ORIGIN AND DYNAMICAL EVOLUTION OF NEPTUNE TROJANS.
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Introduction: Objects orbiting in the Lagrangian L4 and L5 points – called Trojan objects – lie 60° ahead of and behind a given planet in its orbit [1]. In particular, these objects are of great interest because they can be dynamically stable over billions of years, implying that they carry precious information about the early solar system. The total population of large Neptunian Trojans (diameter > 50km) has been estimated to be at least the same as that of Jupiter Trojans of equivalent size [2]. A total of six Neptune Trojans have been found to date [3], and they appear to be primordial objects stable over 4Gyr [2,4,5]. Surprisingly, two of these objects possess high inclinations within the 25–30° range, thus challenging models of Trojan formation [2,6-8].

Motivation: If all Neptunian Trojans are primordial objects that formed during the epoch of the planet's assembly or migration, they can provide information about the primordial disk environment in which Neptune formed/evolved in the early solar system. Thus, the origin and dynamical evolution of Trojans can be used to constrain: i) Models proposed to explain the orbital architecture of the trans-Neptunian region (e.g., Kuiper belt) [9,10]; (ii) Previously proposed Trojan formation mechanisms [2,6,7]; (iii) Details of the migration of the giant planets.

In addition, we aim to answer the following questions: Did the Neptunian Trojans form locally or were captured during migration, or both? How do we explain the high inclination Trojans?

Methods and preliminary results: We performed numerical simulations of several thousand massless objects under the gravitational influence of the four giant planets using the orbital symplectic integrators EVORB [11] and MERCURY [12]. For the automatic detection of Trojans and determination of their resonant properties, we employed the RESTICK code [13].

First stage – planet migration. Firstly, we looked at the dynamics of Trojans with migrating giant planets. The migration followed an exponential behaviour as described in [7]. Four variants were considered: Neptune starting at 18 and 23AU, using two different migration timescales τ=1, 10Myr. In addition, for each variant, a few times 10^4 objects were placed in a cold disk stretching from 1AU beyond the initial position of Neptune to 30AU (representing the outer primordial planetesimal disk), and a cloud of several thousand objects at the L4/L5 points (representing pre-formed Trojans). The initial eccentricities and inclinations of all disks/clouds were e<0.01; i<0.6°. The orbits were integrated for a total time of 5τ, after which the giant planets acquired their current orbits.

Second stage – long-term evolution. From final Trojan populations obtained at the end of stage one, we selected 100 seeds for each disk/cloud (800 seeds in total). We then cloned each seed obtaining $5.8\text{x}10^5$ clones. These clones were integrated over billions of years to investigate their long-term behaviour.

A significant population of Trojans survived in each of the migration scenarios, including objects in horseshoe, L4 and L5 orbits. The distributions of these objects in element space *a-e-i*, and other resonant properties, were obtained. While Trojans captured from the cold disk yielded a wide range of orbital elements e=0–0.3 and i=0–50°, those from the pre-Trojan populations survived in general with e=0–0.1 and i=0–5° (except the variant with Neptune starting at 18AU, τ=10Myr, which showed e=0–0.35 and i=0–40°).

Conclusions and discussion: Our results support the scenario in which Neptunian Trojans were captured from the primordial planetesimal disk during a slow and extended migration of the giant planet. However, a pre-formed Trojan population could also contribute to the observed population, provided one of the following operated: (i) Partial disruption induced by dynamical instabilities during planet migration (or over 4Gyr); (ii) *i*-excitation of a significant part of the population over 4Gyr; (iii) A peculiar size distribution (e.g., a population dominated by small objects discriminated against discovery). We intend to provide detailed statistics about the properties and orbital evolution of Trojans, and make predictions for future observations.

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