The Mars 1:2 Resonant Population

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Icarus, in press

May 2007

Abstract

An excess of around 400 asteroids in the distribution of the semimajor axes of the asteroids is identified by means of numerical integrations as generated by a population of approximately 1000 asteroids evolving inside the exterior resonance 1:2 with Mars. Approximately 200 asteroids are librating around the asymmetric libration centers and their evolution in a time-scale of 1 millon years appears stable but with a strong influence of Mars' eccentricity. The biggest Mars 1:2 resonant asteroid is (142) Polana.

Key Words: Celestial mechanics; resonances, orbital; asteroids, dynamics; Mars

The signatures of Jupiter's mean motion resonances are well evident in the distribution of the main belt of asteroids. Profound *gaps* in the histogram of semimajor axes are related to dynamical evolution with strong eccentricity increments due to the dynamics of the mean motion resonances or due to the secular evolution inside the resonant regime (Nesvorný *et al.* 2002).

Jupiter is not the only planet dominating the dynamics of asteroids' orbits. Three body resonances involving Jupiter, Saturn or terrestrial planets also have been proven to be a source of chaos responsible for the injection of asteroids in the Earth's neighborhood (Nesvorný and Morbidelli 1998; Morbidelli and Nesvorný 1999). Mean motion resonances are present everywhere in the solar system. Whether their effects are detectable or not is determined by their strength which depends on the planet, the particular resonance and the orbital elements of the asteroid's orbit (Gallardo 2006).

Using the numerical method proposed by Gallardo (2006) we elaborated an atlas of the strength of all resonances with all the planets in the region of the main belt of asteroids assuming orbits with eccentricity $e = 0.3$, inclination $i = 10^o$ and arbitrary argument of the perihelion $\omega = 60^o$ just for illustrative purposes. In Fig. 1 we compare this atlas with the histogram of semimajor axes constructed with bins of 0.001 AU from the asteroidal database ASTORB (ftp://ftp.lowell.edu/pub/elgb/astorb.html). The signatures of Jupiter's resonances already mentioned are evident but we note also some excess of asteroids at suggestive locations. In particular there is an excess of around 400 asteroids with respect to the background at the region $2.416 \leq a \leq 2.422$ AU where the relatively strong and isolated exterior resonance 1:2 with Mars is present ($a \sim 2.419$ AU).

In ASTORB database we identified around 4000 asteroids with osculating orbital elements in the range where the resonance 1:2 with Mars should have some influence ($2.415 < a < 2.423$ AU). This is a tiny region in osculating a (Nesvorný *et al.* 2002) which can be deduced performing numerical integrations with some resonant test particles. It is important to note that we are working with nominal orbits that in some cases have uncertainties of the order of the width of the resonance. For example, approximately 20% of these orbits corresponds to one-opposition orbits but this do not introduce any relevant bias in our study.

We numerically integrated the planetary system from Venus to Neptune plus the selected asteroids using the integrator EVORB (Fernández *et al.* 2002) for a time-span of 2×10^4 years with an output of 20 years. Then we calculated the time evolution of the corresponding critical angle $\sigma = 2\lambda - \lambda_M - \varpi$ related to the resonance 1:2 with Mars where λ and λ_M are mean longitudes of the asteroid and Mars respectively and ϖ the longitude of the perihelion of the asteroid. We automatize the analysis by means of an algorithm that calculates a histogram for σ for each asteroid, from 0^o to 360^o using bins of 10^o and looks for concentrations and gaps in each histogram.

The libration period of σ is of order of 10^3 years so the time-span covered by the numerical integration is enough for the identification of resonant motion. Analyzing the output of the numerical integration by the method outlined above we found that around a thousand of objects show librations of σ, that means, evolve inside the resonance. We have also analyzed the other relevant critical angle associated with this resonance, $\sigma_1 = 2\lambda - \lambda_M - \varpi_M$, where ϖ_M is the longitude of the perihelion of Mars. In general σ_1 is not librating except for few cases of orbits with small eccentricity. In these cases we have observed libration of σ_1 instead of σ.

It is known that in the frame of the planar circular restricted three body problem the resonance 1:2 has two *asymmetric* libration centers (Beaugé 1994), one for $\sigma < 180^o$ and another for $\sigma > 180^o$. There are also possible librations in trajectories that wrap both libration centers following a kind of *horseshoe* trajectory in the plane $(e\cos\sigma, e\sin\sigma)$, being e the asteroid's eccentricity, in analogy with some trojan asteroids (Gallardo 2006). At small eccentricities both libration centers collapse and librations around $\sigma = 180^o$ are possible. According to our 2×10^4 years analysis approximately 1000 asteroids from ASTORB are evolving in the resonance distributed so that (i) 21% are librating with libration amplitude ($\sigma_{max} - \sigma_{min}$) less than 180^o; of those, 12% are oscillating around the libration center located at $\sigma < 180^o$ and 9% are oscillating around the libration center located at $\sigma > 180^o$ (ii) 62% are switching between both libration centers or in horseshoe trajectories or librating around $\sigma = 180^o$ with libration amplitude less than 350^o (iii) 17% are alternating between horseshoe trajectories and circulation.

We numerically integrated the same planetary model and this population of about 1000 resonant asteroids for 1 millon years and found that in this time-scale the resonant population is stable. Changes between libration centers and temporary circulations are very common but the number of asteroids experiencing librations is not diminishing but oscillating in phase with the time evolution of Mars' eccentricity (Fig. 2). This behavior is due to the *forced mode* (Ferraz–Mello 1988; Gallardo and Ferraz–Mello 1995) that is a component of the resonant motion due to Mars' eccentricity and proportional to it that produces a periodic modulation of the libration trajectory.

Some of the asteroids located the deepest in the resonance, with small amplitude libration of the critical angle, are 1998 SS50, 2001 UZ65, 1998 TG17, 2003 BO71 and 2002 CS92. In our 1 Myr numerical integration these objects show a very stable evolution, most of the time with a libration amplitude less than 40^o. The biggest asteroid of the resonant group is (142) Polana with an IRAS-derived diameter of 55 km (http://ssd.jpl.nasa.gov/) which is experiencing high amplitude librations ($\Delta\sigma \sim 180^o$). This asteroid is part of a family of asteroids not well understood at present. In particular, looking at the space of orbital elements it seems to be an overdensity of dark F-type asteroids with no clear link with the family (Cellino *et al.* 2001).

It is known that the Yarkovsky effect (Bottke *et al.* 2000) generates a slow migration of small asteroids and could be responsible for an injection of asteroids into the resonance 1:2 with Mars. According to the absolute magnitudes of our sample we can estimate that the smallest asteroids we have integrated have radius of some 10^2 meters and according to Bottke *et al.* (2000) the Yarkovsky effect should generate a drift of some 10^{-4} AU in semimajor axis in a time scale of one millon years. The mean value of the absolute magnitude of the resonant population ($< H >= 16.5$) is slightly greater than the mean value for no the non resonant population ($< H >= 16.3$) but an evident excess of small asteroids in the resonant population is not clearly established. Further analysis of this effect can also be done, for example, looking for signatures of YORP effect (Rubincam 2000) in the rotational properties of this resonant population.

The existence of an excess of objects dynamically dominated by the resonance tell us that the resonant evolution is somehow protected against the depletion mechanisms acting in the asteroid belt like the Yarkovsky effect or chaotic diffusion (Nesvorný *et al.* 2002), probably because the strength of the resonance is enough to overcome those mechanisms and also because no dramatic secular evolution is associated with this resonance.

The Mars 1:2 resonant population at present is defined by around a thousand of known asteroids and constitutes a relatively stable reservoir when compared with its neighborhood. The only parameter that we can clearly distinguish between the resonant and non resonant population is the mean eccentricity which is 0.21 and 0.16 respectively. We have some challenges for the near future: Is this population primordial? Is there a capture mechanism and, if so, what is its nature? Was the population generated by a migrating Mars like Neptune's plutinos and twotinos? Is there a relationship between resonance 1:2 with Mars and Polana's family?

Acknowledgments

The author acknowledges the labor of the anonymous reviewers that substantially improved the original manuscript. This work was developed in the framework of the "Proyecto CSIC I+D, Dinamica Secular de Sistemas Planetarios y Cuerpos Menores".

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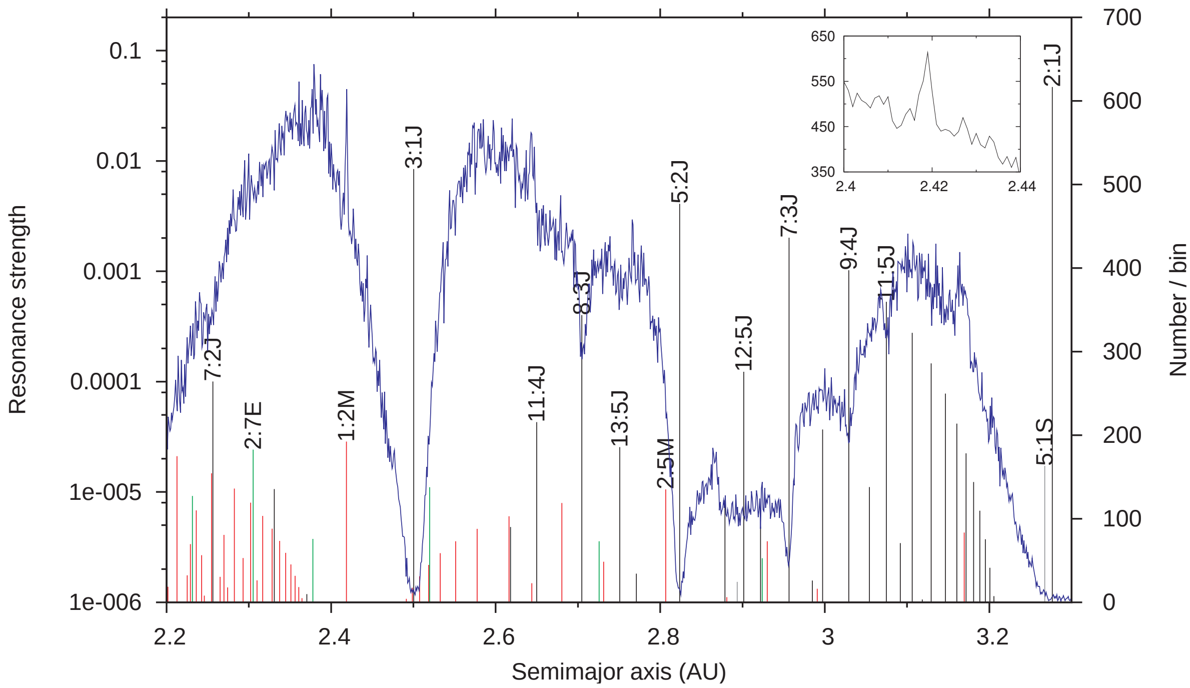

Fig. 1.— Locations of the mean motion resonances in the main belt of asteroids with their associated strengths calculated following Gallardo (2006) assuming $e = 0.3$, $i = 10^o$ and $\omega = 60^o$. Some strong resonances are labeled with the indication of the planet associated. Superimposed is showed an histogram of semimajor axes of the known asteroid population taken from ASTORB database with osculating epoch JD 2454200.5 and using bins of 0.001 AU. Gaps due to resonances with Jupiter are evident and also the excess at $a \simeq 2.419$ AU where the conspicuous exterior resonance 1:2 with Mars is located. The excess covers several bins being the most populated the one at $a = 2.419$ AU with an excess of around 150 asteroids with respect to the background (see the zoom at upper right corner).

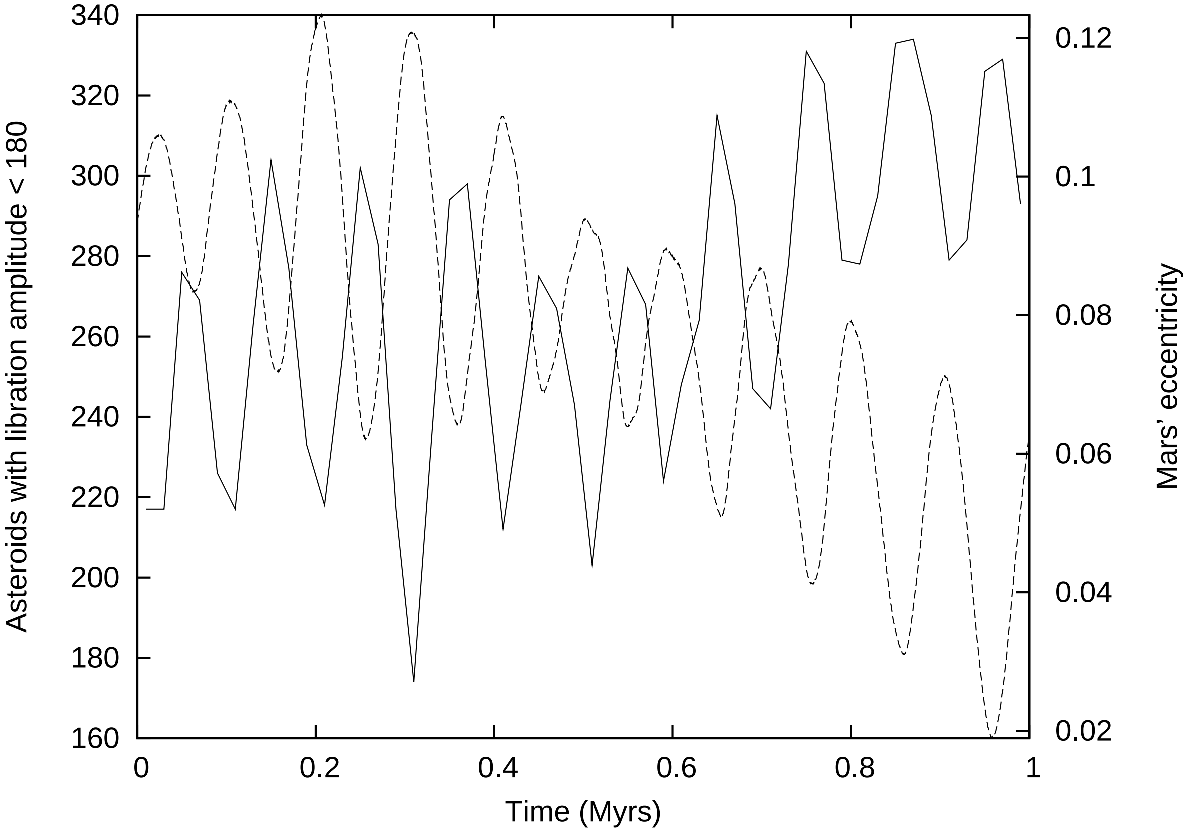

Fig. 2.— Time evolution of the number of known asteroids with libration amplitude ($\sigma_{max} - \sigma_{min}$) less than 180^o (continuous line) and the evolution of Mars' eccentricity (dashed line). The number of librating asteroids does not diminish with time, on the contrary it is strongly linked to the oscillations of the eccentricity of Mars.