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The peculiar orbit of Vysheslavia: further hints for its Yarkovsky driven origin?

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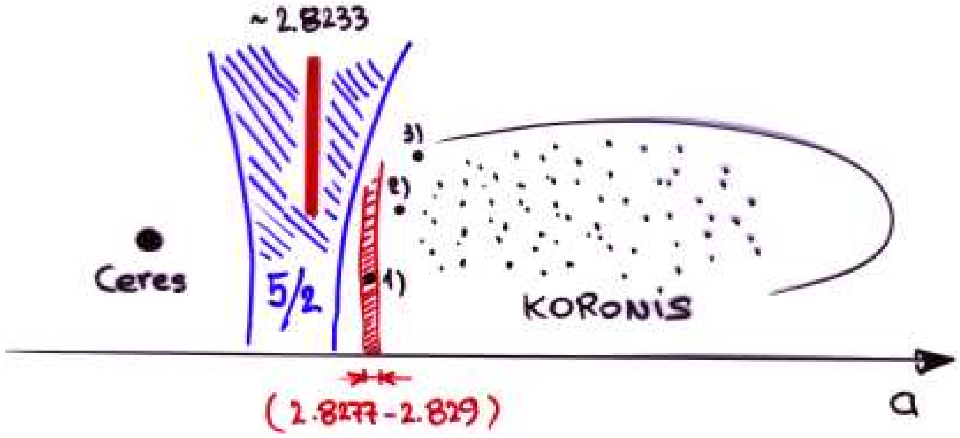
Evolution processes of the asteroid families:

- collisional grinding (secondary collisions)
- chaotic diffusion (only in chaotic regions, diffusion mainly in e and I)
- Yarkovsky diffusion (size-dependent drift in a)



Scheme of the 5:2 resonance surroundings, position of "chaotic zone", asteroids 1) = (2953) Vysheslavia, 2) 1991 UA_2 (7340), 3) 1993 FR_{58} and Ceres

Previous work:

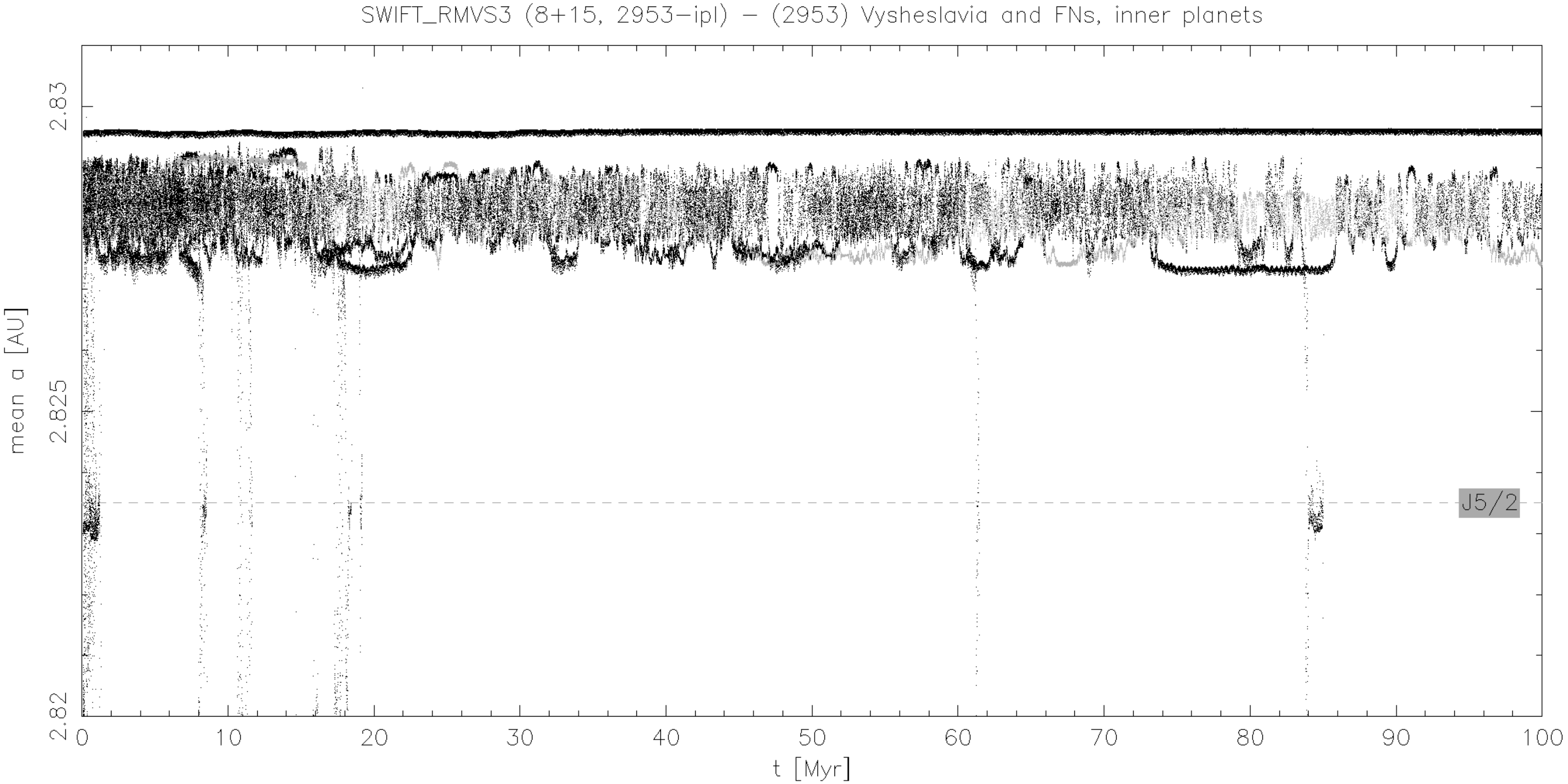
- **Milani & Farinella (1995)** noticed a very short dynamical lifetime of the Vysheslavia-like orbits (>50% close clones die within 30 Myr)
- **Knežević et al. (1997)** — two other Koronis members very close to this chaotic zone

Consequences and scenarii:

- Vysheslavia is an offspring of a secondary collision in the family
- Vysheslavia has been placed on its peculiar orbit by chaotic diffusion or scattering on nearby asteroids (possible role of Ceres?)
- Vysheslavia has been transported on its peculiar orbit by the Yarkovsky drift (0.01–0.02 AU within the estimated collisional lifetime of Vysheslavia; 1.3 Gyr)

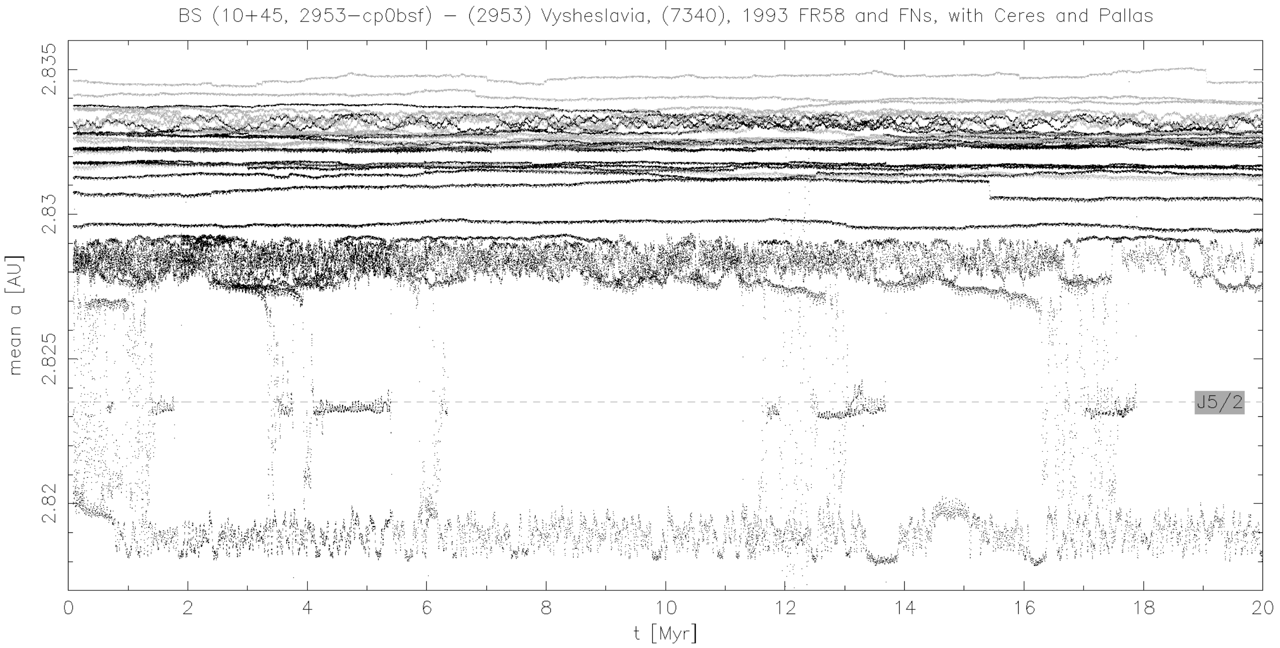
Long-term orbital evolution of (2953) Vysheslavia and its clones

- □ no Yarkovsky effect
- □ integration with **SWIFT_RMVS3**, dt = 36 days
- □ if 4 outer planets only (& barycentric correction) ⇒ longer residence in the 5:2 resonance region

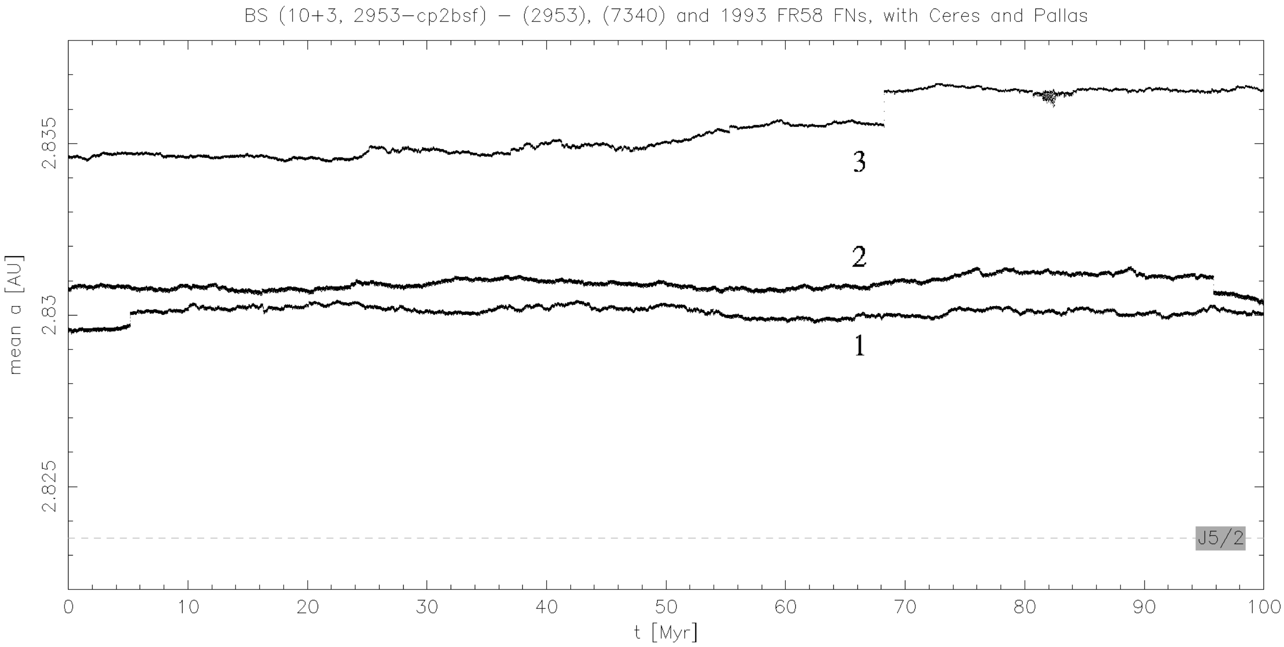


Gravitational perturbations by Ceres and Pallas

- inner planets and asteroids (1) Ceres, (2) Pallas included
- integration with **Bulirsch–Stoer**, $\varepsilon = 10^{-8}$ (close encounters $\Rightarrow$ instability of SWIFT_RMVS3)
- semimajor axis fluctuations $\leq 10^{-3}$ AU, "random walk"

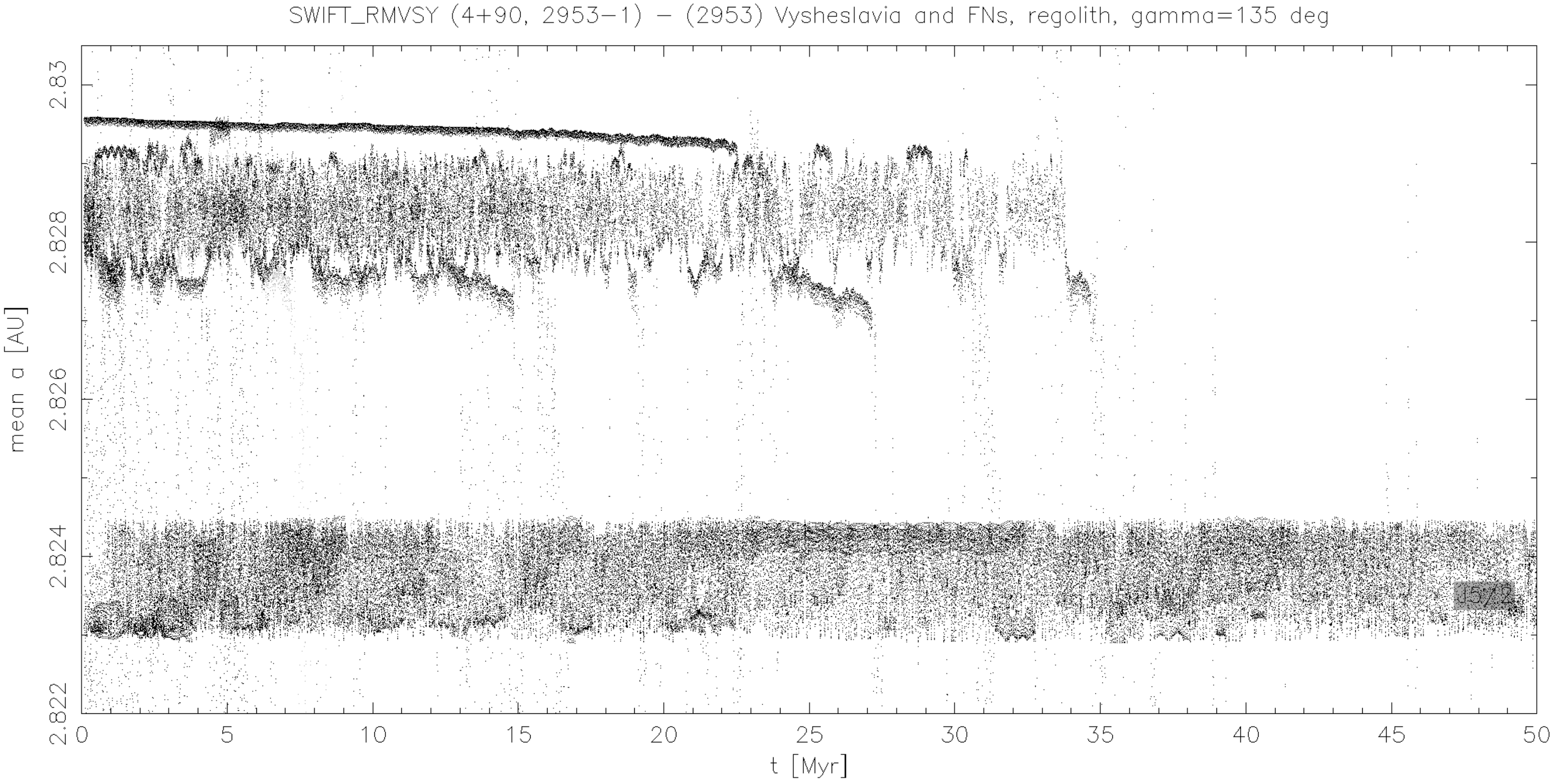


- longer time-span for FN^0_{+3} of (2953) Vysheslavia – curve 1, FN^0_{-3} of (7340) – curve 2 and FN^0_{+3} of 1993 FR_{58} – curve 3
- three large "jumps" during 100 Myr $\Leftarrow$ close encounter with Ceres ($\sim 10^{-4}$ AU)



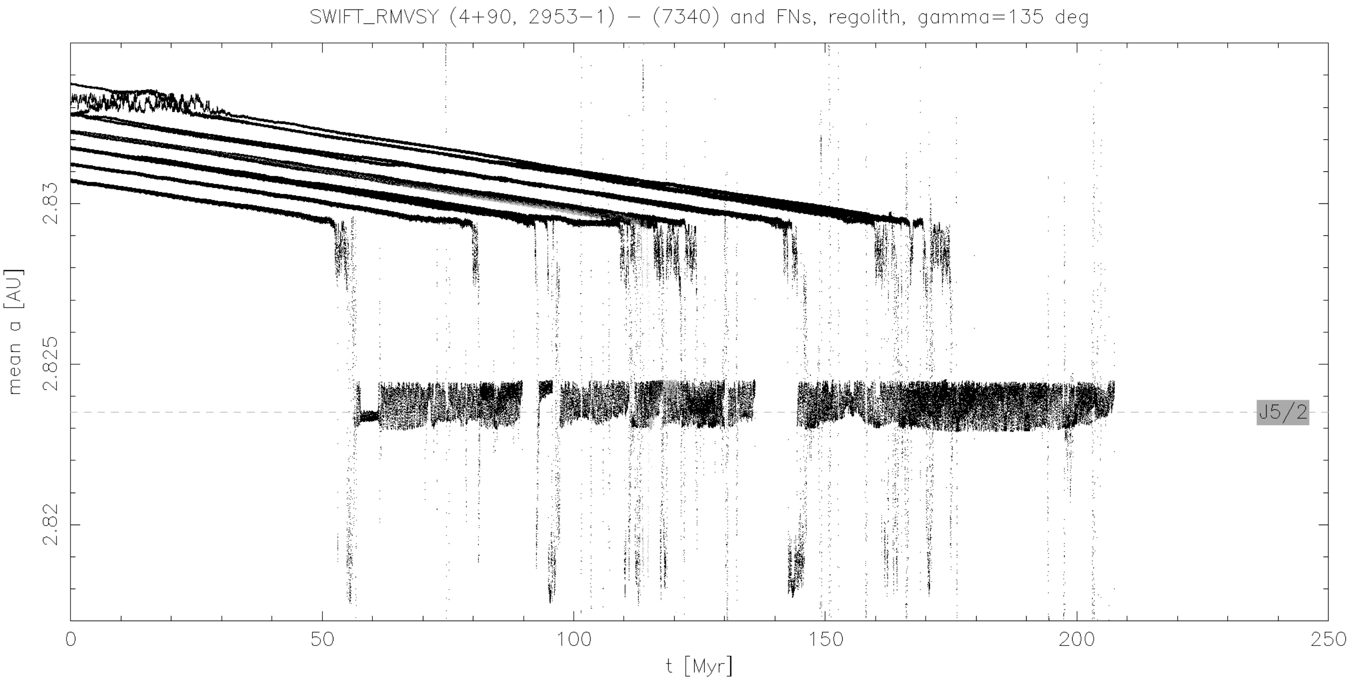
Long-term orbital evolution of (2953) Vysheslavia with Yarkovsky effect

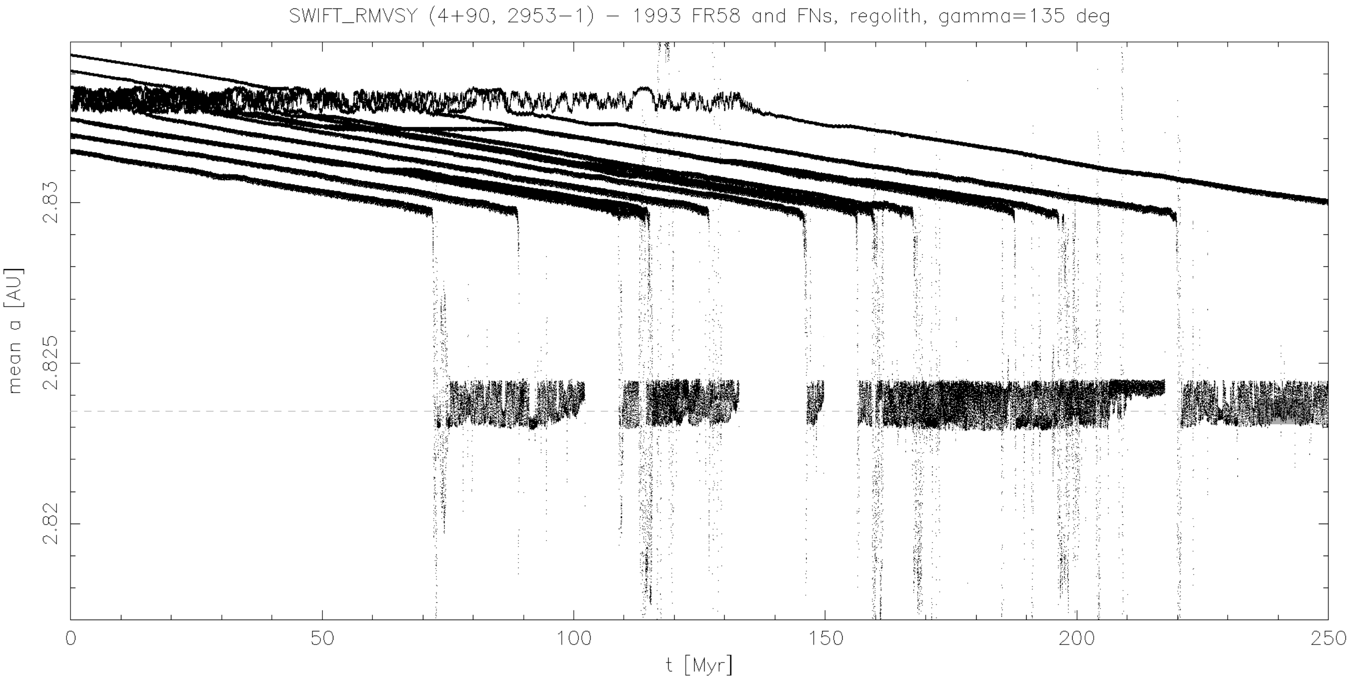
- **Yarkovsky effect** included, low conductivity surface assumed, fixed spin axis orientation (initial obliquity = 135°)
- results in a **shorter lifetime** before falling in the 5:2 resonance



(7340) and 1993 FR_{58} — transport towards the 5:2 resonance

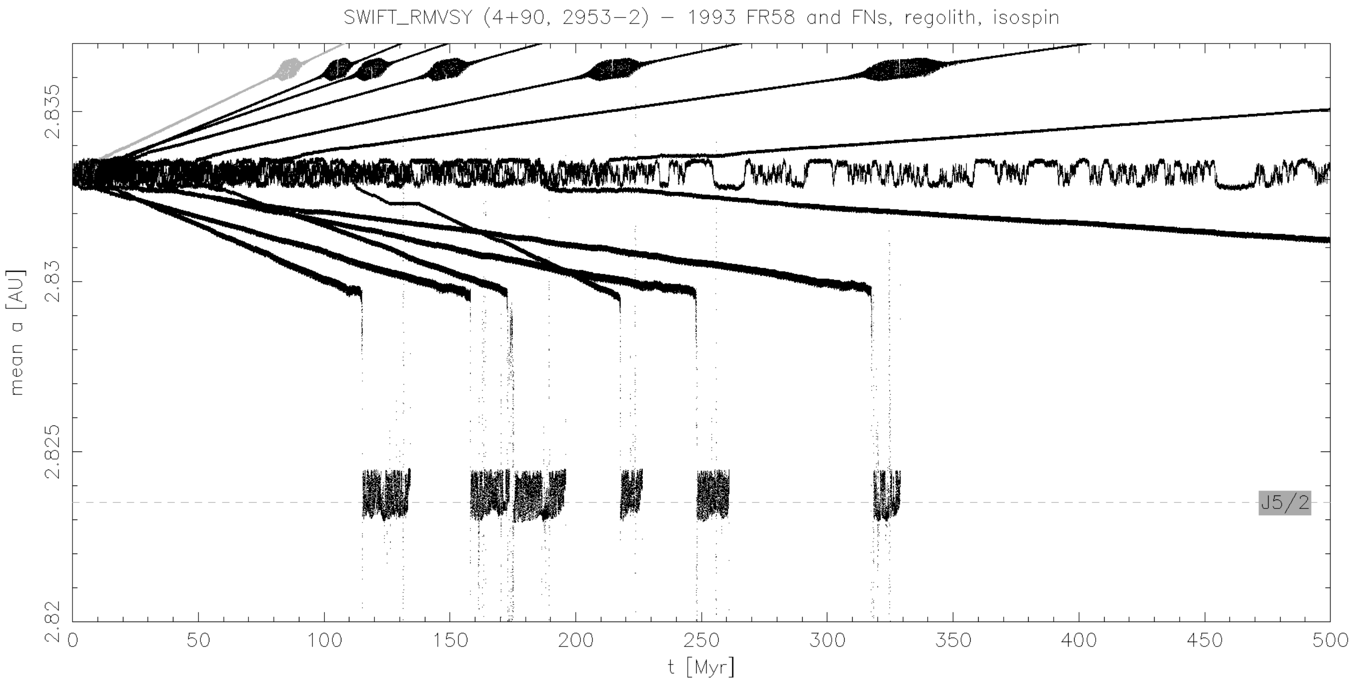
- **Yarkovsky effect** included, low conductivity surfaces (K = 0.0015 W/m/K), fixed orientation of spin axes (initial obliquity γ = 135°)
- (7340), 1993 FR_{58} and their ficticious neighbours reach the 5:2 resonance within 50 – 250 Myr
- two **chaotic zones** between 2.8275 – 2.829 AU (jumped over, when particles drift from higher semimajor axes) and 2.8329 – 2.8335 AU

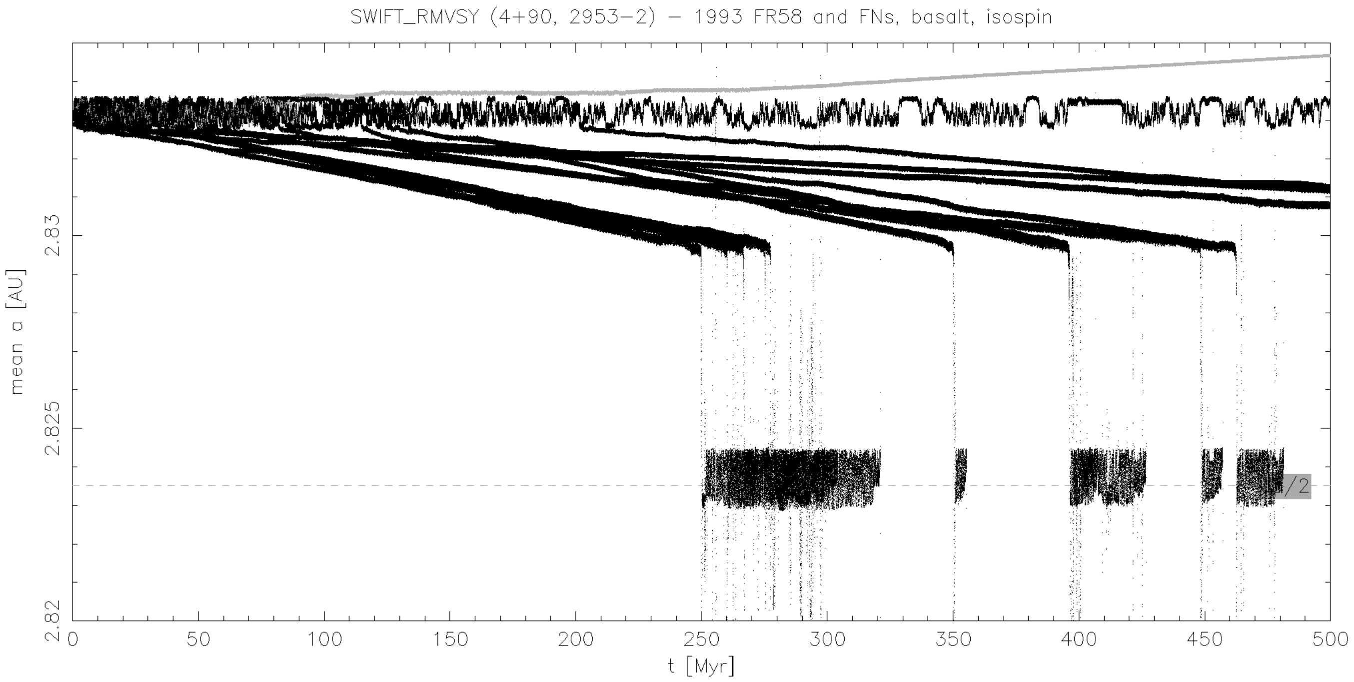




1993 FR_{58} — isotropic spin axes, low and high surface conductivity:

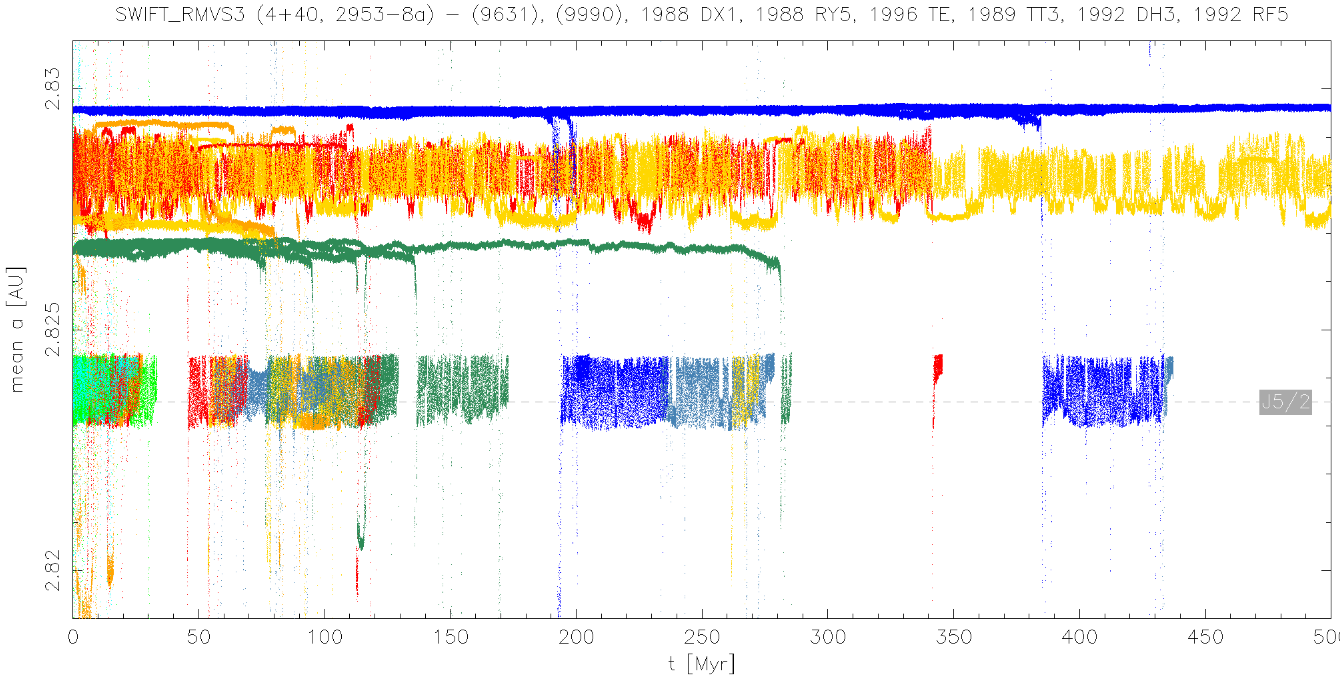
- regolith covered bodies (K = 0.0015 W/m/K) — diurnal Yarkovsky effect dominates, $\sim$ 1/2 of clones drift towards the 5:2 resonance (first fall after 100 Myr)
- bare basalt bodies (K = 1.0 W/m/K) — seasonal variant dominates, most of particles drift to the 5:2 resonance, $\sim$ 2.2 times slower drift





Asteroids in the surroundings of the 5:2 jovian resonance

- asteroids involved — (6814), (8279), (8361), (9631) Hubertreeves, (9990), (10907), (12893), (12936), (13021) ≡ 1988 RY_5, (14440) ≡ 1992 RF_5, 1988 DX_1, 1989 TT_3, 1992 DH_3, 1996 TE, 2000 GQ_6
- orbital elements from recent Bowell's `astorb.dat`, planetary ephemeris DE405 (4 planets)
- numerical integration of real asteroids and close clones ($da = 10^{-7}$ AU), without Yarkovsky, time-span 500 Myr, using SWIFT_RMVS3, dt = 36 days



Median lifetimes before the fall into the 5:2 resonance:

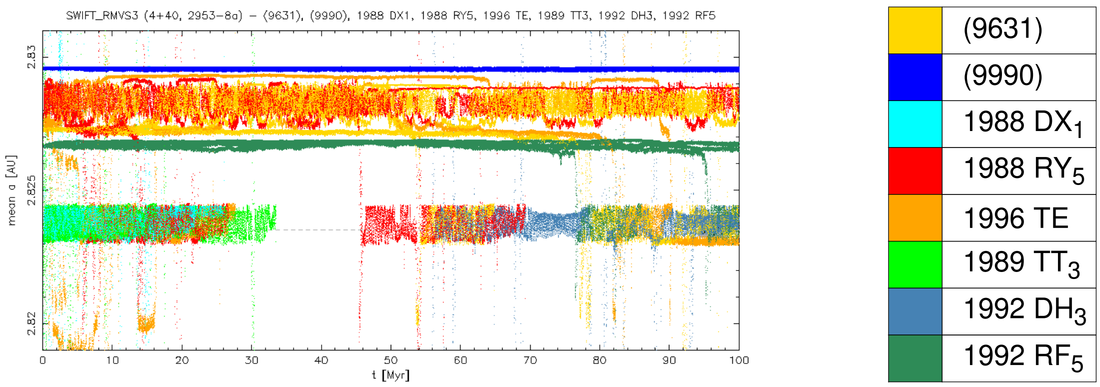
- τ_A — lifetimes for the run without Yarkovsky
- τ_B — simulation including Yarkovsky effect, fixed orientation of spin axes $\gamma = 135°$ (initially), assumed low conductivity surfaces K = 0.0015 W/m/K (see next page)

asteroid	τ_A/Myr	τ_B/Myr
(9631)	268	30
(9990)	395	22
1988 DX_1	0.2	0.2
1988 RY_5	47	11
1996 TE	14	22
1989 TT_3	0.1	0.1
1992 DH_3	239	$>$100
1992 RF_5	116	11

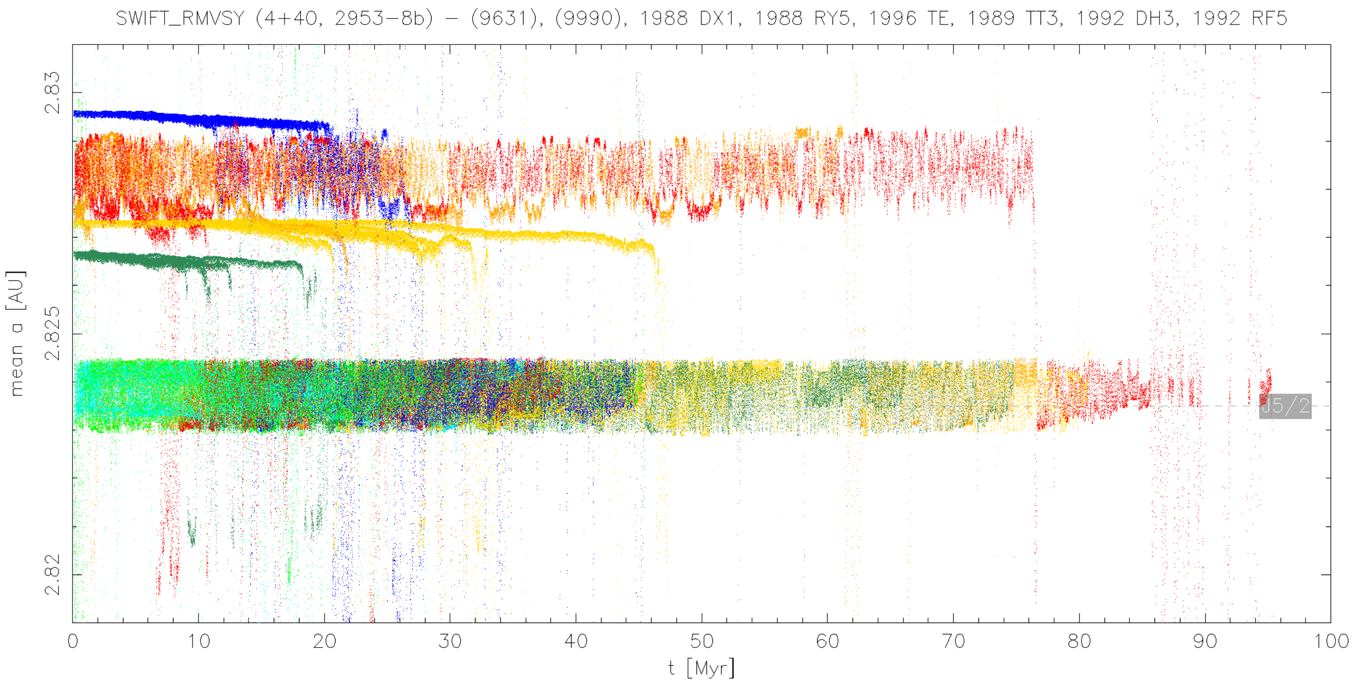
	(9631)
	(9990)
	1988 DX_1
	1988 RY_5
	1996 TE
	1989 TT_3
	1992 DH_3
	1992 RF_5

Behavior of asteroids and their clones:

- (8279), (8361), (10907), (12893), (12936) — initially above the "chaotic zone", stable orbits
- (9990) — stays **above** the chaotic zone for more than 200 Myr
- (6814), (9631), (13021), 1996 TE, 2000 GQ_6 — initially in the chaotic zone, unstable over $\tau \approx 10 - 100$ Myr
- (14440) — stays for 100 Myr **below** the chaotic zone and above the 5:2 resonance
- 1988 DX_1, 1989 TT_3 — initially inside the 5:2 resonance
- 1992 DH_3 — mean elements below the resonance

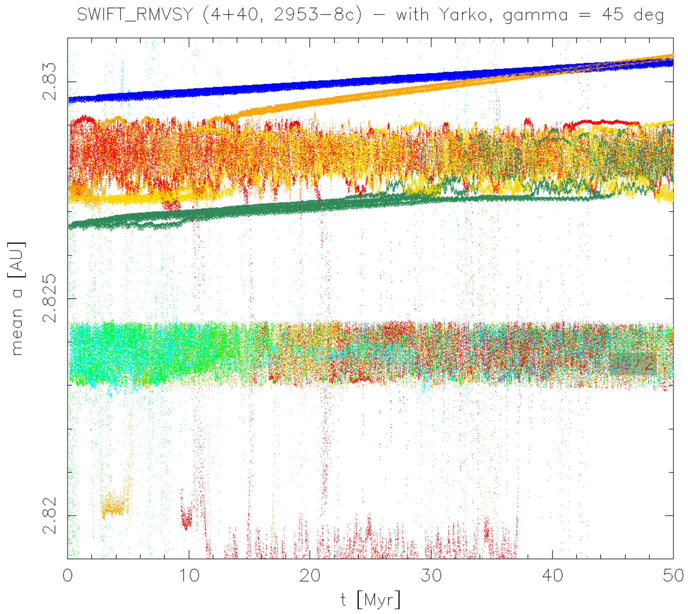


Comparsion with integrations including Yarkovsky effect:



- Yarkovsky parameters: low conductivity surfaces K = 0.0015 W/m/K, albedo 0.2 ($\Rightarrow$ radii 1.5 – 4.3 km)
- fixed orientations of the spin axes, initial obliquity γ = 135° ($\Rightarrow$ drag)

- the spin axes with initial γ = 45° lead to outward drift, longer lifetime of asteroids initially located outside the resonance



Conclusions:

1. The Yarkovsky effect might be efficient in altering positions of small asteroids (km in size) up to 0.01 – 0.03 AU within their collisional lifetime.
2. Such a mobility may drive asteroids onto dynamically unstable orbits. There is a significant difference between the dynamical lifetime of Vysheslavia and the age of Koronis family.
3. The probabilities of a secondary collision placing the bodies on the metastable orbits or gravitational origin due the influence of massive asteroids are low. The Yarkovsky–driven transport is the most probable possibility.

Further work:

- **Photometric and spectral observations** of Vysheslavia (and other small members of the Koronis family)
- **Astrometric observations** of asteroids with poorly known orbits, **discovery** of new, smaller (fainter) asteroids just above the 5:2 resonance
- Study of Yarkovsky–driven leakage of **other asteroid families**

References:

- Milani, A., Farinella, P.: **An asteroid on the brink.** Icarus 115, 209–212, 1995
- Knežević, Z., Milani, A., Farinella, P.: **The dangerous border of the 5:2 mean motion resonance.** Planet. Space. Sci. 45 (12), 1581–1585, 1997

- our web site: `http://sirrah.troja.mff.cuni.cz/~mira/mp/`