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Production and escape of Trojan asteroids by non-gravitational forces at 1.5 au from the Sun

Apostolos Christou (1), Aldo dell'Oro (2), Galin Borisov (1,3), Seth Jacobson (4), Alberto Cellino (5), Eduardo Unda-Sanzana (6)
(1) Armagh Observatory and Planetarium, Armagh, UK, (2) INAF-Osservatorio di Arcetri, Florence, Italy, (3) Institute of Astronomy and National Astronomical Observatory, Sofia, Bulgaria, (4) Northwestern University, Evanston, IL, USA, (5) INAF-Osservatorio di Torino, Torino, Italy, (6) Universidad de Antofagasta, Antofagasta, Chile

1. Introduction

At 1.5 astronomical units from the Sun, the Trojan clouds of Mars represent the innermost stable population of asteroids in the solar system, closer than the inner edge of the Main Belt ($\sim$2.1 au) and the Hungarias ($\gtrsim$1.85 au). The population is dominated by a tight orbital cluster around 2-km (5261) Eureka at L_5 [1] (Fig. 1). It has been proposed [2, 3, 4] that the bulk physical properties and orbit distribution of these small asteroids as well as the existence of relatively large but orbitally isolated Trojans, is most readily explained by the long-term action of solar-radiation-driven forces. In this scenario, YORP-induced rotational fission creates new asteroids ("YORPlets") while Yarkovsky determines their orbit distribution, stability and rate of escape from the Trojan clouds.

2. Methods and Results

Here we quantitatively test this hypothesis. Our principal observables are: (5261) Eureka, its family of 8 asteroids and the family-less Trojans (101429) 1998 VF_{31} & (121514) 1999 UJ_7. We model the population evolution as a birth-death random process and assume it is in a steady state. We then simulate the discovery of Trojans to-date and find that family members of 101429 and 121514, if they exist, are intrinsically more difficult to detect than Eureka's. Their non-discovery can be used as evidence of their non-existence only under the assumption that their brightness relative to the parent asteroid is similar to that in the Eureka family. To find out how efficiently Mars Trojans are lost from the Trojan clouds due to the Yarkovsky effect, we carry out dynamical simulations of test particles originating from these parent bodies. We find (Fig. 2) that objects originating from Eureka and 121514 begin to escape after $\sim$1 Gyr, but that those from 101429 are already lost by that time, probably due to that asteroid's proximity to an eccentricity-type secular resonance [5]. This is the likely cause behind the absence of Trojans in the orbital vicinity of 101429. In contrast, the solitary status of 121514 points to an intrinsic inability of the asteroid to produce YORPlets during the most recent $\sim$20% of the solar system's history, a finding potentially related to 121514's present, low angular momentum rotational state [6], unless the Eureka family formed rapidly during a single fission event.

3. Future Work

New observations will be crucial to making further progress. Facilities such as PanSTARRS [7], GAIA and, especially, the Large Synoptic Survey Telescope [8] will improve on the current level of population completeness of the Trojans (equiv. to a limiting magnitude of $\sim$20) by several magnitudes and should discover a few hundred additional members of the Eureka family (Christou, A. A., IAU 2018 Coll. Proc., in press). This will either confirm the lack of families of 101429 and 121514 or find their brightest members, if they exist. In addition, because the path in the space of libration amplitude vs inclination is deterministic [2], the orbit distribution of family members will help constrain the formation age.

4. Figures

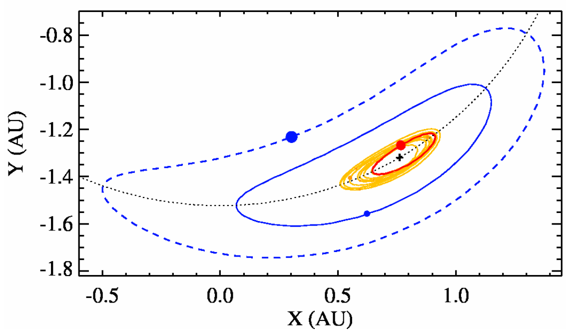

Figure 1: Paths of the 11 known Martian Trojans as of 2019 in a heliocentric cartesian frame rotating with Mars' mean motion: (5261) Eureka (red), its family members (amber) & (101429) 1998 VF_{31} (small blue point) at L_5 and (121514) 1999 UJ_7 (large blue point). The path of that last asteroid, shown as a dashed curve, has been mirrored over and across the Earth-Mars line for convenience. The dotted curve marks the mean heliocentric distance of Mars.

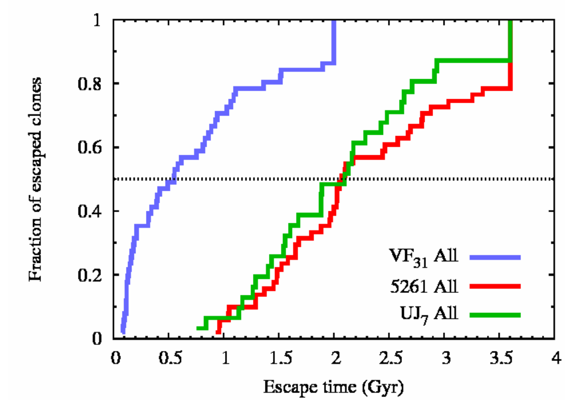

Figure 2: Cumulative distribution of escape time due to Yarkovsky orbital evolution for Martian Trojans originating from Eureka (red), 101429 (blue) and 121514 (green) in our numerical runs. Each curve is terminated by a vertical line to indicate the simulation end time for each object.

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