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Thermal Cracking of the asteroid (3200) Phaethon and the Origin of the Geminid Meteors

M. Delbo (1), J. Wilkerson (2) G. Libourel (1) V. Ali-Lagoa (1) , J. Hanus (1), and P. Michel (1)
(1) Observatoire de la Cote d'Azur - Boulevard de l'Observatoire - CS 34229 - F 06304 NICE Cedex 4 (marcodelbo@gmail.com).
(2) Department of Mechanical Engineering The University of Texas at San Antonio One UTSA Circle San Antonio, TX 78249

Abstract

We investigate the importance of thermal cracking of the near-Earth asteroid (3200) Phaethon for the origin of the Geminid meteors. This is the densest annual meteoroid stream and potential meteorite dropper. Geminds are associated with Phaethon. The latter is likely a chip of the large main-belt asteroid (2) Pallas. Different models have been investigated for the origin of the Geminids, but none of these resulted completely satisfactory to explain the formation of this massive meteor stream.

1. Introduction

While meteor streams are in general associated with comets, the Geminids, which have their yearly peak activity near December 13, are parented by the unusual near-Earth asteroid (NEA) 3200 Phaethon [1].

Phaethon's nature has always been mysterious: while comet nuclei release material due to the sublimation of volatile species, leaving behind dust particles that become meteors when they encounter Earth's atmosphere, most of NEAs do not have activity [2]. Because Phaeton did show activity, it was initially thought to be dormant comet. However, spectroscopic observations showed that Phaethon has an extremely blue reflectance spectrum [3], whereas comet nuclei are usually very red [4]. This observation argued against a cometary nature of Phaethon. Further spectroscopic and dynamical investigation suggested a link with the asteroid (2) Pallas and its collisional family [5]. Moreover, the Geminids have composition and densities consistent with some carbonaceous chondrites that are believed to be of asteroidal origin [6]. From bolide observations, the same authors also pointed out that the Geminids may drop meteorites [6], leading to the tantalising idea that we can receive pieces of Pallas on Earth.

After several attempts, recent observations confirmed the activity of Phaethon near perihelion [7]. The activity was only 10^{-4} of the Geminid stream mass, but, quoting [8], "this raises the possibility that the decay of Phaethon is a continuing process" .This is the position along its orbit where dynamical calculations have shown that the Geminids had to be released [9]. However, the mechanisms responsible for the productions and release of dust from Phaethon remain unknown, albeit several hypothesis have been put forward [8].

1.1. Phaethon's orbit and temperatures

Phaethon has an extremely eccentric orbit, that brings the body at 0.14 au at perihelion, where its surface temperature can reach more than 1000 K (see Fig. 1).

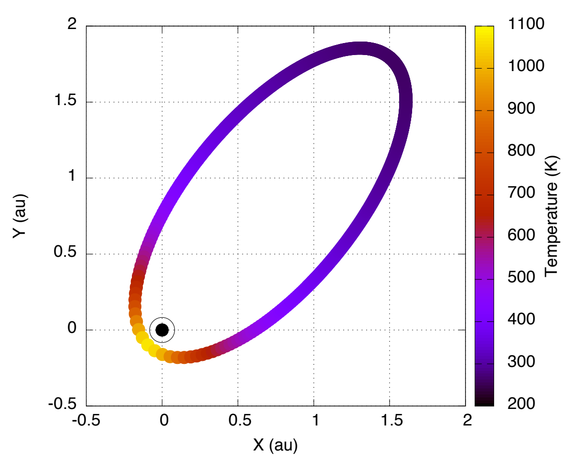

Figure 1: The orbit of Phaethon projected on the plane of the ecliptic. A circle is drawn every day. The colour of the circle gives the asteroid surface temperature at the sub-solar point.

2. Thermal Cracking

It has been recently shown that the variation of the temperatures due to diurnal illumination cycle on asteroids induce thermal fatigue of the surface material [10]. Thermal fatigue is the progressive growth of cracks caused by temperature gradients and differential temperature expansions in inhomogeneous materials, both resulting in mechanical stresses. Eventually cracks reaches a critical size and the material fragment. This is a very effective regolith production mechanisms. It was estimated that for NEAs, mars-crosser and for the inner Main Belt asteroids, thermal cracking produces regolith faster than micrometeorite bombardment, the classical process invoked for regolith formation and development on asteroids [11].

The velocity of crack propagation and thus the time needed for a crack to grow from the surface through the entire rock so that it becomes fragmented, is a strong function of the distance of the asteroid from the sun [10].

2.1. Thermal Cracking at Phaethon's perihelion

We will show here that the rock survival time, or the time it takes a crack to grow through the rock is proportional to $(\Delta T)^{-n}$ where ΔT is the day-to-night excursion temperature on the asteroid and n is the exponent of the Paris law that governs the crack growth rate. In particular, since the rock survival time at 1 au is of the order of 10^4 year for carbonaceous mineralogies and the exponent $n \sim 4$ [10], the rock survival time on Phaethon is of the order of few years at the perihelion temperatures.

Moreover, regolith production by thermal cracking is a continuos process, whose rate strongly increases near each perihelion passage.

We will investigate if and how rock break up at each perihelion passage can produce fresh regolith, a potential source of material to explain the Geminids.

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