A Connection of the 2/1 Resonance Asteroids with the Themis Family?

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Abstract: 2/1 mean motion resonance with Jupiter is known to be populated by several tens of asteroids larger than 2 km; depending on their location in the resonance, the stability of their orbits range from very stable (dynamical lifetime comparable to the Solar system age) to highly unstable (dynamical lifetime ~ 10 Myr) [1]. We consider a hypothesis, that these asteroids are linked to the Themis family, an impact generated asteroidal group which is located nearby, below the edge of the 2/1 resonance. This has been conjectured by Morbidelli *et al.* in [2], who proposed that the family-forming event might have placed some, fastest-escaping asteroids onto their present locations. Further work on the asteroid families indicates, that the initial dispersion of the family is likely to be much smaller than needed to directly place objects in the 2/1 resonance [3]. Here we investigate a possibility, that former Themis members were subsequently transported to their present position in the 2/1 resonance via the orbital drift due to the Yarkovsky force.

Our numerical simulations seem to disprove the dynamical connection between the Themis family and the group of asteroids on stable orbits (the so called Zhongguos). We discuss the probability that at least the Griquas (with lifetime ~ 100 Myr) and the highly unstable asteroids might originate from the Themis family. We also confirm result of Roig *et al.* [1], that the Zhongguos stability is not altered by the Yarkovsky effect, suggesting the case that these asteroids are either

1. outcome of a primordial resonant asteroid disruption (given their very steep size distribution); or
2. collisional ejecta of a secondary (cratering?) event in the Themis family.

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Introduction:

Here we attempt to address the origin of asteroids, which are located inside the 2/1 mean motion resonance with Jupiter and reside on orbits:

1. stable (over the age of Solar system), so-called **Zhongguos** (26 asteroids)
2. quasi-stable (lifetime several hundred Myr), so-called **Griquas** (11)
3. **strongly unstable** (on timescale several 10 Myr or less), (16)

We are testing the hypothesis that bodies originated in the Themis family, which is close to the edge of the 2/1 resonance, and the Yarkovsky effect drove them onto their present locations.

Initial conditions of the numeric simulation:

- 500 TPs, 4 outer planets only, **timespan 1 Gyr**. Distribution of a, e, i elements roughly resembles the part of Themis family closer to the 2/1 resonance (Fig. 1); initial osculating inclinations were $\sin i \in (0.03, 0.035)$.
- **Rotational states:** obliquity $\gamma = 45^\circ \rightarrow$ particles drift outwards, head to the 2/1 mean motion resonance with Jupiter. Rotational periods are equally distributed between 4 and 12 hours.
- As far as the **thermal parameters** of the TPs are concerned, we chose the same as those expected for the Themis family itself: bulk and surface density 1300 kg/m^3, thermal conductivity 0.01 W/m/K, thermal capacity 680 W/kg/K, albedo 0.02, and infrared emissivity 0.95.
- **Size distribution:** radii are ranging from 1 km upto 11 km (Fig. 2). For sake of some analyses TPs were divided in two groups:

  #1 with $R \in (1.7, 11)$ km (minimal drift rate $\frac{\mathrm{d}a}{\mathrm{d}t} = 1\times10^{-5}$ AU/Myr)

  #2 with $R \in (1, 1.7)$ km (maximal $\frac{\mathrm{d}a}{\mathrm{d}t} = 2\times10^{-4}$ AU/Myr)

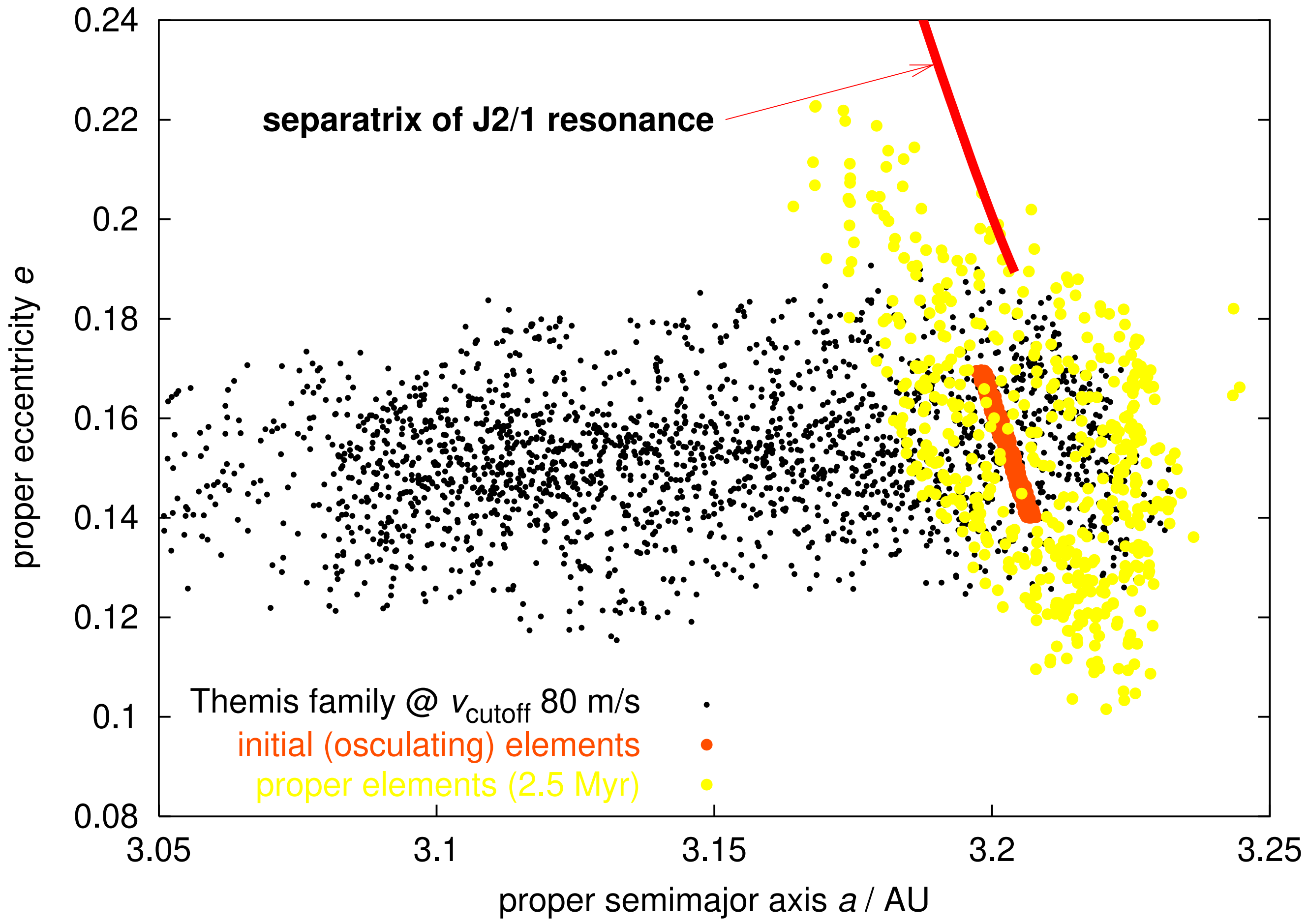

Fig. 1 — Initial proper elements (a, e) of 500 TPs and comparison with the observed Themis family members, identified by the HCM method at 80 m/s cutoff velocity.

Averaging technique, “resonant” elements:

- **Outside the resonance** we usually use on-line filtering based on a sequence of convolution filters (so-called Kaiser windows); in this case we used initial sampling 1 yr and the sequence of four filters AAAB with corresponding decimation factors 10 10 5 3, resulting in an output every 1500 yr, which is free of periods shorter than approx. 1000 yr. After that we calculate “proper” elements by a running window method (the window is typically 5 Myr wide). Additionally, we store the osculating elements, but only every 10 kyr.

- The motion **inside the 2/1 resonance** is dominated by short periodic oscillations of the critical argument libration (approx. 300 – 400 yr) of both semimajor axis and eccentricity. Because the above on-line filter is not properly adjusted to the 2/1 dynamics (and the structure of the resonance becomes completely smoothed by the averaging), we uses a slightly different approach:

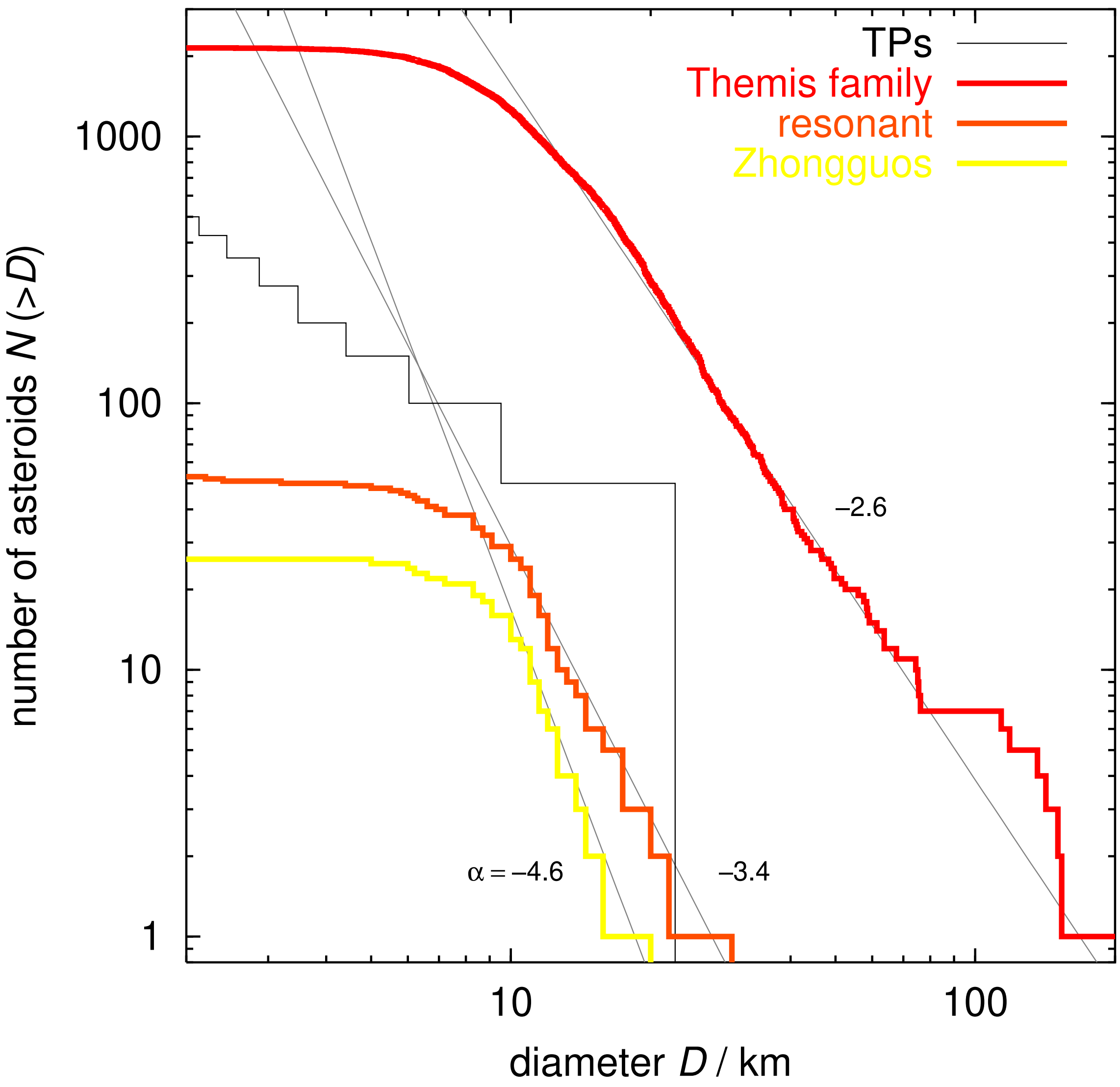

Fig. 2 — Size distributions of Themis family, observed resonant asteroids (all 3 groups), Zhongguos and our TPs. The values of α (power-law $N(>D) \propto D^{\alpha}$ best fits) are indicated.

(The high steepness of Zhongguos size distribution suggests their recent collisional origin [4]; collisionally relaxed populations have distribution with $\alpha \simeq -2.5$ [5].)

To keep the information on the amplitude of (coupled) a, e oscillations, we used a running minimum (or maximum) filter, ie. we restarted the integration (from the osculating elements stored every 10 kyr), ran for 500 yr (what is certainly longer than one oscillation period) and kept only one datum from this short run — the minimum of a and maximum of e.

Unfortunately, aliasing problem could arise from the fact, that medium-period oscillations (approx. 20 kyr) are undersampled. To remove these oscillations completely, we finally applied 1 Myr running window (certainly a method that partially corrupts the fine details of the in-resonance dynamics).

"Transport maps" of the 2/1 resonance:

- We call a colour coded $(a,\ e)$ plot as a "transport map" — see Fig. 3 for explanation.

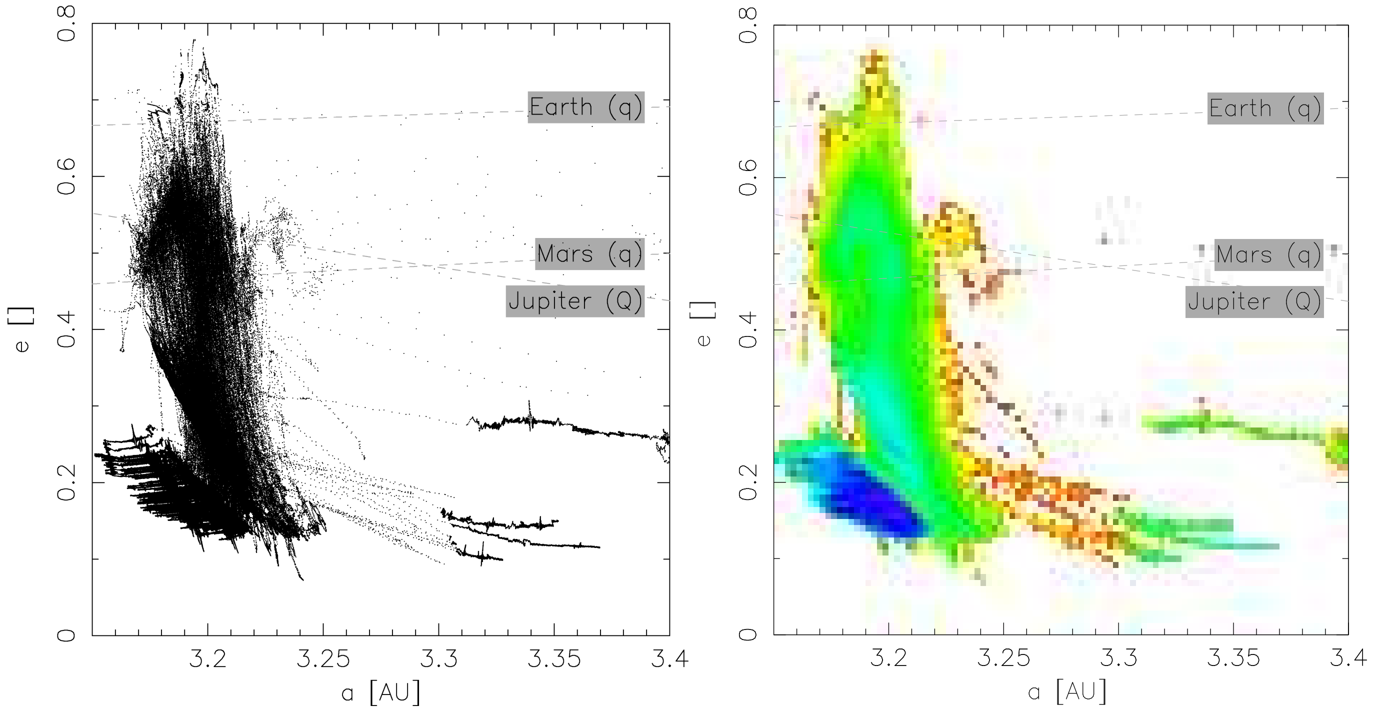

Fig. 3 — (a) Resonant $(a,\ e)$ plot for 250 TPs of set #2. On a usual proper $(a,\ e)$ plot all particles would be located in the middle of the 2/1 resonance and consequently no structures could be seen.

(b) $(a,\ e)$ plot with the same scale, but the colour coding of rectangular cells displays (logarithm of) the total number of test particles, which were located inside the cell, summed over all time steps. blue denotes **stable regions** (occupied by many asteroids for considerably long time), whilst there is little points in the red cells (and no points in white). Lower number of recorded asteroids in a cell means either (i) little TPs from Themis region reach this location or (ii) it is an dynamically unstable region, where TPs reside for only a short time.

- A comparison of the **chaotic diffusion rates** and our transport map is possible on Fig. 5. The well known structures from Fig. 5a (such as fast diffusion on separatrices or stable islands inside the resonance) are also visible on Fig. 5b.

- In spite of that, **we do not observe any long term** (>100 Myr) **captures** of TPs in the 2/1 resonance, resembling **low–inclined** Zhongguos orbits (see Fig. 4 and 6). Moreover, the capture periods might be even somewhat shorter, if we include inner planets in the simulation.

- On the other hand, strongly **unstable asteroids and** partially also (high-inclined) **Griquas might be repopulated** by objects drifting from the region of Themis family (see Fig. 7 and Tab. 1).

The ratio of number of observed Griquas and observed unstable asteroids is $\sim$0.7, while in our simulation this ratio is only $\sim$0.007, ie. hundred times less. (If we expect, that ALL Griquas and unstable are produced by the same mechanism, it should be roughly equal to the ratio of average lifetimes, ie. approximately ten times less.)

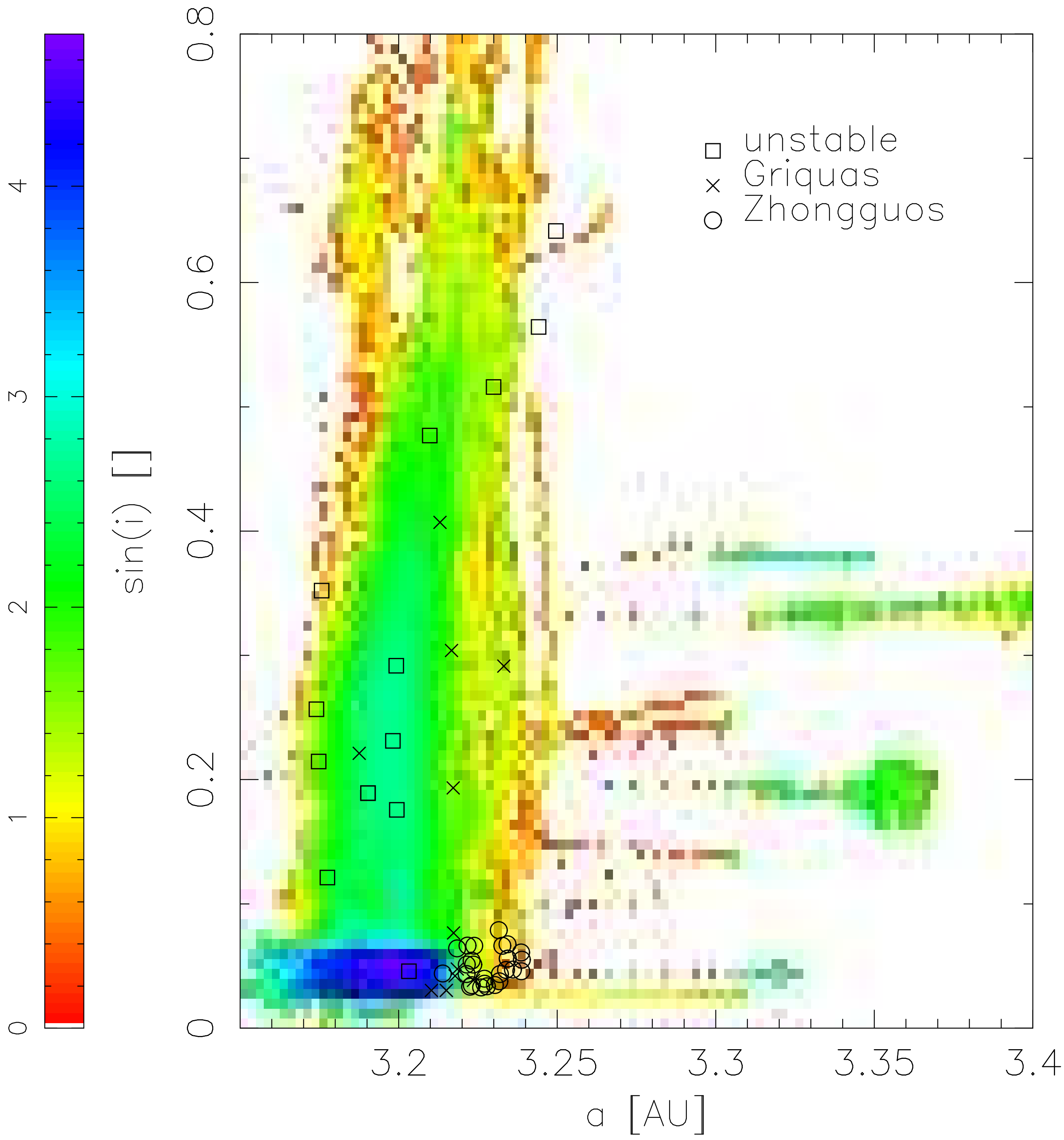

Fig. 4 — (a, sin i) plot with the same colour coding as in Fig. 3. Observed asteroids with three types of orbits are also plotted. It is clearly visible, that secondary resonances cause quick increase of inclination of our TPs and avoid them to reach Zhongguos region.

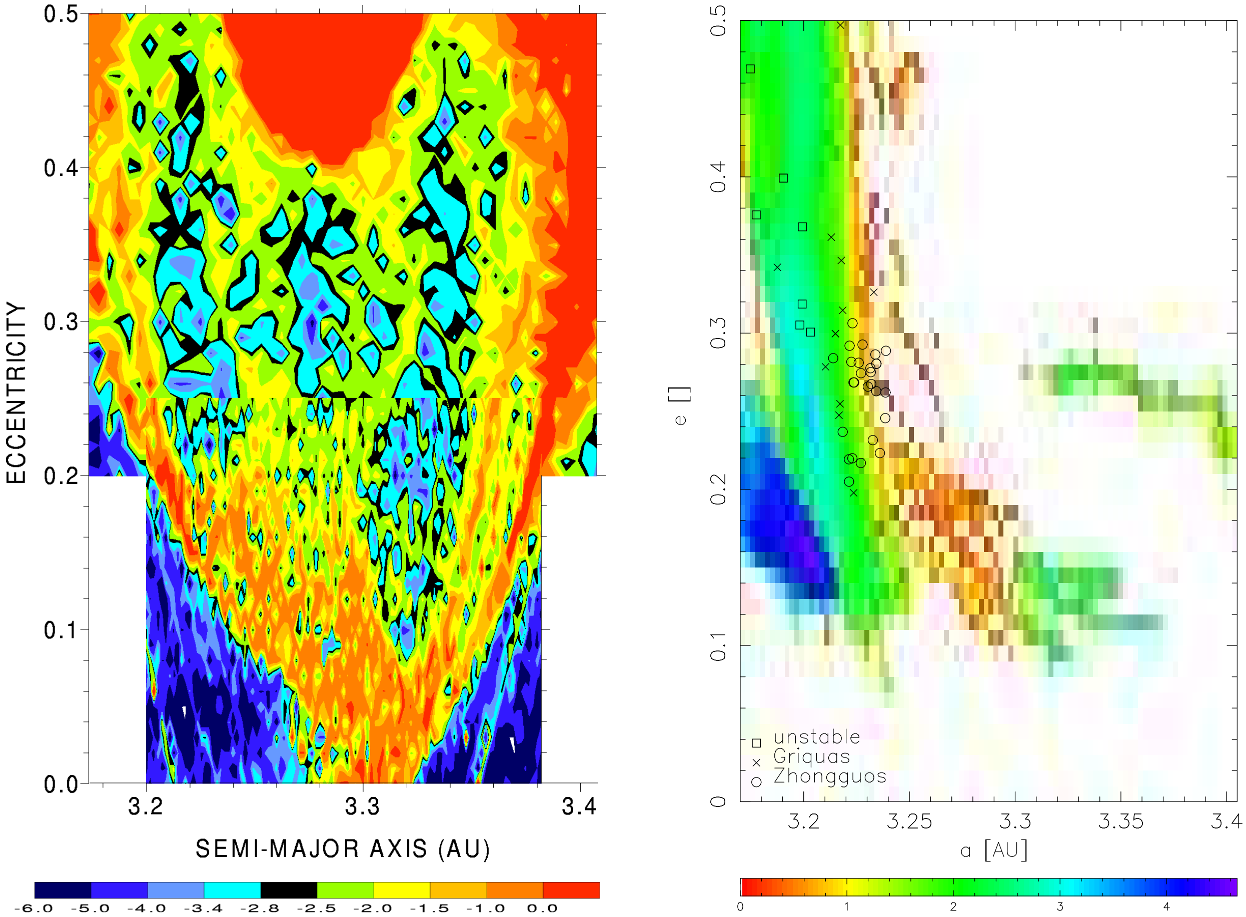

Fig. 5 — (a) A chart of chaotic diffusion in the J2/1 resonance. Red colour represents high values of $\log_{10} |\delta\, \mathrm{d}\varpi / \mathrm{d}t|$, while blue denotes slow diffusion rates. (Adapted from [6].)

(b) (a, e) plot for 250 TPs (set #2), with similar scale and colour palette as in the previous case (a), but the colour coding of rectangular cells now displays logarithm of the total number of test particles, which were located inside the cell, summed over the whole timespan of the integration.

Far most of TPs on Fig. (b) (ie. blue, cyan and green areas) do NOT reach “stable islands” on Fig. (a) (denoted by blue and cyan colours).

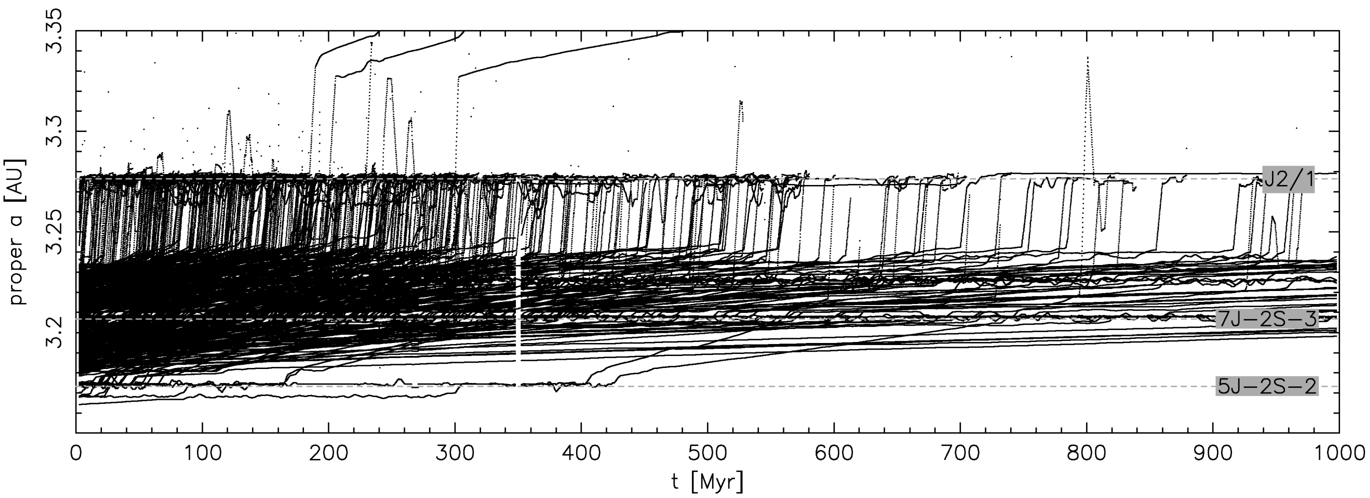

Fig. 6 — Proper (not resonant) $a(t)$ plot for all 500 TPs. As soon as a particle enters the 2/1 resonance and starts to librate (around its center), a large ($\sim$0.04 AU) jump is visible on this plot. (It is caused by the 5 Myr averaging, which effectively “suppresses” the librations and thus all TPs seem to move near the J2/1 center.)

It might be seen clearly that lifetimes of objects inside 2/1 resonance (before their ejection by close encounters with Jupiter) are very short (of the order ~ 10 Myr) and almost no long captures could be observed.

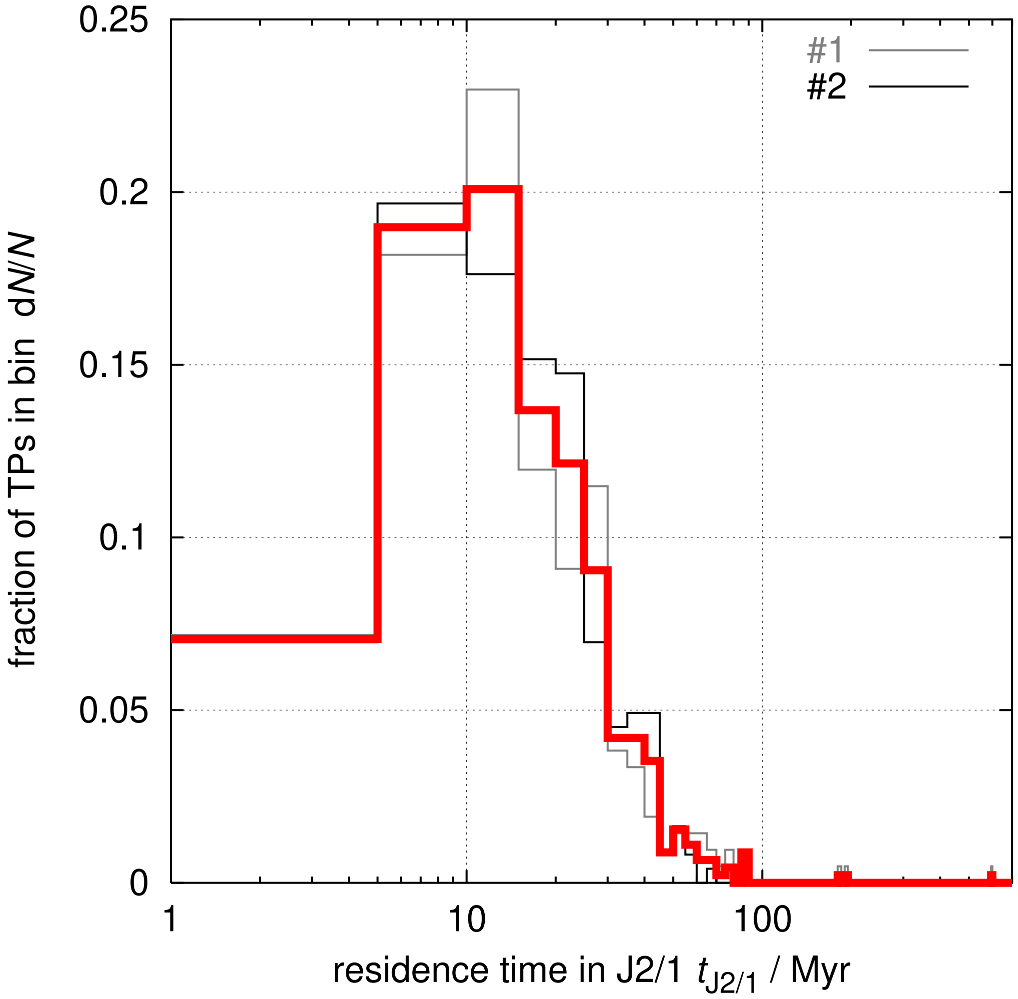

Fig. 7 — Histogram of residence times in J2/1 resonance. Only 3 TPs ($R \simeq 2$ km) have residence times longer than 100 Myr: 185, 191 and 600 Myr. There is no significant difference between sets #1 and #2.

type of orbit	# TPs	fraction
unstable	450	99.3 %
Griquas-like	3	0.7 %

Tab. 1 — Fate of injected particles. Total number of 453 TPs from Themis region entered the J2/1 resonance during the simulation timespan.

Yarkovsky driven diffusion through the 2/1 resonance:

- Four particles (ie. 1.6 % out of 250 TPs of set #2) crossed the 2/1 resonance (see Fig. 3 and 6). (However, remember the inner planets were missing in this simulation, and perihelia of 3 TPs reached Mars crossing region; some of them might be eliminated during this period.)

Stability of orbits inside the 2/1 and the Yarkovsky effect:

- There is no significant difference between residence times in simulations with and without Yarkovsky effect (see an example on Fig. 8).

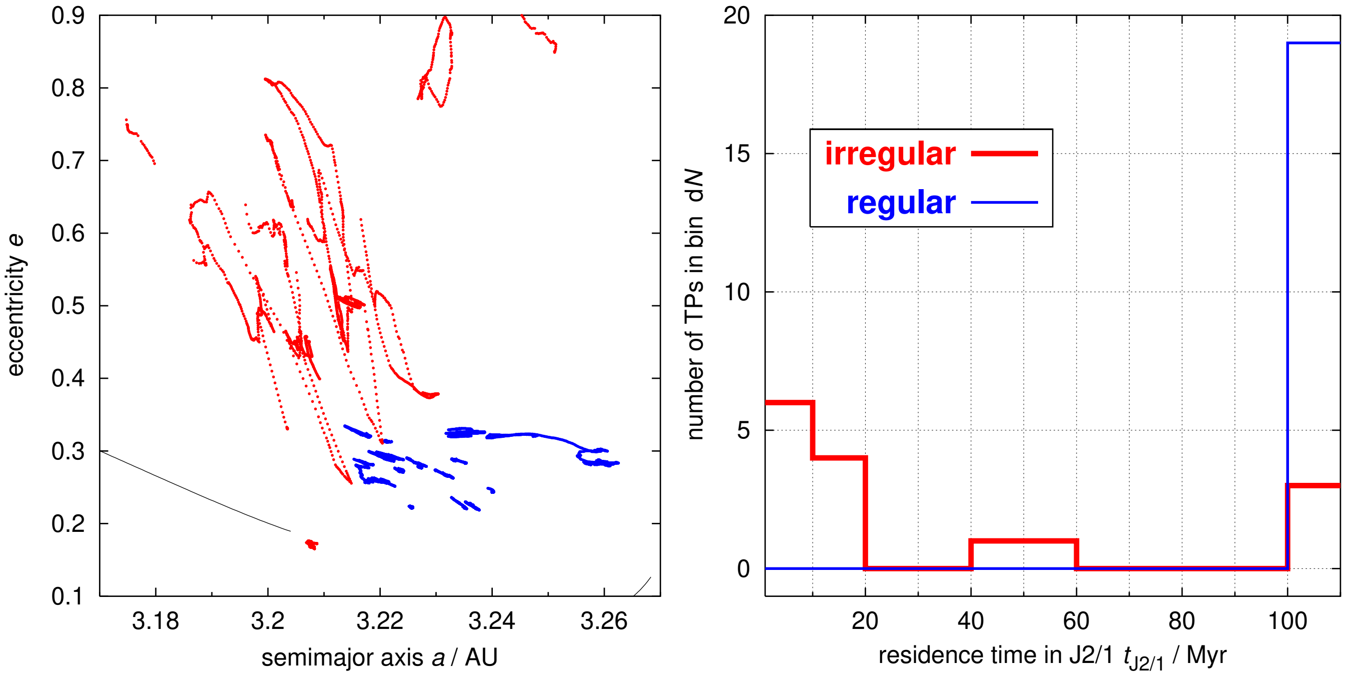

Fig. 8 — (a) Plot resonant (a, e) for 34 asteroids of two groups: 11 red asteroids were unstable on the timescale 200 Myr in a simulation **without** Yarkovsky effect; 19 blue were stable. In this simulation (spanning 100 Myr) the Yarkovsky force affects asteroids.

(b) Histogram of J2/1 residence times for the same simulation. No significant change of orbital (un)stability could be observed.

Conclusions:

- Less than 1 % of Themis asteroids (in the size range 2 – 3.5 km) might be able to cross the J2/1 resonance and even stay on low e, i orbits.
- We observed no significant change of orbital stability (lifetime) of Griquas and Zhongguos between calculations with and without Yarkovsky effect.
- Diffusion paths in (a, e, i) transport maps indicate, that particles from Themis family might be sources in particular of unstable asteroids and partially also of Griquas.
- We did not find any TPs (out of 500) from Themis family, drifting due to Yarkovsky effect towards J2/1 resonance, which could be placed onto Zhongguo–like orbits. Namely inclination of TPs increased soon after they have entered J2/1 resonance, what is probably caused by number of secondary resonances inside. Zhongguos but then have inclinations low, around value $\sin(i) \doteq 0.05$.

- Together with our belief that the initial velocities of the Themis members were not large enough to inplace Zhongguos directly, this would suggest that Zhongguos are unrelated to the Themis family (possibly a residual population initially formed in the J2/1 resonance?).

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