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LONG-TERM EVOLUTION OF NEPTUNE TROJANS

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RESUMEN

Los Troyanos de Neptuno son objetos que comparten la órbita con el planeta Neptuno y se encuentran en un entorno de los puntos de Lagrange L4 y L5 situados 60° "delante" y 60° "detrás" del planeta en su órbita. Hasta el momento se han observado sólo nueve Troyanos de Neptuno. Sin embargo los estudios sobre la estabilidad de esta población indican que ésta debería ser muy numerosa. En el presente trabajo realizamos simulaciones numéricas de la evolución de Troyanos de Neptuno ficticios, para detectar las zonas de estabilidad e inestabilidad de la población y estudiar cómo se produce el escape de los Troyanos a lo largo de la vida del Sistema Solar.

ABSTRACT

Neptune Trojans are objects that share the orbit with the planet Neptune and are in a neighborhood of the Lagrangian points L4 and L5 located 60° "front" and 60° "behind" the planet in its orbit. So far, there have been nine Neptune Trojans discovered. However stability studies indicate that this population should be large. In this work we report the results of numerical simulations of the evolution of fictitious Neptune Trojans, to detect stability and instability areas and also to study the escape of Trojans over the age of the Solar System.

Key Words: minor planets: asteroids — Neptune — Trojan asteroids

1. INTRODUCTION

The first Neptune Trojan was discovered in 2001 around L4 and was named 2001 QR322. Since then five more have been discovered in L4 and three in L5. There are several works concerning the formation and stability of Neptune Trojans and in general it is suggested that they should be a relatively large population, even larger than Jupiter Trojans. Sheppard & Trujillo (2010) performed a survey with the 8.2-m Subaru and the 6.5-m Magellan telescopes, and derived the cumulative size distribution (CSD) of Neptune Trojans. Assuming an albedo of 0.05, they estimated that the CSD is given by $N(>D) \propto D^{-4}$ for diameters $D > 45$ km and in $D \sim 45$ km, it has a break. They also estimated that there could be about 400 Neptune Trojans with $D > 100$ km.

Trojans populations are stable, therefore a large number of them is expected to survive for the age of the Solar System. In this work we study the stability of Neptune Trojans to detect those that can escape and be part of other populations of small bodies somewhere else in the Solar System.

2. NUMERICAL SIMULATION

We numerically integrate fictitious Trojans in the resonance taking as a reference Zhou et al. (2009, 2010). In the first paper, the authors studied the orbits of L5 Neptune Trojans, providing a view of the stability of the population according to inclination. They obtained three stable regions with inclinations in the intervals: $0° - 12°$, $22° - 36°$ and $51° - 59°$. In the second paper, the authors study the global stability of Neptune Trojans depending on eccentricity and inclination. They perform numerical simulations and obtain the dependence of the libration center σ_c with the eccentricity and inclination.

For Trojans around the Lagrange point L5 we define a grid of initial orbital elements of widths $\Delta e = 0.01$ (e =eccentricity), $\Delta a = 0.01$AU (a =semimajor axis) and $\Delta i = 2.5°$ (i =inclination), with 29.9 AU $\leq a \leq$ 30.49 AU, $0 \leq e \leq 0.25$ and $0° \leq i \leq 60°$. We set the argument of perihelion $\omega = \omega_N - 60°$, the longitude of ascending node $\Omega = \Omega_N$ and the mean anomaly $M = M_N + 60° + \sigma_c$, where σ_c is obtained from Zhou et al. (2010) and N means Neptune. A similar procedure was applied for L4 Trojans.

In our numerical simulation, we computed a total of 31,380 orbits of fictitious Trojans around each Lagrange point. We use the numerical code EVORB (Fernández et al 2002.) to integrate the fictitious Trojans (massless particles) under the gravitational

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action of the Sun and the four giant planets, with a step of 0.5 yr and for 4.5x10^9 yr. The cutoff criteria for the program is an encounter with a planet at a distance less than 1 Hill radius.

3. RESULTS

Of the 31,380 initial particles in each Lagrange point, 83% and 82% escaped from the L4 and L5 population, respectively, because of an encounter with a planet and the rest remained in the integration up to the end. From the particles that escaped from L4 and L5 respectively, 69.25% and 71.5% did it by having encounters with Neptune, 30.74% and 28.48% by encounters with Uranus, and a small fraction of 0.0038% and 0.0032% with Saturn. From our output files, we calculate the number of escape particles with respect to the number of survivors and plot this ratio as a function of time in Fig. 1.

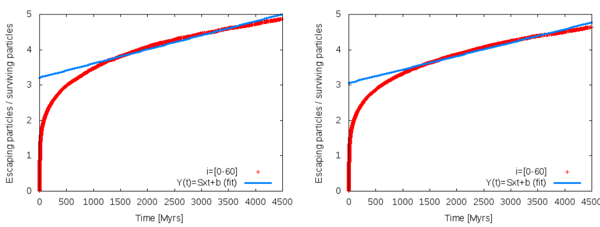

Fig. 1. Escape rate from L4 (left) and L5 (rigth).

At the begining, there are a lot of particles that escape because the initial orbital elements are beyond the stable real region of Trojans, therefore this part of the curve does not reflect their most probable behavior. After 10^9 yr the curve approximates a straight line and that is taken as the long-term behavior of the Trojans. Fitting a linear relation $Y(t) = s\,t + b$ to these curves, we can estimate the current escape rate s of Neptune Trojans:

$$s = 3.98746 \times 10^{-10} \pm 1.611 \times 10^{-12} \mathrm{yr}^{-1} \quad \text{for} \quad \text{L4},$$
$$s = 3.79652 \times 10^{-10} \pm 1.370 \times 10^{-12} \mathrm{yr}^{-1} \quad \text{for} \quad \text{L5}.$$

with intercept values of $b = 3.20894 \pm 0.003965$ for L4, and $b = 3.05839 \pm 0.003392$ for L5.

Assuming that there are 400 Trojans with diameters $D > 100$ km (Sheppard & Trujillo 2010), the rate of escape of Trojans with $D > 100$ km is 1.5×10^{-7} yr^{-1}, i.e. about two Trojans larger than 100 km escape in 10^7 yr, from each Lagrantian point. Taking as a reference the stability regions found by Zhou et al. (2009), in Fig. 2 we plot the fraction of

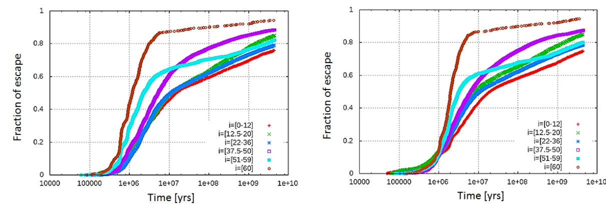

Fig. 2. Fraction of particles that escape according to stability zones around L4 (left) and L5 (rigth).

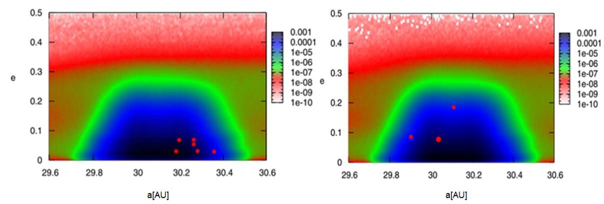

Fig. 3. Stability maps (a vs. e). L4 (left) and L5 (right).

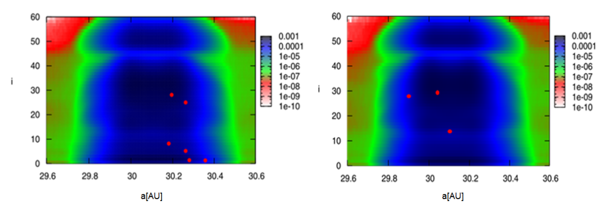

Fig. 4. Stability maps (a vs. i). L4 (left) and L5 (right).

particles that escape from several inclination zones. After 4.5 x 10^9 yr, the three stable regions keep about 20% of the initial objects, the region of inclination (0°, 12°) being the most stable and the one with $i = 60°$ the most unstable.

We also make stability maps (Figures 3 and 4) that show the normalized time fraction spent by the particles in our simulation, in a given value of a, e and i. The color code is indicative of the portion of time spent in each zone (blue for most visited regions, red for least visited). Note in particular the different stability zones in inclination defined by Zhou et al. (2009). The six Trojans observed in L4 and the three Trojans observed in L5 are also shown.

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