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The forthcoming EISCAT_3D as an extra-terrestrial matter monitor

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ABSTRACT

It is important to monitor the extra-terrestrial dust flux in the Earth's environment and into the atmosphere. Meteoroids threaten the infrastructure in space as hypervelocity hits by micron-sized granules continuously degrade the solar panels and other satellite surfaces. Through their orbital elements meteoroids can be associated to the interplanetary dust cloud, comets, asteroids or the interstellar space. The ablation products of meteoroids participate in many physical and chemical processes at different layers in the atmosphere, many of them occurring in the polar regions.

High-power large-aperture (HPLA) radars, such as the tristatic EISCAT UHF together with the EISCAT VHF, have been versatile instruments for studying many properties of the meteoroid population, even though they were not initially designed for this purpose. The future EISCAT_3D will comprise a phased-array transmitter and several phased-array receivers distributed in northern Scandinavia. These will work at 233 MHz centre frequency with power up to 10 MW and run advanced signal processing systems. The facility will in many aspects be superior to its predecessors as the first radar to combine volumetric-, aperture synthesis- and multistatic imaging as well as adaptive experiments. The technical design goals of the radar respond to the scientific requests from the user community. The VHF frequency and the volumetric imaging capacity will increase the collecting volume compared to the earlier UHF, the high transmitter power will increase the sensitivity of the radar, and the interferometry will improve the spatial resolution of the orbit estimates. The facility will be able to observe and define orbits to about 10% of the meteors from the established mass flux distribution that are large or fast enough to produce an ionization mantle around the impacting meteoroid within the collecting volume. The estimated annual mean of about 190 000 orbits per day with EISCAT_3D gives many orders of magnitude higher detected orbit rates than the earlier tristatic UHF radar.

1. Introduction

In this paper we investigate the advantages of the planned EISCAT_3D as an extra-terrestrial matter monitor. Radar observations give access to a part of the mass distribution of meteoroids entering the Earth's atmosphere, which is difficult to quantify using other methods. Larger visual meteors range down to about 10 μg in mass while space-borne impact detectors observe dust particles smaller than 1.0×10^{-3} μg. There has always been a dip in the observed rate vs. size distribution in this size range (Hughes, 1978; Mann et al., 2011). Thus good observations within the radar range covering 1.0×10^{-3} μg to 10 mg masses are essential for an improved understanding of the data gap and for comparison with optical methods. Radar head echo observations have already improved the sensitivity within this range (Mathews et al., 2001), but care must be taken to reduce the significant uncertainties which exist in the calculation of both photometric and ionization masses of meteoroids (Campbell-Brown et al., 2012). This shows a need for systematic simultaneous optical and radar observations. Also, there is still two orders of magnitude uncertainty of 2–300 tons per day between estimates of the cosmic matter influx from observations in space and the extra-terrestrial matter collected from the polar ice cores (Gabrielli et al., 2004; Plane, 2012). It should be noted that the space impact detector carried on the Long Duration Exposure Facility (LDEF) providing the space-based benchmark had a total of only 761 craters after 5.77 years in Earth orbit, and that crater diameter was the measured parameter while the encounter velocity and flight angle distribution had to be assumed (Love and Brownlee, 1993). Detailed knowledge of the statistical properties of the latter parameters derived from new radar observations, as attempted

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previously (Mathews et al., 2001), may allow the space-based mass accretion rate estimation to be improved in the future.

The meteoroid mass-flux maximizes at about 1 μg corresponding to 50 μm-diameter particles located between the space-borne and visual observation regimes (Flynn, 2002). As pointed out above, radars are the best instruments to investigate this size range, which also is called the “threat regime”, since these meteoroids are still quite numerous and have high kinetic energy, corresponding to the momentum of a bullet fired from a small handgun. They can thus harm satellites in orbit and are important to keep track of as a population. Radar observations also cover the size range of objects whose material to a large extent remains in the atmosphere (Mann et al., 2011; Plane, 2012). The remnants of the cosmic dust contribute to the formation of small dust (meteoric smoke or mesospheric smoke), which are an important agent for atmospheric processes at altitudes between roughly 70 and 130 km (Hunten et al., 1980; Megner et al., 2008).

Orbital information is also an important parameter for identifying a potentially interstellar dust component in the meteoroid flux. An analysis of radar observations suggests approximately 0.0008% of observed radar echoes are possible of interstellar origin (Weryk and Brown, 2004), though a reported search in optical observations was inconclusive (Hajduková, 2008). An improved estimate of the interstellar dust in this large size end of its size distribution would provide important information for understanding dust processes in the interstellar medium (Mann, 2010).

The first meteor head echoes at EISCAT were observed in 1990 (Pellinen-Wannberg and Wannberg, 1994). Since the process causing meteor echoes is not incoherent scatter, a new denomination was introduced to distinguish incoherent scatter and other large radars which are able to observe meteor head echoes. The two properties common for these instruments are the high transmitted power and the large antenna apertures. They are thus called high-power, large-aperture (HPLA) radars (Pellinen-Wannberg, 2001). The co-located EISCAT UHF and VHF radars offer a possibility to monitor the same meteors at two different frequencies, 930 MHz and 224 MHz (Wannberg et al., 1996), and get a better understanding of the plasma behaviour in the scattering processes (Pellinen-Wannberg, 2005). The tristatic EISCAT UHF radar also offered a chance to determine the orbits of the meteoroids (Szasz et al., 2008a) and observe fragmentation (Kero et al., 2008b) and polarization features of the meteoroid targets (Wannberg et al., 2011). Finally a connection between enhanced ionospheric charging and a meteor storm has been confirmed (Pellinen-Wannberg et al., 2014). Nowadays the incoherent scatter radars also offer a possibility to monitor the background ionospheric variations while simultaneously observing the meteor head echoes, even though results from such experiments have not yet been reported.

There are about 15 HPLA radars in the world, but none are identical. A summary of the characteristics of the radar facilities used or intended for meteor studies is given in Table 1. They vary in operating frequency, transmitted power and aperture in mirror form or as phased arrays. They are located at quite diverse sites around the globe and give complementary information about the extra-terrestrial fluxes and the atmospheric conditions, which vary with latitude and in time. Due to better understanding of the meteor head echoes and improved algorithms, the rate of meteor orbits per day that a radar can observe on average during a year has increased. This number will be an essential benchmark for improving the total meteoroid mass influx estimates.

In Section 2 we will describe the new EISCAT_3D facility, in Section 3 we will estimate how many meteoroid orbits in average the planned EISCAT_3D can observe per day, and in Section 4 we will discuss all the advantages the EISCAT_3D facility would give as an extraterrestrial matter monitor.

2. The EISCAT_3D facility

The EISCAT radars in northern Scandinavia started operations in the early 1980s with the purpose of studying the solar-terrestrial interaction by monitoring the high latitude auroral electrodynamics. The target for the applied incoherent scatter method is the radar beam filling plasma. Its properties, such as the electron density, electron and ion temperatures as well as an ion

Table 1
Characteristics of HPLA radars essential for meteor observations.

Radar	Geographical location	Frequency (MHz)	Antenna and aperture (m^2)	Peak power (MW)
ALTAIR	Kwajalein Atoll Marshall Islands	160 422	Parabolic dish: 1660	6
AMISR	Alaska, USA Resolute Bay, Canada	440	Phased-array: 715	2
Arecibo	Puerto Rico	430	Spherical dish: 73 000	2
EISCAT UHF	Northern Scandinavia	930	Parabolic dish: 800	2
EISCAT VHF	Northern Scandinavia	224	Parabolic cylinder dish: 4800	1.6
EISCAT Svalbard Radar: ESR	Spitsbergen	500	Parabolic dishes: 800, 1400	1
EISCAT_3D	Northern Scandinavia	233	3–5 phased-arrays: 3–5 × 3850	10
Jicamarca	Peru	49.9	Phased-array: 85 000	1.5
MAARSY	Norway	53.5	Phased-array: 6300	0.8
Millstone Hill	Massachusetts USA	440	Parabolic dishes: 1660, 3525	2.5
MU	Shikaragi Japan	46.5	Phased-array: 8300	1
PANSY	Showa Station Antarctica	47	Phased-array: 18 000	0.5
Sondrestrøm	Greenland	1290	Parabolic dish: 800	3