Crater Size-Frequency Distribution (CSFD) and Chronology of Vesta - Crater Counts Matching HED Ages.

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Introduction: In July 2011 the Dawn spacecraft entered orbit around the Main Belt asteroid 4 Vesta. Dawn has been designed to map the asteroid Vesta and later in the mission the dwarf planet 1 Ceres from various altitudes utilizing three different instruments [1]. The Main Belt is the source region of most impactors in the inner solar system [2,3,4]. For decades the lunar cratering record has been investigated by many scientific groups, which makes it one of the best known planetary surfaces in the Solar System. Therefore, we compare the obtained CSFD of Vesta with that of the Moon and other Main Belt asteroids such as 951 Gaspra, 243 Ida, and 21 Lutetia. We also compare our results of crater counting on Vesta with K/Ar-Ar reset ages of HED meteorites, which most likely originated from Vesta [5].

Asteroid Crater Size-Frequency Distribution: Scaling laws have been derived by several groups, e.g. [6,7] to predict the relation between projectile size and crater size with respect to numerous impact properties like impact speed, angle, target materials, etc. In the present work we utilize the corrected scaling laws by [7]. The CSFD of impact craters on the Moon is well known as well as the respective impact properties. Thus, we can use the lunar CSFD together with scaling laws to predict those of other celestial bodies like asteroids and test them against observations from space probes like Dawn. The left panel of Fig.1 shows a number of measurements of asteroidal crater frequencies. They all show a high similarity in their shapes. The right panel of Fig. 1 shows the lunar CSFD (green curve) in comparison with vertically normalized measurements of the asteroids Gaspra, Ida, Lutetia (red triangles) and Vesta (black squares). The normalization does not change the shape of the measurements but is necessary to align the measurements at the same isochrones. Low gravity targets like small asteroids show a significantly flatter distribution of large craters compared to the Moon. Except for slightly different material properties of different bodies, the scaling is dominated by the impact velocity and surface gravity. This results in highly similar CSFDs of Gaspra, Ida and Lutetia. Vesta, however is much more massive and consequently has a CSFD (black curve) lying in between the lunar CSFD and the shown small-body CSFD (red curve – Lutetia CSFD). The measured crater distributions of the Main Belt asteroids [8,9] fit very well the scaled lunar crater distribution. This is a strong argument for a common impactor source for the Moon and Main Belt asteroids.

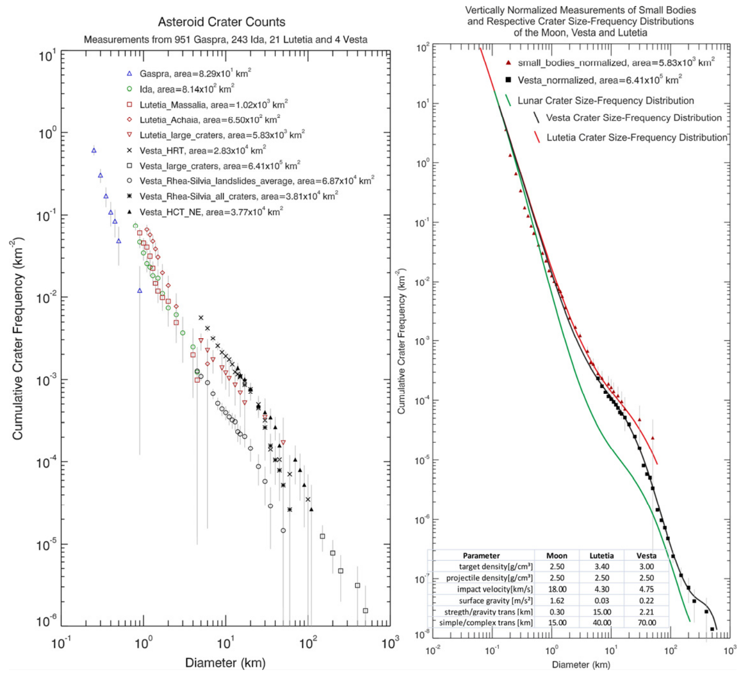

Fig.1: *Left: Crater measurements on asteroids Gaspra, Ida, Lutetia and Vesta show a high intrinsic similarity to each other. Right: Normalized measurements of the small asteroids Gaspra, Ida and Lutetia (red triangles and curve), the lunar curve (green) and the CSFD of Vesta (black curve and squares). Data points for asteroids are derived from measurements in the left panel.*

Asteroid Chronologies: As the lunar surface has accumulated a cratering record dating back to the early history of the Solar System and sample return missions provided radiometrically datable material, we have a ground truth calibrated lunar chronology available, valid over at least the last 4.2 Ga [10]. Scattering processes caused by collisions among asteroids, dynamical interaction with the planets as well as non-gravitational forces strewed projectiles from the Main Belt all over the Solar System [3]. These processes left behind a detailed cratering record on many planetary surfaces less affected by resurfacing processes. The travelling time of meteorites from the Main Belt to e.g.

the lunar surface is short [3]. About an order of magnitude less than the half life derived for the exponential decay in the lunar cratering rate [2].

Thus, it is very likely that any time-dependent development of the impactor population in its source region, the asteroid Main Belt, is directly influencing the cratering records of the planetary surfaces. Therefore, we use a lunar-like chronology for asteroids and scale it to the respective impact rates. Impact rates for asteroids are derived by a statistical analysis of orbital elements of the asteroids following [11]. In order to convert asteroid statistics into chronologies we only use frequencies of observed asteroids and do not use models which extrapolate the number of asteroids to sizes unresolved by current observations. In order to get frequencies of smaller projectiles we use the measured CSFD to convert frequencies of craters formed by projectiles larger than 10 km (complete Main Belt population observed) to crater sizes commonly used for chronologies like 1 or 10 km. Thus, we use trustworthy data of observed projectile frequencies, hard data of observed crater frequencies and utilize a ground-truth derived lunar chronology. These are the major differences to other approaches ([12,13]), mainly based on models derived from the LHB idea [13]. In the current model of [13], observed CSFD and observed number of basins >150 km indicate an unlikely surface age >4.5 Ga for Vesta.

Vesta Crater Retention Ages vs. Ages of HED Meteorites: Vesta and its family members show similar spectral characteristics as the HED meteorites [5]. HED meteorites provide radiometric K/Ar-Ar ages with high probabilities for large impact events at 3.55 Ga, 3.7 Ga, 3.81 Ga and 4 Ga [14]. Several measurements of crater frequencies on Vesta at a global scale clearly show a base age of 4 Ga and resurfacing events at 3.81 Ga and close to 3.7 Ga (Fig.2). For these three events we see a good agreement between ages of HED meteorites and surface ages derived from crater counts. The 3.55 Ga peak in age probabilities [14] is not confirmed by crater counting. Based on the magnitude of the age probabilities from [14] we would expect a global resurfacing like the one at 4 Ga or even larger. In fact there are no impact craters of this age larger than a couple of tens of km. It appears that this K/Ar-Ar reset event at 3.55 Ga did not occur on Vesta but probably another differentiated body like Vesta. The meteorite collections indicate more than 60 to100 differentiated parent bodies, probably similar to Vesta [15,16]. At least three HED ages are consistent with crater counting on Vesta. Probably Vesta is also showing clues of the remaining spikes in HED ages.

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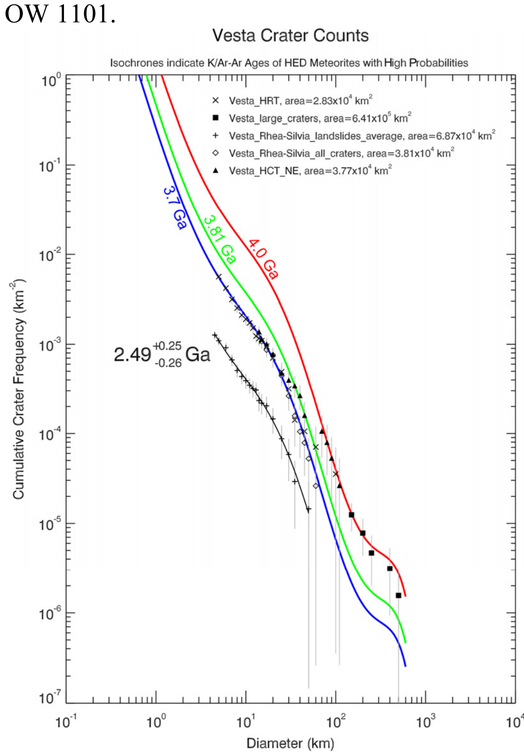

Fig.2: *Vesta crater frequencies align with isochrones of HED ages and prove a very good agreement between crater counts on Vesta and at least three K/Ar-Ar reset ages of HED meteorites. Measurements from the crater floor and ejecta blanket of the Rheasilvia basin (diamonds and crosses) overlap and strongly suggest a formation age of about 3.7 Ga. The landslide originated infill of the Rheasilvia basin shows an average surface age of only 2.5 Ga.*

References

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