EPSC Abstracts
Vol. 6, EPSC-DPS2011-867, 2011
EPSC-DPS Joint Meeting 2011

High mechanical strength of Geminids as a result of thermal stress

D. Čapek (1), D. Vokrouhlický (2)
(1) Astronomical Institute of Academy of Sciences, Ondřejov, Czech Republic (capek@asu.cas.cz)
(2) Institute of Astronomy, Charles University, Prague, Czech Republic (vokrouhl@cesnet.cz)

Abstract

The solar heating causes non-homogeneous temperature field and associated thermal stress inside meteoroids. In the solar vicinity, the thermal stress may override the material strength and meteoroids begin to crack. The destruction of meteoroids begins from the surface and we assume that the fractured material is removed from the surface, which leads to decrease of meteoroid size. The thermal stress is therefore able to change the initial size distribution of a meteoroid stream with sufficiently low perihelion according to material properties of the meteoroids (in particular the tensile strength). We developed a simplified model describing this phenomenon and applied it to Geminids. We found that the thermal stress is able to preferentially remove larger and weaker members of the stream. This may explain the higher mechanical strength observed during their passage through the atmosphere. Our model predicts that resulting meteoroid population should contain larger bodies with high strength and smaller bodies with wider range of mechanical strengths. As a result, we believe that the influence of the thermal stress may explain the unusual mechanical properties of Geminids.

1. Introduction

Geminid stream has perihelion distance which is one of the closest to the Sun (q = 0.14 AU) and it contains meteoroids, which are the strongest and the densest bodies among meteoroid streams. Such unusual material properties of shower meteoroids are usually explained (i) by material properties of parent body 3200 Phaethon [1], or (ii) as a result of intensive thermal processing of weaker parent meteoroids in the perihelion [2].

Here we discuss that the high strength of Geminid meteoroids may be caused by preferential destruction of weaker members by the thermal stress in the solar vicinity.

2. Thermal stress

The meteoroids in the space are subject of solar heating: sunlight heats up the sunlit hemisphere, while the opposite side is cooled down due thermal radiation from the surface. This creates a non-homogeneous temperature field inside and associated thermal stress. The expressions for thermal stress in smaller homogeneous spherical meteoroid with fixed spin axis have been recently derived in [3]. The generalized theory for a body with a particulate surface layer can be found in [4].

As the meteoroid approaches the Sun, the thermal stress grows up. Finally it may override the strength of the body. The destruction of the material starts from the surface and then spreads deeper. The range of fractured volume depends on heliocentric distance, size of the meteoroid, direction of the spin axis with respect to the Sun and the material parameters (especially the tensile strength σ_t).

The fractured volume may be removed from the surface of the meteoroid due to centrifugal forces or due to release of elastic energy during crack formation. As a result, the thermal stress causes the decrease of meteoroid diameter down to some stable value, which depends on the above mentioned parameters.

3. Selective destruction of Geminids

We assumed population of meteoroids on Geminid stream orbit with initial size range from 0.2 mm to 10 cm, uniform distribution of spin axis and material properties corresponding to ordinary (σ_t = 32 MPa) and carbonaceous chondrites (σ_t = 2 MPa). We studied the influence of the thermal stress on these bodies until we obtained a steady-state meteoroid population. We found that meteoroids with σ_t = 32 MPa remain intact, except a few bodies larger than ~7 cm. The population with σ_t = 2 MPa will be affected more profoundly (see Fig. 1). No meteoroid larger than ~6 mm survives and only 20% of bodies larger than ~2 mm are able to survive the action of thermal stress. On the other hand, diameter of meteoroids smaller than ~0.3 mm will not be reduced by destruction due to thermal stress.

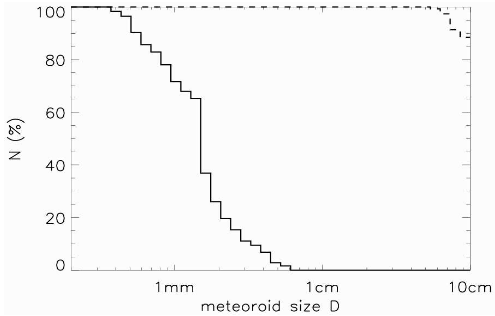

Figure 1: The ratio N of meteoroids with size equal or greater than D, which are able to survive destruction by thermal stress. We assumed orbit of Geminid stream and the tensile strength values $\sigma_t = 2$ MPa (solid line), or $\sigma_t = 32$ MPa (dashed line).

4. Results

The thermal stress is able to remove larger and weaker meteoroids from the Geminid meteoroid stream. Our model predicts the following properties of resulting population modified by thermal stress: The remaining larger bodies are those, which were able to survive the surface destruction by the thermal stress, i.e. meteoroids built from a stronger material. Smaller meteoroids experience smaller thermal stress and thus even weaker members are able to survive. The distribution of strengths of smaller meteoroids will be closer to the primordial one. In our case (limited to two values of σ_t), the threshold between “larger” and “smaller” meteoroids is ~1-2 mm. However, the actual value of this transition size and a distribution of strengths among various sizes depends on (unknown) initial distribution of material properties.

Our model also indicates that explanation of the strong nature of the Geminid material by thermal processing of weaker meteoroids may not be correct. The metamorphosis of the parent material would have to occur very quickly, before thermal stress overcomes the material strength, which is unlikely. This argument, however, is not related to the thermal processing of the material on the parent body.

Acknowledgements

The work of D. Čapek was supported by the Grant Agency of the Czech republic under a contract 205/09/P455. The work of D. Vokrouhlický was supported by the Research Program MSM0021620860 of the Czech Ministry of Education.

References

[1] Licandro, J., Campins, H., Mothé-Diniz, T., Pinilla-Alonso, N., de León, J.: The nature of comet-asteroid transition object (3200) Phaethon, Astronomy and Astrophysics, Vol. 461, pp. 751-757, 2007.

[2] Borovička, J., Koten, P., Spurný, P., Boček, J., Štork, R.: A survey of meteor spectra and orbits: evidence for three populations of Na-free meteoroids, Icarus, Vol. 174, pp. 15-30, 2005.

[3] Čapek, D., Vokrouhlický, D.: Thermal stresses in small meteoroids, Astronomy and Astrophysics, Vol. 519, A75, 2010.

[4] Čapek, D., Vokrouhlický, D.: Thermal stresses in small meteoroids: Effects of an insulating surface layer, in preparation.