Introduction & Motivation

Aims. We hereby present preliminary results of our study focused on the dynamics and collisional behavior of planetesimals embedded in a protoplanetary disc which are delivered into mean-motion resonances with a giant Jupiter-like planet via the aerodynamic drag. As pointed out by Morbidelli & Weidenschilling (2002), resonant perturbations can overcome the damping effects of the drag and produce eccentric orbits in an otherwise cold belt of planetesimals, leading to an increased collisional fragmentation. Our aim is to numerically investigate such a system, addressing the following two problems:

Early capture in the resonances. In a recent work of Chrenko et al. (2015), we realized that stable islands of the 2:1 mean-motion resonance with Jupiter partially retain their stability during a jump of Jupiter (induced by late planetary close encounters). It is thus possible that part of the observed long-lived asteroids consist of primordial objects. An open question is whether a primordial population can ever form inside the MMRs.

Relation to the sizes of primordial asteroids. It remains unclear whether the newborn asteroids were indeed big (Morbidelli et al. 2009) or small (Levison et al. 2015). We aim to investigate how the resonant excitation affects the collisional cascade and the primordial size-frequency distribution.

Method

We simulate orbital evolution of minor bodies embedded in a gaseous disc using a modified version of PARAG, a 2D hydrodynamic code described in Masset (2000).

Features of the current version of our code. ► N-body part of the code treats both massive bodies (planets, embryos, etc.) and a population of massless test particles (planetesimals in our case). We replaced the original Runge-Kutta integrator so that the equations of motion are now solved using the Bulirsch-Stoer integrator (Presse et al. 1992) which subdivides the time step until the desired precision is reached (ε = 10⁻⁸). ► Test particles are subject to the gravity of the Sun and all massive perturbers and also to the drag of the surrounding nebular gas. They do not feel any other acceleration (such as the self-gravity, the gas disc gravity, etc.). Particles are allowed to evolve in 3 dimensions, assuming an exponential vertical profile of the surrounding disc. ► The drag treatment is local, the hydrodynamic quantities (∇v, n, ρ) are interpolated from nine grid cell centers (or interfaces) in the neighborhood of each test particle. This approach is the same as in Morbidelli & Nesvorný (2012). The drag coefficient is thus computed similarly to Adachi (1976).

Features to be implemented. ► Direct self-consistent treatment of collisions is yet to be implemented as well as mutual gravitational interactions of (former) test particles.

Hydro & N-body dynamics

Nebular gas. We simulate a portion of gaseous disc extending from 1 AU to 5 AU, with 200 x 343 resolution of the polar spirals.

The planet-disc interaction is smoothed using the thickness smoothing parameter Q = 6, the aspect ratio is η = 0.0055 and the disc is non-flaring. The gas viscosity is parametrized using the Shakura-Sunyaev α prescription (α = ε / (ηH²), where ε is the local SIS viscosity). The total gas mass is 5 × 10⁻³ M☉.

The work of OC and MB has been supported by Charles University in Prague (project GA UK no. 13-01308S). The synthetic population is split into a rather cold belt (e ~ 0.01) and another 3 Myr, but our model differs in the following manners:

► The synthetic population is split into a rather cold belt (e = 0.01) and a hot part created by the resonant excitation (e = 0.15, as we derive from Figure 1). The hot/cold ratio is a free parameter which can mimic the orbital distribution resulting from our dynamic simulations.

► Do we incorporate the effects of viscous stirring, dynamical friction, isolated bodies, collisional damping and turbulent stirring?

► We note that only collisional fragmentation, reaccumulation and gravitational focusing are accounted for.

► We vary the hot/cold ratio to check if the presence of the excited population can strongly affect the SFD.

Collisions

Here we estimate whether the accretion or fragmentation prevails in an excited planetesimal belt using the Boulder code (Morbidelli et al. 2009). To set up our initial synthetic population, we adopted a final SFD that was derived in Morbidelli et al. (2009) from an accretion model of 100 to 1000 km main-belt planetesimals. As they assumed that Jupiter was not yet formed, we ‘continue’ their simulation, spanning another 3 Myr, but our model differs in the following manners:

► The synthetic population is split into a rather cold belt (e = 0.01) and a hot part created by the resonant excitation (e = 0.15, as we derive from Figure 1). The hot/cold ratio is a free parameter which can mimic the orbital distribution resulting from our dynamic simulations.

► Do we incorporate the effects of viscous stirring, dynamical friction, isolated bodies, collisional damping and turbulent stirring?

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Results

Dynamics, see Figure 1.

A transition from Model 1 to Model 2: Generally, the eccentricity kick gets stronger, perturbations by higher-order resonances start to kick in.

Small planetesimals (R < 0.5 km): The maximum eccentricity kick goes from 0.15 up to 0.2. The eccentricity damping is strong, thus the orbits are isolated fast (relatively to the simulation time span) and the particles continue to spiral inwards until they cross another resonance and so on.

Medium-sized planetesimals (R = 10 km): The eccentricity excitation reaches 0.3. There is a much larger spread of planetesimal positions in the phase space than in the previous case. Several planetesimals that were first excited by the 3:2 resonance eventually reach the 2:1 before their eccentricity is fully damped, thus maintaining a non-circular phase space for a longer time span.

Large planetesimals (R = 100 km): these bodies are rather decoupled from the gas, thus the resonant excitation lasts longer. In Model 3, there is a clump of particles that reside in the 2:1 resonance for the whole simulation span.

Collisions, see Figure 3.

For 0.01 and 0.1 hot/cold ratios, the evolved SFD of the cold planetesimal belt is:

► the same as the initial SFD for D < 20 km, with a wavy tail produced by a fragmentation cascade

► depleted (about half an order of magnitude at most) in the range D = 20 to 2000 km, while the slope does not evolve. This depletion is caused by the gradual accumulation of material leading to the formation of larger objects.

For 0.5 hot/cold ratio, the SFDs do not evolve as much as in the previous cases (fragmentation and accumulation are rather balanced).

Future work: simulation with the gas dispersal; implementation of neglected effects into the collisional model; self-consistent treatment of dynamics and collisions.

References & Acknowledgments


Marzari F., weidenschilling S., 2002, CeMDA, 82, 225.


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