gadgetbelt: a tool for modeling planetary sculpting of massive debris disks

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Introduction

In models of the sculpting of planetesimal disks by planets, the planetesimals are often treated as test particles, with their effects on the planet modeled analytically. However, this treatment is insufficient in regimes in which: 1) a planet's self-gravity cannot be neglected (i.e. early in the disk's lifetime, it may have mass comparable to the sculpting planet), and/or 2) the back-reaction on the planet by a large number of small planetesimals must be simulated (e.g. for modeling stochastic effects). We are adapting gadget (Springel 2005), a cosmological simulation code, for use in non-collisional debris disks, allowing us to model thousands to millions of planetesimals in a reasonable CPU time through gains in speed from gadget's parallel processing implementation and tree code for N-body interactions. We will use this adaption, gadgetbelt, to explore planet-disk interactions in regimes in which the debris disk's mass is comparable to that of the planet.

Development and benchmarking

Treatment of gravitational forces

We retain the gravitational tree algorithm for planetesimal-planetesimal interactions but compute the forces exerted on and by the planet directly. To do so, we implement a cell opening criterion in which every cell is opened when computing the forces on the planet and in which the cell containing the planet is always opened. The figure on the left reveals discrepancies between the full gravitational treatment using mercury and the approximate treatment using the unmodified version of gadget. Numerical stochasticity causes the planet to random walk with larger steps, resulting in a large net migration. The change in the planet's semi-major axis in turn changes the secular evolution timescale, resulting in a different period for the precession of the planet's node and the oscillation of its inclination.

Computational efficiency

We are exploring the computational efficiency of the gadgetbelt, including how the computation time scales with the number of processors. 20 MEarth corresponds to one million 500-km planetesimals.

Gravitational softening

We are optimizing the gravitational softening (smoothing) parameter that also sets the maximum timestep. In the regimes we are exploring, it is not necessary to follow close encounters among planetesimals.

Example: warped disk

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Future Work

Code development and benchmarking

-- Implementation of a higher-order symplectic integrator for planet particles
-- Assessment of computational efficiency
-- Optimization of gravitational softening parameter
-- Implementation of artificial collisional damping force and other user-defined forces

Applications

Stochastic migration

Murray-Clay and Chiang (2006) developed analytical models for the stochasticity of planetesimal-driven migration, caused by the finite size of Kuiper belt objects (KBOs) entering a planet's hill sphere, and a test of the planetesimal size distribution based on today's population of resonant KBOs, but it was not computationally feasible to combine stochastic migration with N-body models of the global dynamics of the Solar System. We will place constraints on the early planetesimal size distribution through global N-body simulations of early Solar System that include both the planetesimal disk and stochastic migration.

Planetary sculpting of debris disks

Previously, we performed a parameter study of Kuiper belt assembly (Wolf et al. 2012, Dawson and Murray-Clay 2012), in which we modeled the KBOs as massless test particles. We will investigate for which masses of the planetesimal disk the constraints we developed hold, accounting for the back-reaction of the disk and self-gravity.

Acknowledgements

References


In a self-gravitating disk, density waves propagate, launched at the disk edge or at resonances. In the latter case, density waves can smear out the excitation of eccentricities and inclinations caused by secular resonances, as explored by Hahn (2003) using the ring approximation.

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