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Passage of bolides through the atmosphere

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Abstract

Different fragmentation models are applied to a number of events, including the entry of $TC_3$2008 asteroid.

1. Introduction

Fragmentation is a very important phenomenon, which occurs during the meteoroid entry into the atmosphere and adds more drastic effects than mere deceleration and ablation. Modeling of bolides fragmentation (100 – 10^6 kg in mass) may be divided onto several approaches. Detail fitting of observational data (deceleration and/or light curves) allows to determine some meteoroid parameters (ablation and shape-density coefficients, fragmentation points, amount of mass loss) [1,2]. Observational data with high accuracy are needed for gross-fragmentation model [1], which is used for the analysis of European and Desert bolide networks data. A number of hydrodynamical models, which describe the entry of the meteoroid including evolution of its material [3, 4, 5 and others), was also applied mainly for large bodies (>10^6 kg) [4,5]. Numerous papers were devoted to application of standard equations for large meteoroids entry in attempts to reproduce dynamics and/or radiations for different bolides, to predict meteorite falls. These modeling efforts are often supplemented by different fragmentation models [6,7,8,9 and others].

The fragmentation may occur in different ways. For example, few large fragments are formed. These pieces initially interact through their shock waves and then continue their flight independently. Progressive fragmentation model suggests that meteoroids are disrupted into fragments, which continue their flight as independent bodies and may be disrupted further. Similar models were suggested in numerous papers, beginning with [10] and initial interaction of fragments started to be taken into account after the paper [11].

The second mode of fragmentation is the disruption into a cloud of small fragments and vapor, which are united by the common shock wave [4]. The formation of a fragment–vapor cloud was observed in the breakup of the meteoroid 1 February 1994 [12], at fragmentation of the Benesov bolide [7], and in other cases. Initially formed fragments penetrate together deeper into the atmosphere and the fragmentation proceeds further. If the time between fragmentations is smaller than the time for fragment separation, all the fragments move as a unit, and a swarm of fragments and vapor penetrates deeper, being deformed by the aerodynamical loading like a drop of liquid or pan-cake [13 and others].

2. The entry of $TC_3$2008

The entry of $TC_3$2008 asteroid over Sudan was observed by numerous eyewitnesses and few detecting systems, including Meteosat satellites [14], infrasonic array and US Government satellites [15]. Meteorite search allowed to find about 300 fragments of meteorite named Almahata Sitta with total mass up to 3.95 kg [15]. Light curve recorded by US DoD satellites wasn't published, but released information about the signal [15] supplemented by independent brightness estimates [14] allows to construct schematic version of possible light curve, for which the total irradiated energy corresponds to reported value of 4 10^{11} J [15]. Entry velocity is quite low V~12.4 km/s, and meteoroid mass is estimated about 50-90 t based on asteroid observation, infrasound record and irradiated light [15].

Liquid-like model allows to reproduce bolide radiation, shape of light curve is dependent on chosen model parameters. The inferred strength at breakups deviates from strength scaling law usually used in modeling [7,8,9]. But this model is not able to estimate size and numbers of formed fragments/meteorites. The possibility to describe the fate of individual fragments, to determine meteorite strewn/crater fields is the main and extremely important advantage of the progressive fragmentation type models. Application of progressive fragmentation model to the entry results in too low irradiated energy and too huge amount of fallen mass in comparison with real event. Modelling of the entry of $TC_3$2008 asteroid demonstrates that its observational data are better reproduced under assumption that large fraction of initial mass was fragmented into clouds of dust (up to 30%). Strength of different pieces of the meteoroid deviates from the strength scaling law. Amount of meteoritic material is poorly estimated, light curve may be fitted if fallen mass is smaller about 100-400 kg.

Dust clouds are often observed at breakups of meter-sized meteoroids at 30-60 km altitudes. Similar clouds were observed in the case of $TC_3$2008 entry. Its mass fraction was estimated as high as up to 13-20% [14]. Estimated mass of µm-sized dust formed after disruption of September 3 2004 bolide is comparable with initial meteoroid mass [16]. The data on particle size and on the mass fraction of parent body, which was dispersed into dust, are still scarce.

3. Comparison with other events

The fraction of initial mass recovered as meteorites is mainly about f_m~0.1-3 % for 11 meteorite falls with detail tracking data on atmospheric passage [17]. The recovered mass is smaller than estimated total fallen mass partially due to incomplete finding. The highest fractions are obtained for two smallest and slowest meteorites (~10%, Lost City and Innisfree), the smallest fractions ($<10^{-4}$) are found for Tagish Lake and Almahata Sitta meteorites, probably due to their specific structure and composition. Observational data for Tagish Lake meteoroid also are better reproduced under assumption that essential fraction of initial mass is converted into dust clouds.

If f_m is about 1-5%, probably there is no large dust deposition during the passage. Entry of these meteoroids is reasonably described in the frame of progressive fragmentation models. Comparison of model predictions with strewn fields permits to understand better details of meteoroid breakups. For example, the Mbale meteorite fragment distribution is better reproduced if a number of pieces following power law distribution are formed in every breakup.

4. Summary

Different fragmentation scenarios occur during the passage of meteoroids 100 -10^6 kg through the atmosphere. There is a number of events, which deposited essential fraction of their masses as dust in the atmosphere. Observational data are still incomplete to make definite conclusion, what fraction of incoming bodies is fragile enough to deposit this dust and how it is related with their structure/composition etc. But even bodies, which deposited much of mass as a dust/vapor, are able to produce meteorites. The total picture of fragmented-body motion is comparatively complicated. Better statistics is needed to estimate parameters of incoming cosmic material and to predict its behavior in the atmosphere. A full set of data, including detailed light curves, photographic trajectories, spectra, acoustic and seismic signals, and data on the composition of found meteorites are highly desirable.

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