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A possible origin of compact systems of hot Super Earths

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Abstract

Earth-mass planets embedded in gaseous protoplanetary disks undergo Type I orbital migration, which can be directed either inward or outward depending on the local disk properties. Special locations exist in the disk toward which planets migrate in a convergent way (Convergence Zones). However, we show that planets do not systematically converge in convergence zones. Rather, they become trapped in chains of mean motion resonances (MMRs). This causes the planets' eccentricities to increase to high enough values to affect the structure of the horseshoe region and weaken the positive corotation torque. The zero-torque equilibrium point of the resonant chain of planets is shifted inward and the planets migrate interior to the Convergence Zone. We show that compact systems of hot Super Earths are a natural outcome of this process. In a disk with an artificial convergence zone at 3 AU, cohorts of resonant planets systematically migrate to the inner edge of the disk whenever there are more than 10 embryos in the disk. In more realistic disks systems of hot Super Earths are also naturally produced, although the evolution can be more complicated. In addition, more distant planets often survive, perhaps representing giant planet cores or terrestrial planets. Finally, we discuss which disks form giant planet cores at a few AU rather than hot Super Earths.

1. Introduction

A major problem in planet formation is the growth of giant planet cores. Convergence zones in protoplanetary disks represent one potential solution to this problem. A planet of a few $M_{\oplus}$ in a radiatively-inefficient region of a disk migrates outward due to a strong corotation torque. The migration slows as the planet enters regions of the disk that cool more efficiently (i.e., have smaller optical depth), and stops when the planet reaches a region in the disk where the total torque is zero Paardekooper et al. (2011). A planet of the same mass that formed farther out in the disk migrates inward to this same orbital distance. These convergence zones can thus concentrate mass within the disk Mordasini et al. (2011).

However, eccentricity do have an effect on the corotation part of the torque (Bitsch & Kley 2010), resulting in a net inward shift of the convergent migration (Cossou et al. 2013), which can help to form close-in, compact resonant systems.

2. Inward shift of equilibrium position

Planets do not actually converge in convergence zones (CZs). Instead, embryos rapidly migrate toward the CZ and are trapped in chains of MMRs. This causes their eccentricities to increase and remain high enough to attenuate the corotation torque. The zero-torque equilibrium point of the resonant chain of planets is determined by the sum of each individual planet torque (sum of attenuated corotation torque and unattenuated differential Linbdlad torque). In practice, the effective zero net torque zone is shifted inward and is most strongly determined by the CZ of the most massive planet in the resonant chain. It is not a true CZ because each planet feels a different CZ (depending on its eccentricity).

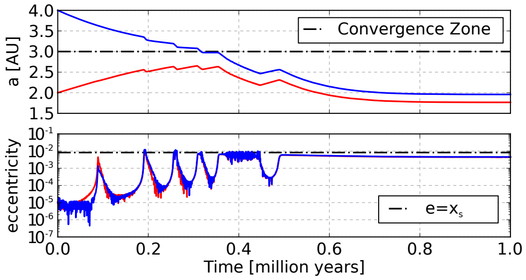

Figure 1: Simulation of the convergent migration of two 1 $M_{\oplus}$ planets toward the CZ at 3 AU including the $\Gamma_C - e$ feedback.

3. Dynamical Outcome

We now use the mercury code Chambers (1999), which we modified by adding the migration torque formulae given by Paardekooper et al. (2011). In our simulations, the surface density profile decreases as a power-law and the temperature profile is computed by assuming that only viscous heating operates inside the disk. Radiative cooling is computed using the opacity table in Bell & Lin (1994).

For different masses and position in the disk, Fig. 2 displays the adimensioned torque profile. The figure can be read as follows : An iso mass (constant y) gives the torque felt by a planet for various positions in the disk. The black line represents the zero-torque zone in the disk.

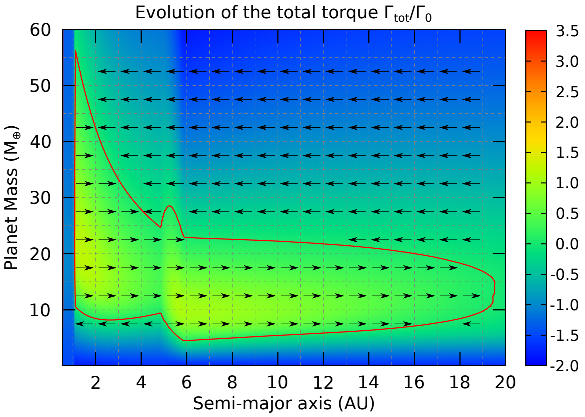

Figure 2: This diagram represent the torque felt by a planet of a given mass and position in the disk. The arrows shows the direction of migration, and the black line show the zero-torque zone.

The inward shift of convergence zone combined with a torque diagram such as the one shown in 2 can give us several outcomes. First, there can be insufficient embryos to create a resonant chain, or embryos can migrate to very different locations or an embryo can be ejected far away in the disk so that it evolve as if isolated from the other bodies. In those cases, the planet will simply migrate to their expected location, ruled by type I migration, either inward or outward, to a zero torque zone. In particular this can create a population of isolated giant planet cores that are perfect candidates to form giant planet far away in the disk such as Jupiter.

Second, resonant chains can be created. The absolute inward shift will be determined by various quantities such as the total number of embryos in the planetary chain, the most massive planet or mass ratio in the system. In any case, the result will be a compact system of planets in Mean Motion Resonances. Increasing the total mass and the number of embryos will result in a few higly massive planets close to the inner edge of the disk in the end.

There can be several ways to stop inward shift of the resonant system. First the system can stabilize to an equilibrium position where the total torque exerted on the resonant system as a whole is almost zero. In this case, the resonant chain can halt anywhere in the disk between the inner edge and the nominal convergence zone.

But the resonnant chain can also halt at the inner edge, where the disk surface density decrease quickly. This sudden change in surface density can revert lindblad torque. Since we consider that below the inner edge, the migration is no longer possible, the compact system stays here in most cases, even if dramatic events can still occurs.

Our 1D model, coupled with type 1 migration model and shifted equilibrium position effect can produce a large range of planet populations, from compact system close to their host stars to far away giant planet cores. A huge set of disks can produce very differents outcomes, especially by varying, even by tiny amount, the surface density, the viscosity and opacity profiles.

References

Bell, K. R. & Lin, D. N. C. 1994, ApJ, 427, 987

Bitsch, B. & Kley, W. 2010, A&A, 523, A30

Chambers, J. E. 1999, MNRAS, 304, 793

Cossou, C., Raymond, S., & Pierens, A. 2013, ArXiv e-prints

Mordasini, C., Dittkrist, K., Alibert, Y., et al. 2011, Arxiv preprint arXiv:1101.3238

Paardekooper, S.-J., Baruteau, C., & Kley, W. 2011, MNRAS, 410, 293