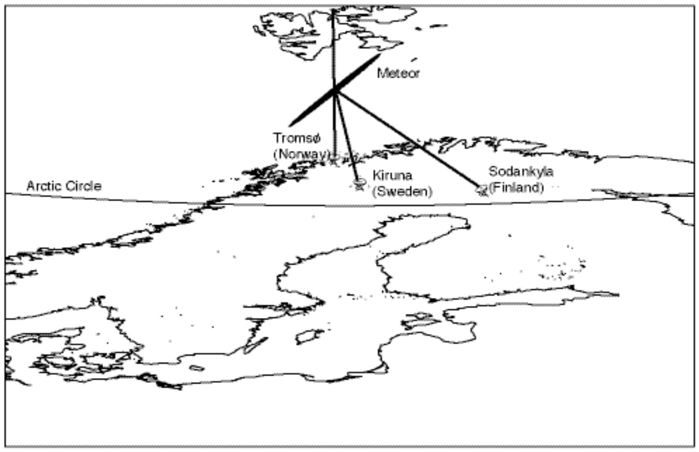

Fig. 1. The EISCAT 930 MHz Tristatic Radar System. This system consists of three 32 m parabolic antennas. The transmitter receiver is located in Tromso and the remote receivers are located in Kiruna and Sodankylä.

METHODOLOGY

The tristatic meteor detections reported in this work were performed utilizing a 13×2 μsec binary phase-shift keyed Barker code pulse emitted from the antenna located at the Tromso site [2,4,6]. When a meteoroid flies through the 3-receivers common volume (Fig. 1) the scattered echo is detected by the receivers located at Tromso, Kiruna and Sodankylä. The k-vector of each site is defined as the unit vector pointing in the direction of the bisector defined by the Tromso transmitter beam and the corresponding receiving site radar beam. By means of a technique based on the radar ambiguity function [2,4,6], the meteor Doppler velocity components in the three k-vector directions are obtained and a three dimensional picture of the meteor path and velocity is constructed. Besides the fact that these measurements are based in the meteor head-echo detection and not the trails, they also differ from previous multi-station classical meteor radar work in that those are instruments detected events by spaced multi-stations. The intervals between the occurrence of meteor trail echo profiles are used to determine its velocity and traveling direction [7].

The results presented in this work include observations from two campaigns. The first one was perform in November 1997 covering an interval from 23:00 hr (UT) of November 16th to 18:00 hr (UT) of November 17th, while the 1998 sample includes a 24 hr interval from 09:00 hr (UT) of the morning of November 17th to the morning of November 18th. Although these observations were performed during the 1997 and 1998 Leonids meteor shower, preliminary orbital analysis suggests that they are not associated with the stream. Furthermore, the meteor hourly fluxes that EISCAT detects appear to be constant during showers and outside of shower times [4,8].

During both campaigns the Tromso radar beam was pointed upwards (elevation: 89.9^{o}, azimuth: 180^{o}). The remote sites' pointing characteristics varied during the 1997 observations, for the purpose of searching for the optimal radar common-volume altitude, while they were fixed during the 1998 observations. During the later period, the Kiruna antenna pointing was 26.8^{o} in elevation and 346.3^{o} in azimuth and the Sodankylä antenna pointing was 13.1^{o} in elevation and 312.7^{o} in azimuth . The common volume was then centered at 105 km of altitude.

RESULTS

A total of 10 successful tristatic detections were achieved during both campaigns, 7 events out of a total 84 in 1997 and 3 out of 132 in1998. An additional 2/3 (1997/1998) events were detected by both, Tromso and Kiruna sites, but were not observed by the Sodankylä receiver probably because of the lower sensitivity of this receiver since it is the one furthest away from the 3-receiver common volume. Since the direction of each velocity component determined using the tristatic configuration presented in this work is along the bisector defined by the Tromso beam and the remote sites, a conversion is needed in order to calculate these velocities in the local orthonormal coordinate system [4]. A local system pointing Eastward, Northward and Downward is chosen. Table 1 summarizes the results. The transformation from this coordinate system to a heliocentric coordinate system is necessary in order to calculate the orbits of the particles at the time they intercept the earth. This is performed by applying standard calculations treated in many celestial mechanics text books [9,10,11]. The resulting orbital elements for the events presented in Table 1 are shown in Table 2.

Table 1. Measured meteor altitudes and velocities for the tristatic detections

Year	UTC	Height (km)	$D_{ownward}$ (km/sec)	$E_{astward}$ (km/sec)	$V_{Northward}$ (km/sec)	V_{Total} (km/sec)
1997	06:02:04	103.5	45.5±0.2	34.7 ±0.1	24.6 ±0.1	62.3±0.5
1997	07:47:34	99.1	33.0 ±1.5	51.5± 0.1	1.2±0.1	61.2±0.9
1997	08:42:36	102.9	3.9 ±0.7	71.1 ±0.3	14.7 ±0.3	72.7 ±0.8
1997	08:48:08	101.3	20.8 ±0.9	79.3 ±0.1	24.9 ±0.1	85.7±0.7
1997	09:18:22	99.7	26.6 ±0.2	62.3 ±0.1	8.0 ±0.1	68.2 ±0.4
1997	15:47:58	102.2	9.6 ±0.7	17.6 ±0.1	-63.1±0.1	66.2±0.4
1997	18:33:20	98.4	9.4 ±0.7	-37.5 ±0.1	-1.2 ±0.1	38.7 ±0.5
1998	12:52:50	102.8	22.3 ±0.7	9.5± 0.2	-65.7 ±0.1	70.0±0.7
1998	13:15:28	98.4	39.8±1.8	-2.3±0.1	-40.0 ±0.1	56.5 ±2.7
1998	16:04:14	103.0	14.6 ±1.2	25.1 ±0.2	-58.9 ±0.2	65.7 ±1.0

For 6 events, out of the 10 presented in Table 2, a heliocentric velocity in excess of 42 km/s, the parabolic velocity, is obtained after subtracting the earth velocity from the above atmosphere velocity. For these events the velocity, latitude (□) and longitude (□) of the local standard of rest (LSR) are also presented. In principle, such objects are termed hyperbolic meteors. In the past years several authors have reported hyperbolic meteors [3,12,13,14]. A detailed analysis of orbital evolution that includes orbital perturbative effects on small hyperbolic particle due to solar radiation pressure, solar magnetic field deflections and gravitational influence of mainly the outer planets Jupiter, Saturn, Uranus and Neptune was presented in [14]. In that work it was concluded that for particles larger than about 100 □m the effects are mainly due to gravitational perturbations alone. Hence having hyperbolic orbits is not sufficient evidence to consider objects as arriving from outside the solar system [14]. Since the sizes of the meteors in the EISCAT sample cannot be determined at this time for lack of observed decelerations, claims of the origin of the present sample cannot be made, although previous efforts involving the radar scattering cross section suggest that the EISCAT meteor size range is 100-1000 □m [15]. Preliminary orbital and radiant results indicate a generic connection of the EISCAT particles with the large radius Arecibo extrasolar particles seen on the same days at 430 MHz [14] . A more detailed orbital analysis of this sample compared with other hyperbolic orbits will appear in a subsequent paper.

CONCLUSIONS

In this paper, we report the first orbital analysis of radar meteors derived from tristatic measurements using the UHF (930 MHz) tristatic EISCAT system. The observations were performed in November 1997/1998 when 7/3 successful tristatic observations were obtained during 19/24 hr observing periods out of a total of 84/132 events detected only by the Tromso receiver. For the tristatic detections the true geocentric velocity as well as very precise radiant information were obtained (Table 2). Preliminary analysis of the calculated orbits show no association with the Leonids meteor stream, although the observations were performed during the shower time, which indicates that most of the meteors that are detected by EISCAT are sporadic in nature. This result agrees with previous EISCAT meteor work. In addition, 6 out of the 10-tristatic events have heliocentric velocities in excess of the hyperbolic limit. A more detailed comparison of these orbits with additional sets obtained using other HPLA facilities is under preparation.

Table 2. Orbital elements for the tristatic measurements

UTC	i (deg)	a (AU)	□ (deg)	q (AU)	e	□	$□_{LSR}$ (deg)	$□_{LSR}$ (deg)	V_{LSR} (km/sec)
06:02:04	150.3	2.33	234.9	0.453	0.81	282.3			
07:47:34	157.7	2.79	235	0.282	0.9	300.7			
08:42:36	145.5	-2.72	55.04	0.886	1.32	35.3	175.2	-62.9	-17
08:48:08	166.6	-0.68	55.05	0.973	2.43	12.3	91	-73.9	-33
09:18:22	174.8	2.45	235.07	0.912	0.63	216.7			
15:47:58	34	-0.151	235.34	0.971	7.43	168.3	66.5	-28.3	-62
18:33:20	27.6	1.64	55.457	0.137	0.92	143.2			
12:52:50	56.5	-0.2	234.97	0.888	5.51	151.5	65	4.4	-48
13:15:28	58.1	-0.37	234.99	0.989	3.7	180.8	243.5	-12.9	-68
16:04:14	37.7	-0.16	235.11	0.964	6.96	166.4	67.4	-23.9	-59

ACKNOWLEDGMENTS

We gratefully acknowledge assistance of the EISCAT staff during the meteor experiment. The EISCAT Scientific Association is supported by the *Centre National de la Recherche Scientifique* of France, the *Max-Planck-Gesellschaft* of Germany, *The Particle Physics and Astronomy Research Council* of the United Kingdom, *Norges Almenvitenskapelige Forskningsåd* of Norway, *Naturvetenskapliga Forskningsrådet* of Sweden, *Suomen Akatemia* of Finland, and the *National Institute of Polar Research* of Japan. A. P.-W. is supported by the European Office of Aerospace Research and Development, Air Force Office of Scientific Research, Air Force Research Laboratory, under Contract No. F61775-01-WE084. This work is also part of the NSF/CEDAR Postdoctoral Fellowship (ATM-0004284) awarded to DJ.

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