Is Vesta Cratering a Record of Primordial Bombardment?

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Introduction: The mission Dawn will provide the first, detailed images of Vesta surface and supply crucial information to constrain its mineralogical and elemental composition through VIR, its imaging spectrometer. Thanks to these data, we will be able to study in depth the crater record on the surface of Vesta and get an insight on its place in the context of Solar System history. Vesta is believed, based on the Hubble observations and ground based observations, to be the parent body of HEDs meteorites. HED meteorites whose dating is very old, to have underwent early to a substantial differentiation. Blichert-Toft et al.[1] have investigated the ^{147}Sm–^{143}Nd and ^{176}Lu–^{176}Hf systematics of 21 whole-rock eucrites, including five cumulates, by MC-ICP-MS. A statistically significant Sm–Nd isochron was obtained on 18 samples with an age of 4464±75 Ma. This means that Vesta can be used as a reasonable model for the early stages of the terrestrial planets formation. Therefore on Vesta we shall find the record of primardial processes affecting old planetary surfaces just after crustal formation.
The primordial bombardment can be related in turn to the final phases of Jupiter and Saturn accretion.

In the framework of our studies on the origin of Jupiter[2] [3], we evaluated the accretion rate during the final phases of Jupiter formation and, through an N-Body code developed on purpose, we evaluated the flux of impactors on Vesta keeping track of their formation zones, which can bear information on their composition. We also evaluated the flux of impactors in the case Jupiter formed earlier than Vesta and underwent to a mild displacement, as hypothesized by the Nice model, and in the case the planet formed later but still radially migrated, to estimate the relative importance of the different processes. We have also considered the importance of the Saturn and other outer planets presence. We will describe the different scenarios and their implications for the evolution of Solar System to provide a reference frame for future studies of Vesta's cratering history.

The Model: 10000 mass points simulating the swarm of planetesimals and total planetesimals mass of 2 Earth Masses are considered. Each body is individually followed, so at each time step we are able to know the velocity and position of each body, as well as its impact velocity with Vesta, if a collision happens. The simulation takes into account of the depletion due to the accretion of the cores of giant planets, that we consider already formed. In the models we use different assumptions on the number of giant planets, from one (only Jupiter) to four (Jupiter, Saturn, Uranus and Neptune). The gas accretion model used are described in Coradini and Magni, 2004 [1]. The inward migration displacement of giant planets is an ad hoc assumption, following the current models, and ranges from 0.8 AU for Jupiter to 3 AU for Neptune

Here we present only the two extreme models, namely the one with only Jupiter and the one with 4 planets. Details of the models are shown hereafter. The simulated bodies (planetesimals) are individually followed with a classic integration method. The aim of the calculation is to evaluate the probability that object impact Vesta.

In order to compute the Vesta cross section, Vesta is spread in a thorus with section equal to the Vesta diameter and radius corresponding to its orbital radius. When the planetesimals cross the torus, the impact probability is simply the fraction of the volume of torus intersected by the crossing planetesimals.

Planetesimal have different compositions depending on their formation region. In this calculation we have assumed that those beyond the so-called "snowline" are icy, while those inside are rocky.
The two considered models are here summarized:
Model A: Jupiter with accretion and migration 0.8 AU, with the following accretion law

$$Mp = Mj + (Mo - Mj)\exp(-t / tau)$$

$$Rp = Rj + (Ro - Rj)\exp(-t / tau)$$

Here Mp and Rp are mass and radius of the growing planet mass, Mj and Rj are Jupiter mass and radius, Mo and Ro are the core mass and radius Tau=2000 yrs is the accretion timescale.
Model B: The presence of Jupiter is considered, togheter with Saturn Uranus and Neptune with timescale of accretion for Jupiter Tau=2000 yrs, Saturn 3000, and Uranus and Neptune already formed .
The assumption reflects the idea that the final phases of Jupiter and Saturn accretion are maily characterized by gas accretion. The accretion of planets and their "mild" displacemnent shapes the structure of the asteroidal belt. In Figure 1 is shown the swarm of objects after 30000 years. At this point in the evolution Jupiter and Saturn are already formed. Initially there is a swarm of about 2 Earth masses, distributed in objects

ranging between 10^{15}-10^{20} g. The mass distribution follows the law:

$$N(m) \propto m^{-\frac{3}{2}}$$

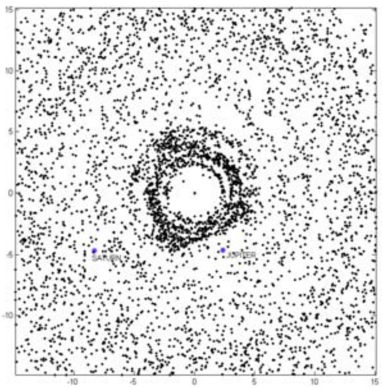

Figure 1 Distribution of planetesimals after 30.000 years.

In Figures 2a and 2b are shown the results of the two models. The figures represent the evolution of the eccentricities of the bodies - able to impact Vesta - as a fuction of time.

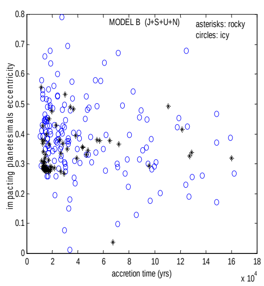

Figure 2 a model a: eccentricity of the bodies impacting as function of time. The blue circles refer to icy bodies, and the black ones to rocky objects**,**

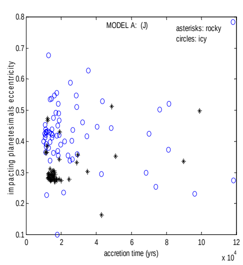

Figure 2 b The same as figure 2a, for Model b.

In figure 3 (a, & b) are shown the outcome of the models. The computed values are strongly different in the two cases.

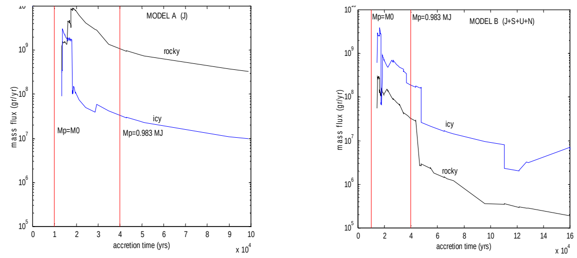

Figure 3 Model a and b In these 2 figures are shown the fluxes of objects bombarding Vesta.

Conclusions: This model shows that the region of Vesta is crossed by several objects, coming from the inner region - from Mars beyond- and from the outer regions, namely from areas beyond the so-called “snow-belt”. The accretion phase and the migration strongly enhance the planetesimals bombardment for each of the models. The planetesimals beyond the snow belt are assumed to be icy. The case in which only Jupiter is considered, is characterized by a larger contribution of rocky planetesimals. The model B, instead, is characterized by a stronger bombardment by icy bodies. Moreover the expected crater distribution on Vesta should be different depending on the different evolution model. In case a, in which it is assumed that Vesta forms at the time of Jupiter formation, the crater distribution is dominated by impact of rocky bodies that should lead to an intense and uniform craterization. The icy planetesimals should contribute marginally to the distribution.Case b is instead characterized a more complex process and also a late bombardment of icy objects could be present. Therefore, depending on the evolution time of Vesta, it can undergo to a different chemical evolution, resulting either totally de-hydrated or partially hydrated object [4], as it seems to be indicated by a possible presence of hydration band at 3 micrometers. Dawn mission will clarify if traces of hydration, even localized are present on Vesta**.**

References:

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