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Transient Terrestrial Trojans: Comparative Short-term Dynamical Evolution of 2010 TK_7 and 2020 XL_5

Carlos de la Fuente Marcos[1] and Raúl de la Fuente Marcos[2]

[1] *Universidad Complutense de Madrid*
Ciudad Universitaria, E-28040 Madrid, Spain
[2] *AEGORA Research Group*
Facultad de Ciencias Matemáticas
Universidad Complutense de Madrid
Ciudad Universitaria, E-28040 Madrid, Spain

ABSTRACT

The Trojan asteroids of Mars and Jupiter are long-term stable, those of Earth are expected to be just transient companions. The first Trojan of our planet, 2010 TK_7, was discovered in 2010 and its resonant state was found to be transient. Here, we provide a preliminary assessment of the current dynamical status and short-term orbital evolution of 2020 XL_5, a recently discovered near-Earth asteroid that might be the second known representative of this elusive population. Our calculations show that the current orbit determination of 2010 TK_7 is consistent with that of a robust, present-day, yet transient, L_4 Earth Trojan. In sharp contrast, the current orbit determination of 2020 XL_5 is still too uncertain and its orbital evolution too chaotic to confirm a current Trojan engagement with Earth, although the nominal orbit shows such a behavior. More observations are required to provide a conclusive answer.

Keywords: Solar system, Asteroids, Trojan asteroids, Near-Earth objects

Until 2010, we had no observational evidence on the existence of Trojan companions of our planet; an early survey carried out between 1978 and 1982 using the 1.2-m Palomar Schmidt telescope failed to find any, but emphasized that the viewing geometry to observe putative Earth Trojan asteroids from the ground is rather unfavorable (Dunbar & Helin 1983). However, solid numerical evidence for the presence of such a Trojan asteroid population had been available for decades (see e.g. Hollabaugh & Everhart 1973; Dunbar 1980; Mikkola & Innanen 1990). Dunbar (1980) first argued that the 13:8 mean motion resonance between Venus and Earth made the tadpole orbits of Earth Trojans inherently unstable. In marked contrast, the Trojan asteroids of Mars (see e.g. Christou 2013; de la Fuente Marcos & de la Fuente Marcos 2013, 2021) and Jupiter (see e.g. Dvorak & Schwarz 2005; Di Sisto et al. 2014) are long-term stable. It is therefore not surprising that the first Trojan of our planet, 2010 TK_7, was discovered by the NEOWISE team (Gilmore et al. 2010) using NASA's Wide-field Infrared Survey Explorer (WISE), a space telescope, and that its confirmed Trojan resonant state was found to be transient (Connors et al. 2011). Here, we provide a preliminary assessment of the current dynamical status and short-term orbital evolution of 2020 XL_5, a recently discovered near-Earth asteroid that might be the second known representative of this elusive population.

The main parameter to classify Earth Trojans is the value of the relative mean longitude, which is the difference between the mean longitude of the minor body and that of Earth. The mean longitude is given by $\lambda = \Omega + \omega + M$, where Ω is the longitude of the ascending node, ω is the argument of perihelion, and M is the mean anomaly. Therefore, the critical angle is $\lambda_{\rm r} = \lambda - \lambda_{\rm E}$. If the value of $\lambda_{\rm r}$ oscillates around 60°, the object is called an L_4 Trojan and leads Earth in its orbit, when it librates around −60°, it is an L_5 Trojan and it trails our planet (see e.g. Murray & Dermott 1999). Numerical simulations are necessary to confirm any suspected resonant behavior. Here, we use N-body simulations carried out as described by de la Fuente Marcos & de la Fuente Marcos (2012) and publicly available input

Corresponding author: Carlos de la Fuente Marcos
nbplanet@ucm.es

data from Jet Propulsion Laboratory's (JPL) Small-Body Database (SBDB)[1] and HORIZONS[2] on-line solar system data and ephemeris computation service (Giorgini 2015). Asteroid 2020 XL_5 was discovered on 2020-December-12 by the Pan-STARRS 1 telescope system at Haleakala.[3] The orbit determination of this Apollo asteroid is based on 22 observations spanning a data-arc of 43 d. Its absolute magnitude is H=20.2±0.5 mag (assumed $G = 0.15$), which suggests a diameter in the range ∼150–1500 m for an assumed albedo in the range 0.60–0.01 (a size of 300–400 m is likely). As of 2021-January-11, its heliocentric orbit determination is: semimajor axis, $a = 1.0009 \pm 0.0002$ au, eccentricity, $e = 0.38729 \pm 0.00008$, inclination, $i = 13.^{\circ}849 \pm 0.^{\circ}002$, $\Omega = 153.^{\circ}608 \pm 0.^{\circ}008$, and $\omega = 87.^{\circ}96 \pm 0.^{\circ}02$.[4] Currently, this object experiences regular close encounters with Venus, sometimes as close as 0.03 au from a planet that has a Hill radius of 0.0067 au. We also collected data for the previously known Earth Trojan, 2010 TK_7 — with heliocentric orbit determination based on 56 observations spanning a data-arc of 2586 d as of 2017-Oct-31, $a = 0.999273055 \pm 0.000000008$ au, $e = 0.1904803 \pm 0.0000005$, $i = 20.^{\circ}89793 \pm 0.^{\circ}00005$, $\Omega = 96.^{\circ}46358 \pm 0.^{\circ}00012$, and $\omega = 45.^{\circ}96835 \pm 0.^{\circ}00011$ (same epoch as 2020 XL_5)— in order to explore the comparative short-term dynamical evolution of the candidate and the Trojan.

Figure 1 focuses on the evolution of λ_r and summarizes our findings for representative orbits, the nominal one and those with Cartesian vectors separated $\pm 0.5\sigma$ and $\pm 1\sigma$ (for 2020 XL_5) and $\pm 3\sigma$ and $\pm 9\sigma$ (for 2010 TK_7) from the nominal values. Figure 1, top panel, shows that although the evolution of the nominal orbit of 2020 XL_5 is consistent with L_4 Trojan behavior, orbits close to the nominal one lead to fully non-resonant evolution. With the current orbit, less than 50% of the control orbits lead to L_4 Trojan behavior. In stark contrast, the evolution of all the control orbits of 2010 TK_7 within $\pm 9\sigma$ of the nominal one (not $\pm 1\sigma$ as in the case of 2020 XL_5) is consistent with L_4 Trojan behavior within about 2000 yr of the current epoch (symmetric). Our calculations show that the current orbit determination of 2020 XL_5 is still too uncertain and its orbital evolution too chaotic —as it may experience close encounters with Venus and eventually with the Earth–Moon system— to confirm a current Trojan engagement with Earth, although the nominal orbit shows such a behavior. More observations are required to provide a conclusive answer. As for 2010 TK_7, we confirm the results in Connors et al. (2011), including its relative stability on timescales of 10^5 yr and its probable jumping nature as it can jump from librating around L_4 to librating around L_5.

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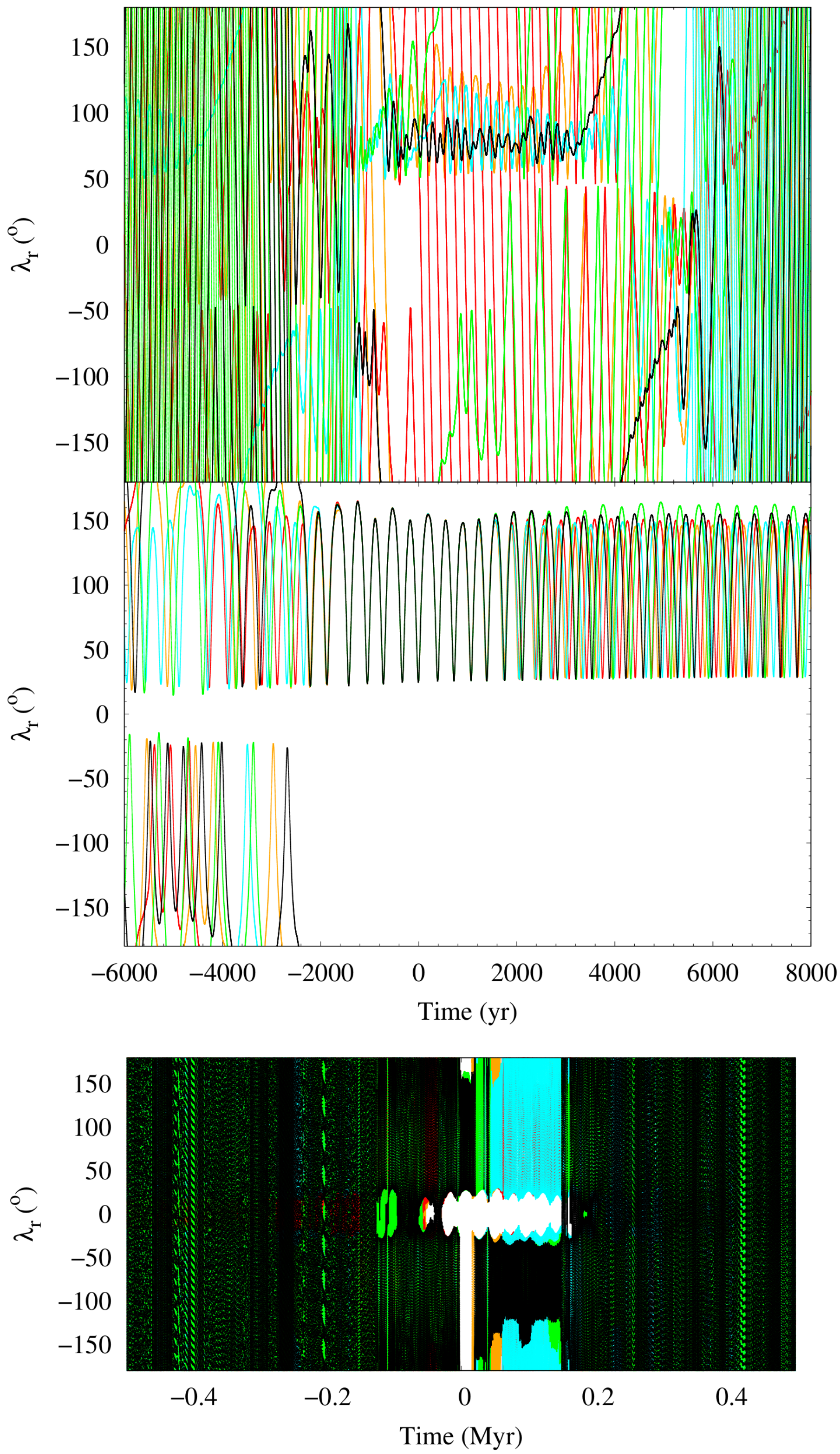

Figure 1. Evolution of the value of the relative mean longitude, λ_r, with respect to Earth of 2020 XL_5 (top panel) and 2010 TK_7 (middle and bottom panels). The results corresponding to the nominal orbits are shown in black. For 2020 XL_5, the results of control orbits with Cartesian vectors separated $+0.5\sigma$ (in green), -0.5σ (in cyan), $+1\sigma$ (in red), and -1σ (in orange) from the nominal values are displayed. For 2010 TK_7, the control orbits have Cartesian vectors separated $+3\sigma$ (in green), -3σ (in cyan), $+9\sigma$ (in red), and -9σ (in orange) from the nominal values. The output time-step size is 0.01 yr for the top and middle panels, and 2 yr for the bottom panel. The input data have as source JPL's SBDB and are referred to epoch 2459000.5 Barycentric Dynamical Time (TDB) that is also the origin of time in the calculations.