INTERPRETING THE CRATERING HISTORY OF BENNU, RYUGU, AND OTHER SPACECRAFT-EXPLORED ASTEROIDS. W.F. Bottke[1], D. Vokrouhlicky[2], R.-L. Ballouz[3], O. S. Barnouin[4], H. C. Connolly Jr.[3,5], C. Elder[6], T. J. McCoy[7], P. Michel[8], M. C. Nolan[3], B. Rizk[3], D. J. Scheeres[9], S. R. Schwartz[3], K. J. Walsh[1] D. S. Lauretta[3]. [1]Southwest Research Institute, Boulder, CO, USA (bottke@boulder.swri.edu). [2]Charles University, Prague, Czech Republic. [3]Lunar & Planetary Laboratory, U. Arizona, Tucson, AZ USA. [4]Applied Physics Lab., Johns Hopkins Univ., Laurel, MD, USA. [5]Dept. Geology, Rowan Univ., Glassboro, NJ, USA. [6]JPL, Caltech, Pasadena, CA, USA. [7]Smithsonian National Museum of Natural History, Washington, DC, USA. [8]Observatoire de la Côte d'Azur, CNRS, Nice, France. [9]U. Colorado, Boulder, CO USA.

Introduction. Asteroid crater retention ages are poorly understood because no one knows which crater scaling laws are applicable to different bodies. By comparing results from a main belt collisional evolution model to asteroid cratering records, however, it is now possible to derive crater scaling laws that provide a good statistical match. We find that fits to craters on Vesta, Lutetia, Mathilde, Ida, Eros, and Gaspra yield crater to projectile ratios near 10. Assuming this scaling law also applies to the largest craters on smaller asteroids (e.g., Toutatis, Itokawa, Ryugu, and Bennu), we obtain crater retention ages that match the likely ages of their source families. Intriguingly, these ages are longer than the expected collisional lifetimes of these bodies. This may suggest (i) most bodies escaping the main belt are ancient survivors, (ii) the timescales of asteroid disruption events need to be reassessed, or (iii) our model/data match a fluke.

Craters on Large Asteroids. All asteroids imaged to date have craters, but the interpretation of these records is still debated. The problem is that we have limited understanding of (i) the main belt size frequency distribution (SFD) for sub-km bodies and (ii) asteroid crater scaling laws. Concerning the latter, laboratory shot experiments and numerical hydrocode results yield crater to projectile ratios ($f = D_{crater}/D_{asteroid}$) that can vary from ~5 to 100 [e.g., 1]. This means crater retention ages on an asteroid could be young or ancient, depending on the choices made for (i) and (ii).

Here we deal with this issue by means of a new approach. Using a collisional evolution model [2], we created several different main belt SFDs by varying the asteroid disruption law (**Fig. 1**). All our results reproduce the observed main belt SFD, the distribution of main belt asteroid families from D_{ast} > 100 km parent bodies, and results from cm-scale laboratory shot experiments. For reference, SFD #1 is from [2]. By fitting main belt SFDs #1-#8 to asteroid crater SFDs using a range of candidate scaling laws (f) and crater retention ages (T), we obtain results that can be tested against additional constraints (e.g., family forming event ages, sample ages, etc.).

In **Fig. 2**, we show how our best fit model SFD and scaling law combinations compare with craters on Vesta's Rheasilvia basin. The f values are in the inset figure. Overall, the best results come from f ~ 10, SFDs #5-#7, and T = 0.9–1.4 Ga. These T values are the same as the dynamical age of the Vesta family [3] and $^{40}Ar/^{39}Ar$ ages from HED feldspar grains [4].

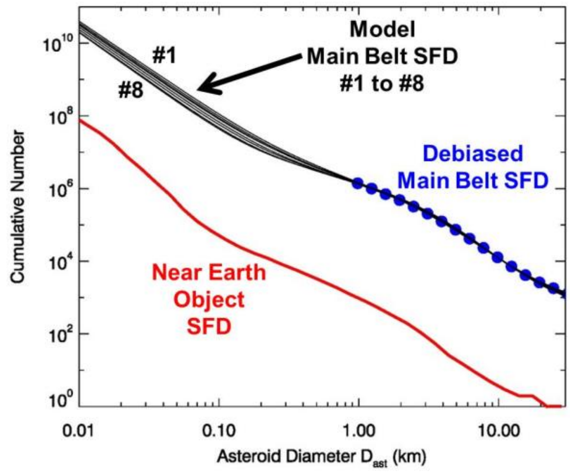

Fig. 1. Our model of the main belt SFD, numbered #1-#8. Our results from #1 match previous work from [2].

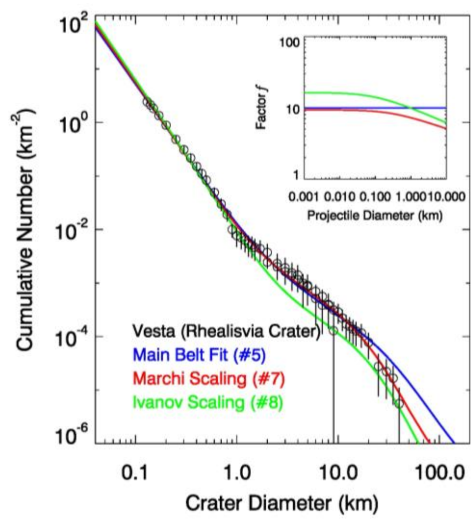

Fig. 2. Rheasilvia's craters vs. model fits for various scaling laws. SFDs from Fig. 1. The inset shows f values for various projectile diameters.

We applied this method to craters on Lutetia, Mathilde, Ida, Eros, and Gaspra [e.g., 5]. In these cases, we also found main belt SFDs #5-#8 and f ~10 provide the best matches. Our results also yield crater retention ages for Ida (2.5 Ga) and Gaspra (1.4 Ga) that match their family's dynamical age [e.g., 6].

Craters on Small Asteroids. Craters on D_{ast}< 3 km asteroids like Toutatis, Itokawa, Ryugu, and Bennu [5,7,8] are challenging to model, partly because their low gravities prevent impact codes from directly computing their final crater sizes but also because erasure mechanisms have removed many D_{crater} < 0.1 km craters. Still, fits to the largest craters on these asteroids yield surprising results.

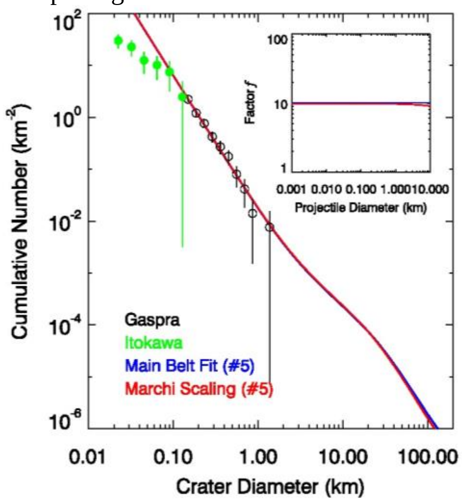

Fig. 3. Model fits for craters on Gaspra and Itokawa. We argue both were once part of Flora family.

Consider Itokawa, a D_{ast} ~0.3 km NEO sampled by Hayabusa [e.g., 6]. All indications are that Itokawa is an escaped member of the Flora family. If we compare Itokawa's largest craters with those of Gaspra, a Flora family member, we find both are aligned (**Fig. 3**). Moreover, T for both matches the $^{40}Ar/^{39}Ar$ ages of Itokawa's samples and the Flora family's dynamical age (i.e., 1.4 ± 0.3 Ga [5, 9]). Though it is small number statistics, it could imply Itokawa's largest craters have never been erased.

Model results suggest that the ages of the Bennu/Ryugu source families are ~0.8–1.4 Ga [10], similar to that of the Flora family. To provide context, we superpose their craters on Gaspra's, while normalizing for their different collision probabilities (i.e., higher for Bennu/Ryugu). We again find an excellent match to the D_{crater} > 0.1 km craters (**Fig. 4**).

Finally, Toutatis' craters (not shown) are a good match for the dynamical age of the Koronis family and the T value for family member Ida (~2.5 Ga).

Discussion. At face value, Itokawa, Toutatis, Ryugu, and Bennu have ancient surfaces for Dcrater > 0.1 km if f ~ 10. Their predicted collisional lifetimes, however, are shorter by a factor of ~5. This contradiction could mean that our matches are flukes. The other possibilities are that (i) the most likely main belt asteroids to escape are long-lived family survivors and/or (ii) we do not yet understand small body disruption. Bennu-Ryugu samples will help us glean insights into this mystery.

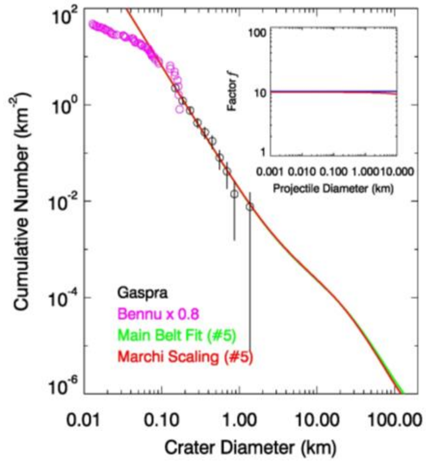

Fig. 4. Bennu craters superposed on Gaspra's craters, with results scaled for collision probability. Gaspra's craters are ~1.3 Ga, yet Bennu's craters line up.

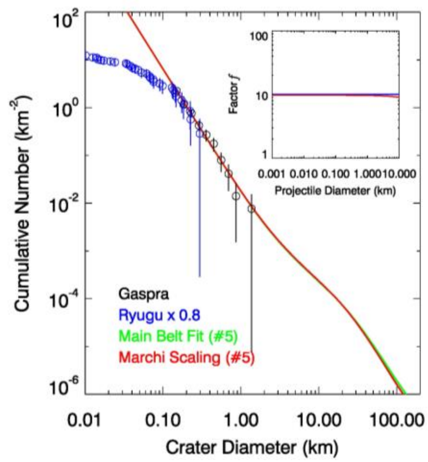

Fig. 5. Ryugu craters superposed on Gaspra's craters.

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