GASPRA'S STEEP CRATER POPULATION WAS PRODUCED BY A LARGE RECENT BREAKUP IN THE MAIN ASTEROID BELT. W.F. Bottke, D. Vokrouhlický, C.R. Chapman, and D. Nesvorný. Southwest Research Institute, 1050 Walnut St, Suite 400, Boulder, CO 80302, USA (bottke@boulder.swri.edu).

Summary. Gaspra's *fresh* craters, which have a surprisingly steep size frequency distribution (SFD), were mostly produced by fragments from the nearby *Baptistina* breakup event that took place ~150 Ma. This means that Gaspra's *eroded* craters may provide the most useful information on the main belt's time-averaged SFD for diameter $D < 0.2$ km asteroids.

Motivation. (951) Gaspra, a 19×12×11 km S-type asteroid, was imaged by the Galileo spacecraft in 1992 [1]. It is located in the prominent Flora family at the inner edge of the main belt. Gaspra was most likely produced by the disruption of the $D > 200$ km Flora parent body. The age of the Flora family (and probably Gaspra itself), according to fossil meteorites produced by the family-forming event, is 470 My old [2,3].

Gaspra's surface shows a complicated and unsaturated crater record for $D_{\text{crater}} > 0.2$ km [4]. Although the power law slope q of Gaspra's total crater size-frequency distribution (SFD) is -2.6 to -2.8 ($N(>D) \propto D^q$), this value is a combination of two populations with different morphological characteristics. Many craters with $D_{\text{crater}} = 0.2$-0.6 km are fresh in appearance, with q values between -3.0 to -3.7. Note that q values near the shallow end of this range are favored by independent crater counters [e.g., 4]. But for $D_{\text{crater}} > 0.5$ km, craters with softened morphology and a shallow slope ($q \sim -2.6$) predominate.

Several ideas have been suggested to explain Gaspra's crater SFD, though none are completely satisfying. Some hypothesize that Gaspra's fresh craters are representative of the time-averaged production population in the main belt (and elsewhere); this would imply that the main belt SFD becomes exceedingly steep for $D < 0.2$ km asteroids [e.g., 5]. This scenario, however, does not explain the shallow slopes of Gaspra's softened/total crater population. It is also inconsistent with main belt SFDs computed from collision modeling work [6] and models of the production SFD needed to reproduce the saturated crater populations on Ida, Eros, and Mathilde [7]. Others have suggested that Gaspra was subject to a large recent impact that preferentially erased small craters via regolith "jolting" and seismic shaking [e.g., 8,9]. While our understanding of crater erasure processes is steadily improving, these models cannot yet explain how the freshest craters on Gaspra obtained a crater SFD slope steeper than the production SFD. Moreover, the large source crater that produced these putative erasure events has yet to be identified.

Our Scenario. To solve the mystery of Gaspra's craters, we investigated Gaspra's regional environment and how it had changed over the last 470 Ma. Using new observational data and numerical tools, we can now explain all aspects of Gaspra's crater record by assuming the following events took place.

(a) 470 Ma. Gaspra was created in the Flora family-forming event.

(b) 150-470 Ma. Gaspra was hit by projectiles from the main belt SFD (with $q = -2.6$ for $D < 0.2$ km). Most of Gaspra's softened craters are from these impactors.

(c) 140-150 Ma. At ~150 Ma, Gaspra's surface was bombarded by a steep swarm of fragments produced by the nearby catastrophic disruption of the $D \sim 170$ km C-type asteroid Baptistina. Baptistina's steep SFD did not last long; comminution by projectiles both inside and outside the family forced its $D < 0.2$ km population into collision equilibrium within ~10 My (i.e., it obtained the same shape as the background main belt SFD). Despite this, the barrage striking Gaspra was so intense that it created most of the fresh craters with $D_{\text{crater}} = 0.2$-0.6 km observed today.

(d) 0-140 Ma. The remnants of the Baptistina breakup and the main belt SFD continued to hit Gaspra. Fresh craters with shallower SFDs "mixed-in" with the steep crater SFD from *(c)*, yielding a slightly shallower crater SFD than that produced by *(c)*.

Evidence in support of this scenario is given below.

Detection/Age of Baptistina Family. The Baptistina family was identified using the Hierarchical Clustering Method applied to the AstDys proper orbital element database [see 10]. A velocity threshold of $V = 47$ m/s yielded 1,100 objects with $H = 11$-19 that could be linked to (298) Baptistina (proper $a = 2.26$ AU, $e = 0.15$, $\sin i = 0.10$). Using Yarkovsky/YORP models to reproduce its a vs. H distribution, we estimate the Baptistina breakup event took place 150 ± 20 Ma [10].

Size of Baptistina Parent Body. SPH/N-body computations [see 11] suggest that the Baptistina parent body was $D \sim 170$ km (assuming 4-5% albedo), roughly the same size as the Veritas parent body that disrupted 8.3 Ma [12]. Unlike that barely-catastrophic disruption, however, the Baptistina parent body experienced a super-catastrophic disruption event; we find the target was pulverized by a ~80 km projectile striking nearly vertical to the surface at 3 km/s.

Baptistina Fragment Distribution. The family SFD created by this impact includes (298) Baptistina ($D \sim 40$ km), and a steep continuum of fragments starting near $D \sim 20$ km. **Fig. 1** shows our effort to reproduce the original family SFD using SPH runs. We also created several model SFDs to estimate fragment sizes below the SPH code's resolution limit (e.g., Fig. 1). For many reasonable test cases, the Baptistina family's initial fragment SFD exceeded the main belt SFD at $D < 0.1$ km. Like the Vertias breakup, Baptistina should have also produced a 3He dust spike on Earth; a probe of ~100-200 Ma terrestrial sediments may help pin down the exact timing of this event [see 13].

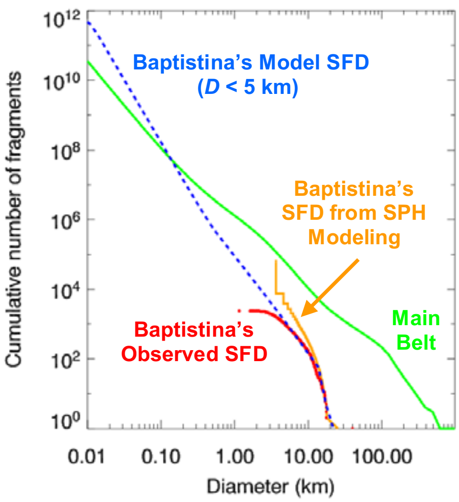

Fig. 1. Size-frequency distribution (SFD) of the Baptistina family compared to the main belt. The SPH model has limited resolution so it gets steeper for small *D*. The model SFD shows one estimate of the family's SFD for small *D*.

Evolution of Baptistina Family. Using CoDDEM, a well-tested code capable of tracking the collisional evolution and dynamical depletion of both the Baptistina family and main belt SFDs simultaneously [6], we tested how long different Baptistina SFDs would survive in the main belt. Our code assumed that the intrinsic collision probability (P_i) of Baptistina fragments with one another was 18×10^{-18} km^{-2} yr^{-1}, while that of the main belt population with one another was 2.9×10^{-18} km^{-2} yr^{-1} [14]. Baptistina SFDs exceeding the main belt SFD were found to readily self-destruct, lasting only ~10 My or so before taking on the same shape as the main belt SFD for $D < 0.2$ km. This explains why small Baptistina fragments do not dominate the inner main belt population today.

Gaspra's Craters and Baptistina. Our last step was to use these results to model Gaspra's crater history over the last 470 My. Input for our cratering code consisted of Gaspra's size, the SFDs of the impactors striking Gaspra between 0-470 Ma, their collision probability with Gaspra, and the crater-scaling relationship for Gaspra. The first two items are found above. For collision probabilities, we used Öpik-like codes [14] to show that Baptistina fragments have P_i values with Gaspra (proper $a = 2.21$ AU, $e = 0.15$, and $\sin i = 0.08$) of 15×10^{-18} km^{-2} yr^{-1}, while "background" main belt objects have 2.8×10^{-18} km^{-2} yr^{-1}. The former value is 5 times higher than the latter one, giving Baptistina fragments an additional competitive advantage over main belt projectiles. For our crater-scaling law, we used the results computed by [7] and assumed that typical projectiles make craters ~12 times their own diameter on S-type asteroids.

Combining these components together, we obtained the results shown in **Fig. 2**. The crater data is from [4]. We find that the inclusion of ejecta from the Baptistina family does a good job of reproducing Gaspra's fresh and total crater SFDs over Gaspra's estimated lifetime.

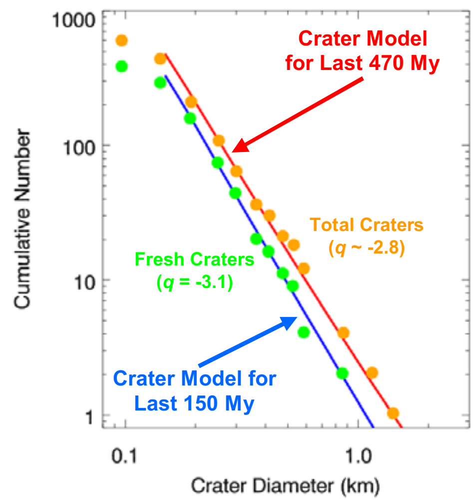

Fig. 2. Comparison between model and observed craters on Gaspra. Here Gaspra is 470 My old and the Baptistina breakup occurred 150 Ma. The Baptistina family is mostly responsible for Gaspra's steep SFD of fresh craters.

Implications. We predict the Baptistina breakup may have produced steep crater SFDs on other nearby asteroids as well. The presence (or absence) of steep crater SFDs on NEAs (e.g., Itokawa) may help us determine their point of origin in the main belt. Because many of Eros's craters are in saturation equilibrium [7], we cannot yet say whether it was affected in some fashion by ejecta from Baptistina.

References. [1] Belton *et al.* (1992) *Science* **257**, 1647. [2] Schmitz *et al.* (2003) *Science* **300**, 961. [3] Nesvorný et al. (2007) *Icarus*, in press. [4] Chapman *et al.* (1996) *Icarus* **120**, 231. [5] Ivanov *et al.* (2002) *Asteroids III* (U. Arizona. Press), 89. [6] Bottke *et al.* (2005) *Icarus* **179**, 63. [7] Bottke and Chapman (2006) *LPSC 2006*, 1349. [8] Greenberg *et al.* (1994) *Icarus* **107**, 84. [9] O'Brien *et al*. (2006) *Icarus* **183**, 79. [10] Vokrouhlický et al. (2006) *Icarus* **182**, 118. [11] Durda *et al.* (2007) *Icarus*, in press. [12] Nesvorný *et al.* (2003) *ApJ.* **591**, 486. [13] Farley *et al.* (2006) *Nature* **439**, 295. [14] Bottke *et al.* (1994) *Icarus* **107**, 255.