EPSC Abstracts
Vol. 6, EPSC-DPS2011-1262, 2011
EPSC-DPS Joint Meeting 2011

Very low strength of interplanetary meteoroids and small asteroids

Olga Popova (1), Jiří Borovička (2), William K. Hartmann (3), Pavel Spurný (2), Edwin Gnos (4), Ivan Nemtchinov (1)*, Josep M. Trigo-Rodríguez (5)
(1) Institute for Dynamics of Geospheres, Moscow, Russia (olga_idg@rambler.ru), (2) Astronomical Institute of the Academy of Sciences, Ondrejov, Czech Republic, (3) Planetary Science Institute, Tucson, USA, (4) Muséum d'Histoire Naturelle de Genéve, Genéve, Switzerland, (5) Institute of Space Sciences, Bellaterra, Spain

Abstract

We have assembled data on thirteen cases of meteorite falls with accurate tracking data on atmospheric passage. In all cases we estimate the bulk strength of the object corresponding to its earliest observed or inferred fragmentation in the high atmosphere, and can compare these values with measured strengths of meteorites in the taxonomic class for that fall. In all thirteen cases the strength corresponding to earliest observed or inferred fragmentation is much less than the compressive or tensile strength reported for that class of stony meteorites. We find a more random relation between bulk sample strength and sample mass than is suggested by a commonly used empirical power law. We estimate bulk strengths on entry being characteristically of the order of 10^{-1} to 10^{-2} times the tensile strengths of recovered samples.

1. Introduction

Physical properties of small asteroids, e.g. their bulk density, porosity or mechanical strength, are important quantities both from purely scientific interest (to understand their formation and history) and from possible future practical reasons (mineral mining, impact risk assessment and mitigation). The mechanical strength is particularly difficult to determine form astronomical observations of asteroids. The strength of meteorites can be measured in laboratory but it may not be representative of the bulk strength of the original meteoroid before atmospheric entry and of the asteroid from which the meteoroid was derived. It has been noted in at least some fireball cases in the past that the meteoroids fragmented in the atmosphere under much lower dynamic pressures than corresponded to the mechanical strength of the recovered meteorites [1-3 and others]. In this paper, we undertake a more complete investigation of this phenomenon.

2. Meteoroid data

We collected data about 13 meteorite falls that have detailed observational data and known orbital parameters. These meteorites include 9 ordinary chondrites of different types, 3 achondrites and 1 carbonaceous chondrite. Their bulk densities are in the range 1.64-3.59 g/cm^3, and their microporosities vary from 0 to ~40%. These bodies entered the atmosphere with velocities 12.4 – 22.5 km/s, and corresponding fireballs had the brightness of about -9.3 - -22 magnitudes. The initial meteoroid masses ranged from 22 to 70,000 kg. Their orbits suggest origins in various parts of the main belt of asteroids.

In all cases where data are available, the bulk strengths upon entry of meteoroids into Earth's atmosphere are much weaker than the strengths of recovered meteorite samples. Bulk strengths of only 0.1 to ~ 1.0 MPa appear typical of the first breakup. If there is enough mass to reach dense atmospheric layers with large velocity, loading pressures of 5 – 10 MPa are typical to cause further severe breakups. ~10 MPa seems to be the upper limit of strength observed during breakup of stony meteoroid material larger than about 1 kg. To produce hundred-kilogram stony meteorites, low initial velocity and shallow trajectory are needed in order to allow enough time for deceleration. In exceptional cases, a meter-sized body may survive 20 MPa and large meteorites or even impact craters may be produced.

We included in our analysis additional observed fireballs that did not have "ground truth" samples. First, we included 13 largest fireballs observed by the European bolide Network. Second and third, to extend the mass range of our sample, we considered also the atmospheric fragmentation of smaller meteoroids studied by [4] and several large meteoroids observed on global scale by satellites [5]. From above data, we conclude that our thirteen cases of observed bolides with meteorite recovery do not represent an unusual class of bolides.

We have considered various sources of uncertainty. There are difficulties in determination of fragmentation points, uncertainties in meteoroid mass estimates. In some cases it is difficult to determine what kind of fragmentation is realized – the loss of small amount of mass under breakup (for example <1%) or total disruption into fragments less than a few percent of the initial mass. In consequence, strength estimates are crude in many cases. As for breakup behavior, there may be additional phenomena besides aerodynamical loading.

3. Summary

In summary, the strength of a meteoroid, prior to its atmospheric entry, appears to be related to its particular history on its parent body, as well as its taxonomic type. The strength as a function of mass seems to be more or less random and we are little bit disappointed that we have not found any evident dependence. We, nevertheless, believe that the apparent poor correlations is not due to bad data or models but it is a natural consequence of the individual collisional history of each individual meteoroid. Probably many meteorites originated in the outer layers of an asteroid, where they suffered impacts and radiation (i.e. gardening) during millions of years, followed by an impact with sufficient energy to eject them from their parent body. More porous objects, e.g. carbonaceous chondrites, may preserve porosity and low density either from initial accretion or associated with the initial fragmentation of the material. The interaction between fragments of disrupted meteoroid (internal friction or other effects during entry) may be the source of additional variations of apparent strength.

Some fraction of the meteoroids appear to be not so single rocks with factures, but very weak bodies with large fractions of fine material that is lost on entry. Almahata Sitta is the extreme known case, with about 90% fine dust and embedded meteoritic rocks of different meteorite classes, suggesting an origin related to regolith on parent bodies, and an appearance perhaps similar to Itokawa.

Many earth-crossing asteroids to be visited by robotic or human missions may thus consist not of single, strong, coherent rocks or metal masses, but rather may be highly fractured. They may thus consist of strong sub-units (individual meteoritic rocks) that are weakly bound together. Smaller pieces near the surface may grade into a transitional -regolith like structure of interlocking fractured pieces, as a result of the surface cratering regime, even if loose regolith has not accumulated. These bolides break up along pre-existing sub-units as they enter the atmosphere, and the resulting pieces may fragment further along pre-existing fractures.

Acknowledgements

This work is supported by the International Space Science Institute (Switzerland).

References

[1] Ceplecha, Z., Brown, P., Hawkes, R.L., Wetherill, G., Beech, M., Mossman, K. Video observations, atmospheric path, orbit and fragmentation record of the fall of the Peekskill meteorite. Earth Moon Planets 72, 395-404, 1996.

[2] Borovička, J., Popova, O.P., Nemtchinov, I.V., Spurný, P., Ceplecha, Z. Bolides produced by impacts of large meteoroids into the Earth's atmosphere: comparison of theory with observations. I. Benesov bolide dynamics and fragmentation. Astron. Astrophys. 334, 713-728, 1998.

[3] Petrovic, J.J. Mechanical properties of meteorites and their constituents. J. Material Sci. 36, 1579-1583, 2001.

[4] Ceplecha, Z., Spurný, P., Borovička, J., Keclíková, J., Atmospheric fragmentation of meteoroids. Astron. Astrophys. 279, 615-626, 1993.

[5] Popova, O., Nemchinov, I. Bolides in the Earth Atmosphere. In: Adushkin V., Nemchinov I. (Eds.). Catastrophic events caused by cosmic objects, Springer, pp.131-163, 2008.