ISBN 978-2-87355-024-4

Proceedings of the International Meteor Conference

La Palma, Canary Islands, Spain
20–23 September, 2012

Published by the International Meteor Organization 2013
Edited by Marc Gyssens and Paul Roggemans

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Editing team and Organization

Publisher: The International Meteor Organization
Editors: Marc Gyssens and Paul Roggemans
Typesetting: $\LaTeX\,2_\varepsilon$ (with styles from Imolate 2.4 by Chris Trayner)

Printed in Belgium

Legal address: International Meteor Organization, Mattheessensstraat 60, 2540 Hove, Belgium

Distribution

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Can we detect large meteoroids outside the Earth's atmosphere?

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There is increasing evidence to suggest that meteoroid streams may harbor large objects, in addition to small dust grains, if the parent comet underwent fragmentation in its past. It is difficult to obtain empirical statistics on the frequency of such large meteoroids however, because their collisions with the Earth's atmosphere would be very rare events. A method suggested to constrain their frequency is to search for them outside the Earth's atmosphere, by carrying out telescopic surveys during meteor showers. In this contribution, we explore the expected apparent brightness of such detections. In the case of the Draconid stream, we find that large meteoroids with diameters ranging between 10 cm and 100 m can be detected when the objects are within a distance of 4×10^2 km and 10^7 km, respectively.

1 Introduction

In the classical model by Whipple (1951), meteoroid streams form by the ejection of dust grains from a gradually sublimating comet nucleus. In this picture, there is an upper limit on the size of the particles that can be lifted from the comet surface by the drag of water vapor (ca. 10 cm), and hence according to this model we do not expect to find very large meteoroids[1] in streams.

Alternative models suggest that the fragmentation of comets, in addition to sublimation, contributes to the creation of meteoroid streams. These models follow on from the discovery that comets are low-density structures, often described as "loosely bound rubble piles" (Weissman, 1986; Whipple, 1989). If indeed comets are porous structures which are prone to breaking up, then the debris streams which they leave behind may well harbor objects larger than 10 cm.

In recent decades, we have seen ample evidence that comets can indeed break apart. For example, Comet 73P/Schwassmann-Wachmann was observed to split into dozens of sub-kilometer fragments in 1995 and 2001. Infrared observations revealed that the Comet produced 11 times more dust grains than usual during the 1995 event (Vaubaillon and Reach, 2010), hence a meteoroid stream of small particles was created at the same time as the family of large fragments. Moreover, multiple kilometer-sized objects have been found to be dynamically associated with the Taurid, Geminid, and Arietid streams (Jenniskens, 2008), suggesting that the parents of those streams once underwent a similar break-up.

The mechanisms thought to be responsible for comet fragmentation include thermal and tidal stresses, radiative spin-up, and collisions (e.g., Davidsson 1999). The sizes, lifetimes, and orbits of the fragments that are produced during such break-up events are not well understood. Decameter-sized subnuclei may have sublimation lifetimes lasting dozens of perihelion passages (Beech and Nikolova, 2001), but their discovery in space remains difficult even for modern asteroid surveys[2]. As a result, their frequency is essentially unknown.

The most remarkable evidence proposed to suggest that meteoroid streams do harbor large objects comes from three major "airbursts" which happened during the 20th century. First, Kresák (1978) pointed out that the timing and radiant of the Tunguska impactor (ca. 50–100 m diameter) is consistent with the object being a fragment of Comet 2P/Encke, and therefore part of the Taurid stream (though the link between Tunguska and the Taurids remains under debate, e.g., see Sekanina, 1998; Asher and Steel, 1998; Jopek et al., 2008).

In addition, Napier and Asher (2009) pointed out that two other major Tunguska-like airbursts in the previous century occured close in time to the Perseids (13 August 1930 in Brazil, see Bailey et al., 1995) and Geminids (11 December 1935 in Guyana, see Steel, 1995). We must note that we do not have a complete picture of all airburst events of the 20th century, however, and it is possible that the timing of these events near meteor showers was just a coincidence.

Nevertheless, there is a clear motivation to investigate the prevalence of large meteoroids in streams. In this contribution, we explore the possibility of observing them using ground-based telescopes. In Section 2, we explain the motivation for this effort, and in Sections 3 and 4, we explore their expected apparent magnitudes.

2 Problem

Because of the rare nature of large meteoroids entering the Earth's atmosphere, it is difficult to constrain their frequency using traditional optical observations (e.g.,

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[1] We use the term "large meteoroid" to denote the population of small solar system bodies with diameters ranging between 10 cm and 100 m. Objects larger than 1 m are commonly called asteroids, though there is no strictly defined boundary between large meteoroids and small asteroids.

[2] The current generation of NEO surveys aim to catalogue 90% of all objects down to 140 m diameter by 2020, but the majority of meter- and decameter-sized bodies will remain unknown.

all-sky cameras). For example, meteoroids with a diameter of ca. 1 m are thought to collide with the Earth only once every few months (Brown et al., 2002), and are hence unlikely to be detected by a single all-sky camera system, which sees only a small fraction of the atmosphere at any given time.

Military surveillance satellites are thought to have the capability to monitor large areas of our atmosphere for these events (Brown et al., 2002), but their data are not available to the public. Infrasonic and acoustic detectors are also well-suited to monitor the entire atmosphere, but fragile cometary fragments do not penetrate the atmosphere very deeply and are prone to be missed by such detectors (Revelle, 1997).

An alternative method suggested to constrain the frequency of large meteoroids is to search for them outside the Earth's atmosphere using telescopes. Such a search is preferably carried out during meteor showers, when these objects are more likely to be in the proximity of our planet. Moreover, this method allows a volume in space to be surveyed which is potentially much larger than the volume which is otherwise sampled by the Earth's atmosphere during a meteor shower.

Attempts have previously been made to observe large meteoroids using telescopes by Barabanov et al. (1996) and Smirnov and Barabanov (1997), who reported the detection of five objects with sizes ranging between 5 m and 50 m during the 1995 and 1996 Perseids. However, a repeat experiment by Beech et al. (2004) during the 2002 Perseids failed to detect any such objects.

In the context of the 2011 Draconid outburst, we explored the possibility to repeat these experiments. While there is no evidence to suggest that the Draconid meteoroid stream formed due to a fragmentation event, parent comet 21P/Giacobini-Zinner is known to have shown brightness fluctuations during the past century.[3] If fragmentation occurred during these active periods, then perhaps some meter-sized bodies exist along with the smaller objects which create ordinary visual meteors. Hence, we decided to use the Draconids as a test-case to understand the apparent brightness of large meteoroids outside the Earth's atmosphere.

3 Brightness of large meteoroids

The apparent magnitude m of a meteoroid before entry in the atmosphere depends on its distance R, diameter D, solar elongation θ, and albedo A, according to

$$R = (3.19 \times 10^3)\, 10^{(m-7.2)/5}\, D \,\sin\frac{\theta}{2}\, \sqrt{A}, \qquad (1)$$

with R given in kilometer and D in meter (Jackson et al., 1994; Beech et al., 2004). For the albedo we adopted $A = 0.04$, corresponding to the albedo of Halley's nucleus (Whipple, 1989). We computed the elongation of the Draconid radiant to be $\theta = 83\overset{\circ}{.}5$ on 8 October 2011.

The constants in Equation (1) were derived empirically using the Full Moon as a calibrator (see Beech et al., 2004). We estimated the uncertainty of this relationship by testing it against the known parameters for Asteroid 2008 TC_3 (Jenniskens et al., 2009), as well as the commonly used diameter-magnitude relationship for asteroids due to Fowler and Chillemi (1992). We found that Equation (1) agrees to within half a magnitude to these independent tests.

4 Results

We used Equation (1) to plot the relationship between magnitude, diameter, and distance (Figure 1).

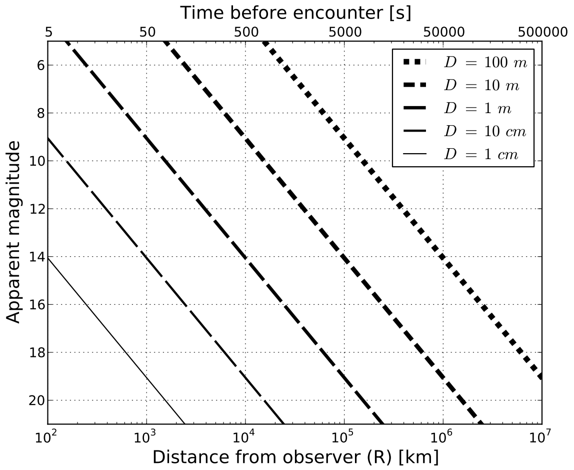

Figure 1 – Expected apparent brightness of large meteoroids in the Draconid stream, as a function of their diameter D and distance R.

We find that at a limiting detection magnitude of +12, which can be achieved using an amateur-class telescope, meteoroids in the size range between 10 cm and 100 m become detectable when they are within a distance of 4×10^2 km and 4×10^5 km, respectively. If such a meteoroid was on a collision course with the Earth, then it would be between 10 seconds and 6 hours away from impact (assuming a geocentric speed of about 20 km/s, which is typical for the Draconids). At a limiting detection magnitude of +20, which can be achieved using a professional-class telescope, objects in the same size range become detectable between 10^4 km (15 minutes) and 10^7 km (6 days) ahead of their encounter.

5 Conclusions and discussion

There is increasing evidence to suggest that meteoroid streams may harbor large objects, in addition to small dust grains, if the parent comet underwent fragmentation events during its history. It is difficult to obtain statistics on the frequency of such large meteoroids, however, because their collisions with the Earth's atmosphere would be very rare events.

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[3] Brightness fluctuations are reported by Kronk for the 1959 return on `http://cometography.com/pcomets/021p.html`, and by Kronk and Meyer (2010) for the 1972 return.

An alternative method suggested to constrain their frequency is to search for them outside Earth's atmosphere during meteor showers. In the case of the Draconids stream, we find that large meteoroids with diameters ranging between 10 cm and 100 m can be detected by ground-based telescopes when they are within a distance of 4×10^2 km and 10^7 km, respectively, from our planet.

We must note however that the ability for a telescope to detect a moving object does not only depend on the apparent brightness, but also depends on the angular speed, which is potentially very large for near-by objects. For the occasion of the 2011 Draconids, we have carried out a more comprehensive simulation of the detectability of large meteoroids, and carried out a telescopic search, the analysis of which is the subject of future work.

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