The formation of Jupiter and the Jovian Early Bombardment. D. Turrini[1], A. Coradini[1], C. Federico[2], M. Formisano[1,3], G. Magni[4], [1] Institute for Physics of Interplanetary Space INAF-IFSI, via Fosso del Cavaliere 100, 00133 Rome, Italy (e-mail: diego.turrini@ifsi-roma.inaf.it); [2] Department of Earth Science, University of Perugia, Perugia, Italy; [3] Department of Physics, University of Rome "La Sapienza", Rome, Italy; [4] Institute for Space Astrophysics and Cosmic Physics INAF-IASF, Rome, Italy.

Introduction: The first phase in the lifetime of the Solar System is that of the Solar Nebula, when the Solar System was constituted by a circumsolar disk of gas and dust particles where planetesimals and planetary embryos were forming. This phase is assumed to start 4568.2 Ma ago [1] with the condensation of the Ca-Al-rich inclusions and to end in less than 10 Ma [2] with the dispersal of the nebular gas.

Across this $\Delta T < 10$ Ma timespan planetary accretion was acting in the Solar Nebula to form the planetesimals, the planetary embryos and the giant planets. According to meteoritic evidences, some of the accreting planetesimals differentiated extremely early in the history of the Solar System, i.e. about 1-2 Ma after the formation of CAIs (see [3] and references therein). Such primordial differentiation was due to the presence of short-lived radionuclides, mainly ^{26}Al and ^{60}Fe (ibid) in bodies larger than 20 - 30 km in radius (ibid). In particular, the spectral connection between Vesta and the Howardite-Eucrite-Diogenite (HED) suite of achondritic meteorites suggests that Vesta formed and differentiated very early in the history of the Solar System, likely only a few Ma later than CAIs (see e.g. [3,4] and references therein).

In the following we report the results of our crossed investigation of the thermal history of Vesta and of the primordial bombardment triggered by the formation of Jupiter. The goal of this project is to assess if the Dawn mission could allow us to probe a previously unexplored phase in the life of the Solar System.

The Model: We simulated the dynamical evolution over 2 Ma of a template of the forming Solar System composed of the Sun, the accreting Jupiter, a swarm of planetesimals, Vesta, Ceres [5,6] and a set of other target bodies [7]. The aim of our simulations was to estimate the effects of the formation of Jupiter on the collisional evolution of Vesta and of other primordial bodies existing in the asteroid belt.

Across the first half of this 2 Ma-long temporal window, Jupiter's core is assumed to accrete from a Mars-sized embryo of 0.1 $M_\oplus$ to the critical size of 15 $M_\oplus$ [5]. Across the second half of the temporal interval spanned by our simulations, Jupiter is assumed to rapidly accrete its gaseous envelope [5], increasing its mass with an e-folding time of 5000 years [8]. While accreting its gaseous envelope, Jupiter could have migrated inward due to exchange of angular momentum with the circumsolar disk (see [9] and references therein). To evaluate the effects of Jupiter's migration, we considered five different scenarios [5]: Jupiter forming at its present position, Jupiter migrating inward by 0.25, 0.5 and 1 AU with an e-folding time of 5000 years and Jupiter migrating inward by 1 AU with an e-folding time of 25000 years.

The planetesimals spans between 2-10 AU, are initially located on low-eccentricity and low-inclination orbits and, in the dynamical model, are represented by 80000 massless particles [5,6]. To evaluate their effects on the collisional history of Vesta, Ceres and the other target bodies we associated to each planetesimal mass and density values and a normalization factor derived by their formation region and the assumed formation scenario [5]. The size-frequency distributions of the planetesimals we considered are those due to their formation in a quiescent [10] or in a turbulent nebula [11] and that due to to the primordial collisional evolution of the asteroid belt [12]. During the dynamical evolution of our template of the Solar System we evaluated the probabilities of planetesimals impacting Vesta and Ceres [5] or other bodies [7] through a statistical approach similar to the method devised by Opik [13]. The effects of the impacts on the target bodies were estimated using the scaling-laws from [14] and [15], the latter in the angle-averaged form supplied by [16].

The Jovian Early Bombardment: Our results indicates that the formation of Jupiter causes a phase of

	Collisionally evolved planetesimals (Morbidelli et al. 2009)			
Migration Scenario	N_{coll}	Crustal Erosion (km)	$Q_D/Q^*_D \geq 0.01$	$Q_D/Q^*_D \geq 1$
No Migration	15158.5	0.17	0.00	0.00
0.25 AU	20976.3	0.21	0.00	0.00
0.50 AU	36132.1	1.61	0.66	0.00
1.00 AU	66419.1	11.57	5.09	0.01

Table 1: the Jovian Early Bombardment in a disk populated by collisionally evolved planetesimals [6] following the size-frequency distribution of the best-fit case from [12].

primordial bombardment we labeled the Jovian Early Bombardment (JEB in the following, [5]). While the migration of Jupiter enhances the intensity of the JEB due to the sweeping of the resonances across the asteroid belt, the formation of the giant planet is necessary and sufficient condition for triggering the JEB [5]. Planetesimals from both the inner and the outer Solar System participate to the JEB, but the leading role in determining the effects of the JEB is played by the planetesimals affected by the 3:1 and the 2:1 resonances with Jupiter [5].The survival of the considered target bodies to the JEB depends on the size distribution of the planetesimals populating the Solar Nebula, the abundance of large planetesimals (i.e. D > 100 km) in the disk being a critical factor to this regard [5,7]. Another critical factor is the location of the target bodies respect to the two previously mentioned resonances [5,7]. If the disk of planetesimals was dominated by large bodies, like in the case of planetesimals formed in turbulent circumstellar disks, the JEB would cause the ablation of bodies of 500 km or smaller [7]. Conversely, disks dominated by small planetesimals (i.e. D < 20 km), like those formed in quiescent circumstellar disks or produced by collisional evolution, represent more favorable environments for the survival of bodies of 200 km or bigger [7]. Planetesimals of 200 km, however, would survive only in the scenario where Jupiter does not migrate [7]. In all other scenarios, they are generally disrupted if Jupiter migrated by 05 AU or more [7].

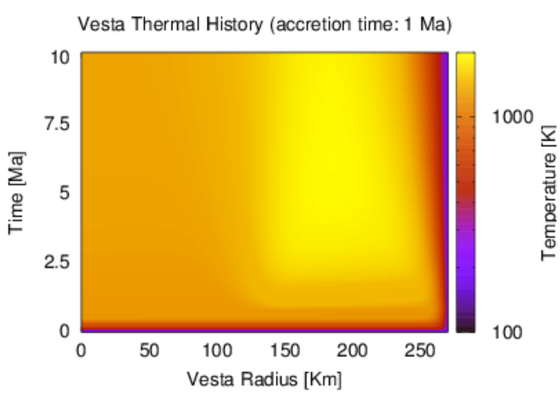

Figure 1: temporal evolution of the thermal profile of Vesta over 10 Ma under the effects of the decay of short-lived radionuclides assuming an accretion time of Vesta of 1 Ma [17].

Vesta and Ceres [5,6] would undergo an intense cratering that would saturate their surfaces with craters as big as 150 km, with a tail of few bigger craters (200-300 km). Under the simplifying assumption of a uniform distribution of the craters, on Vesta the JEB could excavate up to a depth of about 10 km (see Table 1 and [6]). Assuming a depth-to-diameter ratio of 1:7, however, the JEB could excavate the crust of Vesta either locally or regionally (see Fig. 1 and [6]).

The role of Vesta: The geophysical history of Vesta. as inferred by HED meteorites, suggests that its differentiation could have ended in a few Ma: as such, Vesta could be the only body we know of whose solid crust was already formed at the time of the formation of Jupiter. This hypothesis is supported also by the results of theoretical studies of the thermal history of Vesta (see Fig. 1 and [17]). The local or regional excavation of the primordial crust of Vesta would have caused large-scale effusive phenomena similar to the Lunar maria [5,6,18]. Therefore, the data that Dawn mission is collecting on Vesta could allow us to test the Jovian Early Bombardment hypothesis and to investigate the early evolution of the Solar System [19].

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