EPSC Abstracts
Vol. 6, EPSC-DPS2011-1139, 2011
EPSC-DPS Joint Meeting 2011

Planetary Population Synthesis: the importance of the solids accretion rate

A. Fortier (1), Y. Alibert (1), F. Carron (1), C. Mordasini (2), and W. Benz (1)
(1) Physikalisches Institut, Universität Bern, Switzerland, (2) Max-Planck Institute for Astronomy, Heidelberg, Germany

Abstract

In the framework of the nucleated instability model, the formation time-scale of giant planets is very sensitive to the time it takes to build the solid core. The accretion of solids can be described by two different, consecutive regimes: it first proceeds in a very fast fashion, known as *runaway growth*, and later on in a much slower regime, the so-called *oligarchic growth*. The transition between the runaway and the oligarchic growth depends on many parameters (e.g. the isolation mass and the size of the accreted planetesimals), but as a general rule we can assume that an embryo of a Lunar mass is already an oligarch. Then, the timescale to build a 10 Earth masses ($M_\oplus$) core is regulated by the oligarchic regime, as the previous runaway stage proceeds in a negligible amount of time compared to the oligarchic timescale.

In this work we show the results of adopting the oligarchic growth for the core in planetary population synthesis calculations. In previous works (see [1], [2]) a fast solids accretion rate was prescribed, leading to a very fast formation of massive solid embryos. Here we show that when considering the oligarchic growth, the formation of giant planets is more difficult, especially in the outer parts of the disk, where the formation of big planets is almost impossible under these hypothesis. On the other hand, many Earth to Super-Earth sized planets are found in the very innermost parts of the disk. However, if the size of the accreted planetesimals is reduced, the formation of giant planets is more likely, preserving also a large amount of smaller planets. We also consider the formation of planetary systems, including the N-body interaction between the forming planets and the collisions that may occur among them during their migration. In the case of many planets forming in the same disk, we find that the final masses of the planets are smaller (but not too small) than in the case of a single planet per star.

1. The model

The main hypothesis of our model for the population synthesis calculations can be found in [1], [2]. Here we summarize the differences in the physical assumptions between the two works. The protoplanetary disk extends from 0.1 AU to 30 AU, considering that at the inner boundary the surface density satisfies $\Sigma = 0$, and that the initial surface density profile follows a power law, $\Sigma_0 \propto r^{-1.5}$. The disk evolves with time due to accretion onto the star (taking into account the out of equilibrium effect), photoevaporation and accretion onto the planets (this means that the gas accreted by the planets is removed from the disk). The growth of the planets is calculated self-consistently, coupling the accretion rate of solids to the accretion rate of gas. Planet migration is considered: for Type I migration, the isothermal model is adopted with a reduction factor in the migration rate of 0.1. The condition for gap opening takes into account the viscosity of the disk and the standard criterion of the Hill radius being larger than the disk height scale (see [3]).

Regarding the accretion rate of solids, in previous works it was assumed to be very high, close to that of the runaway regime. For the present paper, the oligarchic growth regime for the core is adopted. Following [4], and references therein, we calculate the accretion rate of solids in the framework of the particle-in-a-box approximation of [5], where the accretion rate of an embryo depends on the collision probability of planetesimals. This probability depends on the relative velocity between the embryo and the incoming planetesimals which, in turn, depends on the eccentricities (e) and inclinations (i) of planetesimals populating the disk. As in [4], we solve the full differential equations (out of equilibrium) for e and i all throughout the protoplanetary disk, considering the stirring due to the embryos and the damping due to the gas drag of the nebular gas. In all the cases, the initial values are $e_0 = 2i_0 = 2 \times 10^{-3}$.

Every population synthesis calculation considers the formation of 5000 planets, one planet per disk, randomly distributed in semi-major axis. The seeds for the planetary embryos are of the Moon mass at the beginning of the simulation (this corresponds to $t = 0$). The range for the disk masses is 10^{-2} to 10^{-1} solar masses, and the photoevaporation rate is adjusted to have disk lifetimes not longer than 6 Myrs.

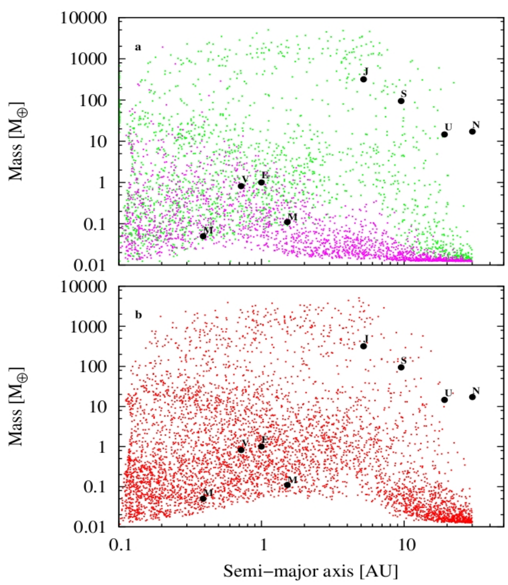

Figure 1: Top panel (a): in green, results for calculations adopting a fast growth for the core; in pink, the same simulation parameters but prescribing the oligarchic growth. All simulations start with the mass of the Moon and the size of the accreted planetesimals is 100 km. Bottom panel (b): cores growing oligarchically, but now accreting 100 m planetesimals.

2. Results

The aim of this work is to show the role of the solids accretion regime in a population synthesis calculation. For that purpose we calculated a planetary population synthesis adopting the accretion regime used in previous works and another one adopting the oligarchic growth model. Results are shown in Fig.1 (a), with the location and masses of the planets of the solar system as a reference. It is evident from the figure that, while in the case of the fast accretion rate there are plenty of giant planets, when the oligarchic growth is adopted, no massive planets are found beyond 1 AU, and there are only a few close to the star. Most of the planets have masses below 10 $M_\oplus$ in the inner part of the disk and below 1 $M_\oplus$ in the outer part. This is due to the fact that formation times are longer than the lifetime of the disk.

It has been shown (e.g. [6]), that if the size of accreted planetesimals is reduced, the formation of planets is accelerated. Smaller planetesimals are more strongly affected by the gas drag, both by the gaseous component of the disk (damping their eccentricities and inclinations, therefore reducing the relative velocities) and by the gaseous envelope of the planet (enlarging the effective capture cross-section). In Fig. 1 (b) we present a simulation considering that the radius of the accreted planetesimals is 100 m. Results for this case are clearly different to those where 100 km planetesimals are adopted, as now the formation of giant planets is much more efficient all throughout the disk.

We have also calculated the formation of planets in planetary systems considering full N-body interactions among the protoplanetary embryos. The mass–semi-major axis distribution for this case is similar to the one shown in Fig 1 (b), although the mean mass of the giant planets is lower. Having more planets growing in a disk means that the same amount of matter has to be shared by many embryos, then the resulting planets are smaller.

3. Summary and Conclusions

We studied the formation of planetary systems in the context of the population synthesis model. The aim of this work was to study the impact of the solids accretion rate in the distribution of final masses versus location in a wide variety of planetary systems. We found that when a realistic accretion rate (oligarchic regime) is adopted, the formation of giant planets is almost impossible within the lifetime of the protoplanetary disk, unless small planetesimals, of about 100 m in radius, are assumed to populate the disk.

References

[1] Mordasini C., Alibert Y., Benz W., 2009, A&A, 501, 1139

[2] Mordasini C., Alibert Y., Benz W., Naef D., 2009, A&A, 501, 1161

[3] Crida A., Morbidelli A., Masset F., 2006, Icar, 181, 587

[4] Guilera O. M., Brunini A., Benvenuto O. G., 2010, A&A, 521, A50

[5] Inaba S., Tanaka H., Nakazawa K., Wetherill G. W., Kokubo E., 2001, Icarus, 149, 235

[6] Fortier A., Benvenuto O. G., Brunini A., 2009, A&A, 500, 1249