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Yarkovsky-driven origin

of the unstable population of asteroids in the 2:1 mean motion resonance with Jupiter

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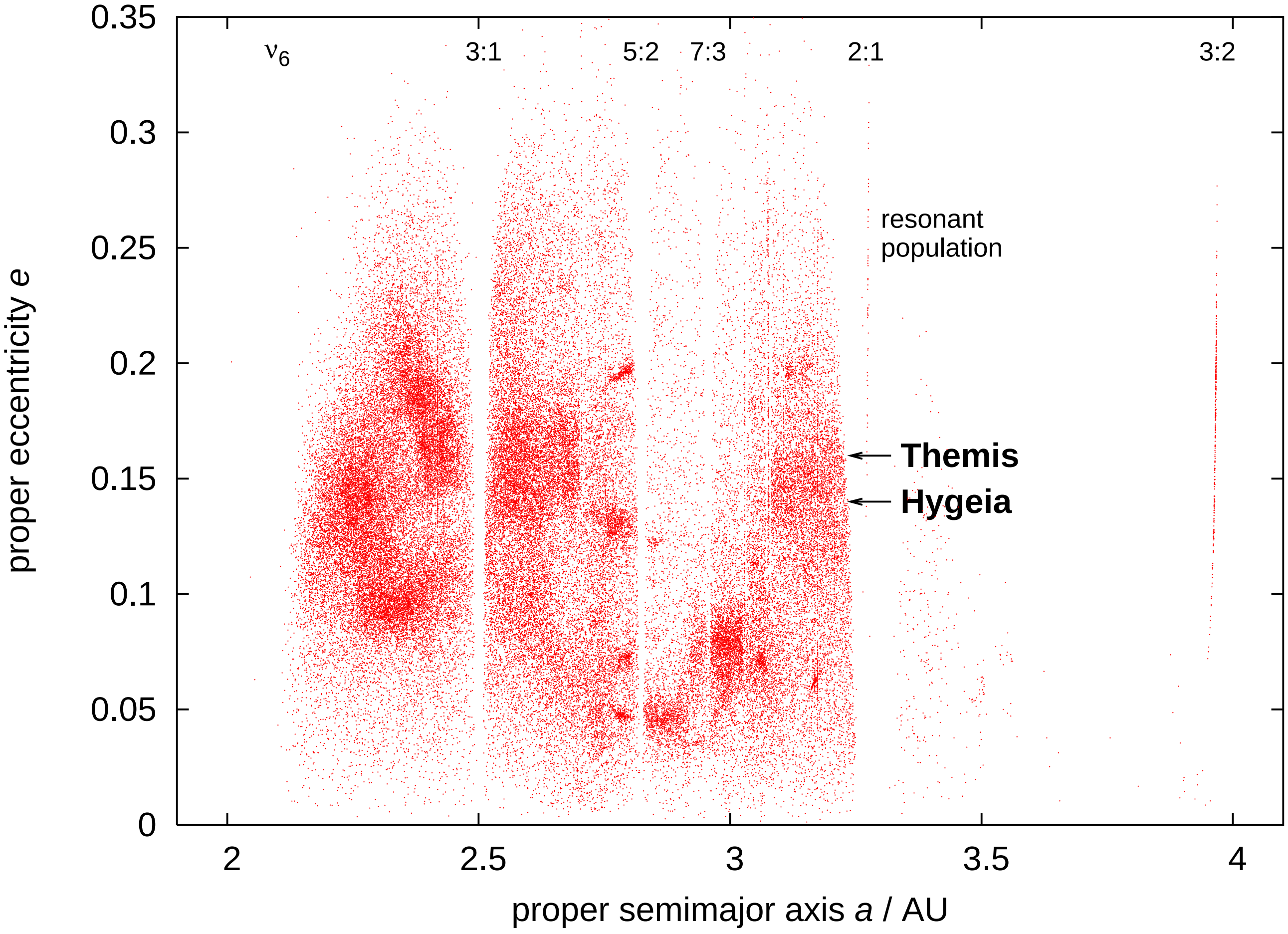
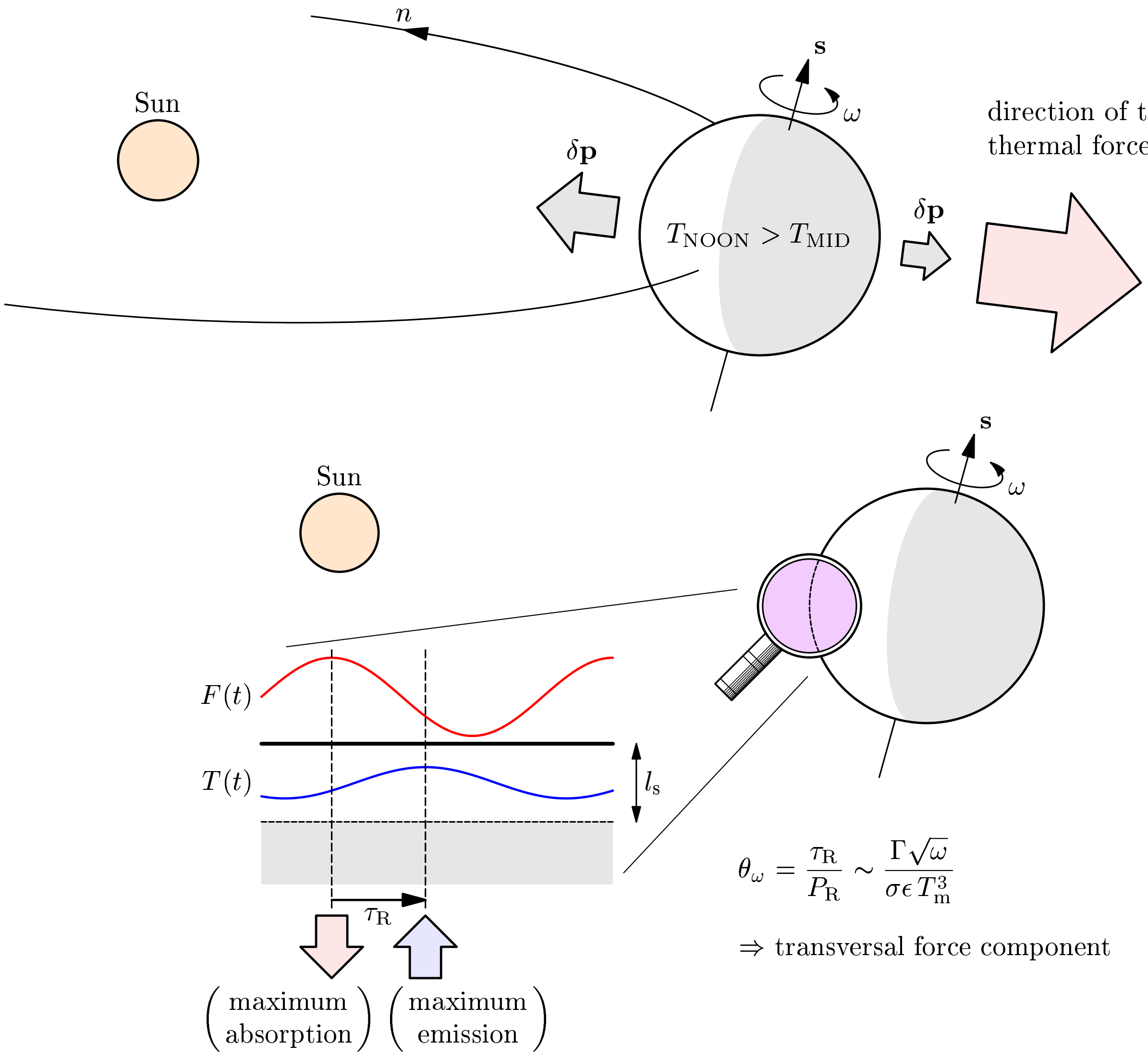

0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
2
2.5
3
3.5
4
proper eccentricity e
proper semimajor axis a / AU
ν6
3:1
5:2
7:3
2:1
3:2
resonant population
Themis
Hygeia



$$\theta_\omega = \frac{\tau_{\mathrm{R}}}{P_{\mathrm{R}}} \sim \frac{\Gamma\sqrt{\omega}}{\sigma\epsilon T_{\mathrm{m}}^3}$$

$\Rightarrow$ transversal force component

Questions to answer:

- evolutionary paths?
- lifetime?
- size distribution?
- # of resonant asteroids?

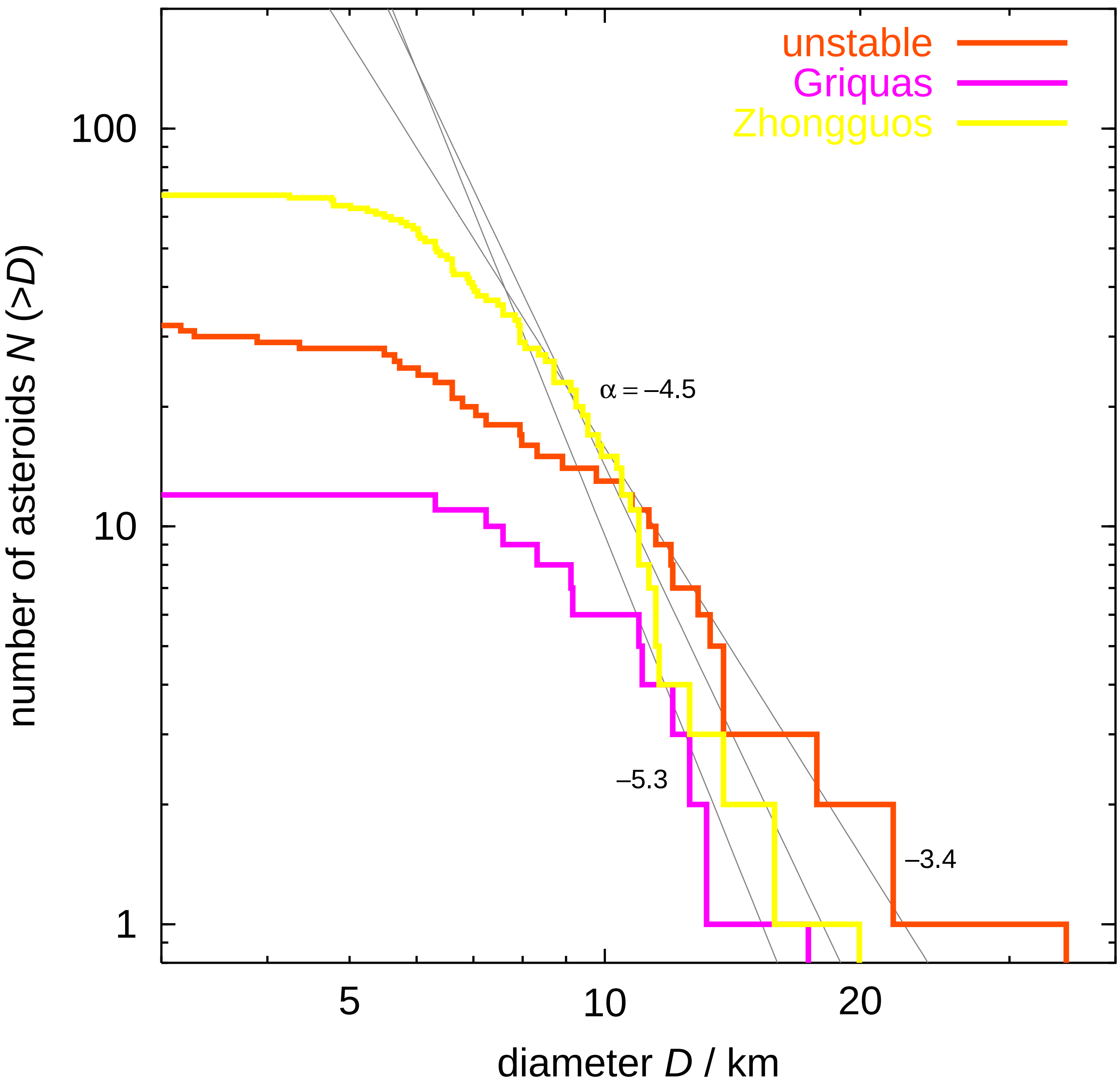
Table of contents:

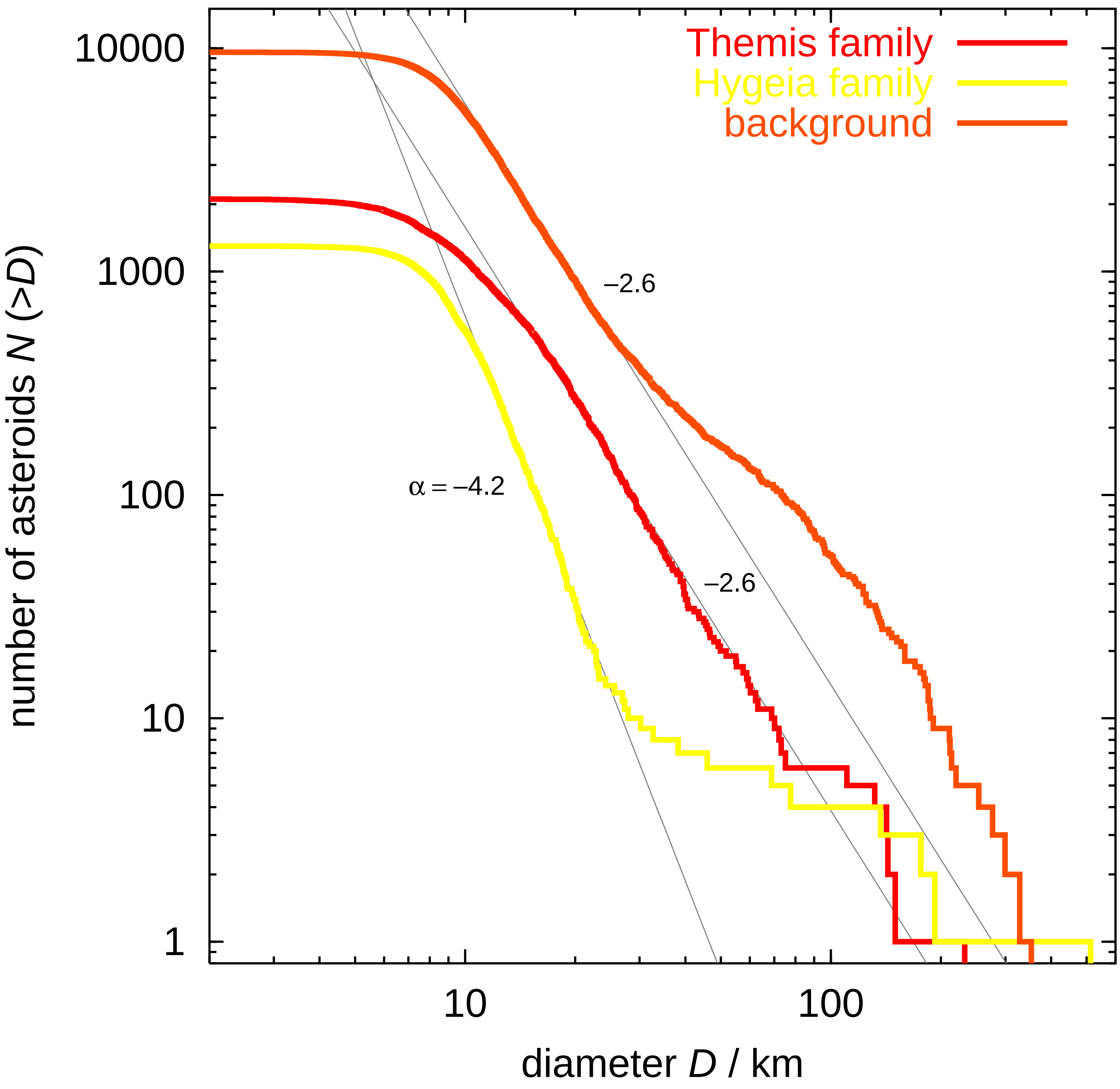
2:1 resonance objects (Roig et al., 2002)**:**

- Zhongguos (stable > 500 My)
- Griquas (~ 100 My)
- highly unstable asteroids (~ 10 My)

Source populations:

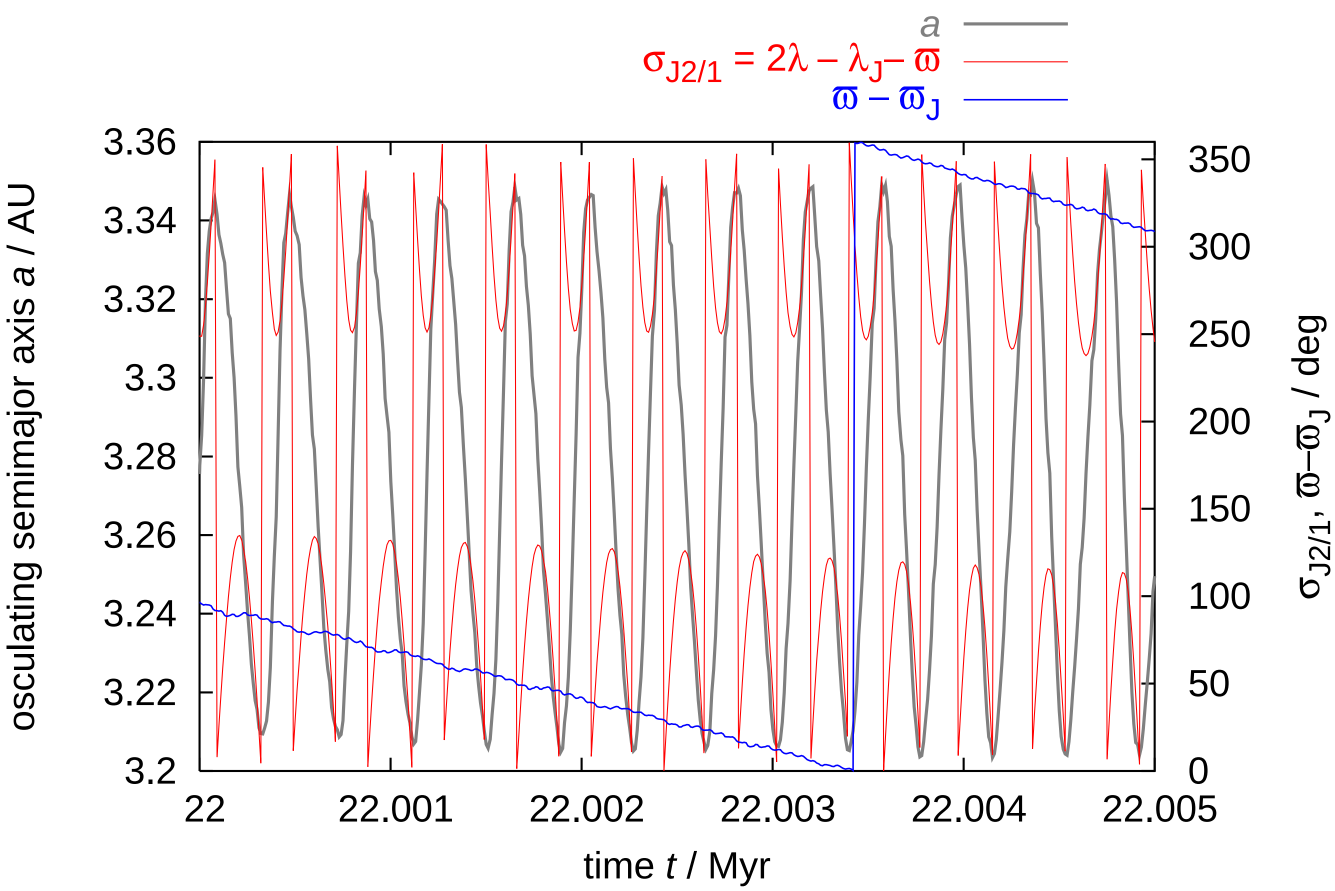
- Themis family
- Hygeia family
- background asteroids

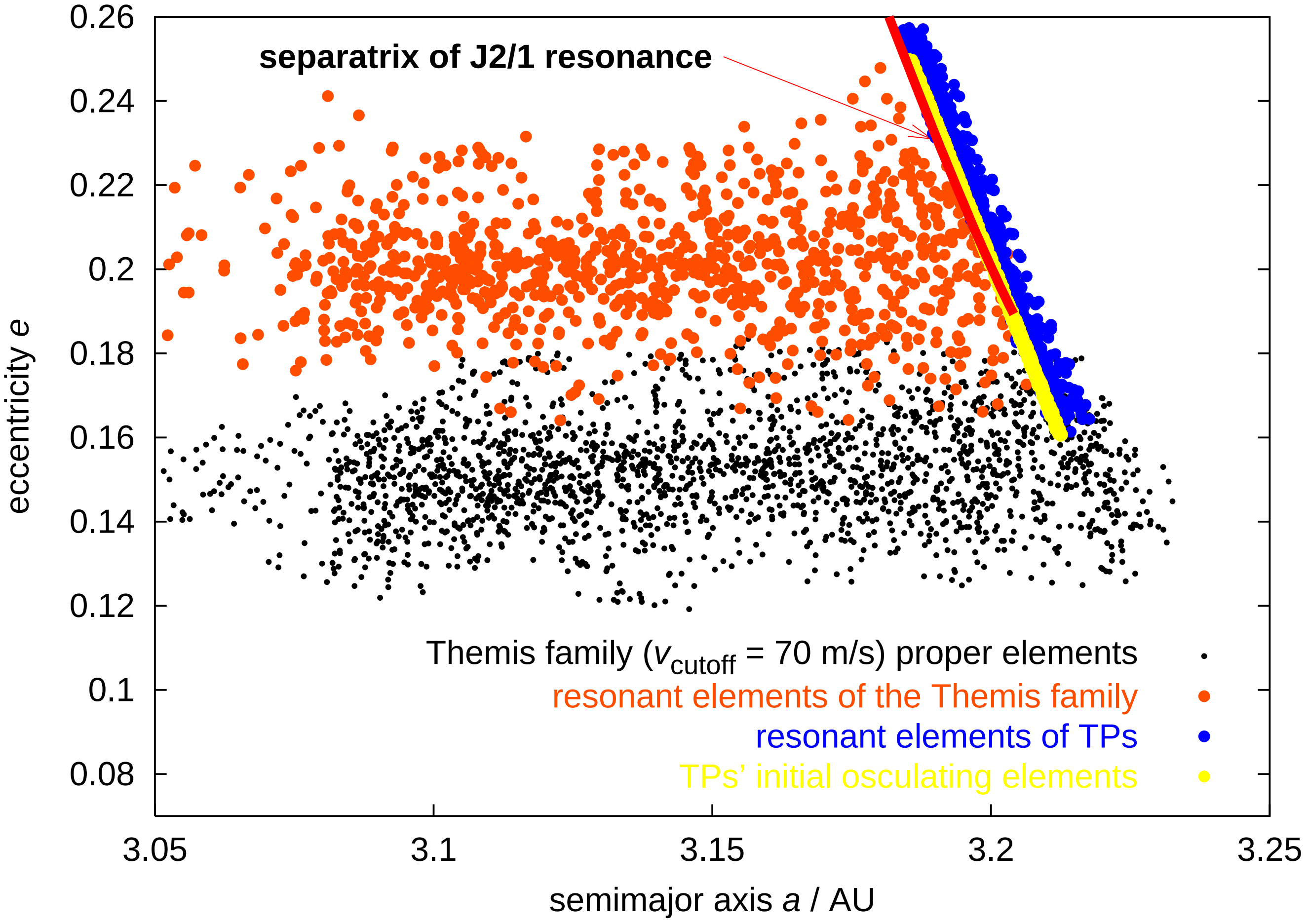

unstable
Griquas
Zhongguos
100
10
1
5
10
20
number of asteroids N (>D)
diameter D / km
α = −4.5
−5.3
−3.4

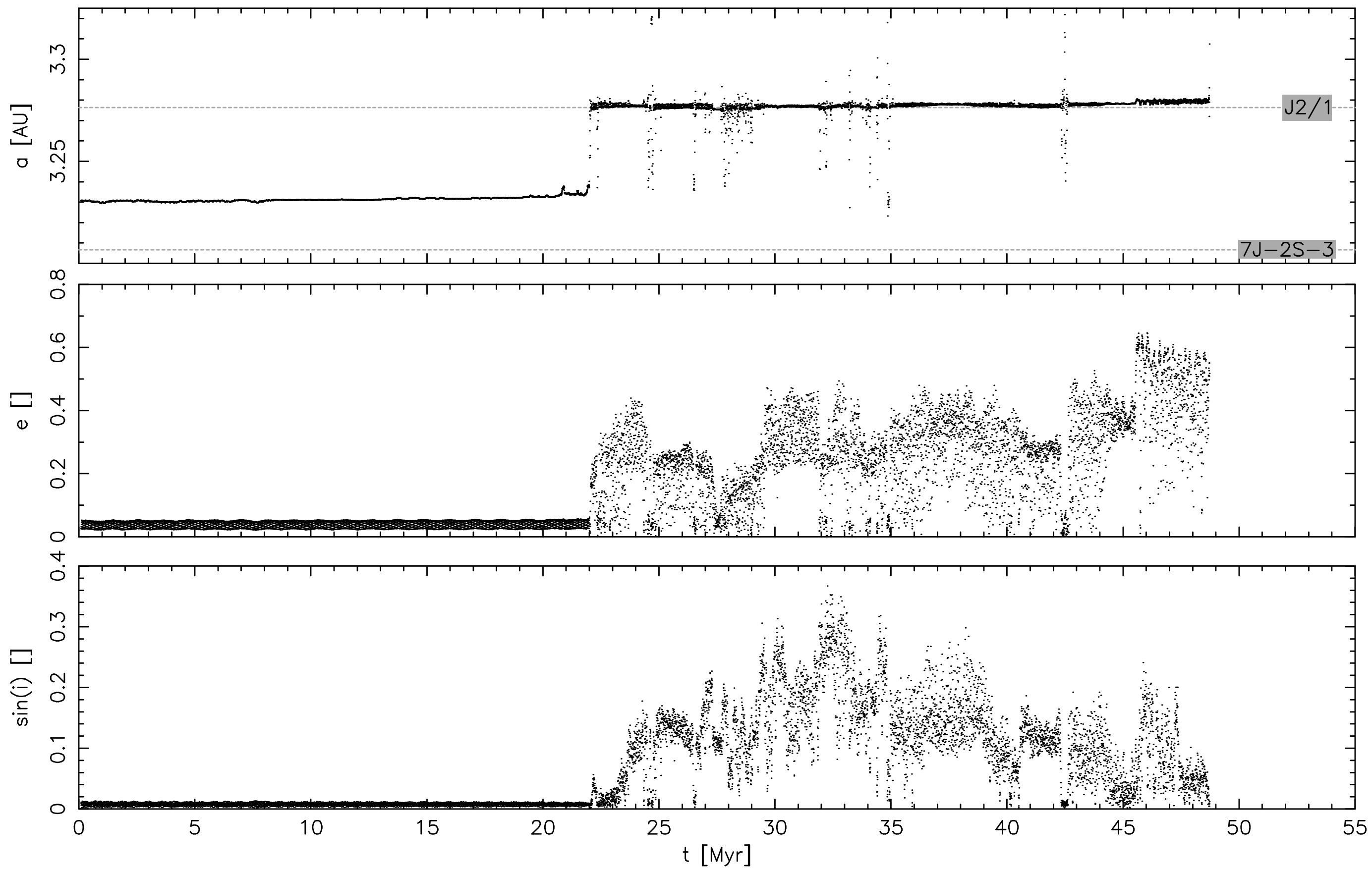

Themis family
Hygeia family
background
10000
1000
100
10
1
10
100
number of asteroids N (>D)
diameter D / km
−2.6
−2.6
α = −4.2

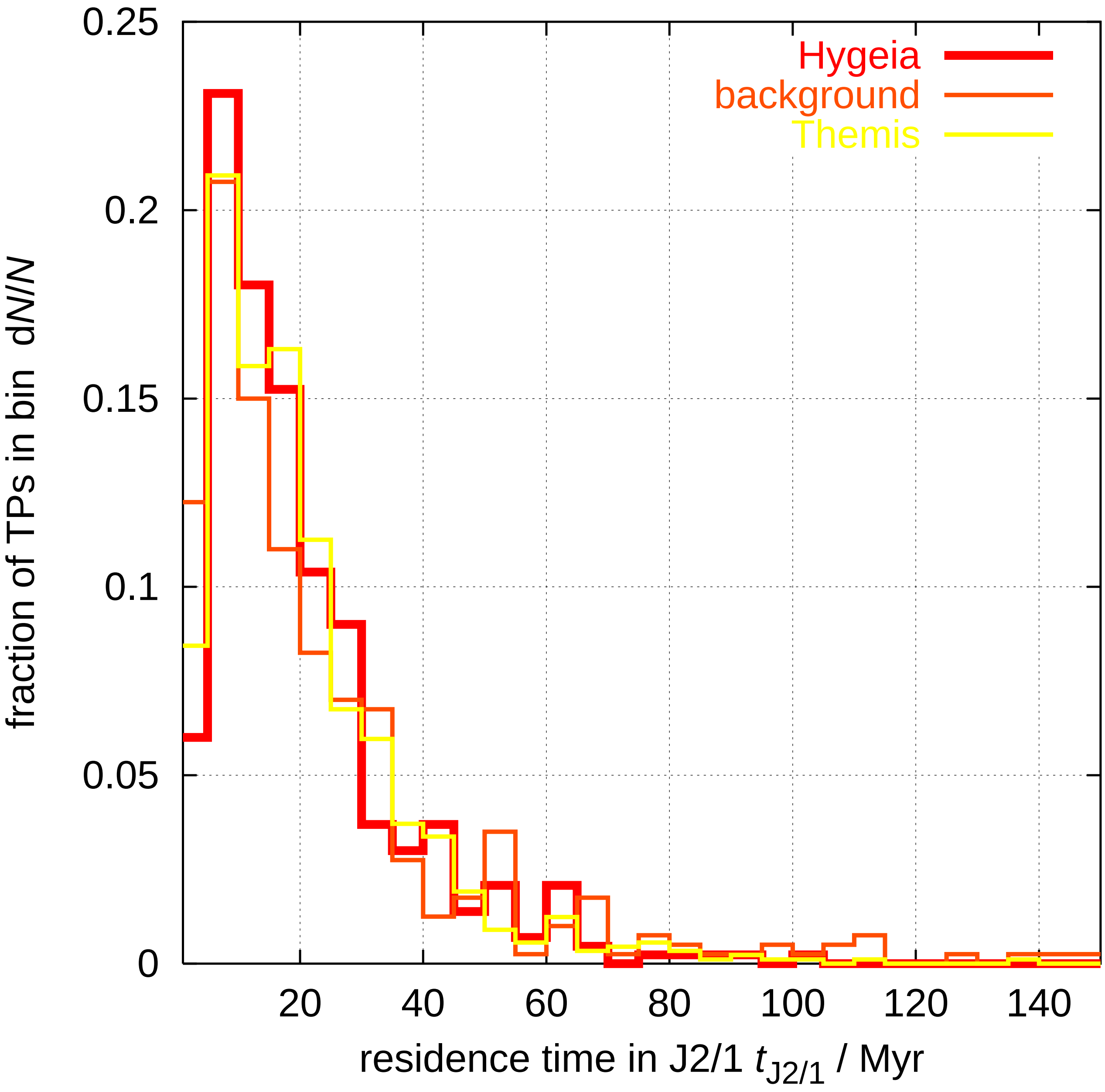
Parameters of the model #1:

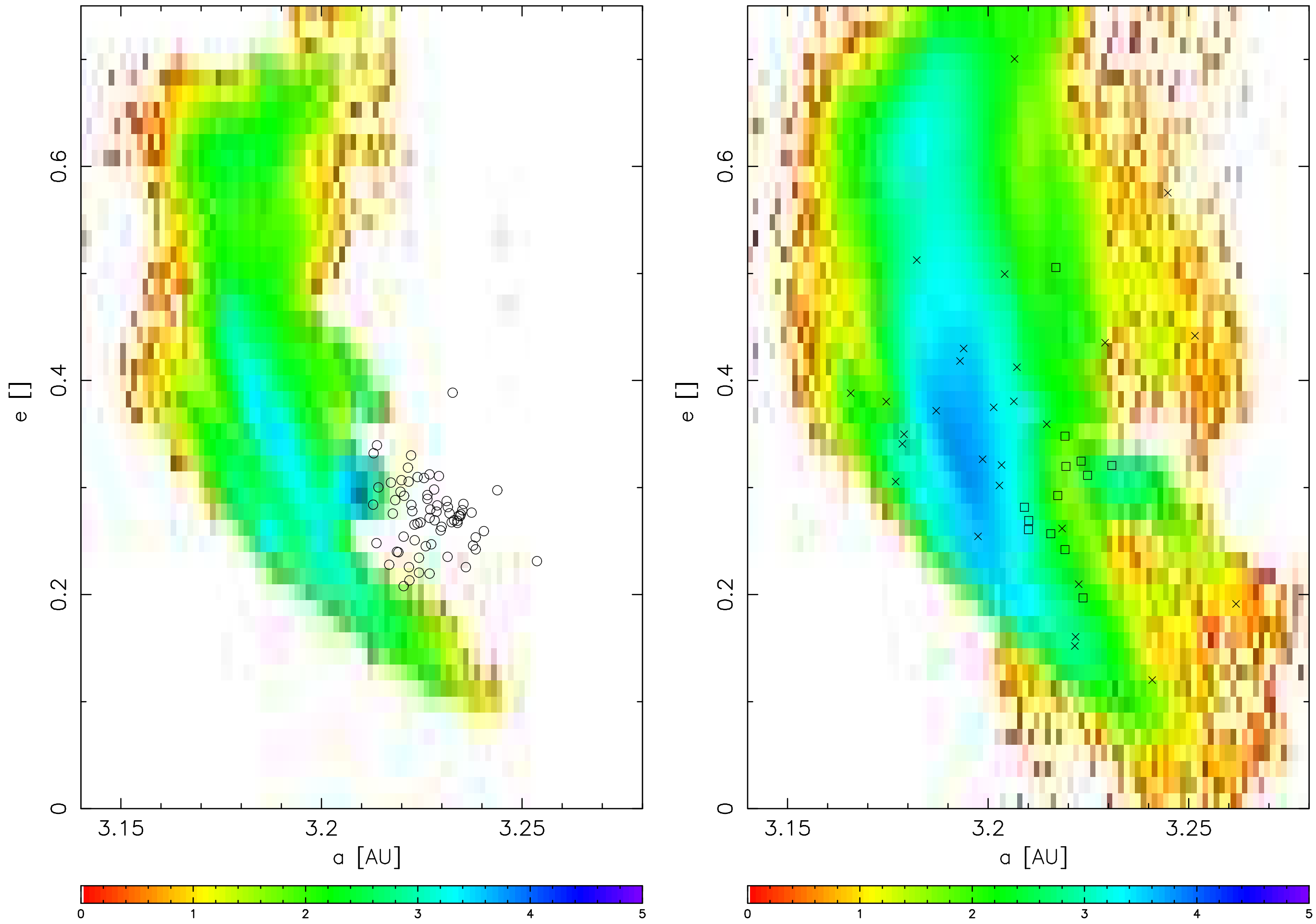
- SWIFT-MVS2-FP-Y integrator, timestep 91 d, timespan 1 Gy (no close encounters, resonant elements filter, Yarkovsky effect)
- 1000 TPs for each source, 4 outer planets
- initial conditions: TPs just below the separatrix of the 2:1 resonance; the range of e and i corresponds to the source population
- rotational states: $\gamma = 45^\circ \to$ outward drift, $P = 4$ to 12 h
- thermal parameters: bulk and surface density 1300 kg/m^3,
  thermal conductivity 0.01 W/m/K,
  thermal capacity 680 W/kg/K,
  Bond albedo 0.02,
  infrared emissivity 0.95

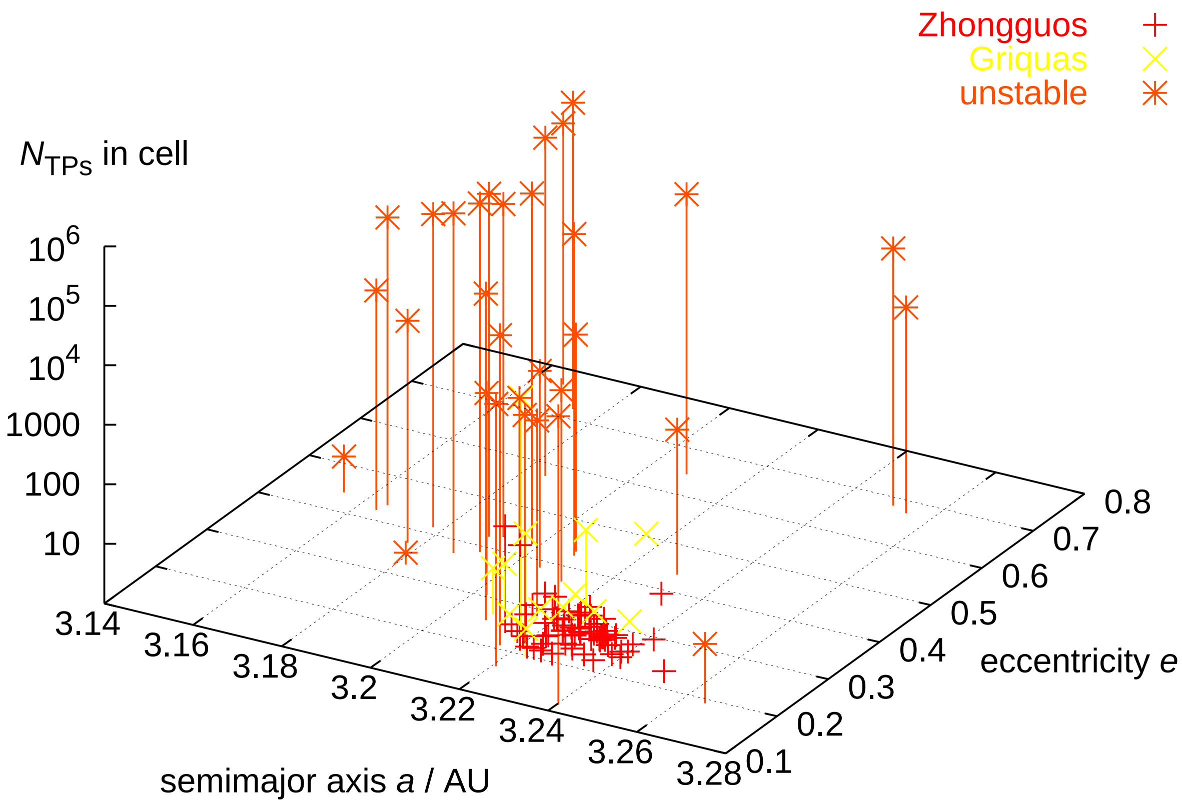

a
σJ2/1 = 2λ – λJ– ϖ
ϖ – ϖJ
osculating semimajor axis a / AU
σJ2/1, ϖ–ϖJ / deg
time t / Myr
3.36
3.34
3.32
3.3
3.28
3.26
3.24
3.22
3.2
350
300
250
200
150
100
50
0
22
22.001
22.002
22.003
22.004
22.005


separatrix of J2/1 resonance
eccentricity e
semimajor axis a / AU
Themis family (vcutoff = 70 m/s) proper elements
resonant elements of the Themis family
resonant elements of TPs
TPs' initial osculating elements
0.26
0.24
0.22
0.2
0.18
0.16
0.14
0.12
0.1
0.08
3.05
3.1
3.15
3.2
3.25


3.3
3.25
a [AU]
J2/1
7J-2S-3
0.8
0.6
0.4
0.2
0
e []
0.4
0.3
0.2
0.1
0
sin(i) []
0
5
10
15
20
25
30
35
40
45
50
55
t [Myr]

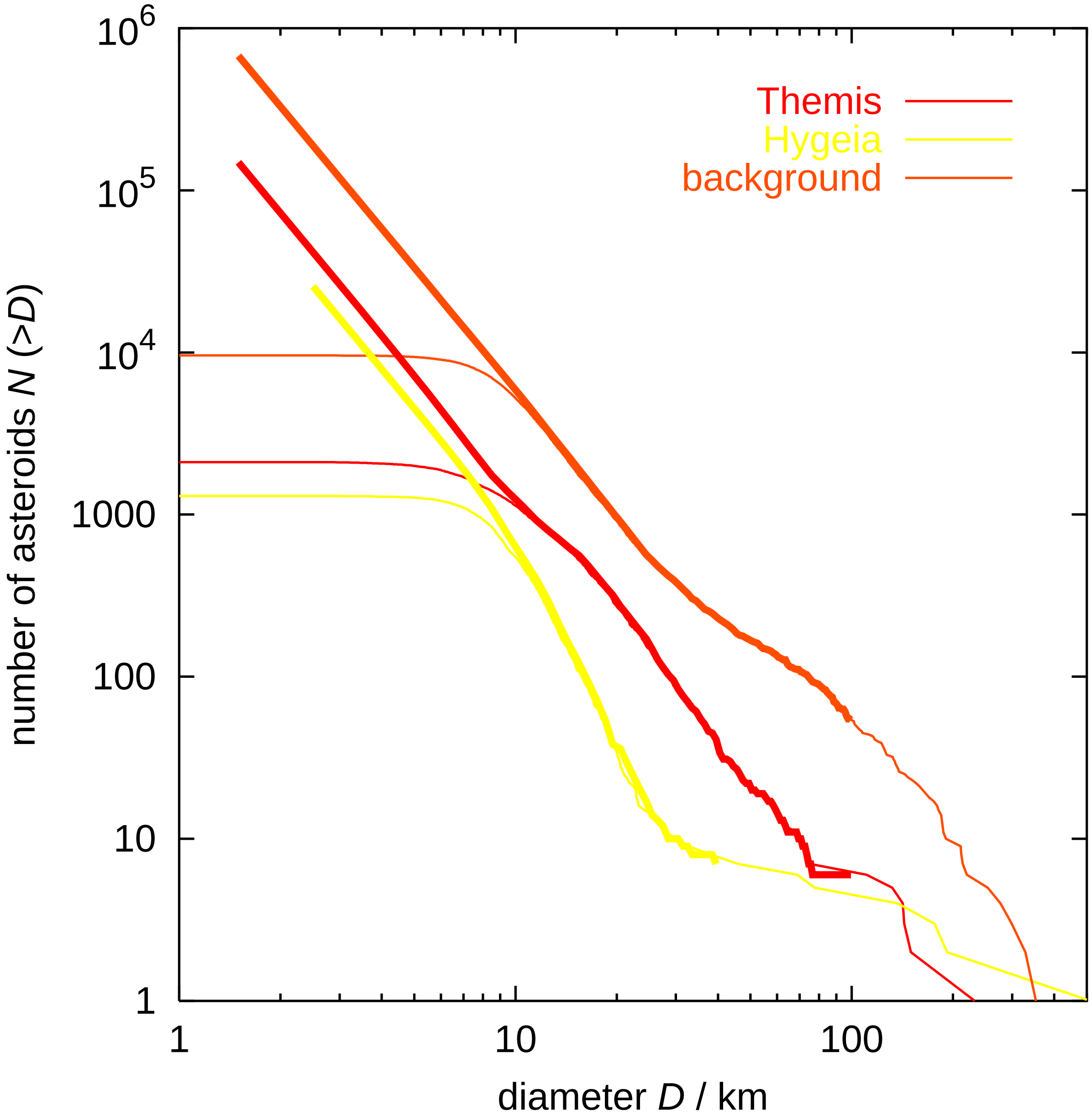

0.25
0.2
0.15
0.1
0.05
0
20
40
60
80
100
120
140
Hygeia
background
Themis
fraction of TPs in bin dN/N
residence time in J2/1 $t_{J2/1}$ / Myr

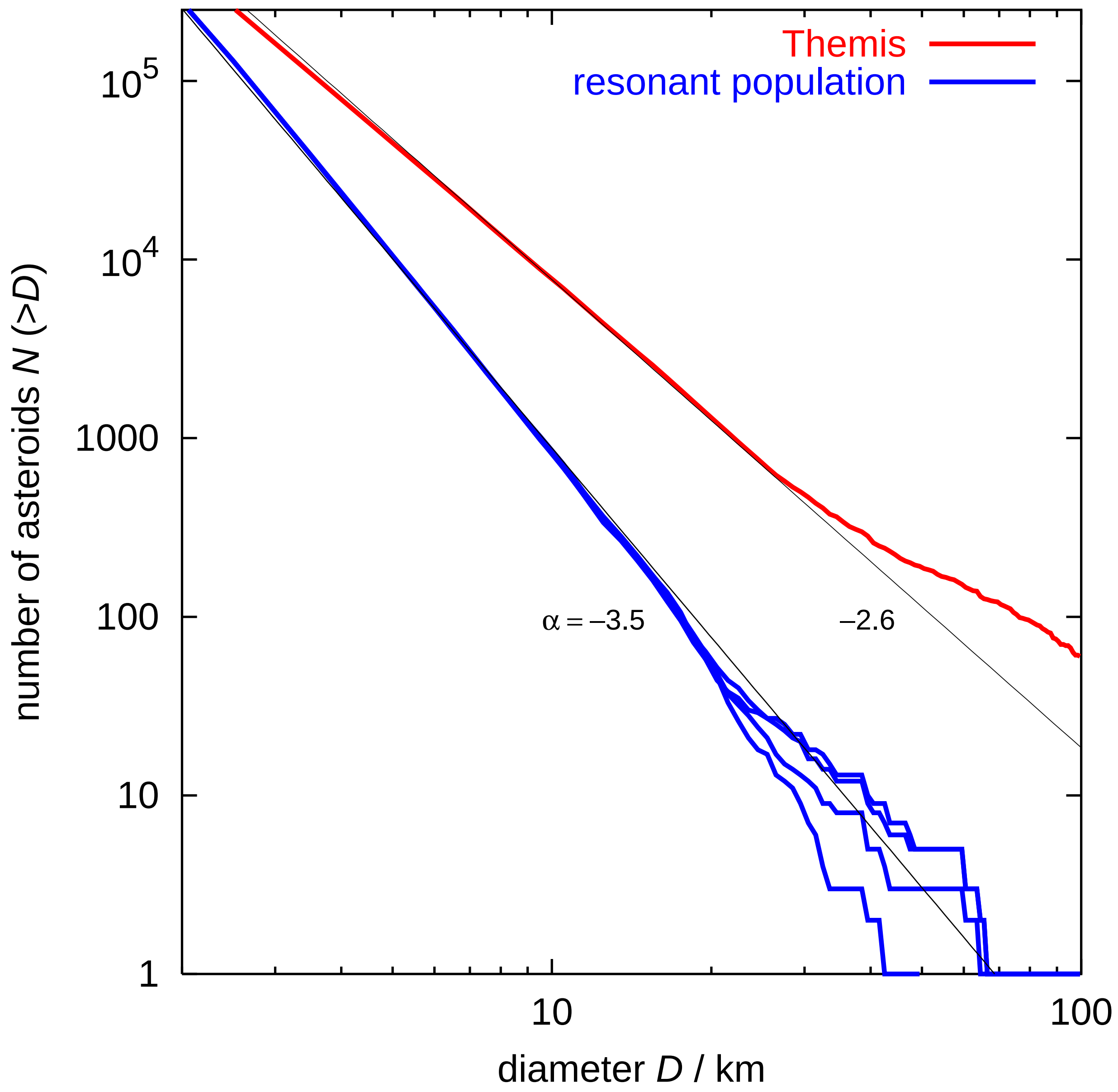

e []
0.6
0.4
0.2
0
3.15
3.2
3.25
a [AU]
0
1
2
3
4
5
e []
0.6
0.4
0.2
0
3.15
3.2
3.25
a [AU]
0
1
2
3
4
5

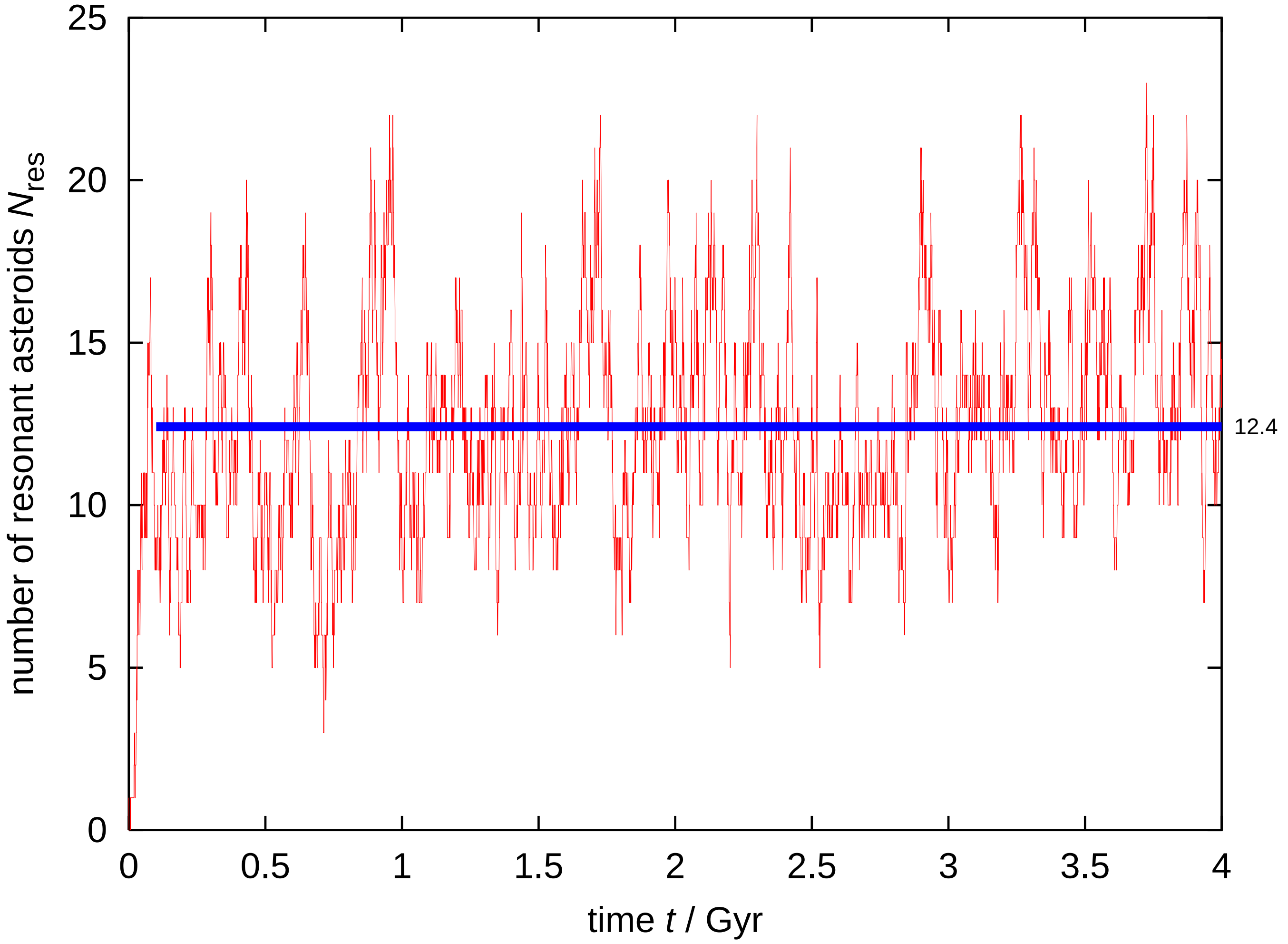

Zhongguos
Griquas
unstable
N_{TPs} in cell
10^6
10^5
10^4
1000
100
10
3.14
3.16
3.18
3.2
3.22
3.24
3.26
3.28
semimajor axis a / AU
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
eccentricity e

Parameters of the model #2:

- semianalytic steady-state model (Morbidelli & Vokrouhlický, 2003)
- Runge-Kutta 4^{th} order integrator, timestep 0.5 My, timespan 4 Gy
- $\sim 130,000$ TPs in total
- semimajor axis evolution $\leftarrow$ Yarkovsky effect
- obliquity–spin–rate evolution $\leftarrow$ YORP effect
- collisional reorientations: $\tau_{\mathrm{reor}} = 16.8\sqrt{[R]_{\mathrm{m}}}\,\mathrm{My}$
- fixed 2:1 resonance border: $e(a) \doteq 10.82 - 3.32\,a$
- lifetime in the resonance $\leftarrow$ **model #1**


Themis
Hygeia
background
number of asteroids N (>D)
diameter D / km
10^6
10^5
10^4
1000
100
10
1
1
10
100


Themis
resonant population
10^5
10^4
1000
100
10
1
number of asteroids N (>D)
$\alpha = -3.5$
-2.6
10
100
diameter D / km

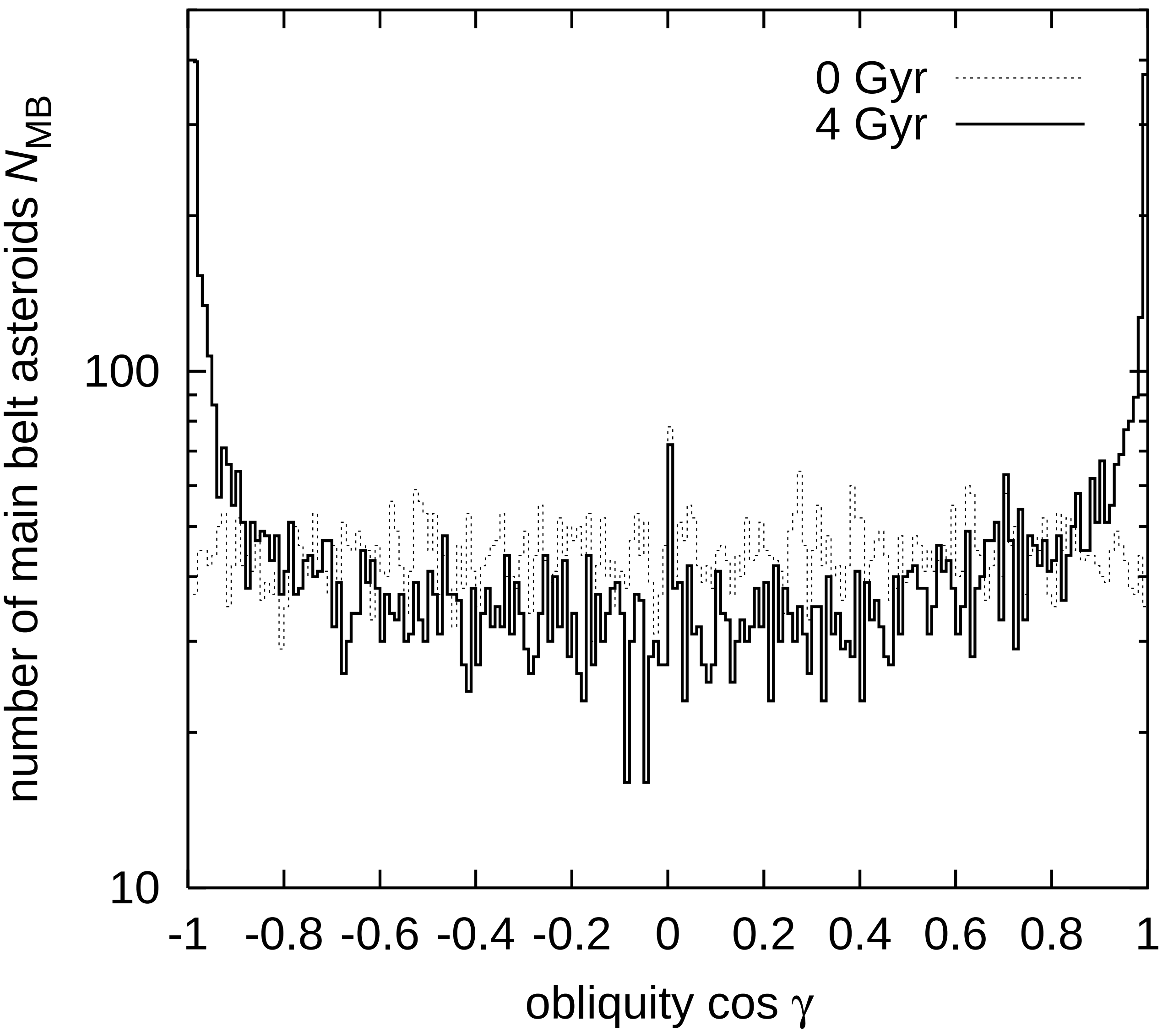

0
5
10
15
20
25
number of resonant asteroids N_{res}
0
0.5
1
1.5
2
2.5
3
3.5
4
time t / Gyr
12.4

Conclusions:

- Yarkovsky-driven asteroids from outside the resonance $\Rightarrow$ highly unstable population inside the 2:1 resonance in steady-state
- Zhonnguos and Griquas are probably of a different origin
- a similar results as for the asteroids in the J7/3 resonance, populated by Koronis and Eos families (Tsiganis et al., 2003)

Future work:

- improvements of the YORP effect model for slow rotators
- observational constrainst for resonant asteroids? (e.g. spin states of unstable asteroids with $\gamma < 90°$; their spectroscopic similarity with source populations)


0 Gyr
4 Gyr
number of main belt asteroids N_{MB}
100
10
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
obliquity cos γ