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The Earth trojans

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Abstract. Asteroids 2010 TK7 and 2020 XL5 are of particular interest because of their behavior, which is similar to the so-called trojan asteroids. In this paper, computer simulations of the orbital evolution of the asteroids in question were carried out using the EPOS software system. The results of the computer simulations suggest that the Earth trojans were not ordinary trojans in the recent past and will most likely shift to another type of orbit in the distant future.

Keywords: asteroids, 2010 TK7, 2020 XL5

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Материалы конференции
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Троянцы Земли

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Аннотация. Из-за схожести своего орбитального движения с так называемыми астероидами троянской группы астероиды 2010 TK7 и 2020 XL5 представляют особый интерес для исследования. С помощью пакета программ ЭПОС в рамках задачи двух неподвижных центров проведено исследование движения этих астероидов с помощью интегрирования уравнений их движения на длительных интервалах времени, смоделирована эволюция их орбит. Моделирование позволяет предположить, что с большой вероятностью тип орбит исследуемых астероидов в далеком будущем изменится.

Ключевые слова: астероиды, 2010 TK7, 2020 XL5

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Introduction

By the time of this research, the list of trojan minor planets contains more than 11800 objects [1]. The vast majority of them are the so-called Jupiter trojans, and all the small bodies swarming around the Lagrange triangular points at 60° ahead and 60° behind any planet in its orbit are called trojans as well. The leading point L_4 and the trailing point L_5 are the positions of stable equilibria, and thus they are of prime interest for different space programs.

In the 2000s, in the frame of the Interplanetary Solar Stereoscopic Observatory (ISSO) project [2], the observational program devoted to the search of massive bodies in the vicinity of the Sun-Earth triangular Lagrange points (L_4 and L_5) was performed at the Pulkovo Observatory (CAO RAS) using its two telescopes (ZA-320M and MTM-500M). Installation of two identical space telescopes in these two gravitationally stable areas of the "Sun-Earth+Moon barycenter" system was a part of the ISSO project, so it was necessary to investigate the neighbourhoods of L_4 and L_5. The software for different computer simulations related to this project was also developed.

However, the discovery of the first Earth trojan asteroid was made only in 2010 by the NASA's WISE infrared astronomy space telescope [3]. A decade later, in 2020, the second Earth trojan was discovered using large telescopes of ground-based observatories [4].

Using the observational data available in the Minor Planet Center database [5, 6], we decided to investigate the orbital evolution and stability of these two asteroids peculiar to our planet.

Orbital analysis

All the computer simulations of orbit evolutions were carried out by using the EPOS software system created at the Pulkovo Observatory [7].

In the frame of the problem of two fixed centers (Sun-Earth+Moon barycenter), numerical integration of the motion equations of the asteroids in question was performed using DE441 numerical ephemerides [8].

Despite the accumulation of errors during the calculations, some certain features of the orbital behavior of the asteroids can be pointed out.

For a better understanding of peculiarity of the Earth trojans, let us first demonstrate the libration motion of the four big Jupiter L_4 and L_5 trojans 1143 Odysseus, 588 Achilles, 3317 Paris and 617 Patroclus during the previous two millennia and the next one. The results are presented in Fig. 1 *a*, *b* as examples of a typical trojan behavior. For this simulation, the same software and databases as for the Earth trojans [5–7] were used. Of course, depending on a number of conditions (vicinity to L_4 and L_5, mass, speed, etc.), the shape of the trojan's orbit may differ, which results in its stability or instability.

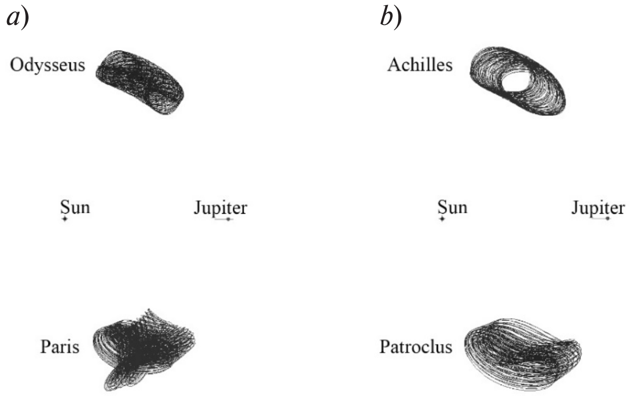

Fig. 1. Libration motion of the Jupiter trojans 1143 Odysseus and 3317 Paris in the time interval between 2022 and 3022 (*a*), libration motion of the Jupiter trojans 588 Achilles and 617 Patroclus in the time interval between 22 and 2022 (*b*)

It should also be noted that in the Earth-fixed moving coordinate systems, any object near the Lagrangian points oscillate in loops along the longitude (e.g. in the frame of the two fixed bodies problem), the size of the loops can vary widely. Sometimes there is a possibility for such objects to "shift" to the C-shaped (horseshoe) orbit, e.g. to cross the unstable equilibrium position L_3 and approach a planet from the other side. In some cases, transition to a simple circular orbit is possible, and that is exactly how asteroids 2010 TK7 and 2020 XL5 behave, according to the computer simulation undertaken in the frame of this study.

2010 TK7, the first Earth trojan

2010 TK7, the first Earth trojan asteroid, was discovered on October 1, 2010 by the NEOWISE team (with NASA's Wide-field Infrared Survey Explorer (WISE)) [3]. It oscillates around the leading Lagrange point L_4, and its estimated diameter is about 0.3 km [9].

The simulation undertaken shows that as the object in question followed a horseshoe orbit, it became the Earth trojan in the middle of the first millennium A.D., it still moves in wide loops to the date and will continue to move in a tadpole orbit for the next several millennia. However, with a high degree of probability, the type of its orbit will then eventually change.

The trajectories of 2010 TK7 relative to two fixed centers (the Sun and the Earth) at two different time intervals are presented in Fig. 2 *a*, *b*.

a) *b*)

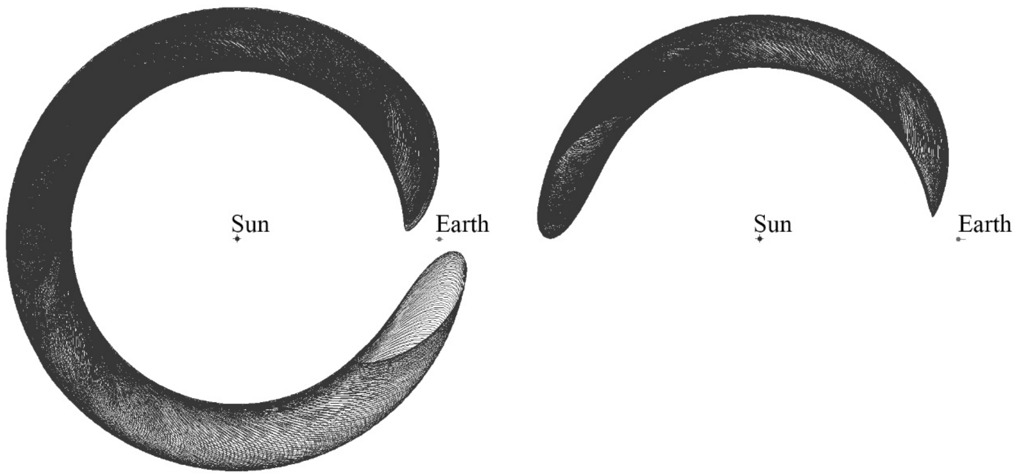

Fig. 2. Trajectory of 2010 TK7 between 22 and 2022 (*a*), trajectory of 2010 TK7 between 2022 and 3022 (*b*)

a) *b*)

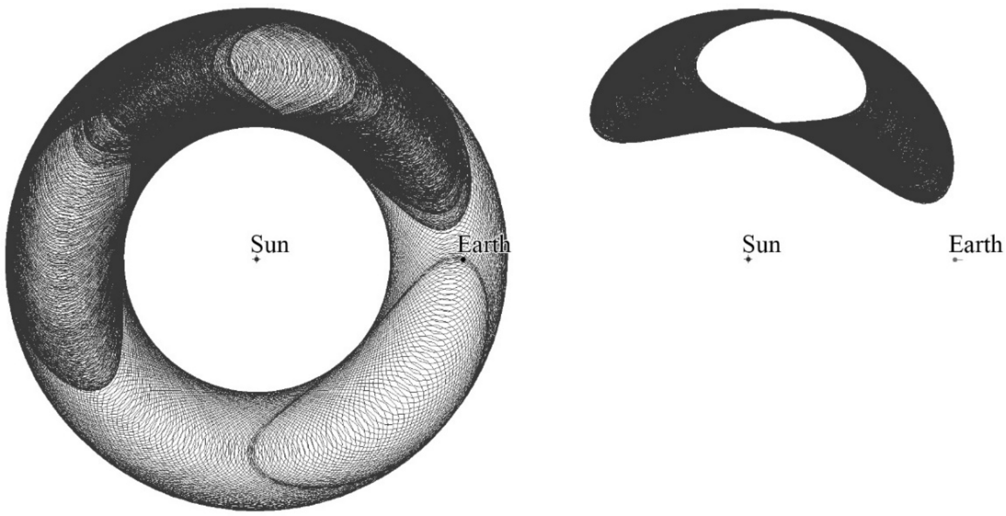

Fig. 3. Trajectory of 2020 XL5 between 1022 and 2022 (*a*), trajectory of 2020 XL5 between 2022 and 3022 (*b*)

(614689) 2020 XL5, the second Earth trojan

2020 XL5, the second Earth trojan asteroid, was first observed on December, 12, 2020 by the Pan-STARRS 1 survey (Haleakala Observatory, Hawaii) [4]. Like the first one, it oscillates around the leading Lagrange point L_4. Its estimated dimeter is about 1.18 ± 0.08 km [10].

The results of the computer modelling of the orbital evolution suggest that asteroid 2020 XL5 has changed three types of orbits over the past thousand years: from a horseshoe orbit, it moved to a circular one, and approximately 400 years ago, it was trapped in the vicinity of L_4. The center of the loops is located far enough away from L_4, and the scale of the loops is too wide (up to the half of size of a horseshoe orbit), which eventually determines the transition to another type of orbit, but not during the next millennium.

Conclusion

Although there is not much observational data available for asteroids 2010 TK7 and 2020 XL5 yet, it is possible to model their orbital evolution using the EPOS software package, part of which was developed for simulations of libration motions of the bodies in the neighborhood of the Sun-Earth triangular Lagrange points (L_4 and L_5) in the frame of the Interplanetary Solar Stereoscopic Observatory (ISSO) project. The results of the simulations, presented in this paper, show that although the Earth trojans are temporarily locked in the vicinity of L_4, they have both changed their types of orbits during the previous two millennia and will most likely change them in the future. Thus, the asteroids in question cannot be considered as the members of the compact cluster of matter in the neighbourhood of L_4, if it exists.

The discovery of the second Earth trojan in 2020 using the ground-based telescopes proved that ground-based observations can actually be useful for investigations of the Sun–Earth L_4 and L_5 neighborhoods, so new observational programs of these areas are considered on the base of the Pulkovo Observatory.

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