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Collisional Growth of Planetesimals

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Motivation
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In the current planet formation paradigm, planets form through collisions. While the size of the primordial planetesimals is not yet established, it is recognized that this collision cascade plays an crucial role not only in determining the growth rate of the bodies but also in determining their internal structure as well as bulk chemical composition. In the case of giant gaseous planets, the nucleated instability scenario begins with the formation of critical cores of order 10 Earth masses through this very process as well. Hence, the process of collisional growth underpins the early formation of all planets massive or not.

The most natural and physically appropriate approach for studying these processes is to perform N-body simulations. Unfortunately, simulating the collisional dynamics of a very large number of bodies (several hundreds of millions) over very long timescales (hundred million orbits) turns out to be computationally prohibitive. Therefore, this approach remains for the moment limited to the late stages of formation when the number of bodies has become tractable. Statistical approaches while allowing treating an arbitrary number of bodies do not provide individual collision histories and therefore cannot address some of the most important issues related to the internal structure of young planets.

By introducing an orbit averaging method based on a Monte Carlo technique that allows integrating the system using time steps much longer than an orbital period, we are in a position to follow the individual collision history of several tens of millions of bodies over long evolution times. Hence, this method effectively bridges the gap between the early small planetesimals and the large embryos for which the evolution can be followed using an N-body approach.

Approach
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The method is based on an orbit averaging Monte Carlo process. The essential advantage of the method is to allow for time steps that are not dictated by the orbital period but rather by the processes that contribute to the changing of the orbits. A number of processes can change these orbits. Presently, the code includes physical collisions (assumed to be perfectly sticking), gravitational encounters (e.g. relaxation), gas drag (Inaba et al. 2001), and type I migration (Fogg and Nelson 2007). In order to model the latter two effects, we assume that the planetesimals are embedded in a gaseous disk for whose time evolution and structure are computed using an alpha-disk model.

We will present various tests of the approach including direct comparisons with N-Body calculations. We will also present the result of a simulation following the individual collisional evolution of several tens of millions of particles by computing for each of them the changes as a function of time in mass and orbital parameters (semi-major axis, eccentricity and inclination).

References

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Inaba, S. et al., Icarus, Volume 149, Issue 1, pp. 235-250 (2001)