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A meteoroid stream survey using meteor head echo observations from the Middle Atmosphere ALOMAR Radar System (MAARSY)

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ABSTRACT

Results from a meteor head echo shower survey using the quasi continuous meteor observations of the high power large aperture radar MAARSY, located in northern Norway (69.30°*N*, 16.04°*E*) are presented. The data set comprises 760 000 head echoes detected during two and half years sensitive to an effective limiting masses below 10^{-8} kg. Using a wavelet shower search algorithm, we identified 33 meteor showers in the data set all of which are found in the IAU meteor shower catalog. We find $\sim$1% of all measured head echoes at these masses are associated with meteor showers. Comparison of shower radiants from this survey with the observation of the Canadian Meteor Orbit radar (CMOR) transverse scattering radar system shows generally good agreement, although there are large differences in the measured durations of some meteor showers. Differential mass indices (s) of $\sim$1.5–1.6 are measured for the Perseids (PER), Geminids (GEM) and Quadrantids (QUA) showers. The Orionids (ORI) show a much steeper mass index of 2.0, in agreement with other observations at small particle sizes, suggesting the Halleyid showers, in particular, are rich in very small meteoroids.

1. Introduction

Meteor showers, in contrast to sporadic meteors, are released from a common parent body, either a comet or asteroid. Study of meteor showers is particularly valuable as the meteoroids released from a single parent body provide direct samples of those particular parents. More generally, understanding how meteoroid streams form and subsequently evolve provide insight into the timing and mode of decay processes of small solar system bodies (Williams and Ryabova, 2011).

Historically, most meteor shower surveys were conducted using optical instruments (Hemenway et al., 1973) or transverse scattering meteor radar systems (e.g. Sekanina, 1970; Brown et al., 2008; Younger et al., 2009; Janches et al., 2013). More recently, shower surveys have been undertaken with dedicated networks such as the Cameras for Allsky Meteor Surveillance project (CAMS) (Jenniskens et al., 2016) and the Southern Argentina Agile MEteor Radar (SAAMER) (Pokorný et al., 2017). Brown et al. (2008) provides an overview of the past shower surveys and the history of meteoroid orbit surveys in general while Jenniskens (2017) provides a contemporary review of the subject. Surveys to date have resulted in a total of 112 meteor showers being designated as established by the International Astronomical Union (IAU)[1]. An additional 589 working showers are also listed by the IAU.

Meteor showers are generally richer in larger meteoroids compared to the sporadic background. The fraction of all meteoroids which belong to showers is estimated to rise to a maximum exceeding 50% at cm-sizes and falls to less than 10% at sub-mm sizes (Jenniskens, 2006).

However, the small-size end of the meteoroid stream spectrum is of interest for several reasons. The very smallest meteoroids in a stream are removed due to the effects of radiation pressure (Burns et al., 1979; Dohnanyi, 1970). This is potentially a very sensitive statistical probe for meteoroid properties (such as bulk density), particularly for highly eccentric orbits. Additionally, streams which are rich in small meteoroids must either be young or have some production source for very small meteoroids (e.g. fragmentation/thermal sintering) as small particles evolve out of a stream most quickly. Streams rich in small particles may also have

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[1] https://www.ta3.sk/IAUC22DB/MDC2007/.

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dynamical effects which preferentially deliver only small meteoroids to Earth intersection (eg. the 2012 Draconids (Ye et al., 2013)). To date no dedicated survey has explored which streams remain detectable at the very smallest meteoroid masses ($\leq 10^{-10}$ kg), though some recent measurements demonstrate that at least some showers contain meteoroids in the order of these masses or smaller.

The meteor shower survey described by Galligan (2000) remains to date the only survey to very faint magnitudes ($M \approx +13$) performed on a nearly complete 'virtual' year comprised of half a million orbits detected with the multi-station transverse scattering Advanced Meteor Orbit Radar (AMOR). This survey, to a limiting mass of order 10^{-10} kg, found only half a dozen streams with significant . They estimate that less than 1% of all meteoroids in their survey could be linked to a definite shower (Galligan, 2000).

Observation of meteor head echoes using high power large aperture (HPLA) radars is a unique method to measure accurate atmospheric trajectories for large numbers of very small meteoroids. Yet, this technique has not been systematically used to survey which streams are present at very small masses. However, using meteor head echoes to obtain information about meteor showers is not a new idea. Hey et al. (1947) were the first to use meteor head echoes to estimate the velocity of the Draconid meteor shower.

More recently, HPLA head echo observations of some showers include: the Perseid and Leonid meteoroids with the ALTAIR system (Close et al., 2000; 2002), the detection of the Eta Aquariids and Perseids with the Jicamarca VHF radar (Chau and Galindo, 2008) and the Orionids and Geminids which have been detected with the MU radar system (Kero et al., 2011, 2013). The Middle Atmosphere ALOMAR Radar System (MAARSY) detected the Geminid meteor stream during a sounding rocket campaign in 2010 (Stober et al., 2013; Schult et al., 2013). These studies collectively demonstrate that very small meteoroids are present in several of the major streams, but the extent and strength of streams at head echo masses is unclear.

To date, all meteor head echo shower campaigns were initiated for specific known showers and were operational on time scales of hours or days, not covering the entire shower period. A complete meteor head echo shower survey has not been done, in part because of a lack of daily observations of head echoes from HPLA radar systems for a period of a year or more.

In November 2013, we started a quasi continuous monitoring experiment with MAARSY on the Northern Norwegian island Andøya (69.30°N, 16.04° E). This experiment configuration is still running and a first analysis on the overall count rate, detection heights, velocities and the dynamical masses of the sporadic meteor background and a comparison with a meteor input function has been presented by Schult et al. (2017).

In this complementary work we identify meteor showers detectable among these 0.7 million orbits using a wavelet approach to identify meteor showers in the same data. This survey comprises the first equivalent full-year shower survey based on meteor head echo observations.

2. MAARSY: meteor head echo observation methodology and analysis

Table 1 summarizes the radar parameters used for the experimental setup in this study. The procedure followed in the raw data analysis shown as a step-by-step process as applied to an example head echo using the same experimental mode as used in this study is detailed in Schult et al. (2017). Here we only briefly summarize the basic interferometric analysis of particular importance in determining radiant accuracy and refer the reader to Schult et al. (2017) for more details.

Table 1
Experiment parameters for the meteor head echo observations used in this study. The experimental setup is also used in the study from Schult et al. (2017). Note that during the first months of the collection period in No. 2013 the experiment was separated into a zenith beam and a 12.4° off-zenith beam (25. November 2013 to 22. March 2014). Here PRF refers to the Pulse Repetition Frequency and IPP the Inter-Pulse Period (IPP).

PRF	1000 Hz
Code	16-bit Complementary Code
Pulse length	16×300 m
IPP	1 ms
Duty cycle	3.2 %
Sampling start range	49.8 km
Sampling end range	134.7 km
Sampling resolution	300 m
Range gates	283
Beam direction	0° zenith

MAARSY is an HPLA consisting of 433 single Yagi antennas with a peak power of about 800 kW and an antenna gain of 33.5 dBi. On reception 16 different channels, representing 16 different antenna subarrays (each of at least seven Yagi antennas) for interferometric calculations are available. The smaller baselines between the subarrays are used to get a first coarse estimate of the individual head echo direction on a pulse to pulse basis, while the longer baselines are later included to provide higher directional precision.

Using the smallest interferometric baselines, the angular ambiguity starts 15.6° from the pointing direction, which includes the main beam and the first three side lobes of the full array radiation pattern (see Latteck et al. (2012); Chau et al. (2014) for details of the beam pattern and procedures used for interferometric solutions). The position of the meteor head echo within the radar beam is calculated for every pulse resulting in a time resolution of 1 ms. Depending on the entry angle, velocity and signal strength of the meteor head echo, the number of data points differ greatly and lie between 15 to 400 (median: 72) with corresponding paths extending from 0.5 to 15 km (median 3.8 km) in length.

As it moves through the radar beam, the meteor head echo passes areas with very different antenna gains. In most cases, the detection of the meteor head echo starts with low signal strength at the edge of the main beam. Approaching the center of the radar beam the SNR increases, resulting in lower uncertainty of the head echo direction. As the meteor leaves the radar beam or the ablation process ceases and the SNR typically decreases again.

Using the interferometric calculation of the meteor location on the plane of the sky together with the known range to the head echo for each pulse, a robust fit is made to the data points versus time for v_x, v_y and v_z to provide an estimate of the trajectory as described in Schult et al. (2013). This takes the form of apparent entry angle and average velocity for each head echo. Points further away from the mean straight-line trajectory get lower weight in the fitting procedure reducing the influence of outliers and the effects of scatter on the fit due to low SNR areas. Independent validation of the robustness of the resulting radiants and speeds has been presented by Brown et al. (2017). That study shows that optical trajectories (determined from triangulation of two camera stations) and MAARSY head echoes had radiants and speeds which agreed to within a degree and $\sim$0.5 km/s respectively.

Figure 1 shows the distribution of the standard errors (one sigma) of the trajectory angles and velocities in relative counts. The figure shows that the elevation angle has on average a smaller statistical error than the radiant azimuth angle. This is because the radiant azimuth is mainly determined by the interferometric analysis while the radiant elevation angle is more linked to the range rate and range resolution. Meteor head echoes with speed errors