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LIPAD Simulations of Giant Planet Core Formation

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Abstract. We present some preliminary results from our investigation of giant planetary core formation using numerical simulations with the Lagrangian Integrator for Planetary Accretion and Dynamics (LIPAD) by Levison *et al.* (2012). LIPAD couples dynamics with collisional evolution, including fragmentation. We start with a cold planetesimal disk using particles of a few kilometres in size. Our simulations show growth from kilometre-sized planetesimals to several Earth-mass sized embryos (tens of thousands of kilometers) can occur. However, these embryos may not be large enough to start runaway gas accretion necessary to build the envelopes of gas giant planets.

Keywords. accretion, methods: n-body simulations, methods: numerical, planets and satellites: formation

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1. Introduction

Gas giant planet cores must reach a critical mass (about 10 Earth masses; Mizuno *et al.* 1978) to initiate runaway accretion of their gaseous envelopes from the solar nebula. Observations of stellar disks (e.g. Hernández *et al.* 2009) show that the gas disk lifetime is only 1-10 Myr. The formation of a massive core on such a short timescale is a major challenge for the core accretion model of planet formation. In this work, we seek to determine dynamical processes that could allow for planetary cores to grow this quickly.

2. Methods

We have performed numerical simulations of giant planet core formation from a disk of planetesimals using a new Lagrangian integrator ("LIPAD") by Levison *et al.* (2012). LIPAD is built on top of the Symplectic Massive Body Algorithm (SyMBA) by Duncan *et al.* (1998). A key feature of LIPAD is the ability to couple dynamics with collisional evolution. For example, unlike other numerical integrators, LIPAD allows planetesimals to grow or fragment in size due to interactions with each other. Thus, entire planets or planetary cores can grow from a planetesimal disk. LIPAD handles the large number of planetesimals and collisions statistically. In addition to the planetesimal tracers (a tracer represents a large number of planetesimals on similar orbits), there are also embryo particles that have full N-body interactions with planetesimals and each other. Finally, LIPAD imposes a minimum size on the planetesimals to keep the number of computed collisions to a tractable amount. When planetesimals fragment to a size below this limit, which was set to 0.5 km in this work, these smallest particles are put into a new class that do not have collisional interactions at all. Instead, a constant inward drift rate (due to aerodynamic drag) is imposed.

3. Results

We start with an initial disk of 10,000 kilometre-sized planetesimal tracers from 4 to 10 AU and integrate for 4.5 Myr and include the drag effects of a decaying gas disk. This is a follow-up on previous work by Levison *et al.* (2010) with the SyMBA integrator.

In our work, we notice that there are three main classes out of outcomes, depending on the imposed drift rate on the smallest non-colliding particle class. When the drift rate is very high, these particles sweep by the embryos too quickly for accretion. When the drift rate is very low, the particles become locked into mean motion resonances with the embryos and this causes both the embryos and particles to drift inwards towards the Sun within a million years. The maximum growth of embryos occur for an intermediate drift rate, where the largest embryos form are about 6 Earth masses in size.

These simulations are best viewed in animated form and examples of the above three cases can be found at: `http://gps.caltech.edu/~hngo/IAUS299`.

4. Conclusions

Our work is the first time this type of integrator has been used to study planet formation in the outer Solar System. We found that the smallest particles in the system played an important role in determining the growth and migration of the embryos, an idea also suggested by Wetherill & Stewart (1993) and by Rafikov (2004). In the previous work by Levison *et al.* (2010), the size of the planetesimals (which were not allowed to change in SyMBA) determined the growth and migration of the embryos. Here, with LIPAD, the planetesimals now can vary in size but now it appears that the resulting growth and migration is dependent on the choice of drift rate for the smallest particles. Future work would involve a more realistic treatment of these smallest particles.

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