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The early impact histories of meteorite parent bodies

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Abstract

Collisions between planetesimals during the early stages of planet formation were fundamental and frequent processes, and are often invoked to explain petrologic features of meteorites. To fully understand the collisional history of a meteorite parent body, and therefore draw conclusions about the conditions in the early Solar System, the number and type of impacts expected on a parent body must be quantified. Using a Monte Carlo model, we have tested some of the impact histories proposed for meteorite parent bodies such as the H chondrite parent body.

1. Introduction

The early Solar System was a violent place for young planetesimals. Collisions with other planetesimals were common, and would have affected the evolution of the bodies that would go on to become the asteroids and parent bodies of the meteorites we find on Earth today. As meteorites provide our strongest evidence of conditions in the early Solar System, a full understanding of the histories of their parent bodies is vital.

2. Methods

A large number of planetesimals would have been present in the early Solar System, each with their own collisional history determined by a series of chance encounters with other planetesimals, and depend on the number, sizes and timing of the collision events. Therefore the impact history of a parent body through time cannot be solved analytically.

In this Monte Carlo model, the impact histories of many thousands of meteorite parent bodies are simulated: Collisions are allowed to occur on the surface until either the body is disrupted, or 100 Myr of model time has elapsed. The frequency, impactor size and velocity of the impacts are chosen based on simulations of the dynamical and collisional evolution of a population of planetesimals and planetary embryos during planet formation [1, 2, 3]. Two dynamical models were used: one with Jupiter and Saturn on orbits with their current inclination and eccentricity ('EJS') and one with the giant planets on near-circular, co-planar orbits, similar to that in the Nice model ('CJS'). The collateral effects of each collision are determined based on the impact parameters: crater sizes can be determined from crater scaling laws (e.g. [4], and references therein); impact heating [5] and disruption [6] can be estimated using shock physics calculations.

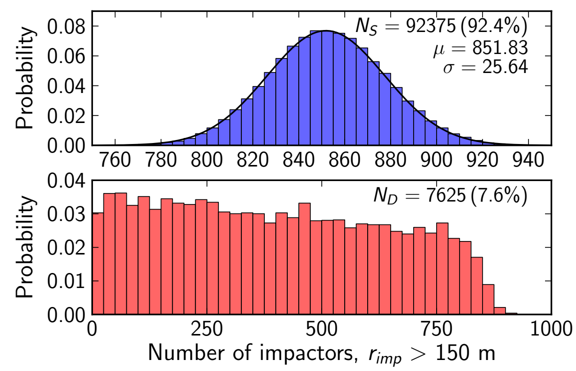

Figure 1: The number of impacts from impactors > 150 m radius during the first 100 Myr, on bodies that survived 100 Myr (top) and those that were disrupted before 100 Myr (bottom), after a total of 10^5 parent bodies were modelled.

3. Results

Parent bodies were separated into two categories: those that were catastrophically disrupted within the first 100 Myr, and those that survived 100 Myr without a disruptive impact event. The average number of impacts on a parent body in each of those populations is shown in Figure 1, for a 100 km radius parent body in the CJS model. 7.6% of bodies were disrupted within

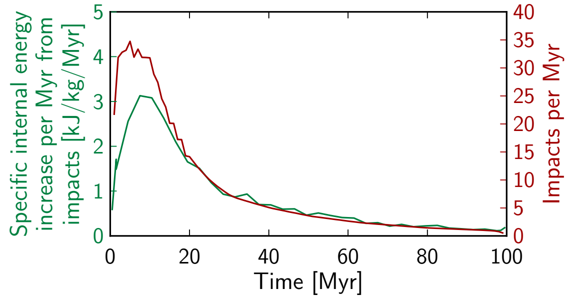

Figure 2: The average specific internal energy increase from impacts (green) and the number of impacts in a given Myr time period (red), as a function of time, after 10^5 parent bodies were modelled.

the first 100 Myr. For those bodies that were not disrupted, $\sim$ 850 collisions with impactors $>$ 150 m in radius were predicted by the model. On average, there was one collision per parent body of impactors greater than 5 km in radius, and one in five parent bodies would have experienced a collision with an impactor $>$ 10 km in radius.

The timing of all impacts can be determined from the model, and is represented in Figure 2. Both the number of impacts and the specific internal energy increase due to impacts follow a similar trend, and show that the first $\sim$ 10–20 Myr is the most important time for impact heating: the same period that radiogenic heating from the decay of short-lived radionuclides (e.g. ^{26}Al) was important.

4. Discussion

In a recent onion-shell model of the H chondrite parent body [7], the authors invoke an impact that excavates to 5.6 km depth to explain the observations of thermal signatures from H chondrite meteorites that were unable to be explained by radiogenic heating alone. Using the Monte Carlo model, we tested this requirement: In the CJS model, 92% of parent bodies experienced at least one impact the excavated to at least 5.6 km depth, and in the EJS model, 77% of all parent bodies experienced such a collision.

The model of [8] suggests impacts played a bigger role in the thermal evolution of the H chondrite parent body, excavating and thoroughly mixing material [9], bringing petrographic type 4 and type 6 material to the surface. From the Monte Carlo model, least 50 collisions per parent body would have brought type 4 material to the surface. The depth of type 6 material in the parent body is not well constrained. In one estimate, it is 11.2 km below the surface; at least one in 5 parent bodies would have experienced a collision bringing material from that depth to the surface. In another estimate, type 6 material is at a depth of just 3.4 km; around 5–10 impacts per parent body would have excavated material from this depth.

We will use the model to further constrain the thermal and impact histories of the CV, CB and IAB/winonaite parent body.

Acknowledgements

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