SF2A 2019
P. Di Matteo, O. Creevey, A. Crida, G. Kordopatis, J. Malzac, J.-B. Marquette, M. N'Diaye, O. Venot (eds)

EFFECT OF THE PLANETESIMAL DISK ON THE POSITIONS OF THE SECULAR RESONANCES

D. Baguet[1], J.-M. Petit[1] and A. Morbidelli[2]

Abstract. During the pre-instability period following the disappearance of the protoplanetary gas disk, the giant planets were in a compact multiresonant orbital configuration, before starting to migrate by interacting with the planetesimal disk extending beyond the orbit of Neptune. It is commonly accepted that the planetesimal disk was divided into two parts: a massive disk extending from Neptune to 30 au and a low mass extension of the disk, extending beyond 30 au. We study the effect of the massive part of the disk on the nodal precessions of the giant planets and of the planetesimals in order to find the positions of the nodal secular resonances. The presence of the massive disk removes the degeneracy of the f_5 nodal frequency and allows for a new secular resonance. We show that for some orbital configurations, the f_5 nodal secular resonance is located in the region where the primordial cold classical Kuiper Belt formed.

Keywords: Celestial mechanics, Kuiper Belt, secular resonance

1 Introduction

In order to reproduce the difference between the dynamically hot and cold populations of the Kuiper Belt, current models of dynamical evolution aiming to reproduce their orbital structures consider that the two populations formed from two different regions. The hot population is assumed to be formed from a massive disk (with a mass within the range $\sim 10-60\,M_\oplus$) extending between Neptune and 30 au and the cold population from a light disk extending beyond 30 au. In current numerical integrations aiming to reproduce the cold population, the action of the massive disk on the objects of the light disk is always neglected (e.g. Batygin et al. 2011; Nesvorný 2015), because otherwise the computation would be too heavy. We investigate the effect of this action in the linear secular theory in order to find the locations of the secular resonances, during the period following the dissipation of the protoplanetary gas disk, when the giant planets were in a multiresonant orbital configuration. Because of this multiresonant configuration, we are only able to look at the nodal secular resonances.

2 Method

We compute the gravitational potential caused by the massive disk by using the method developed by Fukushima (2016) and we add its contribution to the secular nodal precessions of the different bodies. Secular resonances occur where the free precession frequency of a small body, represented as a massless particle, equals one of the eigenfrequencies of the planetary system. With the effect of the massive disk, the total angular momentum of the giant planets is not conserved and it allows for the existence of a new secular resonance, called f_5.

3 Results

Fig. 1 shows the positions of the nodal secular resonances, where the free frequency crosses one of the eigenfrequencies, for the multiresonant configuration 3:2, 3:2, 3:2, 3:2. We can see that if the action of the massive disk is included both on the giant planets and on the small body, the f_5 secular resonance is located near 44 au, which is in the region of the current cold population. The f_6 and f_7 secular resonances remain in the region below 20 au. The f_8 and f_9 secular resonances are pushed toward 30 au. Table 1 shows the positions of the f_5 secular resonance in the different multiresonant configurations proposed by Deienno et al. (2017).

[1] Institut UTINAM, UMR 6213, CNRS, Université Bourgogne Franche-Comté, OSU Theta F-25000, Besançon, France
[2] Laboratoire Lagrange, UMR 7293, Université Côte d'Azur, CNRS, Observatoire de la Côte d'Azur, Boulevard de l'Observatoire, 06304 Nice Cedex 4, France

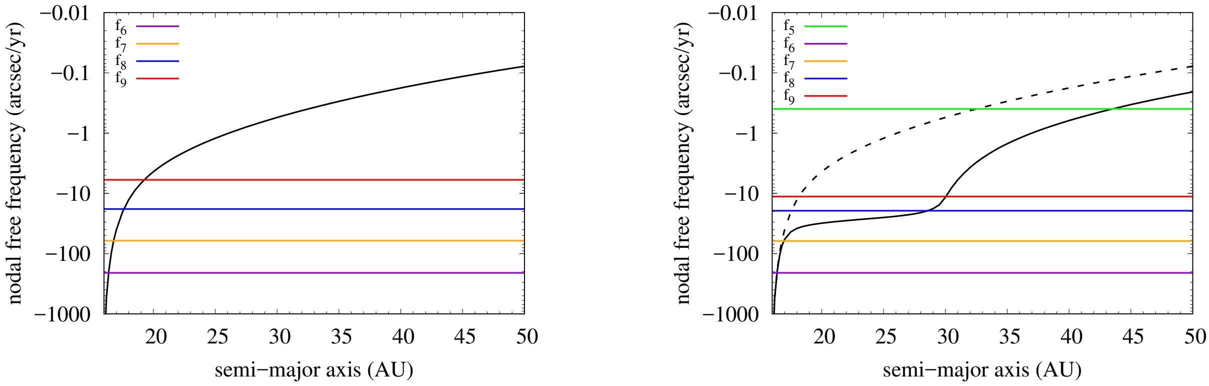

Fig. 1. Nodal free frequency of a small body as a function of its semi-major axis in the configuration 3:2, 3:2, 3:2, 3:2. The horizontal lines are the nodal eigenfrequencies. **Left:** in this model the massive disk is neglected. **Right:** the massive disk is included, with a mass $M_{disk} = 40M_{\oplus}$. The dashed curve is the nodal free frequency in the case where the action of the massive disk on the particle is neglected and the full black curve is the nodal free frequency but in the case where this action is taken into account.

Table 1. Positions of the f_5 secular resonance for different multiresonant configurations of the giant planets and for three different masses of the massive disk.

Orbital configuration	M_{disk} ($M_{\oplus}$)	Position of f_5 (au)
	20	42.7
3:2, 3:2, 4:3, 4:3	40	41.0
	60	40.5
	20	45.0
3:2, 3:2, 3:2, 3:2	40	43.5
	60	43.3
	20	48.3
3:2, 3:2, 2:1, 3:2	40	47.5
	60	47.7
	20	55.1
3:2, 3:2, 2:1, 2:1	40	54.7
	60	54.7

4 Conclusions

We have found that if the action of the massive disk, extending from Neptune to 30 au, on the giant planets and on the small bodies of the light disk is not neglected, the f_5 secular resonance could have been located in the region of the current cold population. This resonance can rise the inclinations of the bodies located in it if the angle between the plane orthogonal to the total angular momentum of the giant planets is misaligned with the plane of the massive disk. This effect has always been neglected but futur numerical integrations have to take it into account.

References

Batygin, K., Brown, M. E., & Fraser, W. C. 2011, ApJ, 738, 13

Deienno, R., Morbidelli, A., Gomes, R. S., & Nesvorný, D. 2017, AJ, 153, 153

Fukushima, T. 2016, MNRAS, 462, 2138

Nesvorný, D. 2015, AJ, 150, 68