The Astrophysics of Planetary Systems: Formation, Structure, and Dynamical Evolution
Proceedings IAU Symposium No. 276, 2010
A. Sozzetti, M. G. Lattanzi & A. P. Boss, eds.

doi:10.1017/S1743921311020655

Simultaneous formation of Jupiter and Saturn

Octavio M. Guilera [1,2], **Adrián Brunini** [1,2] **and Omar G. Benvenuto**[1,2]

[1]Facultad de Cs. Astronómicas y Geofísicas - Universidad Nacional de La Plata, Argentina
[2]Instituto de Astrofísica de La Plata (IALP) - CONICET
email: oguilera@fcaglp.unlp.edu.ar

Abstract. We calculate the simultaneous *in situ* formation of Jupiter and Saturn by the core instability mechanism considering the oligarchic growth regime for the accretion of planetesimals. We consider a density distribution for the size of planetesimals and planetesimals migration. The planets are immersed in a realistic protoplanetary disk that evolves with time. We find that, within the classical model of solar nebula, the isolated formation of Jupiter and Saturn undergoes significant change when it occurs simultaneously.

Keywords. planets and satellites: formation, planets and satellites: individual (Jupiter, Saturn)

1. Introduction

At present, the core instability model is usually considered as the way giant planets formation proceeds. This mechanism was envisaged by Mizuno (1980) by employing static models and later with evolutionary models by Bodenheimer & Pollack (1986) and Pollack *et al.* (1996). Core instability calculations of giant planet formation have been carried out by many groups, e.g., Alibert *et al.* (2005), Hubickyj *et al.* (2005), and Dodson-Robinson *et al.* (2008). Fortier *et al.* (2007, 2009) were the first to consider the oligarchic growth regime for the accretion of planetesimals. However, one usual assumption in detailed simulations of planetary growth is that each planet grows alone in the disk. This would be correct if the population of planetesimals to be accreted by one planet were not appreciably perturbed by the presence of another embryo. At first sight, it may be understood that this is the case if the feeding zone of each planet does not overlap the one corresponding to any other planet. However, this is *not* the case if we include planetesimal migration. This process leads to a net inward motion of planetesimals. A planet will perturb the swarm of planetesimals that may be later accreted by another planet moving along an inner orbit. Moreover, as we show below, even the presence of an inner planet will be able to affect the accretion process of an outer object.

2. Results

In our work Guilera *et al.* (2010), we developed a numerical code to compute the simultaneous formation of giant planets immersed in a protoplanetary disk that evolves with time. We used this code to calculate the *in situ* simultaneous formation of the gaseous giant planets of the solar system. We considered a disk 5 times more massive than the classical "minimum mass solar nebula" of Hayashi (1981). We quantitatively analyzed the effects due to simultaneous formation of Jupiter and Saturn (at its current locations) comparing with the results corresponding to the case of isolated formation. When we refer to isolated formation we mean that we have considered that only one

	Jupiter M_c $[M_\oplus]$	t_f $[My]$	Saturn M_c $[M_\oplus]$	t_f $[My]$
Isolated formation	28.30	2.20	20.51	6.37
Simultaneous formation	29.68	1.96	3.35(*)	$\gg 15$

Table 1. Comparison between the isolated and simultaneous formation of the solar system gaseous giant planets for a disk 5 times more massive than the Hayashi nebula. Here M_c stands for the final core mass and t_f for the formation time.

planet forms in the disk while it evolves. The results we have obtained are resumed in Table 1.

For the case of the isolated formation, we found that both planets are formed in less than 10 Myr. This is in good agreement with the current observational estimations. We also found that the final core masses were in good agreement with the current theoretical estimations. We remark that we assumed that all the infalling planetesimals reach the core's surface without losing mass on their trajectories throughout the envelope, this meaning that M_c really corresponds to the total heavy element's mass in the interior of the planet (core *plus* solids in the envelope).

Considering the simultaneous formation of both planets we see that Saturn has almost no effect on the formation of Jupiter. However, the opposite is not true: the formation of Jupiter, clearly inhibits the formation of Saturn. The simulation was halted at 15 My. At this time, the embryo of Saturn achieved only a mass of $M_c \sim 3.5$ $M_\oplus$ with a negligible envelope (*).

The inhibition of the formation of Saturn is caused by an eccentricity and inclination excitation of the planetesimals related to Jupiter's perturbations. This excitation causes an increment in the migration velocity of planetesimals at the Saturn's neighborhood when both planets are formed simultaneously. The increment in the migration velocity of planetesimals causes the solid accretion timescale to become longer than planetesimal migration timescales, and the solid accretion rate of Saturn (when it is formed simultaneously with Jupiter) becomes less efficient than for the isolated Saturn formation (see Guilera *et al.* 2010). The most important result is that the rapid formation of Jupiter inhibits -or largely increases- the timescale of Saturn's formation when they grow simultaneously.

References

Alibert, Y., Mordasini, C., Benz, W., & Winisdoerffer, C. 2005, *A&A*, 434, 343

Bodenheimer, P. & Pollack, J. B. 1986, *Icarus*, 67, 391

Dodson-Robinson, S. E., Bodenheimer, P., Laughlin, G., Willacy, K., Turner, N. J., & Beichman, C. A. 2008, *ApJ* (Letters), 688, L99

Fortier, A., Benvenuto, O. G., & Brunini, A. 2007, *A&A*, 473, 311

Fortier, A., Benvenuto, O. G., & Brunini, A. 2009, *A&A*, 500, 1249

Guilera, O. M., Brunini, A., & Benvenuto, O. G. 2010,*A&A*, 521, A50

Hayashi, C. 1981, *Progress of Theoretical Physics Supplement*, 70, 35

Hubickyj, O., Bodenheimer, P., & Lissauer, J. J. 2005, *Icarus*, 179, 415

Mizuno, H. 1980, *Progress of Theoretical Physics*, 64, 544

Pollack, J. B., Hubickyj, O., & Bodenheimer, P. *et al.* 1996, *Icarus*, 124, 62

https://doi.org/10.1017/S1743921311020655 Published online by Cambridge University Press