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The Capture of Jupiter Trojans

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Abstract

The origin of Jupiter Trojans remained mysterious for decades. Particularly, it was difficult to explain the excitation of the inclinations of the Trojan population [1]. In 2005, Morbidelli et al. [2] proposed a scenario of capture from the trans-Neptunian disk, in the framework of the so-called "Nice model" [3,4]. This scenario explained in a natural way the observed orbital distribution of Trojans. The Nice model, however, evolved in the years, in order to satisfy an increasingly large number of constraints. It now appears that the dynamical evolution of the giant planets was different from that envisioned in [2]. Here, we assess again the process of capture of Trojans within this new evolution. We show that (6-8)$\times10^{-7}$ of the original trans-Neptunian planetesimals are captured in the Trojan region, with an orbital distribution consistent with the one observed. Relative to [2], the new capture mechanism has the potential of explaining the asymmetry between the L_4 and L_5 populations. Moreover, the resulting population of Trojans is consistent with that of the Irregular Satellites of Jupiter, which are captured in the same process; a few bodies from the main asteroid belt could also be captured in the Trojan cloud.

1. Introduction

The capture mechanism proposed in [2] was related to the smooth migration of Jupiter and Saturn across their mutual 1:2 mean motion resonance. A number of studies [5,6] showed, however, that a smooth migration of the giant planets is inconsistent with the orbital structure of the terrestrial planet system and of the asteroid belt. The terrestrial planet orbits would have become too excited [5] and the asteroid belt distribution would have been skewed towards large inclinations [6]. While the former problem occurs only if the migration of the giant planets happened after terrestrial planet formation, the latter holds whatever the timing of migration [7].

Consequently, it was concluded that the real evolution of the giant planets had to be of the "jumping-Jupiter" type. In this evolution, the orbital separation between Jupiter and Saturn increases abruptly, as a result of encounters with a third, Neptune-mass planet. This kind of evolution happens in a small fraction of the simulations of the "new Nice model" [8] with four giant planets, but happens more frequently if one assumes that the original giant planet system contained an extra-planet of Neptune's mass [9].

In the jumping-Jupiter evolution, Jupiter and Saturn do not migrate across the 1:2 resonance; instead they jump across it. Thus, the mechanism for the capture of Trojans investigated in [2] is not applicable any more. The capture of Trojans has to be re-investigated, and this is what we do here (see [10]).

2. Results

During the evolution of the giant planets, many planetesimals in the trans-Neptunian disk are destabilized and transported towards the orbit of Jupiter, following a pathway similar to the one delivering Jupiter-family comets today. When Jupiter's orbit jumps due to an encounter with another planet, planetesimals that are near the orbit of Jupiter can find themselves into the tadpole regions of the new orbit of Jupiter. This way, they are captured as Jovian Trojans. Most of the captured planetesimals are unstable on the long term. Thus, our simulations covered not only the phase of encounters between Jupiter and another planet, but also the subsequent smooth migration of Jupiter's orbit till the current configuration and, furthermore, the 4Gy of evolution in the framework of the current Solar System. Overall, we find that (6-8)$\times10^{-7}$ of the original trans-Neptunian planetesimals are captured in the Trojan region and survive until today. This implies that the disk contained (3-4) × 10^7 planetesimals with absolute magnitude $H < 9$ (corresponding to diameter D = 80 km for a 7% albedo).

During the planetary encounters, planetesimals are also captured as irregular satellites of Jupiter [11]. We have checked that the ratio between the populations of irregular satellites and Trojans captured in the simulations is in good agreement with the observed ratio.

A main difference with respect to the capture mechanism in [2], is that the new mechanism has the potential of explaining the observed 30% asymmetry between the L_4 and L_5 populations. The resulting population ratio depends on the geometry of the encounter between Jupiter and the other planet. For instance, if the planet crosses one of the two tadpole regions, the latter results less heavily populated than the other libration region, not crossed by the planet. Asymmetries of 30-80% are common in our simulations, although their precise determination suffers from small number statistics.

Another difference is that the capture of Trojans in [2] occurred at the very beginning of the planetary instability. At that moment, the asteroid belt was not yet destabilized. Thus, bodies from the main asteroid belt could not be captured as Trojans. The new capture mechanism, instead, takes place during the last encounter of Jupiter with a planet, and therefore after the onset of planet instability. This opens the possibility that also asteroids could be captured as Trojans, although we have not yet quantified their capture probability. Potentially, this can explain the C-type objects observed in the Trojan population (a minority relative to the dominant D-type population). It also opens the possibility that a few S-type asteroids might exist in the Trojan cloud and be discovered in the future.

3. Summary and Conclusions

The capture of Jupiter's Trojans is an essential feature of the Nice model. In fact, primordial Trojans would not survive the dynamical instability and migration of the giant planets. So, they have to be captured during the instability and/or migration phase for the model to be coherent. The original Nice model was consistent with the existence of Jupiter's Trojans, but was then found to have problems concerning the orbital evolution of asteroids and terrestrial planets. The new Nice model was showed to resolve the problems of the original model. This work completes the study of the new Nice model, showing that it is also consistent with the existence and the orbital (and physical) properties of Jupiter's Trojans.

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