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Resonant Asteroid Families

a Wealthy Source of Information on Planetary Migration

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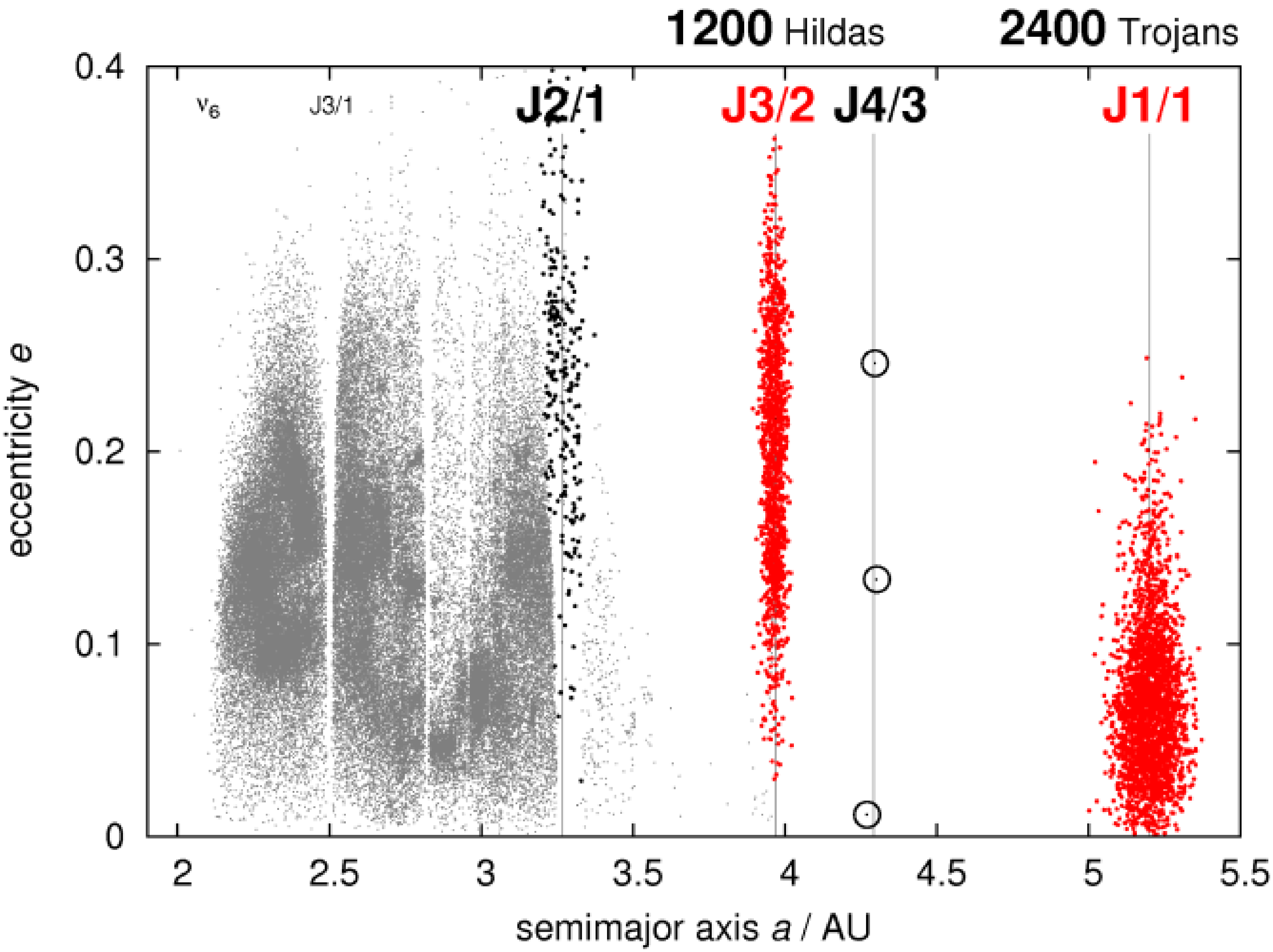
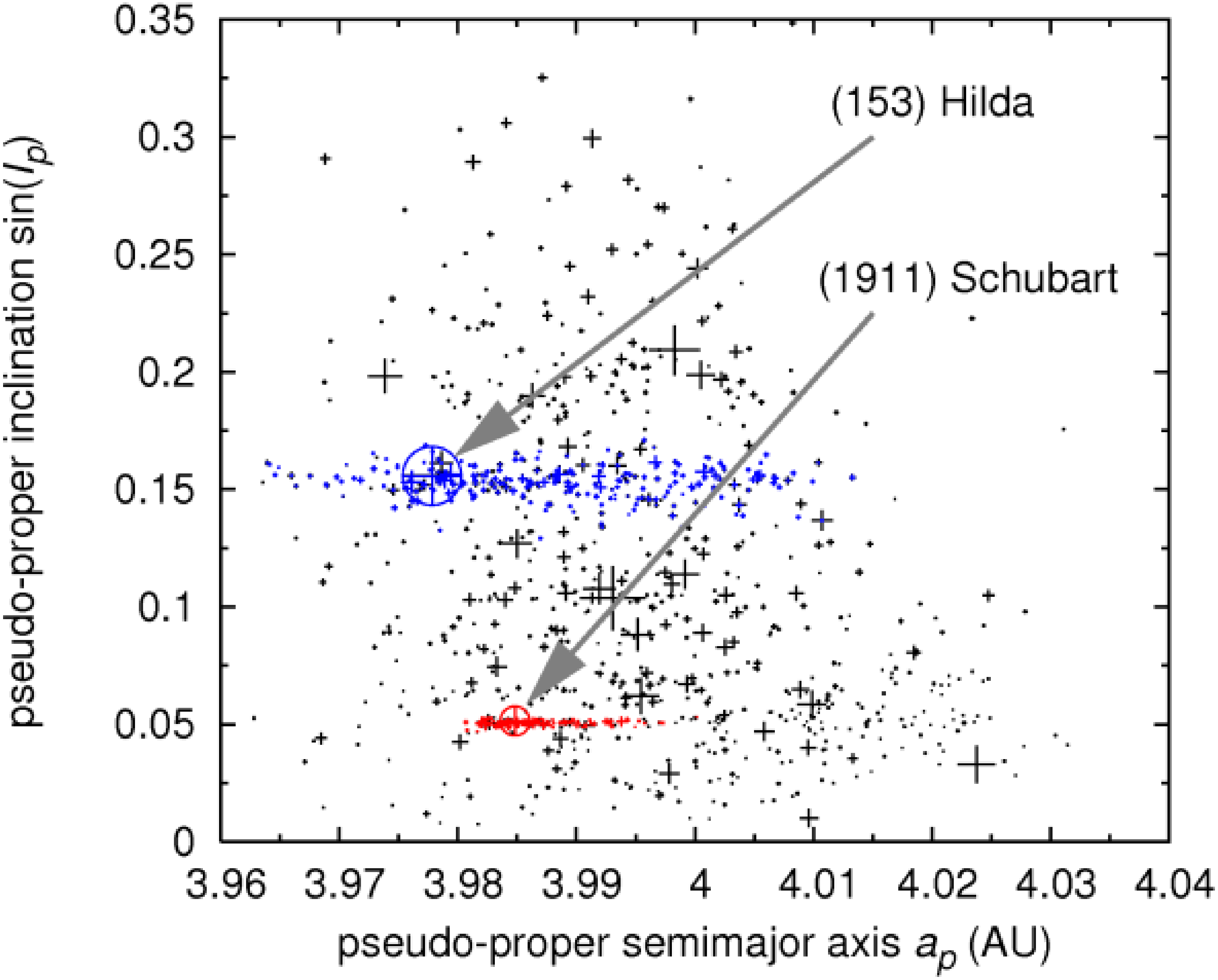
Table of contents:

Resonant populations:



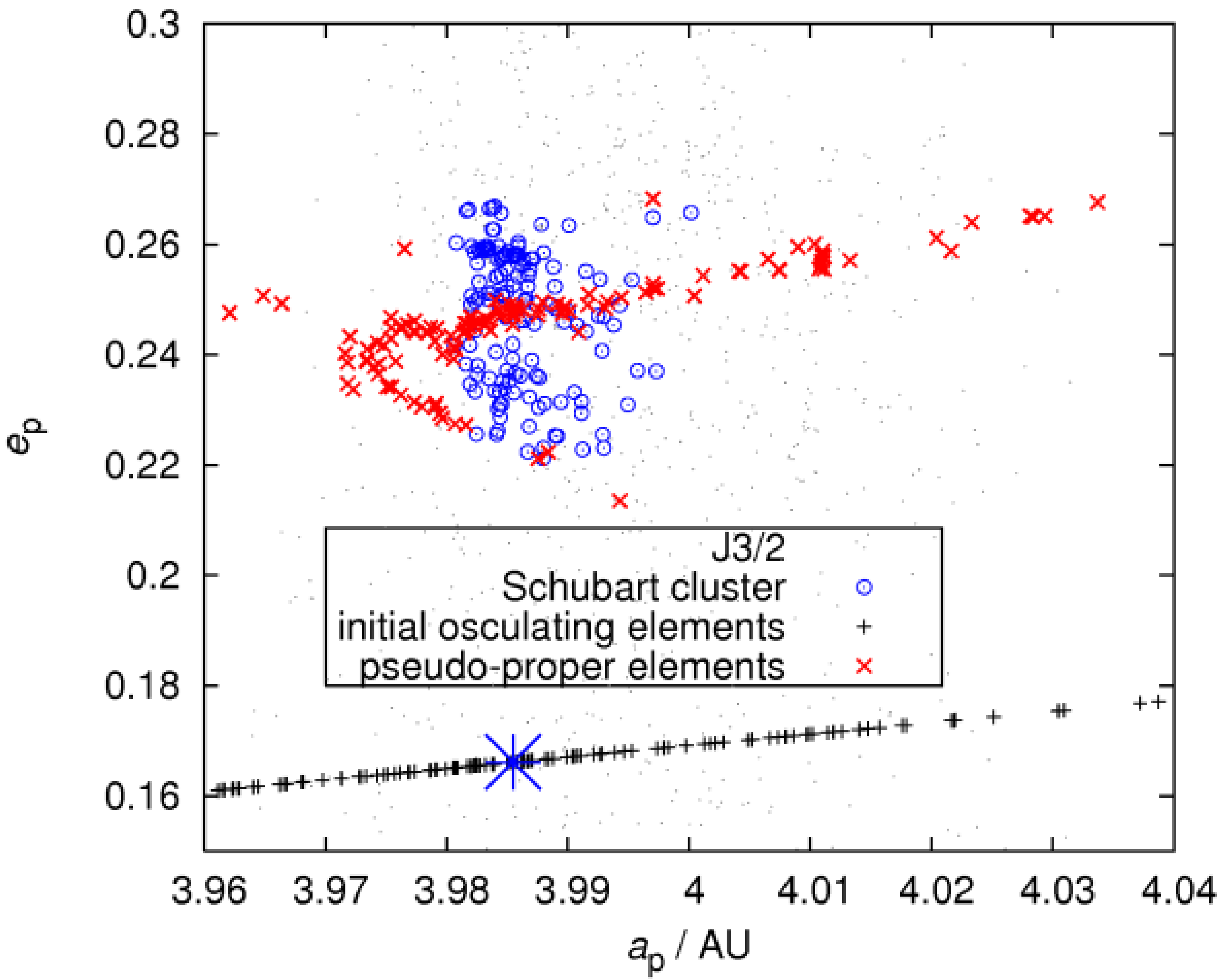
- families in J3/2 and J1/1, no families in J2/1, J4/3
- motivation: migration of Jupiter, collisional models

J3/2 — pseudo-proper elements:



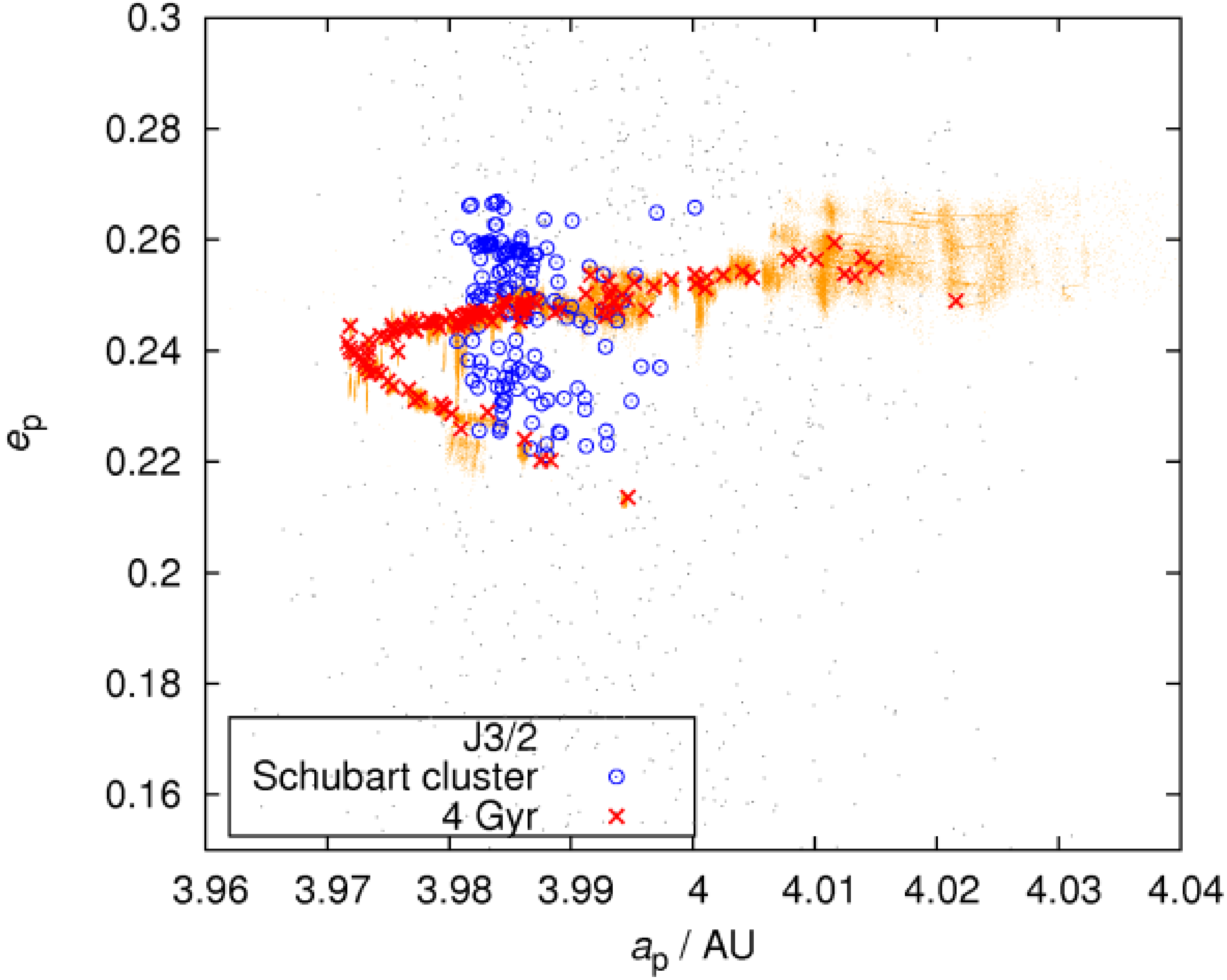
- a distinct collisional Schubart family (Schubart 1991); $v_{\rm cutoff} \simeq 60\,$m/s, $\sim 100\,$km parent body, LF/PB $\simeq 0.25$, C/X-type members, SFD steeper than J3/2.
- Hilda family at higher inclinations; $\sim 200\,$km PB

Simulated impact in J3/2:



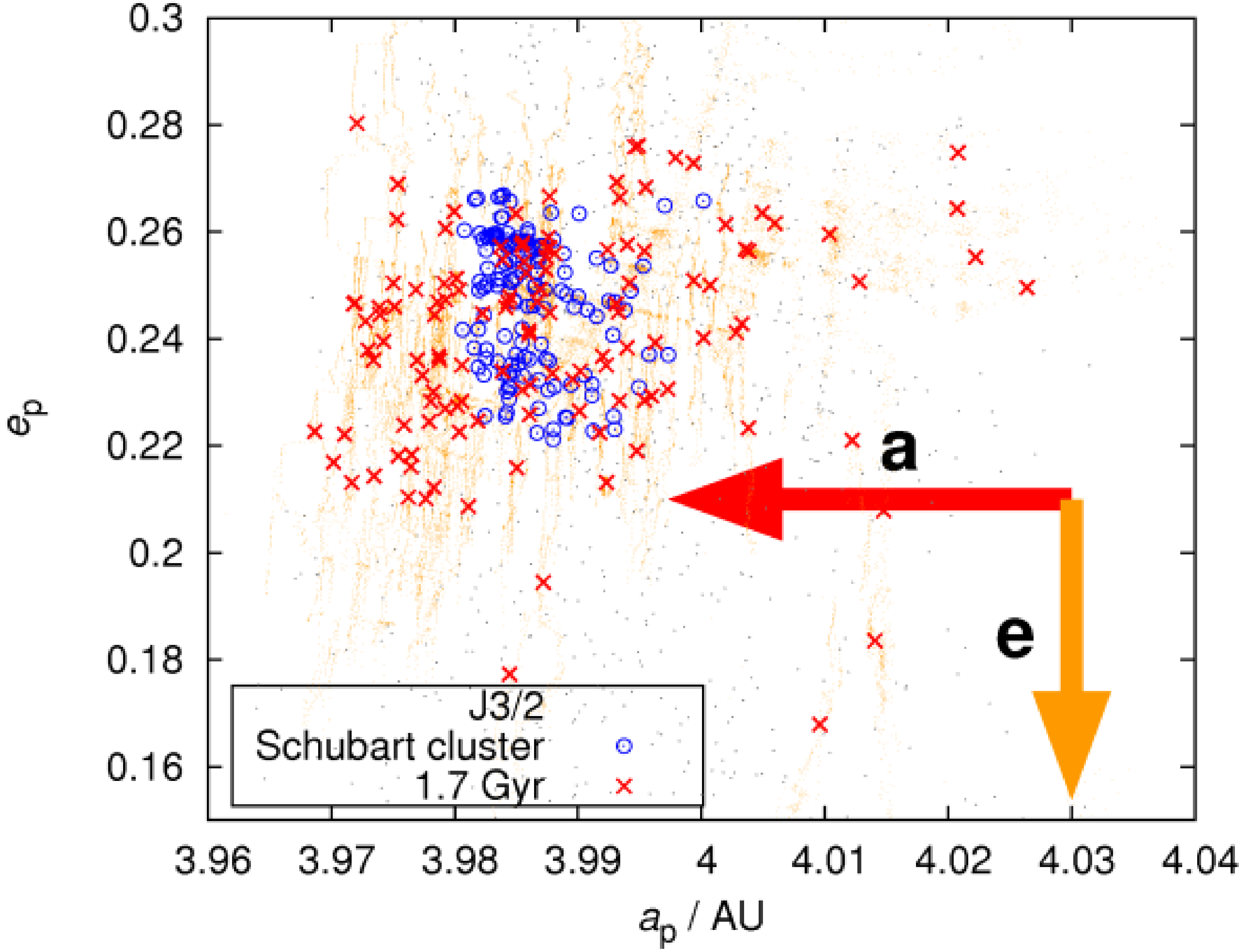
- a disruption of a 100 km PB; isotropic velocity field with $v_{\rm mean} = 50\,{\rm m/s}$, $f = 0$, $\omega + f = 180^\circ$
- 'mapping' of the osculating elements into pseudo-proper

Impact in J3/2 — evolution over 4 Gyr:



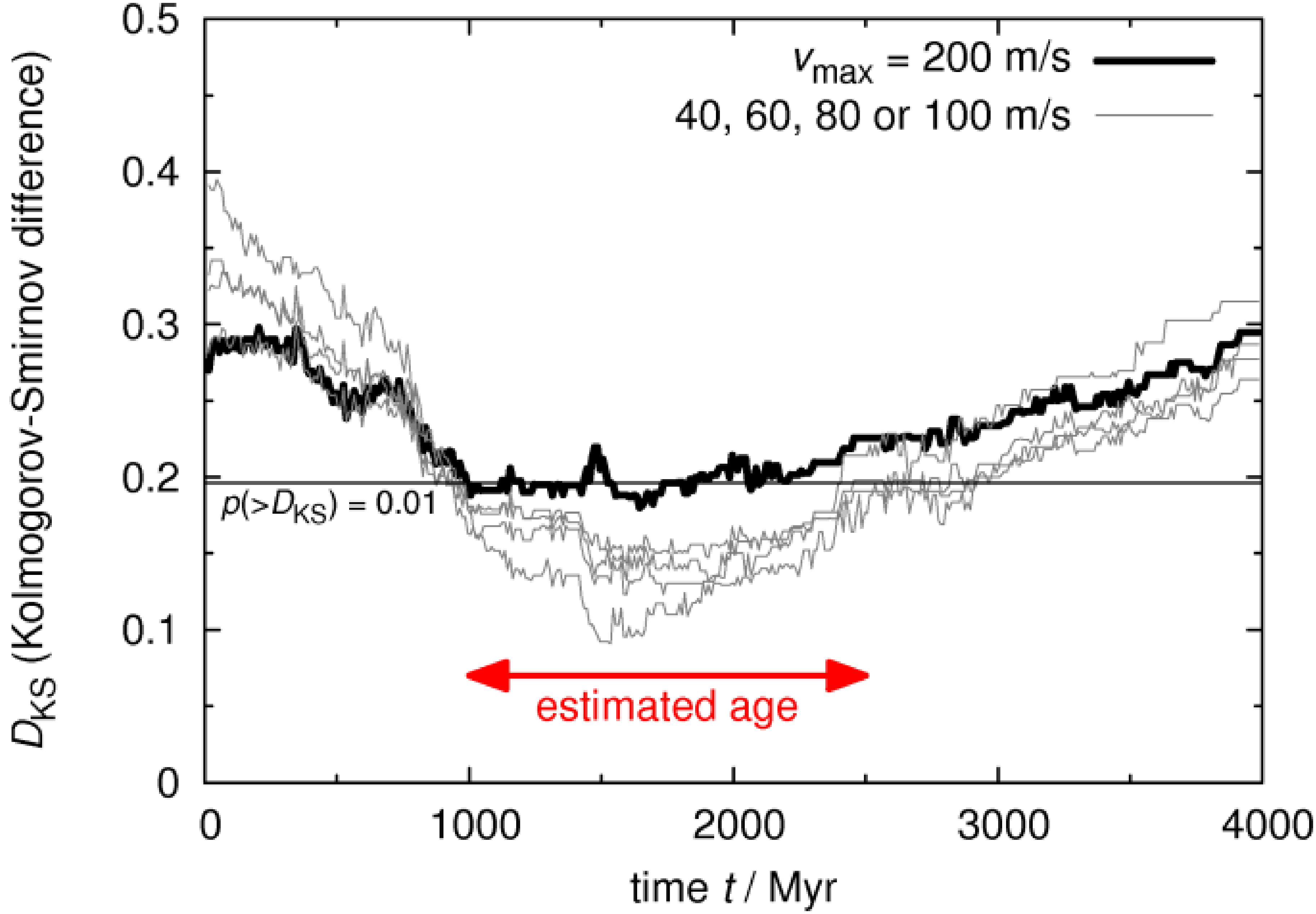
- N-body simulation, SWIFT integrator, 4 planets only
- the shape of the swarm is well preserved for 4 Gyr
- problem: observed Schubart family has larger spread in e

Impact in J3/2 — Yarkovsky effect:



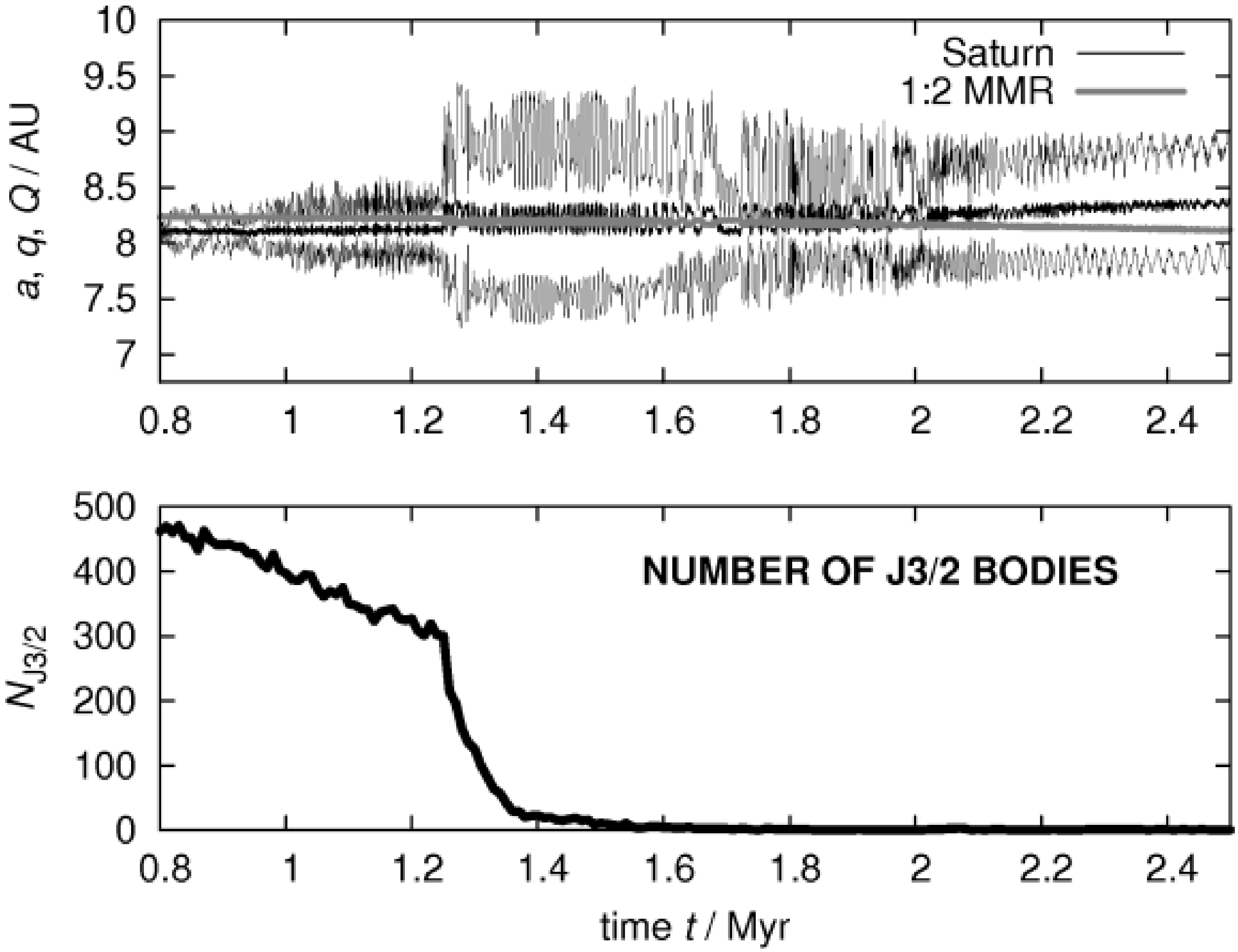
- usually, YE causes a drift in semimajor axis, but...
- Yarkovsky effect and resonant lock combined
  $\Rightarrow$ systematic drift in eccentricity

Schubart family — age:



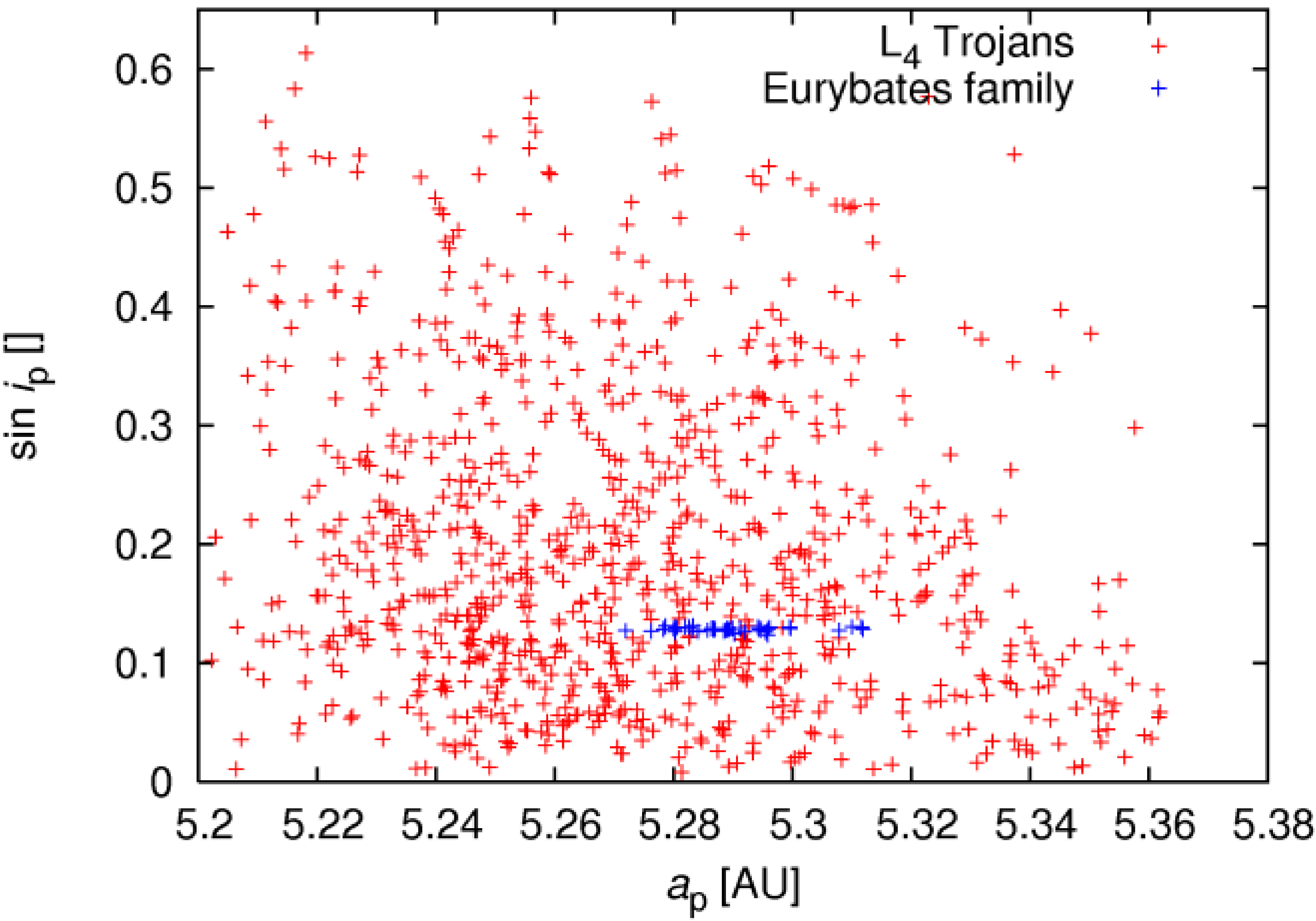
- K-S test of e-distributions for Schubart $\Rightarrow$ 1–2.5 Gyr old
- $\gtrsim 4$ Gyr for Hilda (LHB origin?)

Hilda vs 2:1 Jupiter–Saturn resonance:



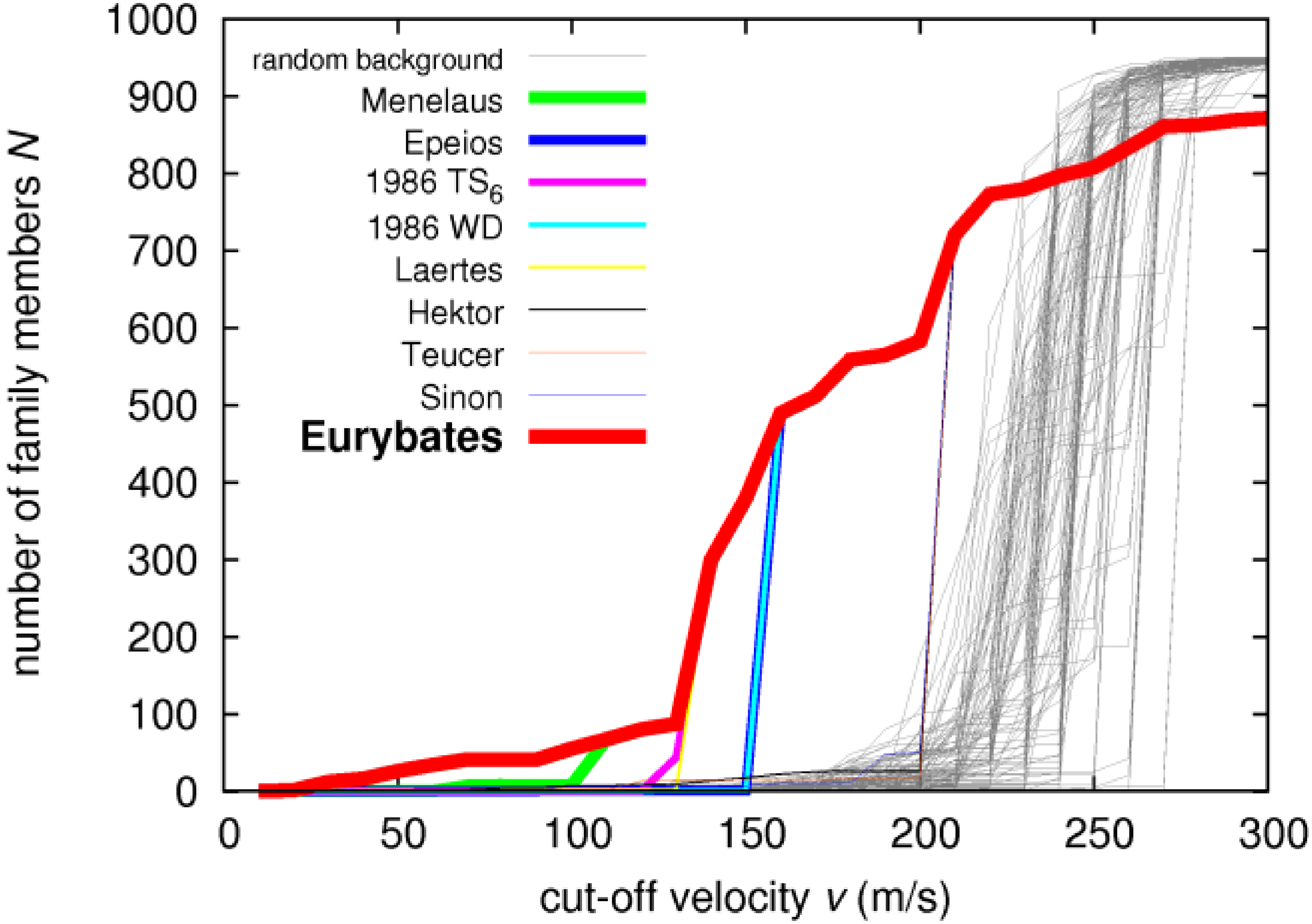
- J3/2 population is strongly unstable during 2:1 resonance crossing (Brož & Vokrouhlický 2008)
- Hilda family have to be *younger* than the time of 2:1 (collisional probabilities might be higher early after 2:1)

Trojans — how many families?



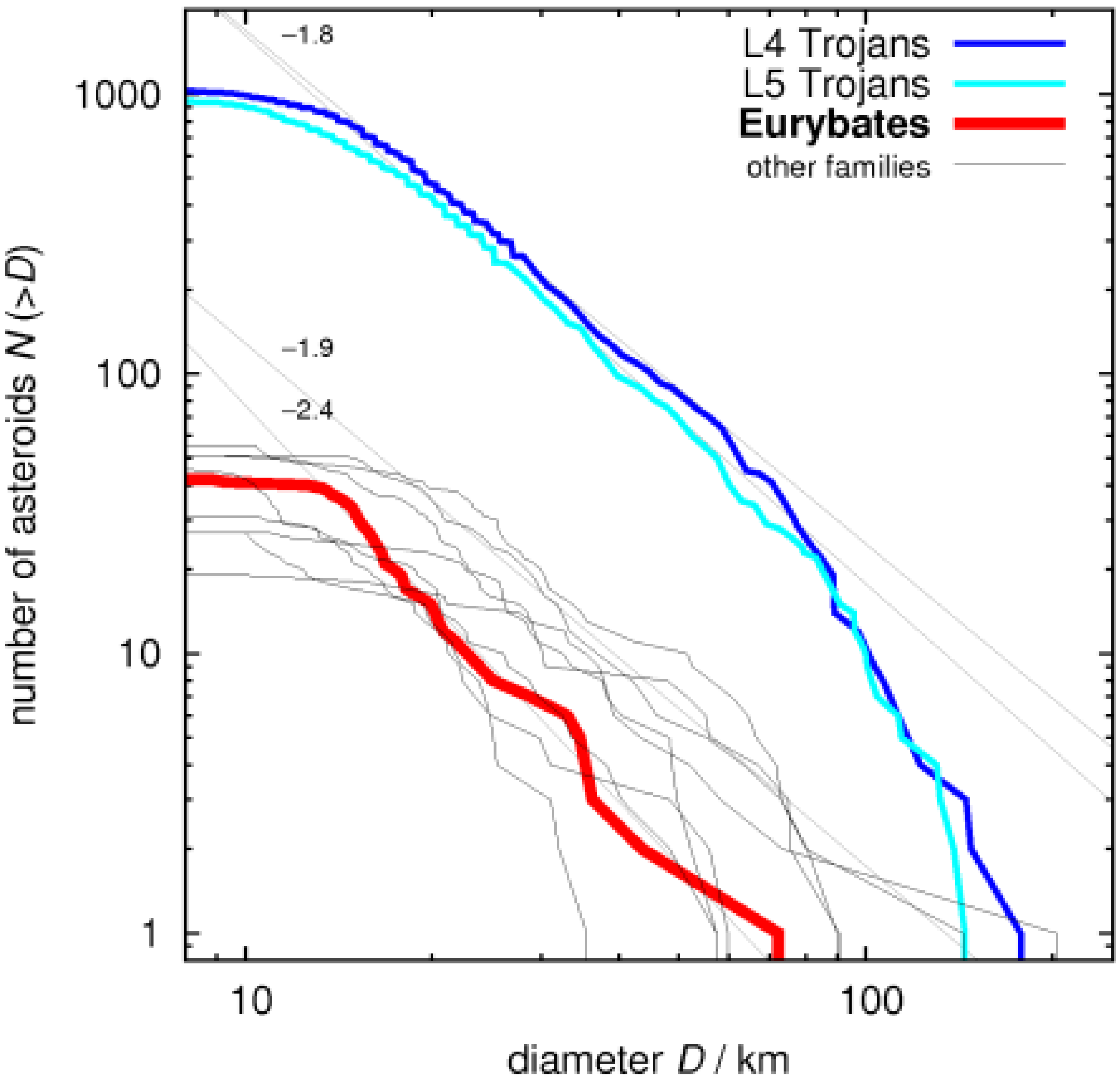
- $\sim$1000 bodies in each L_4 and L_5 cloud
- definitely not many prominent clusters...

Trojans — only 1 family in L4?



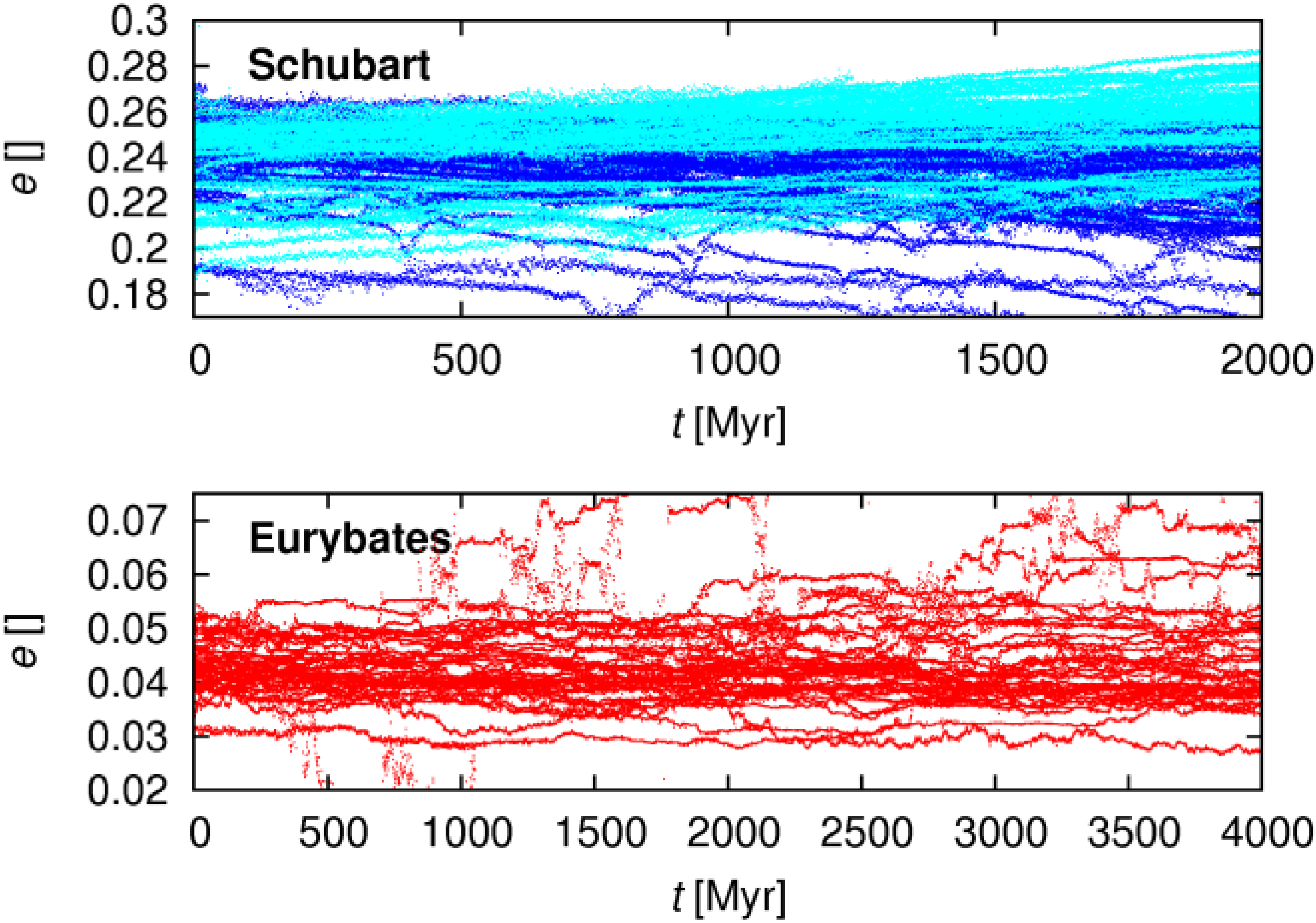
- $N(v_{\mathrm{cutoff}})$ plots compared with (random) background
- Eurybates family is the most robust case; it has only C-type members, no D-types (Roig *et al.* 2008)

Eurybates family — SFD:



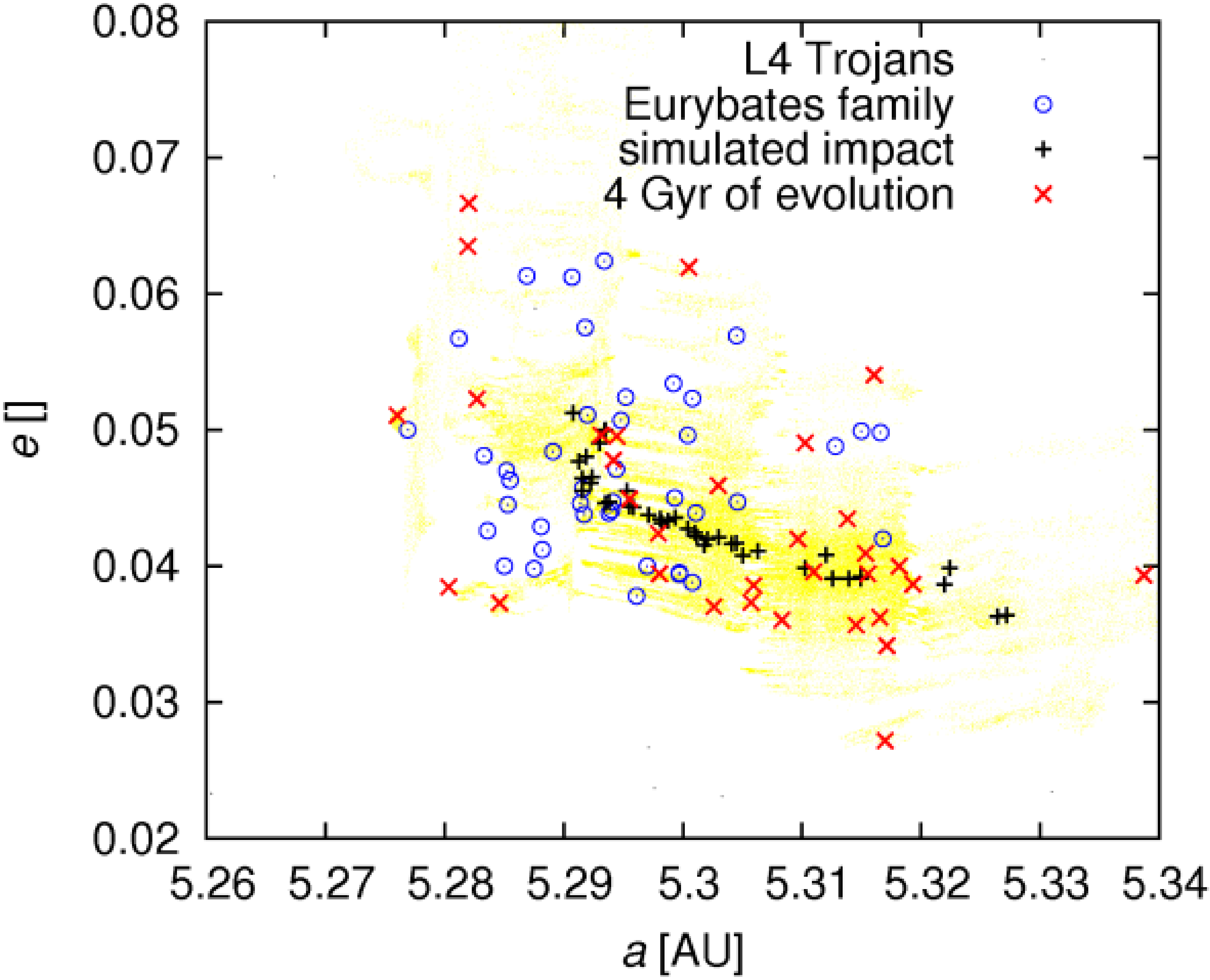
- only Eurybates has steeper SFD than the background
- 1 collisional family among Trojans consistent with J3/2
  $\Leftarrow$ disruption of a 100 km parent body is a rare event
  $\simeq$ 1 per 4 Gyr (Dahlgren 1998)

Eurybates family — no Yarkovsky effect:



- evolution with/without Yarkovsky effect is the same
- different dynamics in 0^{th} order resonance
  $\Rightarrow$ no systematic drift in e, only chaotic diffusion

Eurybates family — chaotic diffusion:



- present shape was attained due to the chaotic diffusion
- age might be 1–4 Gyr (‘filament’ must disappear)

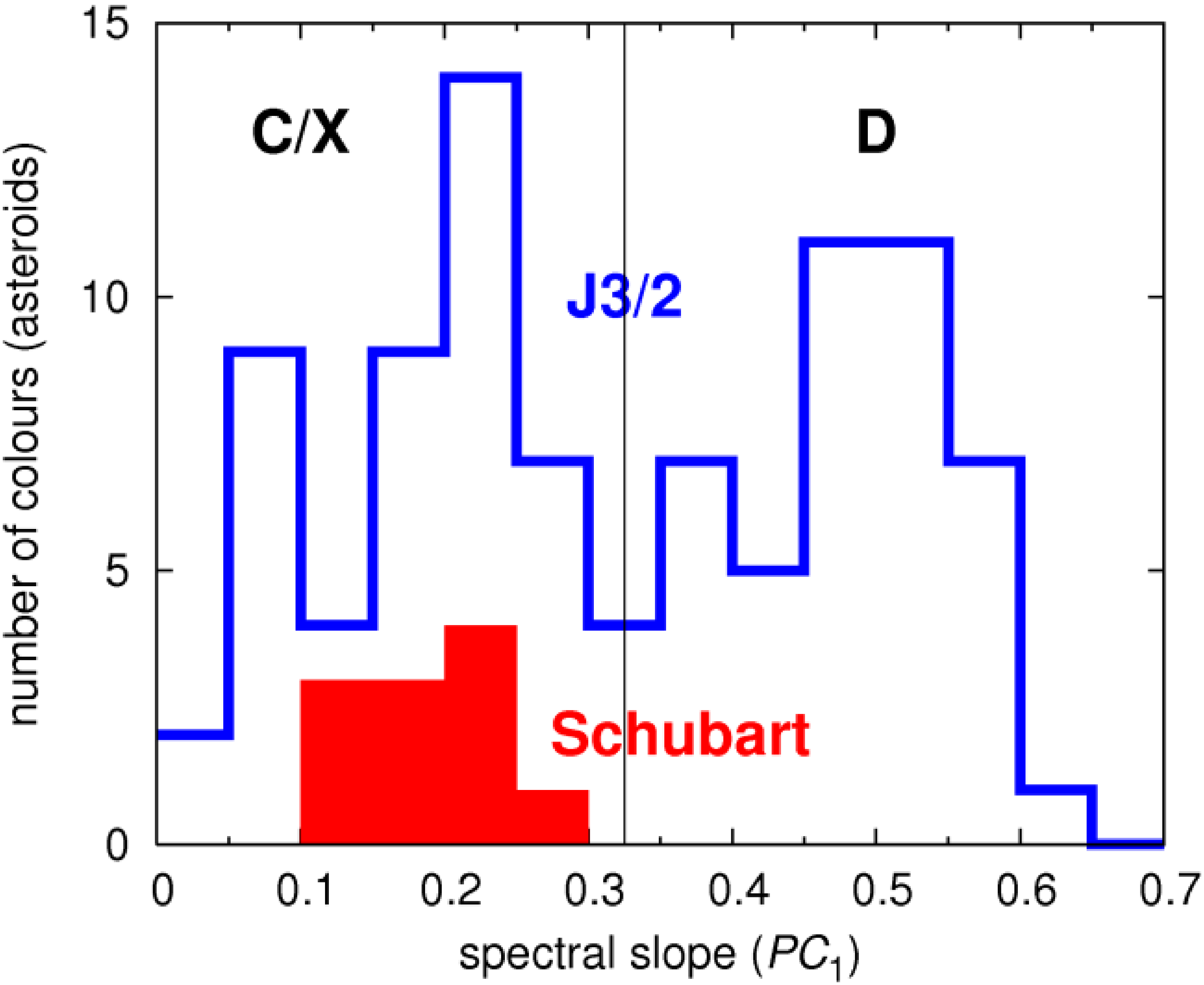
Conclusions:

- resonant Yarkovsky effect (in 1^{st} order resonances)
- two collisional families in the J3/2 resonance (probably old, shallower SFD $\leftarrow$ different from MB)
- one collisional family among Trojans

Future work:

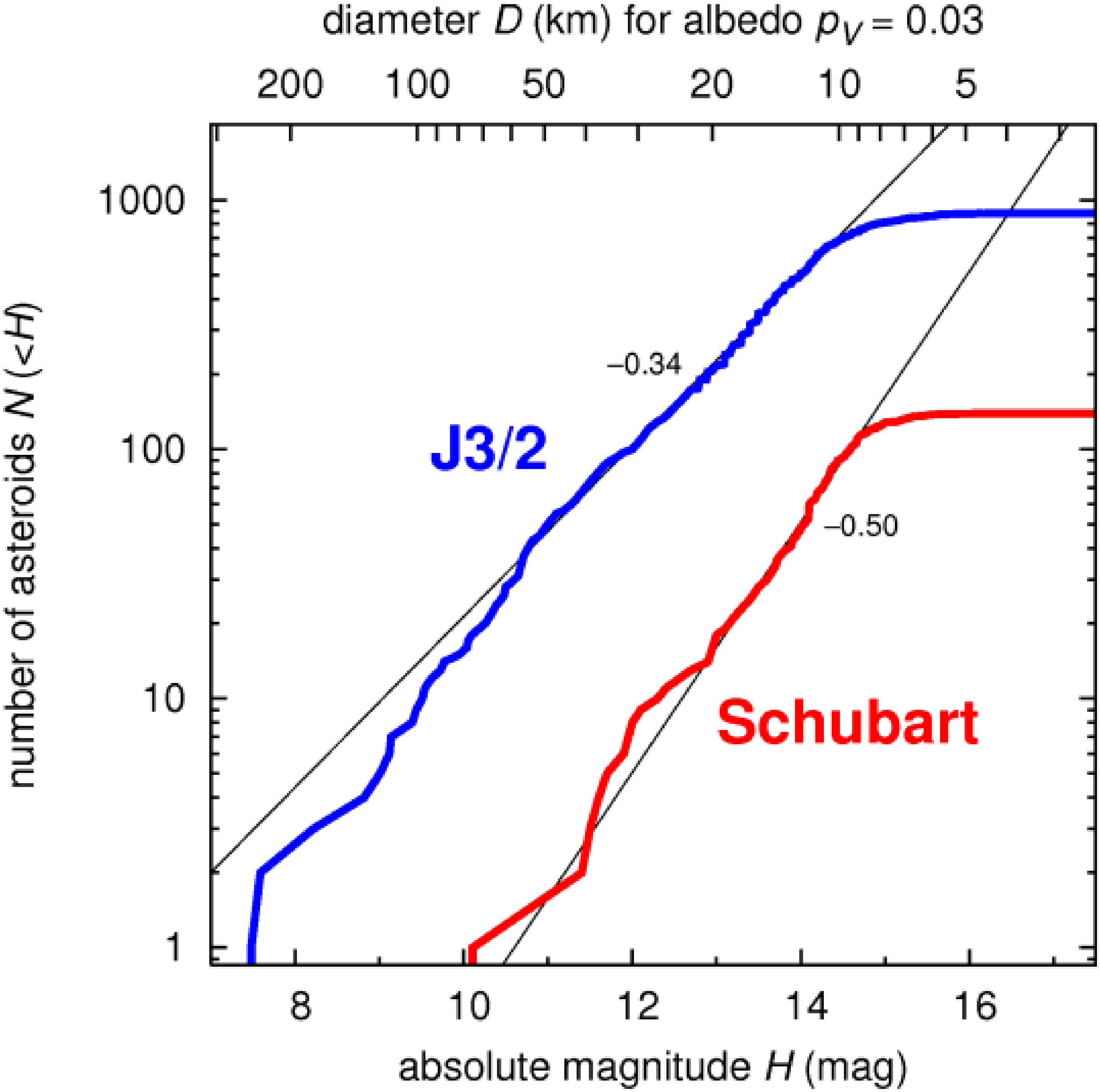
- (e, H) plot with a signature of the YORP effect $\Rightarrow$ more precise ages of resonant families?
- stability of resonant families during planetary migration
- repopulation efficiency from the main belt

Schubart family — colours:



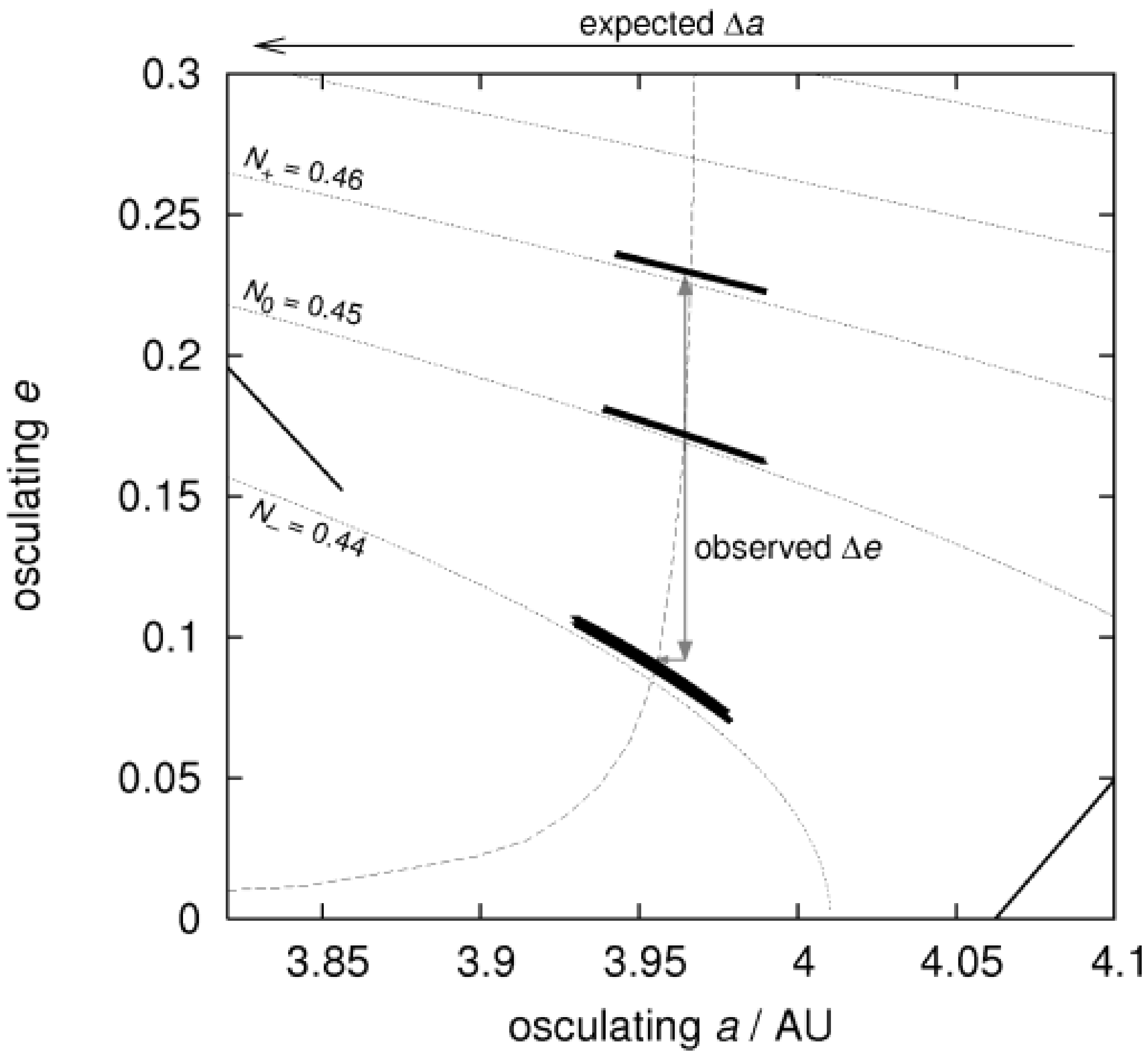
- SLOAN colours of J3/2 bimodal (C/X- and D-types)
- Schubart cluster only C/X-type ⇒ collisional origin

Schubart family — SFD:



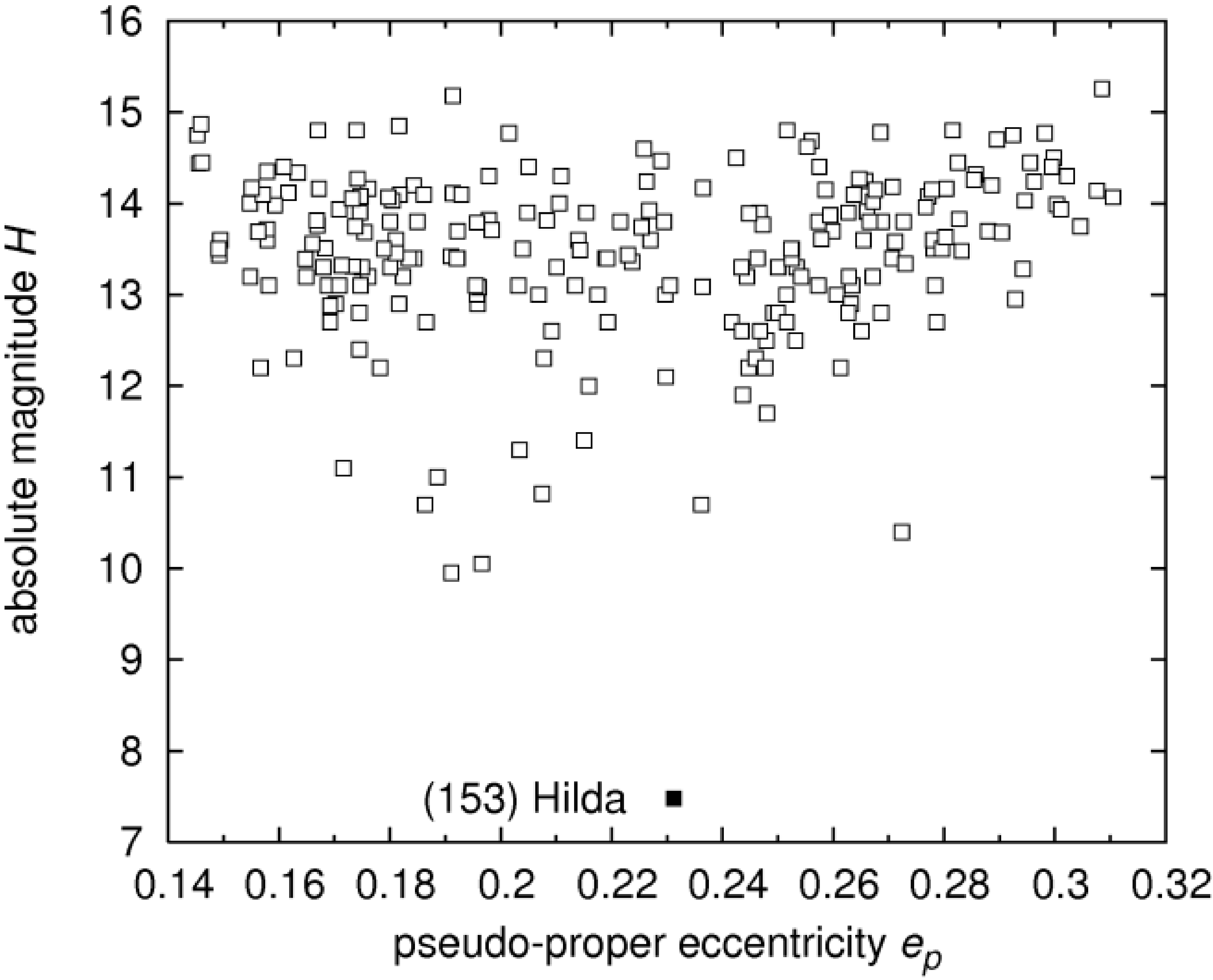
- Schubart family significantly steeper than the rest of J3/2 $\Rightarrow$ collisional origin (but not as steep as MB families)

Yarkovsky drift in e (RTBP):



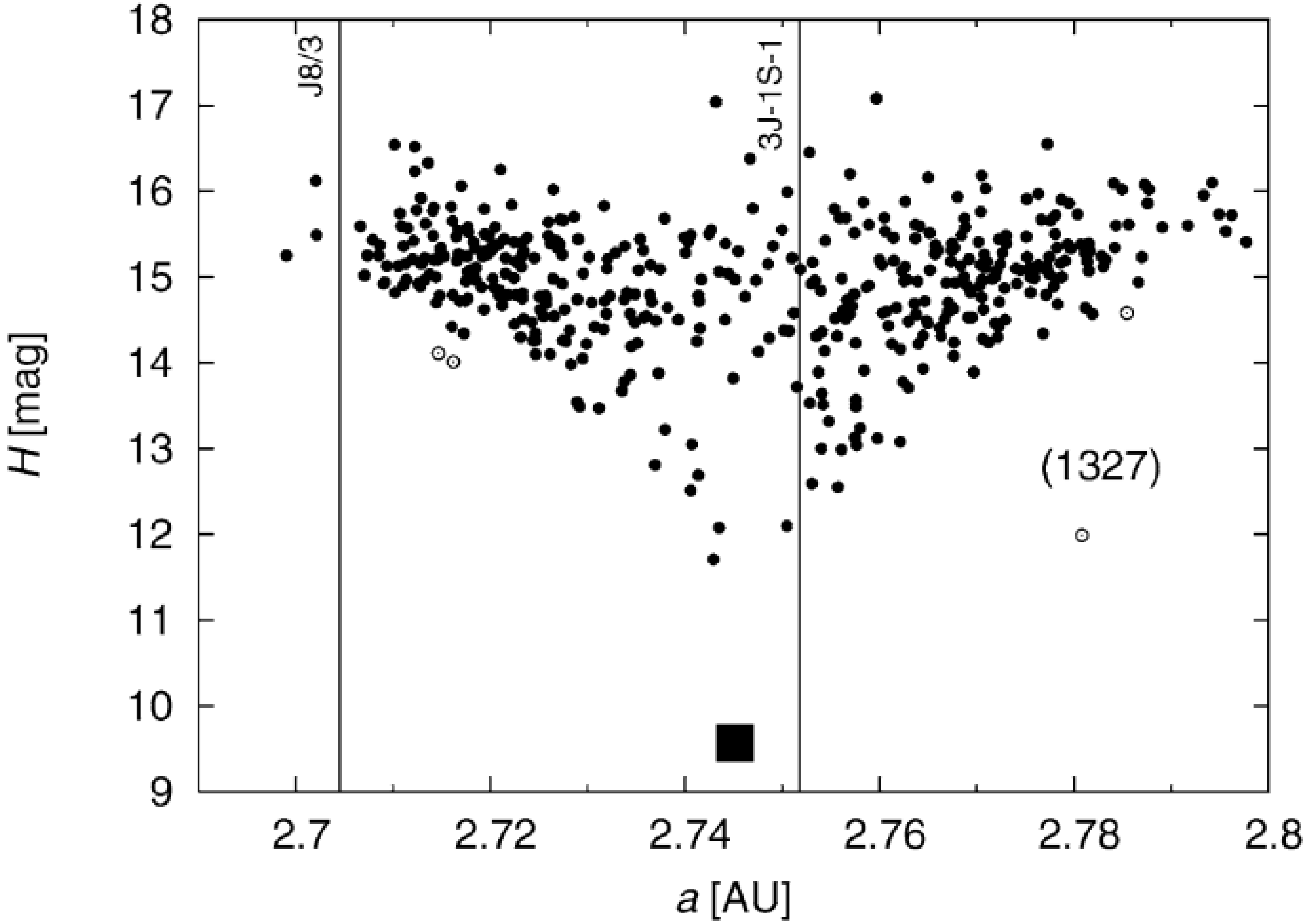
- object is locked in the libration centre, a is almost fixed
- adiabatic invariant $N = \sqrt{a}\left(\frac{p+1}{p} - \sqrt{1-e^2}\cos i\right)$ evolves linearly

Hilda family — (e, H) plot:

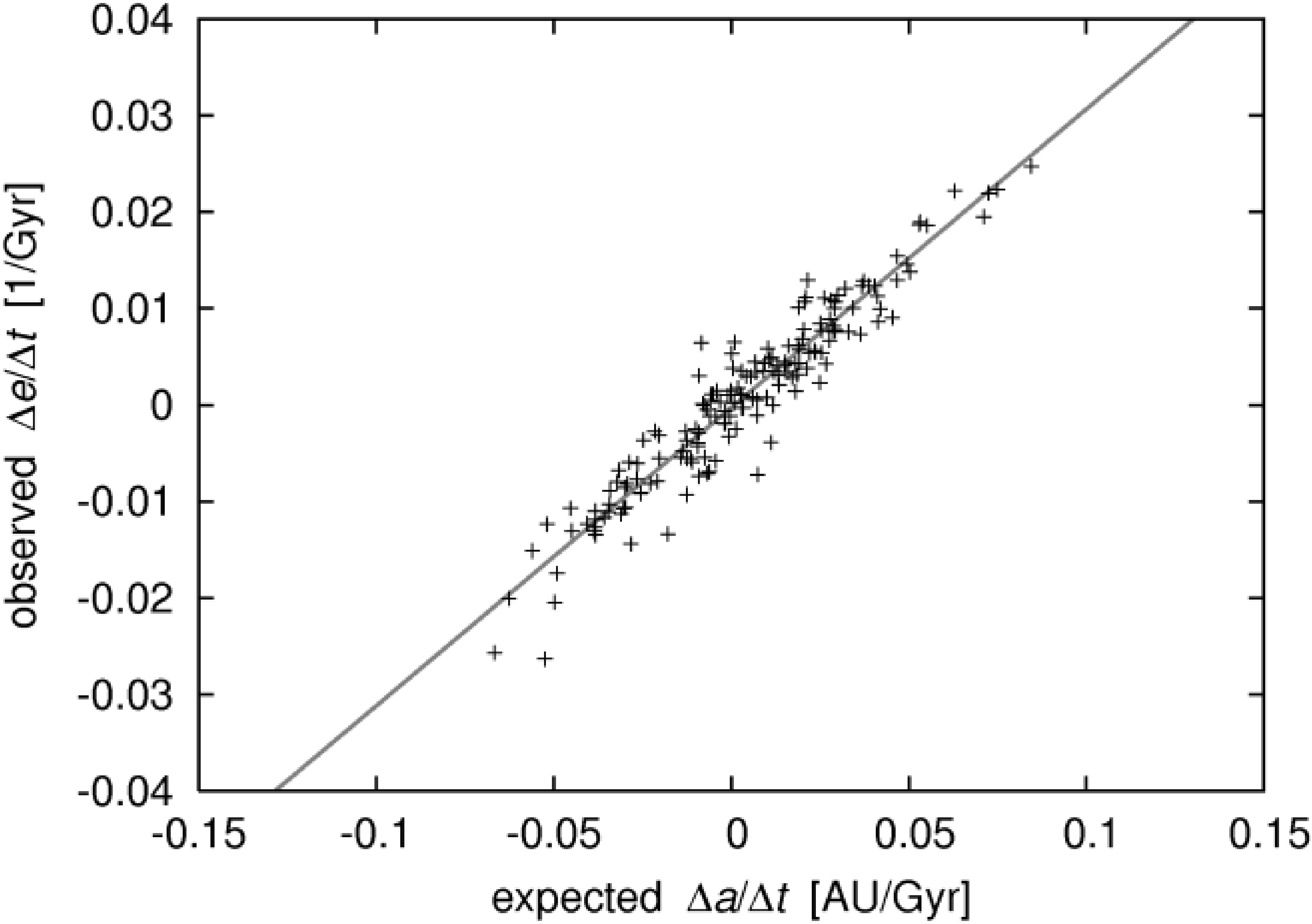


- ‘ears’ like in (a, H) for Eos, Erigone, Massalia, Merxia, …
- YORP effect changes spins $\Rightarrow$ more precise age?

A comparison with Merxia family (a, H):

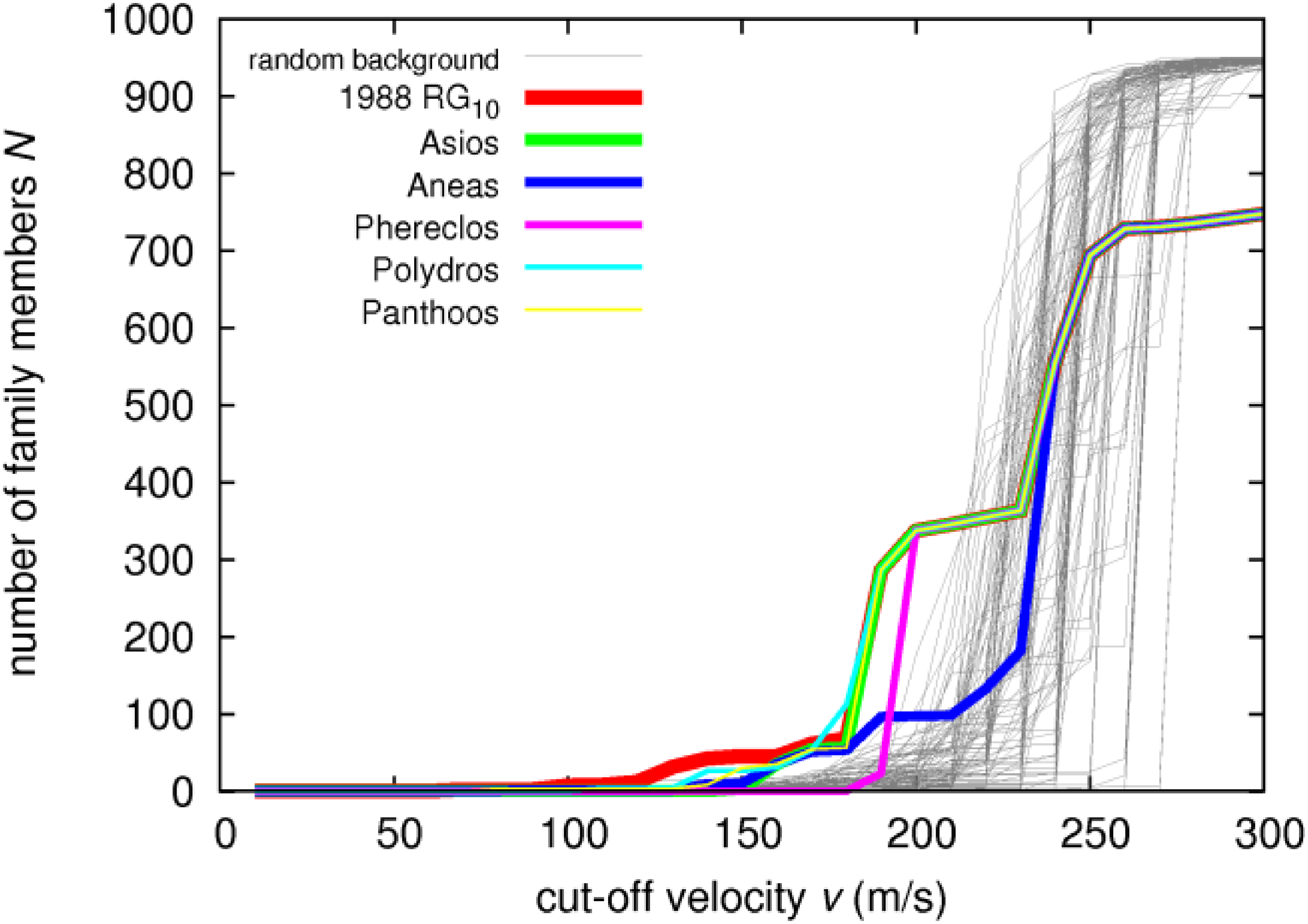


Hilda — expected Δa vs observed Δe:



- linear dependence $\Rightarrow$ the same code as for (a, H)

Trojans — is clustering in L5 real?



- e. g., the proposed Aneas family is essentialy a middle portion of the cloud, not a distinct grouping; it contains more D- than C-types (Roig *et al.* 2008), but this can be due to the overall inclination-taxonomy dependence