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The circumstellar environment of terrestrial planets
I. Behavior of protoplanetary cores under the influence of rapid migrators

Tomek Sołtysiński *

Institute of Physics, University of Szczecin,
Wielkopolska 15, 70-451
Szczecin, Poland

%pagestyleempty **Abstract:** We investigate the evolution of young protoplanets under the influence of rapidly passing giant through their swarm. A nonhomogenous system of protoplanetary cores affected by a gas drag is modelled and we perform numerical experiment to see its response to rapidly migrating giant planet. We are particularly exploring a little cell of parameter space of such swarm, looking for the cores highest survival rate. This rate is still high enough to avoid the fate of the Last of Mohicans and quarantees further formation of terrestrial planets close to their original location.

1 Introduction

The origin of terrestrial planets is complex and not fully recognized process. It depends on formation and evolution of solid content of protoplanetary disk as well as its interaction with surrounding medium under influence of radiation. This surrounding exhibits phenomena like migration, coagulation and collisional dynamics which all have enormous impact on the entire environment in which these planets forms. According to the results of exoplanet search (Schneider, 2004) most of found exoplanets doesn't correspond to those known from Solar System.

The phenomena like planet migration drived by protoplanetary disk is very probable explanation. Being known for tens of years it was suspected to be slow in linear regime and fast in the case of nonlinear interaction. Both are not rapid enough to pass through the region of young protoplanets without its total destruction done mostly by pushing them onto the star.

Recently Artymowicz and at the same time Papaloizou & Masset (2003) has shown that corotation region close to giant migrator may drive its migration much more rapid even in the case of a disk of typical mass like those observed around TTauri and HAEBE stars. This is new, previously unknown mode recently classified as type III migration (Artymowicz 2004).

*tomasz_s@vp.pl

We are investigating what are the consequences of such event for a swarm of nonhomogenous colliding protoplanets placed in the region of terrestrial planets of Solar System.

2 Numerical methods

To evolve our models we have applied standard n-body techniques with individual time step control for each body (Binney & Tremaine, 1987) extended to double precision mode. We allow all bodies to aglomerate and all collisions are treated as inelastic. In real physical protoplanets system around 90 % of colliding mass is contained in resulting body thus we are simply adding colliding masses and assign it to a final protoplanet. All protoplanets are also being damped by the interaction with surrounding gaseous medium. To test and set the accuracy of our method we set a 1 M_J planet on circular orbit around 1 $M_\odot$ star at the distance 0.1 AU and we kept the dissipation of system's energy to be less than 0.01 % within $1.5 \cdot 10^5$ yrs. The test model was not damped by gas. To test the correct physical behavior of models we first followed the simulation of a test set of particles as in (Papaloizou & Larwood 2000). Next we performed test runs for models with different damping constants until the system have reached stable equilibrium.

3 Disk setting

To explore parameter space of planetesimal disk we run four models, each consisting of 200 planetesimals, one migrator of 1 Jupiter mass and a star. All models have mass distribution according to power law with index equal to -2.5. Models has different initial surface density profiles (azimuthally averaged). Properties of models are shown in tables.

Max. mass	$\Sigma = r^{-3/2}$	$\Sigma = r^{-1/2}$
0.01	Model 1	Model 2
0.3	Model 3	Model 4

Total mass of each disk is $1M_\oplus$ and central body is a $1M_\odot$ star. Each body has been settled between 0.5 and 1.5 AU according to disk's surface density profile. In models 1 & 2 they are separated by at least 20 Hill radii from each what is post-oligarchic stage and keeps them in isolation. Masses in models 3 & 4 are randomly distributed along the radius within given surface density profile. This condition makes them to be almost at the end of their oligarchic growth and close to their isolation mass.

4 Disk evolution.

The models were run for 15000 yrs. We set the damping timescales to 1000 years for eccentricity and inclination damping what corresponds to minimal mass solar nebulae (MMSN). The migrator was moving inward on the same timescale. Such timescale is not possible for standard migration modes unless the mass of nebula is extremally high. Assuming type III migration this migration timescale is well justified although has to take place inside a gap. The effect of a gap is not modelled here. The protoplanets are no migrating as its timescale is few orders higher than that of migrator and may be neglected.

The mean eccentricity of swarm is shown on figure 1. Pumped by rapidly passing giant planet it is highly increasing to the values much higher than its equilibrium level. It has

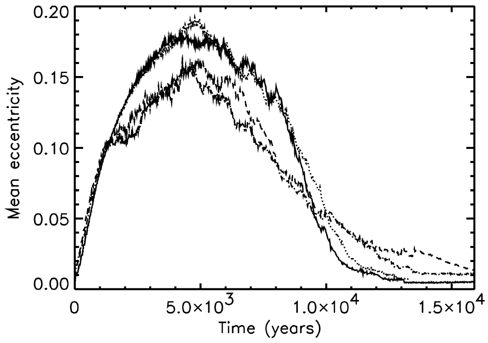

Figure 1: Mean eccentricity evolution. Model 1 - solid line, model 2 - dotted line, model 3 - dashed line, model 4 - dashed-dotted line.

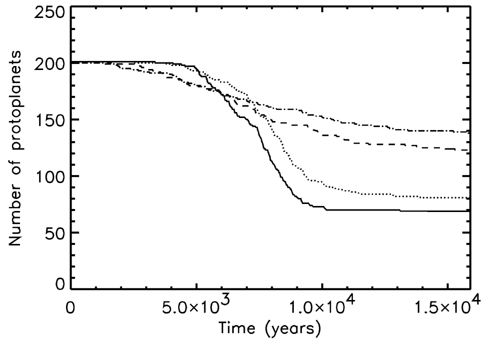

Figure 2: Number of protoplanet in time in each model. Model 1 - solid line, model 2 - dotted line, model 3 - dashed line, model 4 - dashed-dotted line.

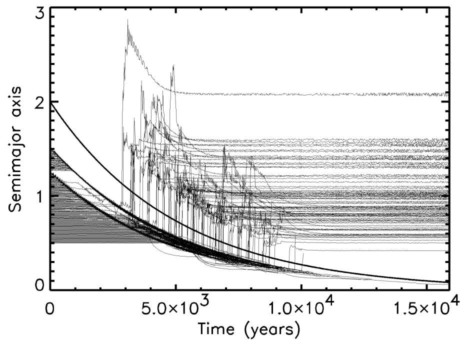

Figure 3: Model's 2 semimajor axis of protoplanets evolving in time. The heavy migrator starts from 2.0 AU.

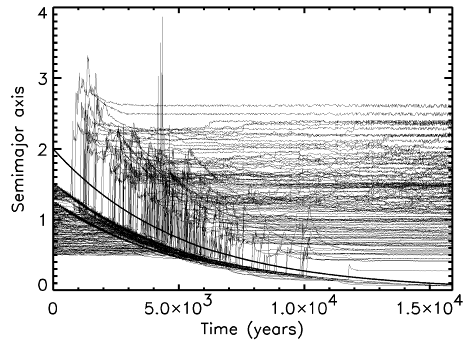

Figure 4: Model's 4 semimajor axis of protoplanets evolving in time. The heavy migrator starts from 2.0 AU.

similar character for all models. We notice some dependence of the maximum value on mass distribution which is less by 15 % for models with higher mass range diversity. Figure 2 presents the protoplanet number during evolution. It exhibits the same dependence as seen on fig. 1 providing twice higher collision rates for more uniform distributed systems (model 1 & 2). Figures 3 & 4 shows the position of semimajor axis during entire simulation of two example runs. This behavior looks similar in all cases giving higher distortion and more distant ejection for less uniform distribution. A few protoplanets are kept in resonance with migrator and are being pushed on crossing orbits. Some of them are moved behind the snow line. Due to damping by gas they finally return to excited but stable equilibrium state. In this stage the gravitational scattering is compensated by effective damping what leads to stable configuration supporting further evolution of terrestrial cores.

5 Discussion. Avoiding the Last of Mohicans scenario.

The very high survival rate during and after the migrator passage of protoplanets quarantees avoiding the Last of Mohicans scenario unlike its original literature ancestor. In the case of slow migration terrestrial cores are mostly and efficiently rejected from their locations in *habitable zones*. They are being moved out of the inner system by rejection or pushing onto a star sharing the fate of the real Mohicans, what we have confirmed by some runs not presented here. In the case of our rapid migration, we have 30-60 % of survivors and stable population of large protoplanetary cores. This strongly favours their further evolution allowing for resonant trapping and gathering of volatiles.

Excited protoplanets are able to explore the region even as far as 4 AU. Then they have high eccentricities and are quickly damped by the surroundings of dusty and gaseous medium as well as dynamical friction inside the swarm. Very high eccentricity, in the case of MMSN higher than $1.1H/r$ where H is disk semiheight and r distance from a star, is able to generate net torque exerted on the core by the disk in that way that it starts to gain angular momentum and migrate outward (Papaloizou & Larwood 2000). If this process takes place it may serve as an efficient way of providing well developed cores, being even few times size of the Earth, to the region when they may gather a gaseous envelope and become another giants. The reversal of direction of migration is favourable when each excited body remains on highly enough eccentric orbit for several tens or hundreds orbits.

The final, excited and damped swarm is spread out by around an AU. This increases mutual separation of protoplanets decreasing their collisions rate and exchange of angular momentum what further makes gravitational scattering less efficient.

More complex exploration of parameter space of the disks and swarms pumped by rapidly passing giant planet the reader will find in Edgar, Sołtysiński, Artymowicz (2004).

The process investigated through this study should have provided observational signatures like rapidly changing disk density perturbations by spiral waves and pushing protoplanets toward a star according to rapid migration of giant, changing rate of dust and solid content production according to collisional evolution (Thébault et al., 2003) and forcing bodies to enter crossing orbits, and finally changing disk matter distribution. This is going to result in varying flux distribution as well as modified spectral energy distribution. As this sort of phenomena is going to be the most violent and detectable at the inner part of a disk its observational study is still beyond the scope of present facilities and is going to be a possible target for post-VLTI facilities in forthcoming new era of high resolution imaging.

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