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Vesta, Ceres and the Jovian early bombardment

D. Turrini (1), G. Magni (2) and A. Coradini (1)
(1) Institute for Physics of Interplanetary Space, INAF, Italy
(2) Institute for Space Astrophysics and Cosmic Physics, INAF, Italy
E-mail: diego.turrini@ifsi-roma.inaf.it

Abstract

Radiometric dating of meteorites and observations of circumstellar disks indicate that the differentiation of planetesimals due to short-lived radionuclides and the formation of giant planets took place on similar timescales in the forming Solar System. The asteroids Vesta and Ceres, targets of Dawn space mission, could be surviving witnesses of such very ancient times and supply precious information on the timing of planetary formation processes. We here describe the results of our investigation of the collisional histories of these two bodies under the hypothesis the one or both were already present when Jupiter formed.

1 Introduction

From observations of circumstellar disks we know their median lifetime is about 3 Ma, with observed values spanning between $1 - 10$ Ma [4, 7]. During this timespan, solid material accreted to form the first planetesimals and planetary embryos, from which the cores of the giant planets originated. The chronology of the early Solar System obtained from chondrites, achondrites and differentiated meteorites indicates that the first solids to form were the Ca-Al-rich inclusions [1]. Chondrules formed about $1 - 4$ Ma later than CAIs, while differentiated bodies generally appeared a few million years later [9]. However, as reviewed by [9], meteoric evidences suggest that for some planetesimals Al^{26}-driven differentiation took place early in the history of the Solar System, i.e. about 1 Ma after the formation of CAIs.
The Ar-Ar ages of the oldest HED meteorites possibly linked to Vesta suggest a primordial differentiation. Due to the short decay time of Al^{26}, the accretion of Vesta would then date back prior to the formation of Jupiter and its surface could bear the marks of such event. Ceres instead could represent the only surviving member of the population of planetary embryos which filled the Main Belt region. [12] and later [2] suggested that the mass depletion observed in the Main Belt could be explained as the effect of now-lost planetary embryos which, before being removed by Jupiter's perturbations, efficiently cleared the excess mass from the Main Belt.
We here present the improved results of our investigation of the early collisional histories of Vesta and Ceres, first described in [11], under the hypothesis the one or both asteroids were already present when Jupiter formed.

2 The model

To explore the early collisional history of Vesta and Ceres we simulated the evolution of a template of the early Solar System composed of the Sun, the accreting Jupiter, the two asteroids and a disk of 8×10^4 massless particles extending between $2 - 10$ AU and representing the planetesimals. We simulated the formation of Jupiter through an heuristic approach based on the hydrodynamical simulations described in [6]. The time assumed for the formation of Jupiter's core is 10^6 years, which is about the lower limit predicted by theoretical models. The gas accretion phase is reproduced in more detail: the assumed timescale of mass growth is 5×10^3 years, basing on [6] and consistently with [5], and the system is let evolve for 10^6 years. Since Jupiter could have migrated during its formation, we performed four sets of simulations considering different migration scenarios ($0, 0.25, 0.5$ and 1 AU). Note that this migration is not the one described in the so called *Nice Model* and responsible of the Late Heavy Bombardment.
The collisional histories of Vesta and Ceres have been reproduced statistically by evaluating the impact probabilities of the massless particles which crossed the orbits of the two asteroids. For further details on the collisional treatment we refer the reader to our manuscript in preparation [10].

3 Results

Our results show that, if Vesta or Ceres were present when Jupiter formed, they would have been impacted by a flux of planetesimals equal to about 10% of their present masses. Different dynamical families of impactors participated to this early bombardment: planetesimals located at the boundaries of the feeding zones of the two asteroids, planetesimals located near orbital resonances with Jupiter and planetesimals from the outer Solar Systems injected on eccentric orbits by the giant planet. The crater populations produced in the different migration scenarios vary as a function of Jupiter's radial displacement. Major craters (i.e. whose diameter is greater than 50 km) are mostly due to planetesimals from the outer Solar System for Jupiter forming at its present location. For increasing values of the initial displacement the contribution of resonant impactors become predominant, aside from the few craters bigger than 200 km. The delivery of volatile-rich bodies formed beyond the Snow Line is also influenced by the extent of the radial migration. In all these cases, the variations do not scale linearly with the extent of Jupiter's migration due to the excitation of orbital resonances in the outer Solar System.

4 Conclusions

The population of craters reproduced in our simulations represent the mark of Jupiter's formation on primordial planetesimals which formed at the very beginning of the Solar System's life. Such craters would be totally or partially obliterated by later bombardment events, like the Late Heavy Bombardment, and therefore would be likely difficult to identify. However, the timing of Jupiter's formation and that of the Al^{26}-driven differentiation of planetesimals are similar. If planetesimals still possessed liquid mantels when Jupiter formed, this early bombardment phase could have caused the formation of magma seas. Therefore, if the timing of the differentiation processes and that of Jupiter's formation matched for Vesta and/or Ceres, we could be able to identify such features in the images Dawn mission will soon supply.

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