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Vesta, Ceres and the Jovian Early Bombardment

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Abstract

Vesta and Ceres are among the oldest objects that formed in the Solar System, likely predating the formation of the giant planets. Through their histories, the surfaces of the two targets of the Dawn mission would have suffered several periods of intense bombardment which shaped their present morphologies. Here we report the results of our investigation of the collisional histories of Vesta and Ceres at the time of the formation of Jupiter. The formation of the giant planet caused in fact an intense early bombardment in the asteroid belt. In those scenarios where they survived, both asteroids had their surfaces saturated by craters as big as 150 km and a few as big as 200 - 300 km. In the case of Vesta, such Jovian early bombardment would have significantly eroded the crust, likely exposing the upper mantle or causing effusive phenomena similar to lunar maria.

1. Introduction

Vesta and Ceres are among the oldest bodies in the Solar System and likely formed when the Solar Nebula was still present and the giant planets were accreting their planetary cores. Through the radiometric ages of HED meteorites, we know that Vesta was possibly one of the first bodies to form and differentiate in the Solar Nebula, predating the formation of Jupiter and surviving the violent evolution of the early Solar System. The formation time of Ceres instead is unknown, but it should not postdate that of Jupiter by far, since the perturbations of the giant planet rapidly stopped planetary accretion in the Main Asteroid Belt.
Through their histories, the two targets of the Dawn mission would have suffered several periods of intense bombardment (see [2] and [5] for an in-depth discussion). The data we presently possess on Ceres hint that the volatile-rich surface of the dwarf planet likely did not retain marks of the most ancient impacts (see [4] and references therein). The case of Vesta is different and Vesta has the potential to unveil the evolution of the early Solar System at the time the Solar Nebula was still present (see e.g. [2] and references therein). Here we discuss the results of our investigation of the collisional evolution of Vesta and Ceres at the time of the formation of Jupiter, assumed to be the first giant planet to form in the Solar System.

2. The Model

We simulated the dynamical evolution of a template of the forming Solar System at the time of the formation of Jupiter's core and the subsequent accretion of its gaseous envelope. Our template of the forming Solar System was composed of the Sun, the accreting Jupiter, Vesta, Ceres and a swarm of 8×10^4 massless particles representing the disk of planetesimals and spanning between $2 - 10$ AU from the Sun. We followed the evolution of our template of the Solar System for a temporal interval equal to 2×10^6 years. We modeled the formation process of the giant planet through a semi-empirical approach: the timescales and the other parameters were derived from [1] and [3]. In our semi-empirical model we considered also the effects of planetary migration due to the disk-planet interactions during the formation of Jupiter (see e.g. [6] and references therein). During the dynamical evolution of our template of the Solar System we evaluated the probabilities of planetesimals impacting Vesta and Ceres through a statistical approach. We refer the interested readers to [7] for details on the numerical and physical model.

3. The Results

The rapid formation of Jupiter changed the dynamical equilibrium in the Solar Nebula, destabiling part of the planetesimals of the protoplanetary disks and triggering an intense bombarmdent in the orbital region of the asteroid belt (Jovian Early Bombardment, JEB in the following). The JEB is mainly due to two populations of planetesimals [7]: planetesimals ejected by the resonances with Jupiter (the $3:1$ and the $2:1$

resonances in the inner Solar System and the $3:2$ and $7:6$ resonances in the outer Solar System) and planetesimals formed beyond the Snow Line and scattered into the inner Solar System by Jupiter. The survival of Vesta and Ceres to the JEB depends on the size distribution of the planetesimals populating the Solar Nebula. The abundance of large planetesimals in the disk is a critical factor for the survival of the two asteroids. If the disk of planetesimals was dominated by large bodies (i.e. $D \geq 100$ km), like in the case of planetesimals formed in turbulent circumstellar disks, the two asteroids would not have survived the JEB [7]. Conversely, disks dominated by small planetesimals (i.e. $D \leq 20$ km), like those formed in quiescent circumstellar disks or produced by collisional evolution, represent more favourable environments for the survival of Vesta and Ceres [7]. In all scenarios where they survive the JEB, Vesta and Ceres underwent an intense cratering that saturated their surfaces with craters as big as 150 km, with a tail of few bigger craters ($200-300$ km). Craters as big as the south pole impact basin on Vesta (D $\approx$ 400 km) are characterised in these cases by extremely low probabilities (of the order of a few per cent). Under the simplifying assumption of a uniform distribution of the craters, the JEB would have excavated a depth of about $10-15$ km on Vesta and of $20-30$ km on Ceres [7].

4. Discussion and Conclusions

According to our results, the JEB should have excavated the Vestian crust and exposed, locally or possibly even globally, the underlying mantle or caused the formation of fractures or of uncompensated negative gravity anomalies on the surface of the asteroid. The former would have caused the solidification of the exposed mantle and the formation of a new basaltic crust. The latter would have caused extensive effusive phenomena from the underlying mantle, in analogy with lunar maria. According to thermal modeling of the internal evolution of Vesta (see e.g. [2] and references therein), the asteroid was characterised by a molten mantle and by a crustal thickness of about $10-20$ km at the time of the JEB. As a consequence, the crustal excavation due to the JEB should have brought on the surface of Vesta material from its interior, which would be characterised by a different composition respect to the original surface. The observations of Dawn mission at Vesta thus have the potential to unveil not only the early history of the asteroid but also that of the young Solar System.

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