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A semi-empirical model of atmospheric fragmentation of meteoroids

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Abstract

We present a model of fragmentation of meteoroids based on observed bolide light curves and decelerations. The model reveals fragmentation points and estimates fragment masses. As an example the DN 231210 Eucla bolide is shown.

1. Introduction

The fact that almost all meteoroids encountering the Earth's atmosphere are subject to fragmentation during the atmospheric flight is well known. The classical equations of ablation, deceleration and radiation of single non-fragmenting meteoroids fail to explain the real observations of meteors. In particular the light curves differ from the ideal ones. This is true both for faint meteors and bright bolides.

There are several models of meteoroid atmospheric fragmentation in the in the literature [e.g. 4, 5, 6]. Here we present a new model, which is a combination of our previous erosion model developed for faint meteors, in particular Draconids [2] and an ad-hoc fragmentation modeling of the Jesenice bolide [9].

2. Model description

The model is designed for bright bolides with complex fragmentation histories but can be used for any meteor. The used data are the bolide dynamics, i.e. the positions along the trajectory (lengths or heights) as a function of time, and the bolide light curve, i.e. absolute magnitude as a function of time (from radiometers) or as a function of height (from photographs). The data can be supplied for the whole bolide or for individual observed fragments. The bolide trajectory is assumed to be known. In fact, the only parameter needed is trajectory slope, which relates length and height.

First, the user enters the data for the starting point, namely time, height, velocity, mass, and density of the meteoroid (ρ_m), the ablation coefficient (σ) and the ΓA value (drag coefficient × shape coefficient). Density profile of the atmosphere for the given location and date must be also supplied. Deceleration, ablation and radiation of the meteoroid and all fragments are then computed from the integral solution of the classical meteor equations [7] with fixed time step (usually 0.02 s). The coefficients ($\Gamma A, \sigma, \rho_m$) are kept constant until the next fragmentation. The luminous efficiency is the same function of velocity and mass for the whole bolide [see also 8]. We used luminous efficiency directly proportional to velocity and about two times larger for large meteoroid masses (>> 1 kg) than for small particles (<< 1 kg), namely 5.0% and 2.5%, respectively, at 15 km/s. The model does not compute rigorously the beginning of the bolide – the heating and start of ablation.

The user has to find fragmentation points on the basis of light curve shape (flares or other sudden changes), deceleration or other indications (e.g. directly seen fragments). At a fragmentation point, meteoroid is suddenly converted into one or more of the following objects: 1. Individual fragments. 2. Groups of fragments of the same mass and physical parameters. 3. Dust, i.e. large number of small particles. 4. Eroding fragment, from which the dust is released gradually. The fragment can be eroded out totally or partially. The parameters of the dust (immediately released or eroded) are the upper and lower mass limits, mass distribution index, mass sampling parameter (defining the mass bins), and the coefficients ΓA, σ, ρ_m. The parameters of the fragments are mass, the coefficients ΓA, σ, ρ_m, multiplicity (for groups of fragments), percent of eroded mass and erosion coefficient (both for eroding fragments only).

For computing the bolide light curve, contributions of all fragments and dust particles at a given time are summed together. For dynamics, the position of the leading fragment is compared with observations, unless more fragments have been observed directly.

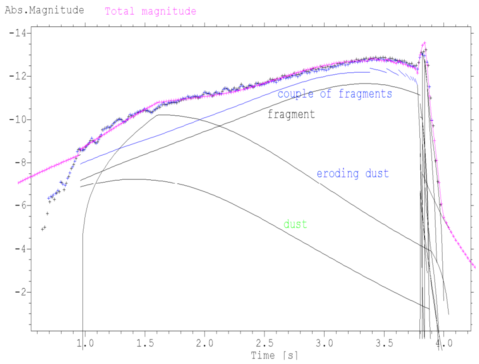

Figure 1: Light curve of Eucla bolide. Dark crosses are radiometric observations. Computed curve is in magenta. The contributions of fragments and dust are also shown.

3. Example

The model has been applied to the Košice bolide and meteorite fall [3] and to several other bolides including meteorite falls (Mason Gully, Križevci). In Fig. 1, the fit of the light curve of the DN 231210 Eucla bolide observed by the Desert Fireball Network in Australia [1] is shown. The bolide entered the atmosphere on a steep trajectory (slope 75° from horizontal) with a velocity of 17 km/s. The bolide was remarkable by the fact that it was photographed down to a quite low height of 21 km but unlike other deeply penetrating bolides, its radiation stopped very suddenly after a moderate terminal flare. We were able to explain the observations with a model in which a ~ 50 kg meteoroid fragmented first at a height of 66 km (time 1.0 s) into three pieces of similar mass of ~ 17 kg and only a small amount of dust (~0.5 kg). About 15% of the mass of two of the three fragments were eroded away during the next 0.7 s, forming a hump on the light curve. The eroded particles were of mass of the order of gram. At a height of 28 km (time 3.4 s) the two fragments started to split progressively into smaller and smaller pieces in a series of break-ups. The other fragment remained intact until the height of 23 km (3.8 s), where it disrupted catastrophically into sub-gram particles. Probably only one large piece, of about 0.2 kg, survived. This relatively complex scenario is needed to explain both light curve and deceleration. No meteorites were found.

4. Applications

The model enables us to find fragmentation points and to estimate the meteoroid masses before and after the fragmentation. The velocity, v, at the fragmentation point is also known. The dynamic pressure, acting at the meteoroid, $p = \rho v^2$ (ρ is atmospheric density), can be therefore computed. The dynamic pressure can be considered equal to the strength of the mass involved in fragmentation. The distribution of the strength in various meteoroids can be studied this way. The masses of expected meteorites can also be estimated.

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