THE ROUGHNESS OF VESTOIDS, VESTA, AND OTHER SMALL BODIES AS A CLUE TO THEIR COLLISIONAL HISTORY. B. J. Buratti[1], M. D. Hicks[1], J. K. Hillier[2], J.-Y. Li[3], V. Reddy[4], [1]Jet Propulsion Laboratory California Inst. of Technology, 4800 Oak Grove Dr. 183-401, Pasadena, CA 91109, Bonnie.J.Buratti@jpl.nasa.gov. [2]Grays Harbor College, 1620 Edward P. Smith Dr., Aberdeen, WA 98550, jhillier@ghc.edu. [3]University of Maryland, Deparment of Astronomy, College Park, MD 20742, jyli@astro.umd.edu. [4]Max Planck Inst.for Solar System Research, Katlenburg-Lindau, Germany, reddy@mps.mpg.de.

Introduction: The small bodies in the Solar System are generally thought to be fragments of larger bodies. In some cases, they may be unconsolidated planetesismals, offering clues to the early conditions in the solar nebula and its overall architecture. In both cases their surfaces speak of the collisional processes at work in various locations in the Solar System.

One important clue to understanding the collisional processes on small bodies is the roughness of the surface. Macroscopic roughness on a planetary surface includes everything from clumps of particles to craters, mountains, and ridges. The collisional history and age of a planet's or moon's surface can be understood by counting craters on spacecraft images, but an equally powerful tool in deriving roughness is through the use of models that compute the photometric effects of rough facets on the surface. This technique is especially useful because it can "see" the effects of features that are below the resolution limit of the camera.

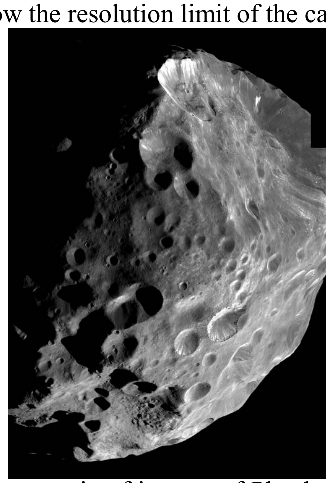

Figure 1. An mosaic of images of Phoebe obtained by the *Cassini* spacecraft in June 2004, showing a heavily bombarded surface. The derived photometric surface roughness is correspondingly high.

Roughness models: Rough features of all scales alter the specific intensity of a planetary surface in two ways: the local incidence and emission angles are changed by alteration of the surface profile from that of a smooth sphere, and they remove radiation from the scene by casting shadows. Two formalisms have been developed to quantitatively model this effect: Hapke's mean slope model [1], and the crater roughness model [2]. The first model is characterized by a surface covered with features with a mean roughness slope angle θ, while the second model is defined by a surface covered (or partially covered) by craters with a defined depth-to-radius parameter. Figure 2 shows an example of a theoretical surface with ever-increasing depth-to-radius ratios.

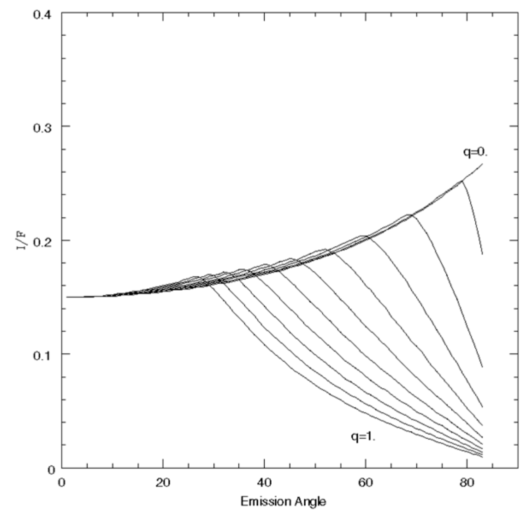

Figure 2. The predicted specific intensity (I/F) as a function of the radiance emission angle for the crater roughness model, with depth-to-radius values (q) ranging from unity to zero. The value of the rough parameter produces a characteristic inflection in the functional form of the curve, leading to a unique determination of it.

Observations and model fits. Spacecraft and ground-based observations have been fit to roughness models over the past two decades. Table 1 summarizes a selection from these results. For easy comparison the depth-to-radius fits have been converted to mean slope angles.

A collection of new telescopic data on vestoids, believed to be fragments of the main belt asteroid 4 Vesta, the first *Dawn* spacecraft target, and the source of the HED meteorites, was obtained in anticipation of the *Dawn*-at-Vesta orbital mission starting in the summer of 2011[3]. Solar phase angles at very large angles, which are not attainable for objects in the Main Belt, were obtained for several vestoid Near Earth Objects (NEOs). A complete Hapke model was fit to the vestoid NEO data, the existing ground-based data on Vesta, and the early survey data from *Dawn*. Figure 3 shows the results of the model with the full collection of observations.

Table 1 – The Roughness of Selected Small Bodies

Object	Single scattering albedo	Slope angle (º)	Reference
Vestoids + Vesta	0.510	32	This work
Average C-type	0.037	20	[4]
Average S	0.23	20	[4]
Phoebe	0.07	32	[5]
19/P Borrelly	0.020 0.057	20 ~35	[6] [7]
Moon	0.25	20	[8]

Results and discussion: One important result is the higher roughness derived from modeling the suite of measurements of Vesta and vestoids. Early *Dawn* images of Vesta (Figure 3) do show a heavily cratered surface, although it is important to realize that the photometric model is capable of observing the effects of rough facets below the resolution limit of the camera. Our result implies Vesta and its family have had a more violent collisional history, comparable to that of the Saturnian satellite Phoebe, which has been battered by the family of outer irregular Saturnian satellites [9]. Another possibility is that Vesta's mechanical properties or mineralogy may be unusual. An additional factor may be a substantial regolith: forming rough aggregates of particles. Our result supports recent radar findings that igneous rocky asteroids – the E and V types - have the largest surface roughness [10].

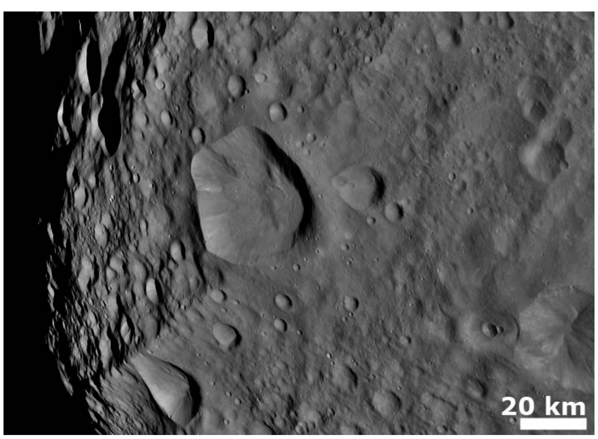

Figure 3. A *Dawn* image from August 2011 showing heavily cratered terrain on its surface.

This result should be considered preliminary, as it is difficult to derive unique photometric parameters from disk-integrated observations. More solid results will be derived as disk-resolved data from *Dawn* is analysed and the roughness of various terrains is fit. Roughness parameters will be compared to crater-counting statistics to define an independent method of determining the chronology of Vesta's surface.

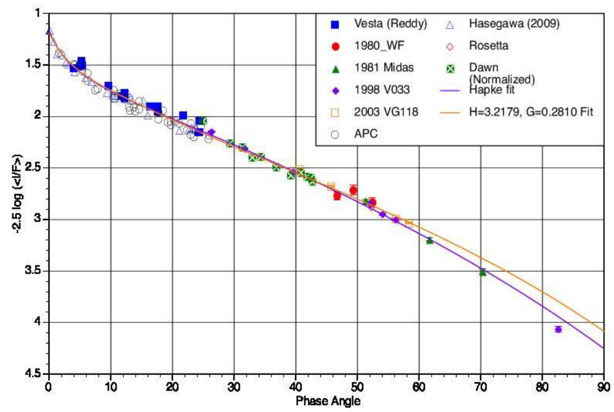

Figure 4. A composite disk-integrated solar phase curve of ground-based data on 4 Vesta [11, 12], early *Dawn* survey full-disk observations, Rosetta observations [13], and ground-based NEO vestoid data. The blue line gives the best-fit Hapke model, corresponding to a roughness mean slope of 32º. The red line is a best fit for the IAU standard asteroid model with H and G parameters, which are related to the slope of the phase curve and the so-called opposition surge at phase angles below 5º.

References: [1] Hapke. B. 1984. *Icarus* **59,** 41. [2] Buratti, B. and J. Veverka 1985. *Icarus* **64,** 320. [3] Hicks, M. et al. 2012, submitted to *Icarus*. [4] Helfenstein, P. and J. Veverka 1989. In *Asteroids II.* (R. Binzel, T. Gehrels, and M. S. Matthews, Eds.), 557. Univ. of Arizona Press, Tucson. [5] Buratti, B. J. et al. 2008. *Icarus* **193,** 309. [6] Buratti, B. J. et al. 2004. *Icarus* **167,** 16. [7] Li, Y.-J. et al. *Icarus* **188,** 195. [8] Buratti, B. J. *Icarus* **61,** 208. [9] Bottke, W. F., et al. 2010. *Astron. J.* **139**, 994. [10] Benner, L. et al. 2008. *Icarus* **198,** 294. [11] Hasegawa et al. 2009. *LPSC* **40,** #1503. [12] Reddy, V. et al. 2012. *Icarus* **217,** 153. [13] Fornasier, S. et al. 2011. *Astron. & Astrophys.* **533,** L9.

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