Impact erosion of Near Earth Asteroids.

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Introduction: The investigation of Near Earth Asteroids (NEAs) is at the center of numerous spacecraft missions in the recent past, present, and future of space exploration in both, public and private sector [1]. Not only are NEAs potential valuable targets for the space mining industry, but some of these asteroids are also potentially hazardous objects on a collision course with Earth or Mars. For the purpose of planetary protection as well as asteroid mining, understanding the nature of these objects in all possible facets before a space mission sets sail is key to optimize the spacecraft for their respective missions [2]. In this work we study the erosion rate of NEAs due to the natural bombardment by smaller projectiles and discuss what this implies for the top few centimeters of surface material that is usually probed by sample return missions.

The Model: Our evaluation of the impact erosion of NEAs is based on the well-known lunar cratering record and lunar chronology [3] that is scaled to asteroidal bodies [4,5]. The lunar chronology system converted to the asteroids is called "lunar-like chronology" in order to distinguish between this approach and alternatives that are not based on lunar ground truth. We do this scaling for 100 different sizes of asteroids ranging between 100 m and 100 km diameter. We calculate model crater frequencies on each of these sample bodies for 1000 different crater diameters, equally spaced on a logarithmic scale between the crater size formed by the smallest projectile covered by the lunar crater production function (lunar crater Ø: 10 m ≙ projectile Ø: ~ 0.3 m) and the largest crater possible on each of the sample bodies. The largest possible crater is defined as the diameter of the asteroid. The Rheasilvia basin on 4 Vesta is a well-documented example for this case [4]. For each crater size, we calculate the number of craters formed by impacts over a time period of 100 Ma. In addition, we calculate how much impact ejecta is escaping the asteroid in dependence of the respective crater and asteroid sizes. The total volume of the lost ejecta then is the volume lost at each crater size times the number of craters in each crater size that formed over 100 Ma, cumulated over all crater sizes.

Since the impact rate and impact velocity is dependent on the orbital geometry of the asteroids, we give examples for different dynamic groups of asteroids, i.e. Inner Main Belt, Apollo, Amor, and Aten asteroids.

Used scaling models: For scaling crater sizes from the lunar surface to asteroids, we follow the approach of [4] with updated scaling laws by [6]. Since many of the small asteroids visited by spacecraft appear to be rubble piles we use the scaling for porous rock. For scaling the chronology function, again we follow [4]. The required values for impact probability and impact velocity are computed based on [7]. This computation is done for each set of the exemplary orbital elements of the dynamical asteroid groups presented here (Table 1).

Table 1: Orbital elements of 4 Vesta, 2062 Aten, 1862 Apollo, and 1221 Amor asteroids [8].

Asteroid	Vesta	Aten	Apollo	Amor
Pericenter [AU]	2.15	0.7901	0.647	1.084
Apocenter [AU]	2.57	1.143	2.29	2.755
Eccentricity	0.09	0.183	0.5598	0.435
Inclination [°]	7.14	18.934	6.355	11.877
Semi-Major Axis [AU]	2.36	0.9668	1.47	1.919

The ejecta scaling is taken from [9] and tested for impact craters on 4 Vesta. Here we use the "Glass Micro Sphere" analog material resulting in 5×10^5 km^3, escaped Rheasilvia ejecta, consistent with [10].

Results: Fig. 1 shows the material loss due to escaping impact ejecta in relation to the different asteroid sizes as ratio of the change of the mean asteroid radius and the original asteroid radius.

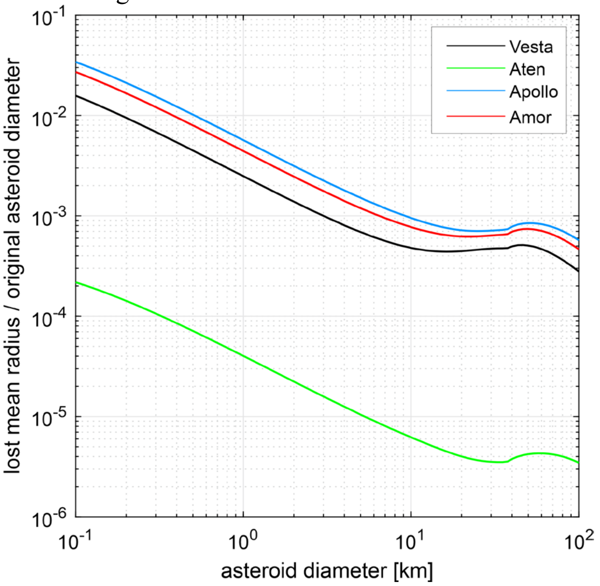

Fig. 1: Material loss due to impact erosion over 100 Ma expressed as relative reduction in mean radius w.r.t. the original size of the asteroids.

Fig. 2 shows the loss of material as absolute change of the asteroid radius.

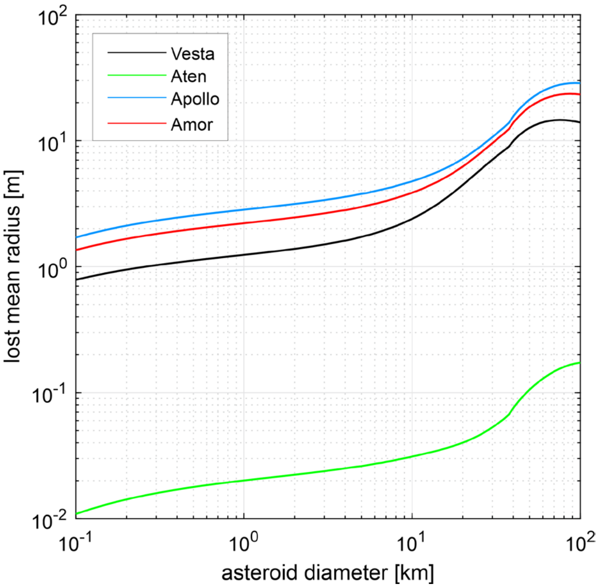

Fig. 2: Material loss due to impact erosion over 100 Ma expressed as absolute reduction in mean radius.

Given the same projectile population (asteroids) for each of the analyzed asteroid groups, all graphs within each figure are similar but not exactly the same, because of the effects of different crater scaling caused by variable impact velocities and impact probabilities. At moderate eccentricity the impact erosion rate for inner Main Belt asteroids (orbital elements are taken from 4 Vesta) is significantly higher than for the Aten group, because of the high number of potential projectiles inside the asteroid Main Belt. Apollo and Amor asteroids also pass through the Main Belt in parts of their orbits but are characterized by higher eccentricities and/or higher orbital inclination and thus experience even higher erosion rates than objects permanently inside the Main Belt, due to the resulting higher impact velocities.

In general we would expect a higher impact erosion rate on small bodies because their low escape velocity allows more material to escape from the body. On the other hand, small bodies have a smaller cross sectional area and therefore are hit less frequently than larger bodies. Fig. 1 indicates that small asteroids indeed lose more material relative to their absolute size than larger asteroids. However, due to their larger cross sectional area and their ability to form larger craters large asteroids lose more material in absolute terms (Fig. 2). This trend is valid for body diameters of up to ~ 100 km. At larger sizes the self-gravity of the asteroids retains enough impact ejecta, that even larger bodies lose less material. At some point that is reached for bodies such as Vesta and Ceres, the gravity is large enough to retain enough material in a way that no significant material loss due to impact cratering occurs over long time scales, resulting in a well gardened regolith layer mixing original target material with various impactor materials. Larger bodies (Ø > ~1000 km) even gain mass due to the mass influx of the impacting projectiles, while only small amounts of ejecta are able to escape. These results imply that material sampled from even a few meters depth of small Main Belt or small Main Belt crossing asteroids still is relatively fresh and less affected by space weathering processes than small asteroids that completely stay out of the Main Belt. The absolute erosion rate for Aten group asteroids, therefore is about an order of magnitude lower than for the other three groups of this study. Thus, space weathering could alter surface materials more significantly on asteroids with orbits most similar to that of Earth.

All results presented here are estimates that should be accurate by the order of magnitude as a consequence of uncertainties in crater- and ejecta scaling as well as orbital instability of planet crossing objects over discussed time frames.

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