Icarus 253 (2015) 142–148

Contents lists available at ScienceDirect

Icarus

journal homepage: www.elsevier.com/locate/icarus

Search for meter-sized bodies in meteoroid streams

Marco Micheli [a,b,c,*], David J. Tholen [b]

[a] SSA NEO Coordination Centre, European Space Agency, 00044 Frascati (RM), Italy
[b] Institute for Astronomy, University of Hawai'i, Honolulu, HI 96822, USA
[c] Istituto di Astrofisica e Planetologia Spaziali, Istituto Nazionale di Astrofisica, 00133 Roma (RM), Italy

ARTICLE INFO

Article history:
Received 13 September 2014
Revised 12 January 2015
Accepted 18 February 2015
Available online 11 March 2015

Keywords:
Meteors
Near-Earth objects
Interplanetary dust

ABSTRACT

We present the results of a ground-based observational effort to detect large meter-sized meteoroids in known meteoroid streams, while they are still moving in space a few hours to days in advance of their approach to Earth. Although no stream objects have been detected in any of the targeted streams, our observations are sufficient to place meaningful constraints to the population of objects in this poorly explored size regime. In particular, for at least two streams (Geminids and Taurids) we give evidence that the lack of objects is limited to the meter to decameter size range, while significant populations exist for both smaller and larger sizes. This information, when combined with other properties of the streams, is useful to better clarify the possible physical mechanisms that may be involved in the formation of at least some streams of possible asteroidal origin.

1. Introduction

During its orbit around the Sun the Earth crosses various trails of debris left behind by other Solar System objects. The most prominent of these debris trails, known as meteoroid streams, are responsible for the major meteor showers on Earth. The majority of them are thought to be originated by cometary objects, which easily leave small particles along their orbit as a direct consequence of their outgassing activity. There are however other streams that are coorbital with inactive asteroidal bodies, and are therefore thought to originate from them through different physical processes.

Among these likely asteroidal streams, the most impressive ones is the Geminids (GEM, IAU#4), which has been firmly linked to (3200) Phaethon, a B-type asteroidal body with very low perihelion distance. The large complex of streams known as the Taurids (TAU, #247) is also a plausible candidate for at least a partial asteroidal origin, since its only major cometary member, comet 2P/Encke, is likely not sufficient to explain the complex structure of the stream.

In this work we present the results of our attempts to optically detect large meteoroids traveling in known meteoroid streams, observing its radiant from the ground a few hours or days before the meteoroids have closest approach with the Earth.

These observations allow us to put constraints on the particle size distribution of the observed streams, especially in the intermediate size range (a few meters in diameter) that has been poorly probed before, because objects in this range are too rare to significantly contribute to the meteor population, but at the same time too small to be routinely discovered in space by asteroid surveys without a targeted observational effort.

An observational study of this kind on the Perseid (PER, IAU#7) stream has been attempted by Barabanov et al. (1996), who reported multiple positive detections of supposed stream members, thus implying an unusually high spatial density of meteoroids of the decameter scale. However, their results could not be confirmed by Beech et al. (2004) who, although working with a smaller aperture instrument, should still have detected a handful of candidates if the Barabanov et al. (1996) conditions were repeated.

A wider search by Barabanov and Smirnov (2005), using the same approach of Barabanov et al. (1996) but targeting additional showers, also resulted in detections of various large bodies, up to sizes of ~20 m. However, only one of the showers investigated by the authors was analyzed in this work, although with a much wider spatial coverage and a significantly greater depth.

Another similar work in the literature is an optical detection of the dust trail of the Leonid (LEO, IAU#13) meteoroid stream (Nakamura et al., 2000), obtained by stacking multiple wide-field images of the true radiant area (after accurately removing stars, zodiacal light and other background contributions); however, the authors only observed the diffuse glow from the light scattered on the small meteoric particles, without searching for any individual large object in the stream.

---

* Corresponding author at: SSA NEO Coordination Centre, European Space Agency, 00044 Frascati, RM, Italy.

E-mail addresses: marco.micheli@esa.int (M. Micheli), tholen@ifa.hawaii.edu (D.J. Tholen).

http://dx.doi.org/10.1016/j.icarus.2015.02.019
0019-1035/

2. Methods

To devise an observational strategy appropriate for our goals, it is necessary to understand a few key properties of meteoroid streams, especially regarding the size and spatial distribution of the particles that compose them.

The basic idea behind our observational method is that during an active meteor shower, meteoric particles of various sizes are coming toward Earth from a specific point in the sky, the shower's radiant. This fact gives us enough information to know the optimal time and sky coordinates to maximize our chances of successfully detect larger bodies in the stream.

The ideal observational time would obviously be around the peak of the shower's activity, ideally a few hours to days in advance, so that the densest region of the stream could be directly imaged by the telescope. However, for some showers it is known that most large particles tend to concentrate a bit before or after the main activity of smaller meteors[1]; in such cases, because our goal is to detect larger bodies in the stream, our strategy would be optimized to target the time of approach of these likely larger bodies.

The optimal pointing of the telescope is also easy to determine. On a first approximation, the best area to observe would be the radiant of the stream, because that is the direction from which the objects are coming. Furthermore, particles coming toward Earth from the radiant would have a lower velocity component in the tangential direction, which would result in a lower speed in the plane of the sky, making them easier to detect and minimizing trailing losses. There is however an important caveat to remember when scheduling the pointings; the true radiant of the stream, corresponding to the direction from where the meteoric particles are coming, does not exactly correspond to the observed radiant of the meteor shower, due to the vector addition of the particles velocity with the Earth's own velocity along its orbit. To make sure that our observations were pointed at the optimum spot to maximize the detection of incoming meteoroids, we designed our observational strategy by distributing meter-sized synthetic particles along the orbit of the stream, computing the ephemeris and observability properties (magnitude and speed) of each particle and targeting the region of sky where they were more easily detectable with the specifications of our instruments.

More information about the actual observational strategy will be given below, with specific reference to the instruments we used in this search.

2.1. Stream characterization

To make this analysis more quantitative, it is necessary to devise a proper mathematical description of both the streams and the measurements we want to obtain.

The first step is therefore to describe the stream of meteoric particles with an appropriate mathematical model, which takes the key aspects of the problem into consideration. The simplest description of a stream of particles, at least from the point of view of this work, is characterized by only a limited number of properties. The most important parameters are related with the particles that constitute the stream itself, their sizes and their numbers. This information is usually modeled in terms of a simple power law distribution, with an exponent index and a normalization factor. For the purpose of this work, we can model the number density of particles of a given diameter with an expression of the form:

$$f(D) = \frac{dn(D)}{dD} = f_0 \left(\frac{D}{D_0}\right)^{-\alpha} \tag{1}$$

where n is a numerical particle density, in m^{-3}, D is the particle diameter (normalized to $D_0 = 1$ m), and f_0 is a normalization constant that parameterizes the information on how rich in particles a stream is. In this formalism, if we need to know how many particles of a certain size range are present in a given volume, it is sufficient to integrate the above Eq. (1) in both particle diameter and volume:

$$N = \int n(D)dV = \int \left(\int_{D_{min}}^{D_{max}} f_0 \left(\frac{D}{D_0}\right)^{-\alpha} dD \right) dV \tag{2}$$

In the case of an actual stream, the integration limits in both integrals are determined by the observational strategy, the sky conditions, and the 3-dimensional properties of the stream.

The easiest integration limits to parameterize are those in physical volume. Each observational field pointed to the radiant area will actually correspond to a cone in tridimensional space, with its tip centered at the observer's location, and aperture corresponding to the angular sky coverage of our observational pattern (Ω). The radial extension of the cone is theoretically infinite; however, we must remember that the streams we are modeling are localized in a specific "toroidal-like" region of space, and do not extend uniformly to the whole Solar System. For this reason, we need to constrain the integration cone using the actual width of the stream as our integration limit. To first order, we can estimate the size scale of a given stream from the width of its activity profile in solar longitude space (w), as observed during the associated meteor shower; this size can be converted into a linear dimensional scale given the known speed of the Earth crossing it, and can furnish us with an approximate upper limit for our volume integral.

The integral in particle diameter space is a bit less straightforward, because of the different limiting factors that come into play during an observation. It is easy to understand that the upper limit in size that can be observed with our method is theoretically infinite, because larger particles are obviously easier to observe. On the other hand, the lower size limit is determined by two main factors. The first and most direct one is the limiting magnitude of the images obtained by the telescope, which can easily be quantified for each night and instrument combination. For each radial distance Δ, the limiting magnitude can be converted into a corresponding absolute magnitude[2] by

$$H_{lim} = V_{lim} - 5\log_{10}\Delta \tag{3}$$

and given an estimate of the particle's albedo (we assume $p_V = 0.12$ for this purpose[3]) this absolute magnitude can in turn be converted into a limiting diameter that can be used in the integration.[4]

---

[1] This behavior is due to the fact that radiation pressure and other non-gravitational effects are mass-dependent, and act differently on meteoroids of different sizes. As a result, heavier particles (like the ones we target in this search) stay closer to their purely gravitational trajectories, while smaller meteoroids tend to drift away and separate from them. Depending on the geometry of the encounter between the Earth and the stream, larger particles can therefore cross the Earth's path earlier or later. The effect is only evident in a few streams, with the Geminids (GEM, IAU#4) being the most obvious case, possibly because of their peculiar low-perihelion orbit.

[2] This equation is valid under the assumption that both phase effects and heliocentric distance dependence are negligible, because the radiants we target are usually close to opposition, and the particles we are observing are all in the immediate vicinity of the Earth ($r \sim 1$ au). These assumptions (and others in the following) are justified because the goal of these computations is to estimate the order of magnitude of the expected detections, and not the exact number.

[3] Our choice of using $p_V = 0.12$, instead of a value around $p_V = 0.04$ commonly used for cometary objects, is justified by the assumption that we do not want to bias our search by assuming that the particles are cometary in nature. Furthermore, most of the streams we will target are likely made of particles that are not typically dark, because they are known to be originated by moderate or high albedo progenitors, or meteorite analogs.

[4] It is important to note at this point that this integration limit will depend on the topocentric distance Δ, which is one of the variables of integration of the second volume integral. This fact needs to be taken into account when the actual integration is performed numerically.