EPSC Abstracts
Vol. 8, EPSC2013-390, 2013
European Planetary Science Congress 2013

New features of the Martian Trojan clouds

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Abstract

New stable Martian Trojans are identified within the Minor Planet Center list of asteroids. All lie within the L_5 (trailing) Trojan cloud. A clustering of proper elements exists around 5261 Eureka. It is statistically significant even when taking into account the restricted space of orbital elements within which stable Martian Trojans could exist. This feature is likely the natural end result of the collisional processing or, alternatively, the rotational fission of a progenitor L_5 Trojan of Mars. It offers a new testing ground for models of the physical and dynamical evolution of small bodies.

1. Introduction

Trojan asteroids are confined by solar and planetary gravity to lead 60° ahead (L_4) or trail 60° behind (L_5) a planet's position along its orbit [1]. Mars is the only terrestrial planet known to host stable Trojans [2, 3], two at L_5 and one at L_4. The debate of the existence and origin of terrestrial planet Trojans is coming to the fore [4, 5] due to the upcoming Gaia [6] and NEOSSat [7] missions as well as new deep, wide field sky surveys such as PanSTARRS [8] and LSST [9].

Table 1: Proper elements and absolute magnitude H of Martian Trojans. All are L_5 librators except 1999 UJ_7. New Trojans are marked in bold.

Designation	H	D_p* (°)	e_p	I_p (°)
(5261) Eureka	16.0	11.4	0.0570	22.20
(101429) 1998 VF_{31}	17.0	38.1	0.0817	32.07
(121514) 1999 UJ_7	16.9	70.7	0.0346	18.05
(311999) 2007 NS_2	17.8	13.9	0.0444	20.96
2011 UN_{63}	19.7	13.8	0.0466	21.58
2011 SC_{191}	19.4	17.4	0.0717	19.15

* The full proper amplitude of libration

2. New Trojans

Searching through the Minor Planet Center database[1] produced 6 asteroids with orbital elements similar to those of existing Trojans. Three of those (see Table 1) were observed on at least two oppositions, so their orbits are reasonably secure. The numerically integrated nominal orbits of these three asteroids, as well as those of 100 randomly-generated clones per object, librate around the L_5 point at the present time (Fig. 1) and continue to do so for the full 10^8 yr duration of the simulations. Longer integrations [10] demonstrate stability, over Gyr timescales, of these asteroids and, in addition, 2001 DH_{47}. This raises the total number of stable Martian Trojans to 7.

3. Evidence for L_4/L_5 asymmetry

All Martian Trojans but one librate around L_5, a statistically unlikely outcome (probability of 6%) if equally likely discovery at L_4 or L_5 is assumed. Since all the asteroids were discovered by general-purpose asteroid searches, this likely reflects a real asymmetry in the Martian Trojan population rather than the result of observational bias. Further, the new objects are significantly fainter than previously known Trojans (Table 1) while the most recent dedicated search produced no new discoveries [11]. These facts argue strongly that we are seeing the results of the gradually increasing limited magnitude of asteroid surveys, to be extended even further by PanSTARRS and LSST.

4. The Eureka cluster

There is an apparent similarity between the proper elements of Eureka and the three new objects (Table 1). A statistical analysis shows that the degree of "clustering" within the phase space domain for stable Martian Trojans [2] is significant at the 3% level[2]. The implication is that either there is a (hitherto unknown) mechanism that brings Trojan orbits together or that these

[1] Available at http://www.minorplanetcenter.net/db_search

[2] Conservatively assuming that 2001 DH_{47} is *not* part of the cluster; calculation of its proper elements is in progress

objects, which we collectively refer to as the Eureka cluster, are genetically related.

5. Implications and future work

Given these new results and the (albeit limited) available physical information on these objects, likely origin scenarios include the collisional comminution of larger parent bodies or the formation of the smaller objects by rotational fission [12]. Notably, unlike most objects in the inner solar system, Martian Trojan asteroids do not suffer from the effects of planetary close encounters. This makes them ideal testing grounds for models of orbital and rotational evolution under non-gravitational forces and torques. A programme of physical characterisation of known Trojans, combined with new results on $H > 20$ Trojans by the next-generation sky surveys [5], will advance our understanding of the origin and evolution of these intriguing members of the solar system and, possibly, offer clues to terrestrial planet formation.

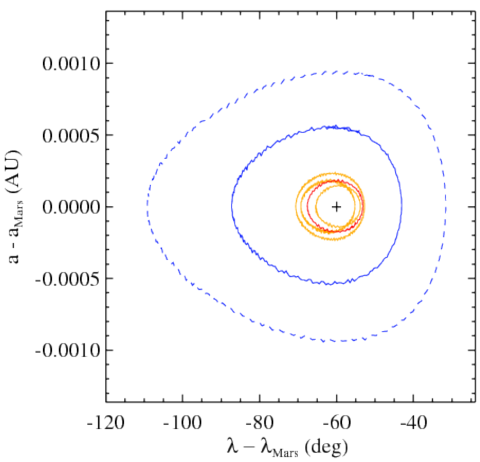

Figure 1: Libration of known Martian Trojans around the corresponding Lagrange point ("+" sign). In order of decreasing libration amplitude, they are: (121519) 1999 UJ_7 (blue dashed), (101514) 1998 VF_{31} (blue), (5261) Eureka (red); (301999) 2007 NS_2, 2011 SC_{191} and 2011 UN_{63} (amber).

Acknowledgements

The author wishes to acknowledge the SFI/HEA Irish Centre for High-End Computing (ICHEC) for the provision of computational facilities and support. Astronomical research at the Armagh Observatory is funded by the Northern Ireland Department of Culture, Arts and Leisure (DCAL).

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