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Illuminating the bombardment history of the outer solar system

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Abstract

We use crater counts assembled from high resolution Cassini ISS imagery of three saturnian satellites, Phoebe (~ 220 km diameter), Hyperion (~ 270 km diameter) and Mimas (396 km diameter) as inputs into a sophisticated cratered terrain evolution model. Using appropriate scaling relationships, we determine the size frequency distribution (SFD) of small impactors in the saturnian system. We show through dynamical models that this population is dominated by objects originating in the Kuiper belt, and that the flux of main belt asteroids is negligible. We also show that while our derived saturnian system impactor population SFD has many characteristics in common with the main belt SFD, it is distinctly different.

1. Introduction

The Late Heavy Bombardment (LHB) has long remained a puzzling and controversial topic in solar system chronology [1–5]. Recently, it has been suggested that the LHB was not limited to the Moon, but was a solar system-wide event caused by a dramatic rearrangement of the orbits of the giant planets [6–9].

It has been shown that the size frequency distribution of craters in the ancient terrains of the Moon, Mars, and Mercury are well matched by that of the main belt asteroids [8, 10–12]. However, all dynamical models for the LHB to date that are based on giant planet migration predict that the primordial Kuiper belt was very massive [13–17]. These models suggest that the mass flux of cometary population should have been comparable to or dominate over that of the asteroidal population in the inner solar system [7]. However, testing this requires a constraint on the small end of the Kuiper belt SFD that is relevant to crater counting, which is currently poorly known [18]. Here, we use the cratering record of the small saturnian system satellites Hyperion, Phoebe, and Mimas to constrain the outer solar system impactor population.

2. The Cratered Terrain Evolution Model (CTEM)

Recent advances in computing technology and our understanding of the processes involved in crater production, ejecta production, and crater erasure have permitted us to develop a Cratered Terrain Evolution Model (CTEM) which simulates the appearance of a terrain after bombardment by an input projectile population over time [11]. Our previous study showed that the heavily-cratered regions of the lunar surface represent a crater population which is in crater density equilibrium, but which still retains the shape of the impactor population which produced it [11]. Specifically, the SFD of the impactor population which best reproduces the crater density curve for heavily-cratered regions of the lunar surface is nearly identical to that of the current main asteroid belt (MAB), as suggested by Strom et al. [8], and points to the MAB as the primary source for impactors in the inner solar-system. As we show below, we can apply the CTEM to recover the SFD of the impactor population of small saturnian satellites to obtain the outer solar system impactor SFD.

3. Small saturnian satellite craters

We investigate the impactor population for the outer solar-system, beginning with the small saturnian satellites. These bodies share the unique characteristics of: (1) having been imaged at high-resolution by the Cassini ISS; (2) are small enough such that impact cratering is the dominant geologic process; and (3) have very low escape velocities ($< 170 \mathrm{~m~s^{-1}}$) such that secondary cratering is negligible on these bodies – all circular (hyper-velocity) impact craters can be assumed to originate from objects either in heliocentric orbit or planetocentric orbit around Saturn. So far, adequate crater count statistics have been assembled for satellites Phoebe, Hyperion and Mimas. We use these crater counts as constraints in CTEM, by matching the observed crater SFDs with model runs crater counts.

4. Constraining the source region for saturnian satellite impactors

Fig. 1 shows the cumulative size-frequency distribution for a common, heliocentric impactor population which is capable of reproducing the crater count data for Phoebe and Hyperion, as compared to the cumulative size-frequency distribution for the main belt asteroids [19, 20]. Note that the vertical position of the (bold) curve is currently arbitrary and will be constrained with further modeling. In addition to this single-source curve, a dual impactor source, consisting of larger, heliocentric impactors and smaller, planetocentric impactors is also possible, and will be investigated. It is important to note, however, that all attempts to utilize the MAB as the common impactor source for all three satellites have failed, regardless of assumed impact speed. This points strongly to a unique outer solar-system impactor source for the saturnian satellite system.

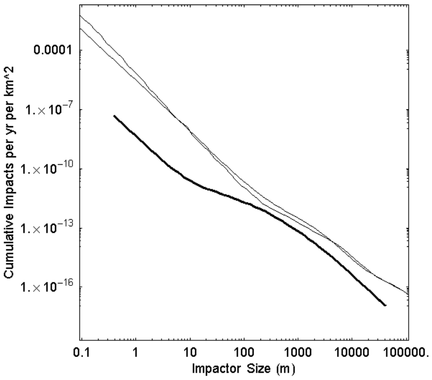

Figure 1: (bold) The impactor population which best recreates the crater distributions on the small saturnian satellites, compared to (thin) two MAB models [19, 20]

In addition, we have performed an N-body study of the dynamical erosion of the asteroid belt over the age of the solar system [21]. One result of this study is an estimate of the relative impact flux of objects originating in the MAB onto major planets. On a per unit area basis, we find that that the total asteroidal impactor flux in the Saturn system is $\sim 2 \times 10^{-3}$ that of the inner solar system.

5. Summary and Conclusions

We used a cratered terrain evolution model to constrain the outer solar system small body impactor population using small icy satellites of Saturn. We conclude that main belt asteroids are an implausible source of impactors in the outer solar system, and that the SFD obtained here may be used to constrain the small end of the Kuiper belt population that is too faint to observe directly.

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6 References

[1] Turner G. et al. (1973) *LPSCIV*, 4, 1889. [2] Tera F. et al. (1973) *Abstracts of the Lunar and Planetary Science Conference*, 4, 723. [3] Tera F. et al. (1974) *Earth and Planetary Science Letters*, 22, 1. [4] Ryder G. (1990) *EOS*, 71, 313. [5] Chapman C.R. et al. (2007) *Icarus*, 189, 233–245. [6] Levison H.F. et al. (2001) *Icarus*, 151, 286–306. [7] Gomes R. et al. (2005) *Nature*, 435, 466–469. [8] Strom R.G. et al. (2005) *Science*, 309, 1847–1850. [9] Minton D.A. and Malhotra R. (2009) *Nature*, 457, 1109–1111. [10] Strom R.G. et al. (2008) *Science*, 321, 79. [11] Richardson J.E. (2009) *Icarus*, 204, 697–715. [12] Head J.W. et al. (2010) *Science*, 329, 1504–1507. [13] Hahn J.M. and Malhotra R. (1999) *AJ*, 117, 3041–3053. [14] Thommes E.W. et al. (2002) *AJ*, 123, 2862. [15] Hahn J.M. and Malhotra R. (2005) *AJ*, 130, 2392–2414. [16] Tsiganis K. et al. (2005) *Nature*, 435, 459–461. [17] Levison H.F. et al. (2008) *Icarus*, 196, 258. [18] Minton D.A. et al. (2008) *Workshop on the Early Solar System Impact Bombardment*, 1439, 43. [19] Bottke W.F. et al. (2005) *Icarus*, 175, 111–140. [20] O'Brien D.P. and Greenberg R. (2005) *Icarus*, 178, 179. [21] Minton D.A. and Malhotra R. (2010) *Icarus*, 207, 744–757.