ORIGIN AND DYNAMICAL EVOLUTION OF NEPTUNE TROJANS

Patryk Sofia Lykawka[1]*, Jonathan Horner[2], Tadashi Mukai[1] & Barrie W. Jones[2]

[1]Dept. of Earth & Planetary Sciences – Kobe University, Japan

[2]Dept. of Physics and Astronomy – The Open University, United Kingdom

patryk@dragon.kobe-u.ac.jp

INTRODUCTION

Objects orbiting around the Lagrangian L4 and L5 points of a planet's orbit – called Trojan objects – lie 60° ahead of and 60° behind that planet in its orbit [1]. These objects are of great interest because they can be dynamically stable over billions of years, and may therefore be able to tell us a great deal 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 Jovian Trojans of the same size [2]. A total of six Neptune Trojans have been found to date (Fig. 1) [3]. These objects appear to be primordial, stable over four Gyr [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].

The currently known Neptunian Trojans and their libration amplitudes

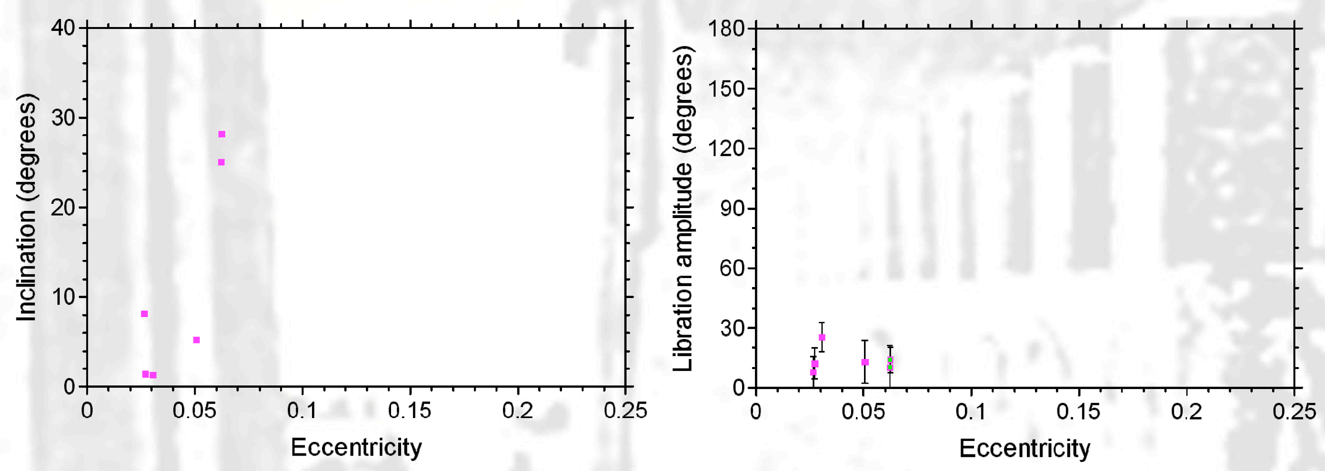


FIGURE 1: Neptunian Trojans. The observational data was taken from the AstDys database http://tinyurl.com/65op2k on the 24th April 2008. All six Trojans orbit around the L4 point. The libration amplitudes were averaged over individual values calculated for the nominal object + 100 clones after integrating their orbits ten Myr into the future. Libration amplitude refers to the maximum angular displacement from the center of libration during resonant motion.

Initial conditions (18AU case)

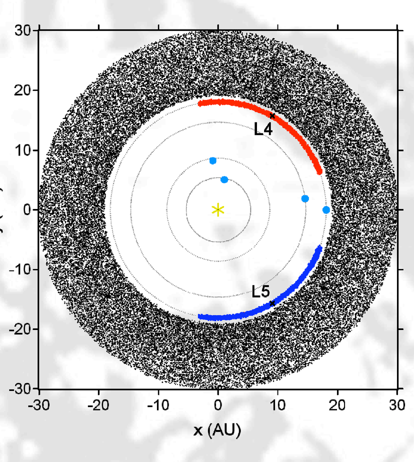


FIGURE 2: Composite of the initial conditions for the variant scenario with Neptune starting at 18AU. Objects orbiting around L4 and L5 points, and a disk of bodies beyond the location of Neptune are shown.

The origin and dynamical evolution of Neptunian Trojans can be used to constrain: **i)** Models proposed to explain the orbital architecture of the trans-Neptunian region [9,10]; **(ii)** Previously proposed Trojan formation mechanisms [2,6,7]; **(iii)** Details of the migration of the giant planets. **Outstanding questions:** Are the six Neptune Trojans stable over billions of years? Did the Neptunian Trojans form locally or were they captured during migration, or both? How do we explain the high inclination Trojans? How do Neptunian Trojans relate to other small body populations?

METHODS

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].

Observed Neptune Trojans. We followed the nominal orbit + 100 clones of each body for 4Gyr.

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]:

$$a_n(t) = a_n - \Delta a_n \exp(-t/\tau)$$, where a_n is the semimajor axis of the giant planet.

Four variants were considered: Neptune starting at 18 and 23AU ("*N18AU*" and "*N23AU*"), using two different migration timescales τ =1, 10Myr ("*fast*" and "*slow*" migration). For each of these four variants, a few times 10^4 objects were placed in a cold disk stretching from 1AU beyond the initial position of Neptune to 30AU ("DISK"), and a cloud of several thousand objects were placed at the L4/L5 points ("INSITU"). All disks/clouds started with initially e<0.01; i<0.6°. The orbits were integrated for a total time of 5 τ , after which the giant planets acquired their current orbits (Fig. 2) .

Second stage – long-term evolution. From the final Trojan populations obtained at the end of stage one, we selected 100 surviving seeds for each disk/cloud (800 seeds in total). We then cloned each seed obtaining 5.8x10^5 clones. These clones were integrated over 4Gyr.

MAIN RESULTS

Stability of observed Neptunian Trojans and other properties

- With the exception of 2001 QR_{322}, the majority or all clones of other Neptune Trojans survived over 4Gyr. Overall, these bodies showed no significant changes in orbital or resonant properties

Origin and dynamical evolution of Neptunian Trojans

- A significant population of Trojans survived in each of the migration scenarios, including objects in horseshoe, L4 and L5 orbits showing varied properties (Fig. 3).
- 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 scenario *N18AU*-slow migration, which showed e=0–0.35 and i=0–40°).

Neptunian Trojans at the end of planet migration

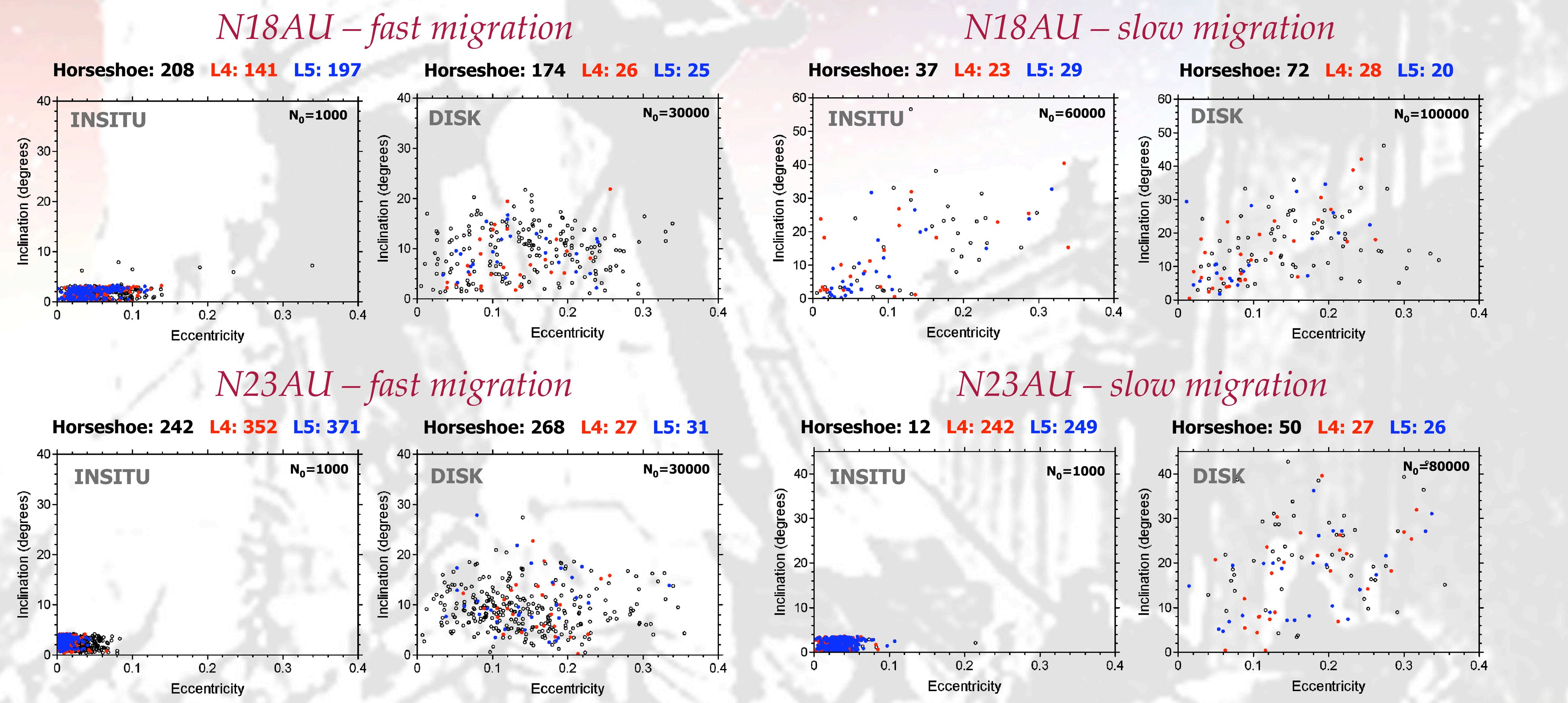
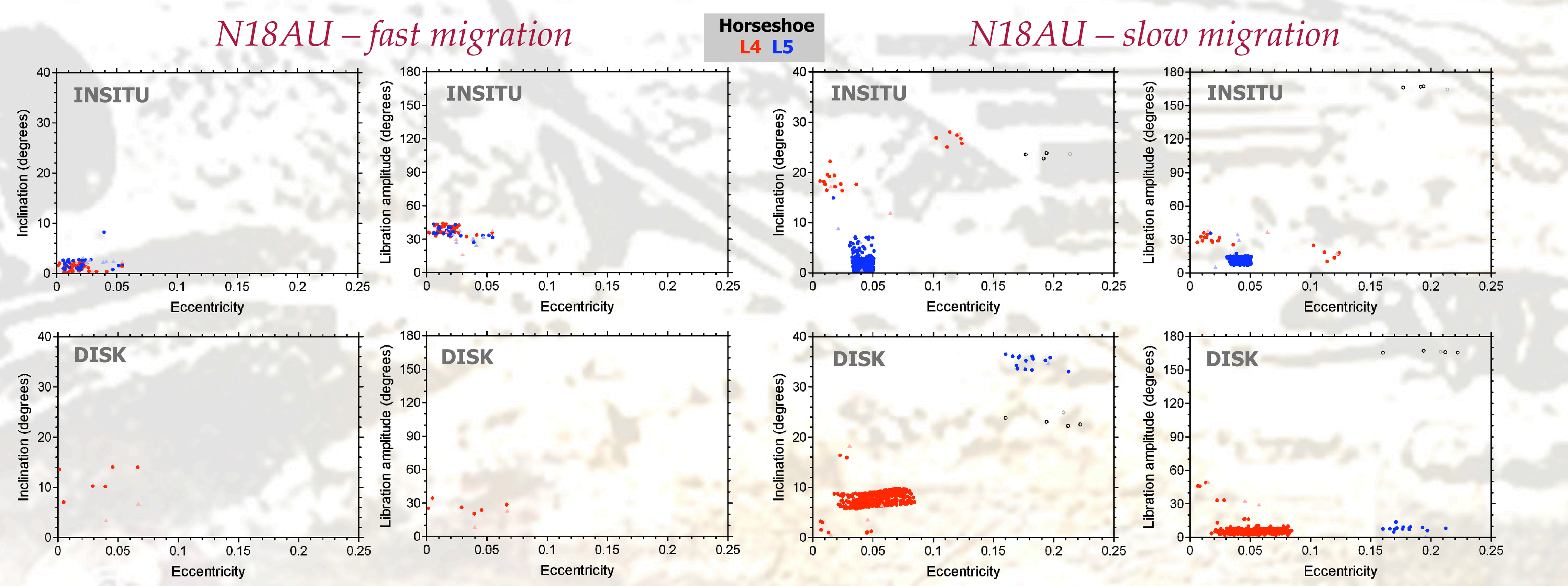


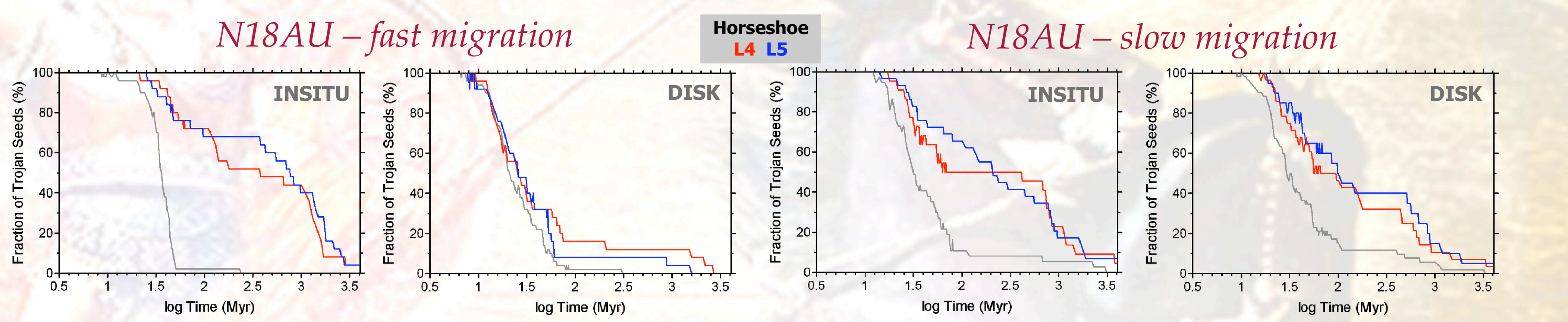
FIGURE 3: Neptunian Trojans surviving after the giant planets migrated to their current orbits for each of the four variants (Neptune starting at 18 or 23AU, and slow or fast migration). The number of Trojans are given according to the resonant behaviour: horseshoe, L4 and L5 orbits. Objects that were initially in Trojan orbits and in the planetesimal disk beyond Neptune prior to migration are referred as "INSITU" and "DISK". The initial number of used objects is given by N_0.

Neptunian Trojans after 4Gyr of dynamical evolution



- Despite the wide conditions at the end of planet migration, only Trojans with small eccentricities and libration amplitudes less than ~45° (L4/L5 orbits) can survive for 4Gyr.

Stability of Neptunian Trojans over 4Gyr



CONCLUSIONS

1. The six Neptunian Trojans currently known appear to be stable over the age of the solar system
2. Pre-formed Trojan populations evolved with little dependence on planet migration parameters. Retention fractions after migration were 20-95%. However, strong disruption induced by dynamical instabilities is possible during a slow and extended migration of Neptune (*N18AU*)
3. Trojan populations captured from the planetesimal disk showed wide range of orbital properties. However, capture efficiency was quite low though: ~0.5-1% (τ =1Myr) and ~0.1% (τ =10Myr)
4. No significant i-excitation was found among the Trojan bodies in the simulations over 4Gyr
5. Neptunian Trojans may represent the remnants of both pre-formed Trojans and bodies captured from the disk during a slow and extended Neptunian migration

[1] Murray & Dermott (1999) [2] Sheppard & Trujillo (2006) [3] http://cfa-www.harvard.edu/iau/lists/Trojans.html [4] Horner & Evans (2006) [5] Nesvorny & Dones (2002) [6] Chiang & Lithwick (2005) [7] Hahn & Malhotra (2005) [8] Li et al. (2007) [9] Lykawka & Mukai (2008) [10] Levison et al. (2008) [11] Brunini & Melita (2002) [12] Chambers (1999) [13] Lykawka & Mukai (2007)