DETERMINING THE MAIN BELT SIZE DISTRIBUTION USING ASTEROID CRATER RECORDS AND CRATER SATURATION MODELS.
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Motivation. The cratered surfaces of asteroids imaged by spacecraft (e.g., Gaspra, Eros, Ida, Mathilde), if properly interpreted, provide critical constraints that can be used to (i) determine how the main belt size frequency distribution (SFD) has evolved over Solar System history and (ii) glean insights into the physical nature of the asteroids themselves. A serious problem, however, is that most asteroids have crater records that are in/near "*saturation equilibrium*", a state where the erosive and destructive effects of subsequent cratering prevents the crater density from increasing [1,2]. For this reason, it is often argued that only Gaspra, whose surface shows a steep non-saturated population of fresh craters (differential power law index q = -4.3 ± 0.3 [3]), can be used to discern the "real" main belt SFD.

Model. Here we show that considerable information on the production SFD can be determined even from saturated terrains. To this end, we created a numerical model called CRASAT that tracks how the SFD of a cratered surface [of the form $N\,(>D) \propto D^{-(q+1)}$] changes with time with respect to an impacting population. Our code is similar to previous efforts [4,5], in that craters with diameter D_{crater} are placed sequentially on a large square surface (3000 × 3000 in arbitrary units) according to an input SFD. The location and size of each crater are chosen using random deviates and are recorded. Craters are defined by their rims; when 50% of a crater's rim has been removed by overlapping craters, we assume it is no longer recognizable. When a new crater is formed, it obliterates everything underneath provided $D_{crater} > D_{under} / f$, where $f > 1$. Thus, the rim of D_{under} can be erased if enough small craters land on it. The code tracks the progress of the crater SFD throughout the simulation. The code only reports results for craters with $f < D_{crater} < 1500$, though it includes the effects of tiny craters with $D_{crater} < f$.

Calibration. To test CRASAT and numerically determine f, we compared our results to lunar craters formed at Sinus Medii. According to [1], the crater production SFD for 200 < D_{crater} < 500 m has a differential power-law slope of q = -4.8. For 10 < D_{crater} < 100 m, however, the slope changes to q = -2.8, diagnostic of the "rollover" that occurs when cratered surfaces attain saturation equilibrium [1,2]. **Fig. 1** shows CRASAT results using the same production populations and a range of f values. The best fit between model runs and data was found for f = 9.

Production Runs. Using the value f = 9 in CRASAT, we investigated how different crater SFDs reached saturation equilibrium on our test surface. To compute crater SFDs relevant to those found on the observed asteroids, we assumed our crater function followed a broken power law reminiscent of the predicted main belt size distribution between 0.1 m and 3 km [6] (i.e., $-4.5 < q_a < -3.0$ for $1 < D_{crater} < 200$ and $-2.9 < q_b < -2.0$ for $200 < D_{crater} < 1500$). As craters accumulated on our surface, we output CRASAT results at regular intervals. To account for stochastic variations, we ran each test case 5 times with different random seeds. Finally, we scaled our output results to the range of craters found on different asteroids, with chi-square methods used to compute best fit cases.

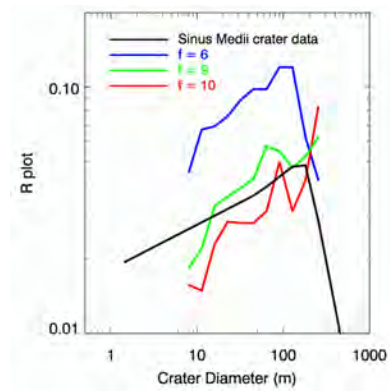

Fig. 1. Comparison between observed crater data from Sinus Medii (black curve) [1] and f = 6, 9, 10 runs from CRASAT. All model crater SFDs have reached saturation equilibrium, explaining their shallow slopes. Best fit is for f = 9 (green).

(243) Ida and (433) Eros. We first applied our results to craters on (243) Ida, a S-type asteroid in the Koronis family [7]. **Fig. 2** shows that on a standard log-log R-plot, where the differential crater frequencies have been divided by D^{-3} [8], Ida's craters plot near R = 0.1-0.2 and are saturated for D_{crater} < 1-2 km. The crater production SFD providing the best fit to the data has q_a = -3.5, q_b = -2.6, and D_{elbow} = 2.5 km. Note that these *crater* SFD slopes are remarkable similar to those predicted by [6] for the *asteroid* SFD in the main belt (q_a = -3.6, q_b = -2.6). Similar results were found for D_{crater} > 0.1 km on (433) Eros.

Interestingly, Ida's saturated R-values are 3-5 times higher than those for Sinus Medii (**Fig. 1**). This tells us that while the saturation slope is always $q \approx -3$, the equilibrium spatial density depends on the slope of the crater SFD (e.g., [1]). This result should be highly useful in interpreting the meaning of crater SFDs on planetary surfaces throughout the Solar System.

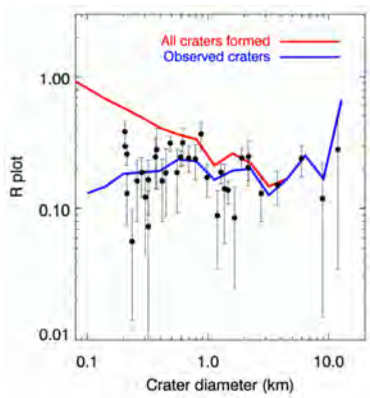

Fig. 2. Crater data from (243) Ida (black points) and best-fit CRASAT run (q_a = -3.5, q_b = -2.6, D_{elbow} = 2.5 km) (red/blue). Red line shows number of model craters formed on surface. Blue line, which should be compared with data, shows "saturated" model craters still visible on the asteroid's surface.

(253) Mathilde. Mathilde is a C-type asteroid whose physical properties are poorly understood. Still, like Ida, its crater data plots near *R* = 0.1-0.2 [7] (**Fig. 3**). Our best fit runs from CRASAT suggests that the crater production SFD has parameters near q_a = -3.6, q_b = -2.4, and D_{elbow} = 4.5 km. Thus, Ida, Eros, and Mathilde were apparently struck over time by the same main belt SFD observed today.

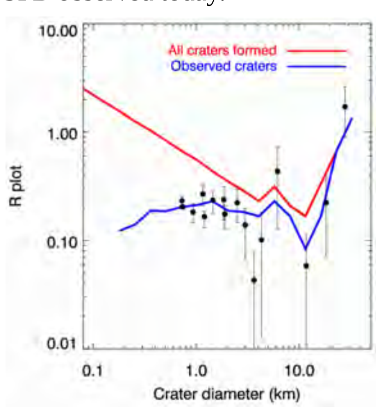

Fig. 3. Crater data from (253) Mathilde (black points) and best-fit case (q_a = -3.6, q_b = -2.4, D_{elbow} = 4.5 km) (red/blue). See Fig. 2 for details.

Note that we can use the value of D_{elbow} to estimate a crater-scaling relationship for C-type asteroids. According to [6], the main belt SFD has an inflection point at *D* = 0.2 km that must correspond to the D_{elbow} value on Mathilde. The ratio of the two values (4.5 km/0.2 km) tells us that a typical main belt projectile makes a crater 22.5× its diameter on Mathilde. For reference, the same projectile makes a crater 12.5× its diameter on Ida/Eros (i.e., 2.5 km/0.2 km). Thus, main belt projectiles make craters nearly twice as large on C-type Mathilde than on S-types Ida/Eros. This information may help us deduce the nature of cratering events on C-type asteroids (i.e., the importance of cratering by compaction [9,10]).

(951) Gaspra. Gaspra's crater record is highly unusual. It is covered by fresh 0.2-0.6 km craters that follow a slope of *q* = -4.3±0.3 [3], steeper than those derived above for Ida, Eros, and Mathilde. At the same time, Gaspra also has numerous "soft" subdued 0.2-1 km craters with Ida-like *R*-values (0.1-0.2). How can these contradictory data be reconciled?

First of all, the presence of subdued craters with *R* = 0.1-0.2 tells us that the *q* = -4.3 population *cannot* have been hitting Gaspra very long; if it had, the saturation level for the older craters would evolve to $R \approx$ 0.04-0.08 (i.e. values comparable to Sinus Medii). Instead, the older craters were most likely produced by the same SFD striking the other asteroids. Accordingly, Gaspra's fresh crater SFD must come from a recent transient event rather than from time-averaged conditions. We cannot yet say whether they were produced by a local disruption event (e.g., a small breakup in the Flora family) or something more pronounced (e.g., the disruption of the *D* > 170 km asteroid Veritas 8.3 Ma; [11]).

Support for our scenario may come from Gaspra's population of 0.1-0.2 km craters, whose *R* values are lower (0.03-0.08) than similarly-sized craters on Eros (0.08-1.2). Using CRASAT, we simulated how a steep crater SFD affects a saturated cratered surface with *R* = 0.1-0.2. We found that small craters, while remaining in saturation equilibrium, are steadily driven to lower *R* while moderate-sized craters take longer to be affected. These results are very consistent with Gaspra's craters.

Conclusions. Most of the craters on Ida, Eros, Gaspra, and Mathilde are in saturation equilibrium. They were predominately formed by a shallow main belt SFD ($q_a \approx$ -3.6). The steep crater SFD on Gaspra was produced by a recent event and does not represent time-averaged conditions in the main belt. Scaling laws derived from our results indicate that projectiles make craters twice as large on C-type Mathilde than on S-type Ida/Eros.

References. [1] Gault, D.E. (1970) *Radio Sci*. **5**, 273; [2] Melosh, J. (1989) *Impact Cratering*, Oxford; [3] Chapman, C.R. *et al.* (1996) *Icarus* **120**, 231; [4] Woronow, A. (1978) *Icarus* **34**, 76; [5] Chapman, C.R., McKinnon, W.K. (1986) *Satellites* (U. Arizona. Press), 492; [6] Bottke, W.F. et al. (2005) *Icarus* **179**, 63; [7] Chapman, C.R. (2002) *Asteroids III* (U. Arizona. Press), 315; [8] Arvidson, R.E. et al. *Icarus* **37**, 467; [9] Housen, K.R. & Holsapple, K.A. (2003) *Icarus* **163**, 102; [10] Asphaug, E. *et al.* (2002) *Asteroids III* (U. Arizona. Press), 463; [11] Nesvorny, D., et al. (2003) *Ap. J.* **591**, 486.