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Chaotic transport of Main Belt asteroids in Martian resonances

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Abstract

A major question in planetary science is the source regions and parent bodies of NEAs and meteorites [1]. In the contemporary view, these are first produced as fragments of larger asteroids in the Main Belt [2, 3], then mobilized by chaotic orbital evolution [4, 5] and Yarkovsky radiation forces [6, 7] until their injection to the terrestrial planet region through dynamical "escape hatches" [8]. The process of orbit mobilisation of MB asteroids is a relatively unexplored chain in this link, with implications for the past evolution and genealogy of bodies in the asteroid belt [5, 9] but also efforts to debias the observed NEA population [10, 11].

We are pursuing a project to quantify the efficiency of Mars resonances to mobilise Inner Main Belt asteroids (ie those with a<2.5 au) through intensive numerical simulations. We complement, and expand on, earlier work [4, 12, 13] by systematically mapping out the mobility rate of asteroids both within and outside resonances and over a wide region of phase space. We initially consider only point-mass gravitational forces, since these would affect all asteroids independently of size. Pinning down the long-term effect of gravity alone would also help to separate it out in later simulations that include non-gravitational forces.

Here, we focus our attention on the 1:2 & 4:7 exterior mean motion resonances with Mars. Both of these, but especially the 1:2 resonance, visibly affect the orbital distribution of asteroids in their vicinity (Fig 1) and therefore we expect them to be important individual drivers of asteroid orbit evolution.

Our principal finding from these simulations is that, while there is little change in e & I outside these resonances, asteroids in the resonances undergo significant chaotic evolution. This implies that resonant asteroids can slowly migrate away from the family they belong to and ultimately become Mars-orbit crossers.

However, the magnitude of the changes is different for the two resonances and even between asteroids within the same resonance. For instance, the change in I is significantly higher within the 4:7 than the 1:2 resonance, probably because the 3rd order resonance allows interaction between numerous strong multiplets involving the node. At the same time, orbits in the 1:2 resonance with $e \simeq e_{\rm Mars}$ diffuse faster in e than more eccentric orbits within that resonance. There, the varying eccentricity of Mars may be modulating the frequency of hopping between the two principal multiplets, with strengths proportional to e and $e_{\rm Mars}$ respectively.

In conclusion, our findings show that local dynamics play an important role in mobilising asteroid orbits. Therefore, models of the IMB as a dynamically evolving population with asteroid production and loss will require careful calibration over a sufficiently large number of different locations.

1. Figures

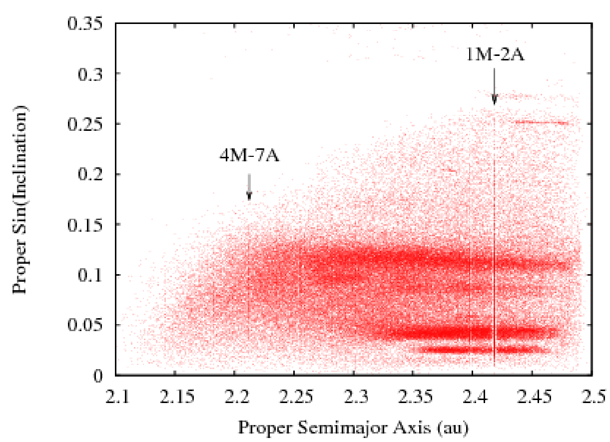

Figure 1: Phase portrait of asteroid orbits in the IMB. The arrows indicate the locations of the xM-yA exterior Martian resonances where the asteroid completes x revolutions for every y revolutions of Mars.

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