UNCOVERING THE IMPACTOR POPULATION FOR THE OUTER SOLAR SYSTEM FROM SATURNIAN SATELLITE CRATERING RECORDS. J. E. Richardson[1], D. A. Minton[1] P. Thomas[2], and M. Kirchoff[3], [1]Purdue University Department of Earth & Atmospheric Sciences, 550 Stadium Mall Drive, West Lafayette, IN 47907 (daminton@purdue.edu),[2]Center for Radiophysics and Space Research, Cornell University, Ithaca, NY [3]Southwest Research Institute, 1050 Walnut St., Suite 300, Boulder, CO 80301

Introduction: An apparent spike in the impact flux onto the Moon, including the formation of large lunar basins, such as Imbrium and Orientale, after ~ 4 Gy ago has been attributed to an event called the Late Heavy Bombardment (LHB) [1–4]. The Late Heavy Bombardment (LHB) has long remained a 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 on 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, but which is currently poorly known [18]. Here, we use the cratering records of seven saturnian satellites to constrain the outer solar system impactor population, and show that the Kuiper belt is the most likely source region for these impactors. We also demonstrate that in order to reproduce the cratering record on these satellites, impactor flux levels ∼2-3 orders of magnitude higher than current flux levels are necessary, indicating a period of heavy bombardment in these satellite's earlier histories.

Cratered Terrain Evolution Model (CTEM): Recent advances in 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 ('saturation'), but which still retains a shape indicative 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. In this work, we apply the CTEM to recover the SFD of the impactor population of the saturnian satellites to obtain the outer solar system impactor SFD.

Saturnian satellite cratering records: We investigate the impactor population for the outer solar system using seven saturnian satellites (Phoebe, Hyperion, Mimas, Tethys, Dione, Rhea, & Iapatus), all of which have been imaged at high-resolution by the Cassini ISS. The three small satellites (Phoebe, Hyperion, & Mimas), crater-counted by P. Thomas, are small enough such that endogenic processes are negligible, and have very low escape velocities ($< 170\ \mathrm{m\ s^{-1}}$), such that secondary cratering is negligible. The four larger satellites (Tethys, Dione, Rhea, & Iapatus), crater-counted by M. Kirchoff, use selected regions for small crater counts wherein the effects of endogenic processes are minimal. Comparison of the four larger satellite cratering records to those of the three smaller satellites indicate very little "contamination" from either secondary or sesquinary (planetocentric) impactors, except perhaps on the smallest scales ($<\sim$1 km crater diameter).

Constraining the source region for saturnian satellite impactors: Fig. 1 shows the relative size-frequency distribution [19] of the derived, heliocentric impactor populations capable of reproducing the crater count data for our seven satellites. This is compared to the relative SFD for the main belt asteroids [20, 21] and outer solar system cometary impactors [22,23]. These derived impactor population curves display much better agreement with the outer solar system cometary population (originating in the Kuiper belt), derived by Zahnle [22] and extended to large sizes via observation [23], than with the observed SFD of main belt asteroids. Within crater count data and modeling errors, all attempts to utilize the MAB as the common impactor source for these satellites have failed, for a variety of assumed impact speed or target material properties: pointing strongly to a unique outer solar system impactor source for the saturnian satellite system.

In addition, Fig. 2 shows the cumulative size-frequency distribution [19] of the derived, heliocentric impactor populations capable of reproducing the crater count data for our seven satellites, as compared to the cumulative SFD for the main belt asteroids [20, 21] and cometary outer solar system impactors [22]. Within our CTEM, the impactor flux levels required to reproduce the crater count statistics for each of the small saturnian satellites within a 5 Gyr time-span requires impactor flux levels that are 2-3 orders of magnitude higher than Zahnle's estimates for the current impactor flux level in the outer solar system [22]: pointing strongly toward earlier periods of much higher impactor flux levels within the bombardment histories of each of these satellites. That is, each has experienced earlier periods of heavy bombardment, the scars of which remain evident in their

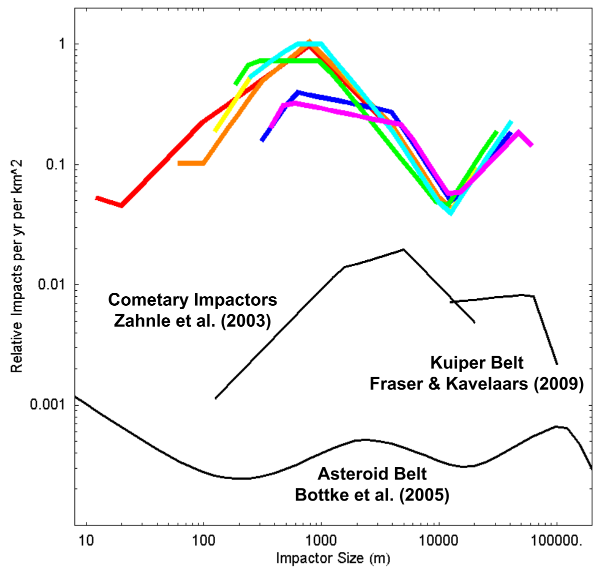

Figure 1: Derived saturnian system impactor population relative size-frequency distribution plots, emphasizing the differences in population shapes as a function of size. The saturnian system impactors are most similar to the derived shape of the OSS cometary (Kuiper belt) population. Colors: red = Phoebe, orange = Hyperion, yellow = Mimas, green = Tethys, cyan = Dione, blue = Rhea, purple = Iapatus.

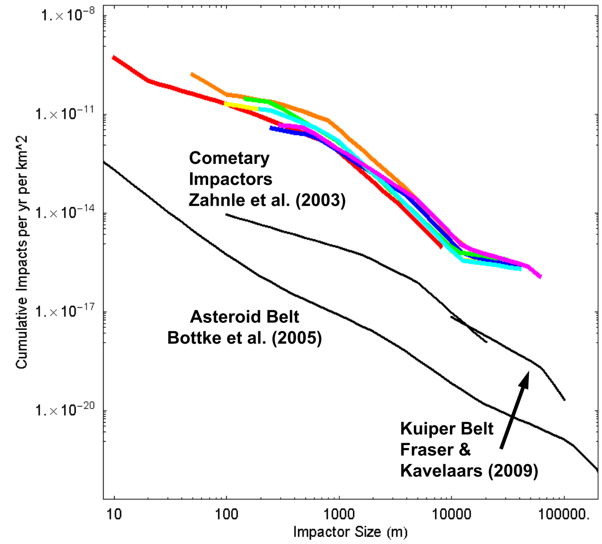

Figure 2: Saturnian system impactor population cumulative size-frequency distribution plots, emphasizing the differences in absolute flux levels for each population. The cratering records of the saturnian satellites require a bombarding population 2-3 orders of magnitude higher than estimates of the current impactor flux level in that region. Colors are the same as those in Fig. 1.

current cratering records.

In addition, we have performed an N-body study of the dynamical erosion of the asteroid belt over the age of the solar system [24]. 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.

Summary and conclusions: We used a cratered terrain evolution model to constrain the outer solar system small body impactor population using seven satellites of Saturn. We showed in Fig. 1 that this population is distinct from the main asteroid belt, and numerical simulations show that the contribution of main belt asteroids to the outer solar system is negligible. 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. Additionally, as shown in Fig. 2, model reproduction of the current cratering record of the small saturnian satellites requires earlier periods of much heavier bombardment when compared to current estimates of the impactor flux in the outer solar system.

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