LONG TERM STABILITY OF MARS TROJANS. H. Scholl, *Observatoire de Nice, France, scholl@obs-nice.fr*, F. Marzari, *Dept. of Physics, University of Padova, Italy*, P. Tricarico, *Dept. of Physics, University of Padova, Italy*.

We study the long term stability of Mars Trojans over the solar system age. A first screening of the parameter space of Mars tadpole orbits with the Frequency Map Analysis method allows us to outline a limited number of orbits with higher stability. The subsequent N–body long–term integration with a symplectic integrator allows us to test their survival over the solar system age.

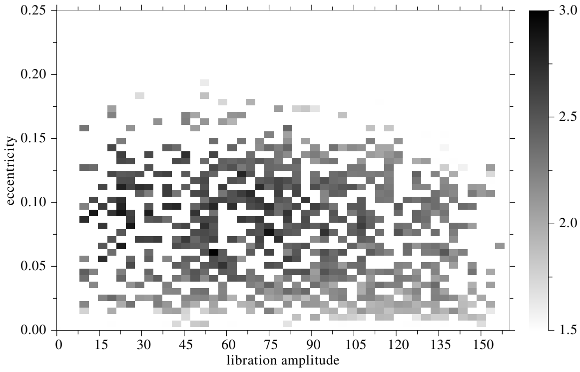

Figure 1: Diffusion portrait of Trojan orbits for an initial inclination of $25°$ and different values of proper eccentricity and proper libration amplitude. The diffusion speed is measured as the negative logarithm of the standard deviation of the proper frequency in the h, k variables [4]. Higher values of the standard deviation means lower diffusion speed and higher stability.

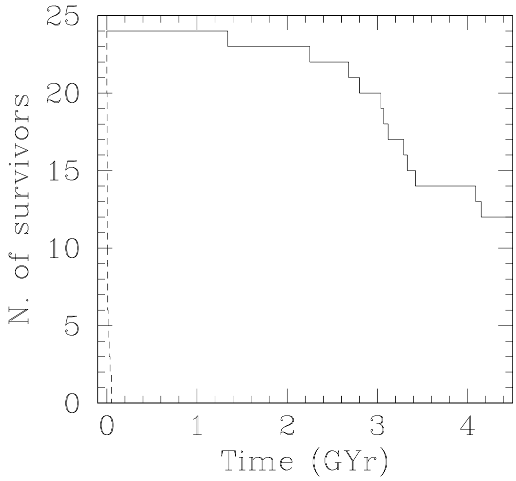

Figure 2: Survival curves of two different samples of Mars Trojans. The dashed line refers to the set of Trojans with high diffusion speed. It drops to 0 very quickly. The continuous line shows the evolution of the Trojans with low diffusion speed. This sample has a half–life of 4.5 Gyr.

Among the inner planets, Mars is the only one to have Trojan asteroids. (5261) Eureka and 1998 VF31 perform at present tadpole orbits around the L5 Lagrangian point of Mars. The stability of the orbits of Martian Trojans has been investigated by [1,2] via direct numerical integrations over limited timescales up to 100 Myr. Both Eureka and 1998 VF31 maintain their tadpole behaviour over this timescale and our integrations confirm that Eureka and a group of clones are stable over an extended period of 500 Myr. Stable zones were found by the same authors [1,2] for inclinations in between $15°$ and $40°$. To asses whether these bodies, and possibly additional ones within the stable zones, can be primordial, a longer term numerical integration is needed, at least over the solar system age. This is a demanding task when one wants to integrate a large number of fictitious bodies, since the numerical model must include all the planets, including Mercury. The timestep must necessarily be short.

By employing the Frequency Map Analysis (FMA) [3,4] we can partly overcome this problem by reducing the number of fictitious Trojans to integrate, since we can outline the stable region in the phase space with a limited computational effort. The FMA method measures the diffusion speed of a large number of test Trojan orbits. The stability of Mars Trojans is described by their diffusion in a phase space defined by proper libration amplitude and proper eccentricity for fixed proper inclination. The resulting figures are called diffusion maps and they show where stable orbits are located in the space of proper elements. The major advantage of this method is to require short term numerical integration of test Trojan orbits to outline the stability properties. A large portion of the parameter space can be investigated in this way.

We found lower diffusion speeds for inclinations around $25°$, in agreement with [1,2] and the corresponding diffusion map is shown in Fig. 1. The darker squares represent less chaotic orbits that are possibly stable over longer timescales. According to Fig. 1, the most stable and compact region is located at proper eccentricities in between 0.05 and 0.15, and at libration amplitudes lower than $90°$. Within this region, where the lowest diffusion speeds are found, we have selected 24 bodies and integrated them over the solar system age. For comparison, we integrated also the orbits of 24 bodies with the highest diffusion speed to test their stability. We used the WHM integrator [5] to perform all the numerical integrations which is part of the SWIFT software package [6]. Each virtual Trojan orbit is computed over a time span of 4.5 Byr within a 9–Body model including all the planets from Mercury to Neptune.

In Fig. 2 we show the survival curves of the two sets of putative Trojans. The sample with high diffusion speed is unstable on a short timescale and all the bodies escape from the Trojan cloud within 50 Myr. On the other hand, the sample with low diffusion speed is more stable and 12 bodies (50% of the sample) survive over 4.5 Gyr. This implies that a primordial population of Mars Trojans could have survived over the age of the Solar System. This population should be searched in the stable region outlined in Fig. 1.

Even though half of the Mars Trojan orbits survive over the solar system age, there is evidence that they are all in a weakly chaotic region. Firstly, the diffusion speed of the longest surviving Mars Trojans is much faster than that of Jupiter Trojans [4]. Secondly, the time evolution of the libration argument and eccentricity of surviving Mars Trojans looks chaotic like for the non-surviving cases. This is illustrated in Figs. 3 and 4. The respective upper case refers to a surviving and the lower to a non-surviving case.

The survival of Mars Trojans can be affected by the Yarkovsky effect, a weak recoil force due to thermal reemission by rotating asteroids. It is well known that the Yarkovsky effect may be responsible for the delivery of a large number of kilometer–sized bodies to the NEA source resonances [7,8] by causing a slow drift of the semimajor axis. The same force is also suspected to be responsible of the orbital diffusion seen among the small members of families in the asteroid belt. Tadpole orbits are sensitive to non–gravitational forces in particular to gas drag [9]. As a consequence, it is reasonable to expect that the Yarkovsky drag force might have some effect on the long term stability of Mars, Earth, and Venus Trojans. In particular, it might not be a coincidence that the two known Mars Trojans (1998 VF31 needs further observations to be confirmed as a Mars Trojan) both librate around L5. In [9] it has been shown that L5 is more stable than L4. We are performing additional simulations of the 24–body sample of stable Mars Trojans including the Yarkovsky effect. Preliminary results indicate that bodies perturbed by the Yarkovsky force have a more chaotic behaviour.

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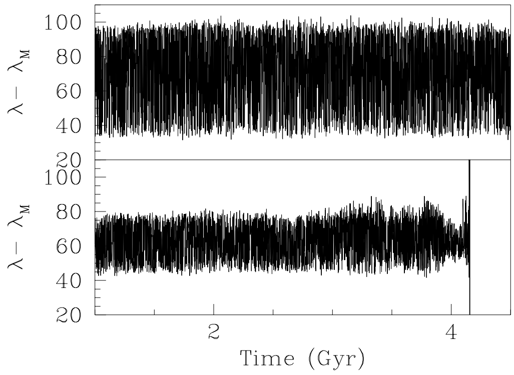

Figure 3: Time evolution of the libration argument of the 1:1 resonance for two fictitious Mars Trojans

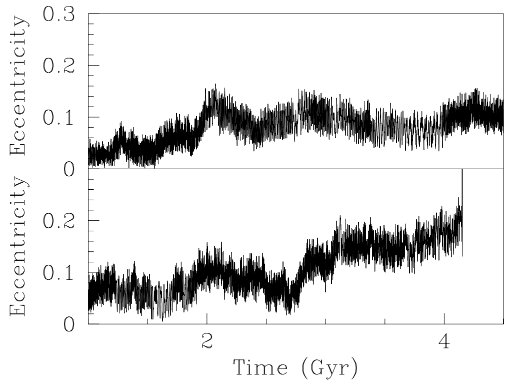

Figure 4: Time evolution of the eccentricity of the same cases shown in Fig. 3. The eccentricity is slowly increasing leading towards escape from the tadpole orbit.