Asteroid families versus the Late Heavy Bombardment

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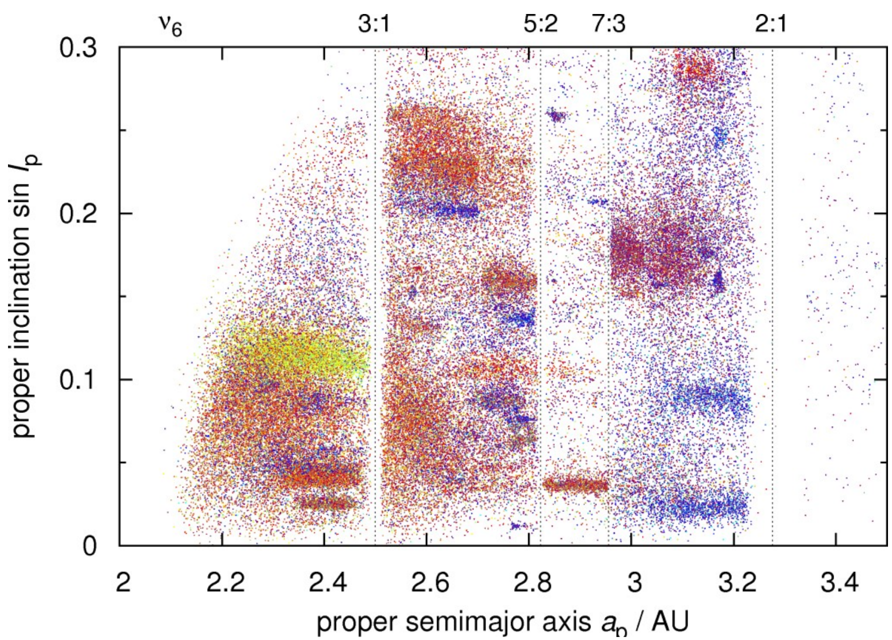

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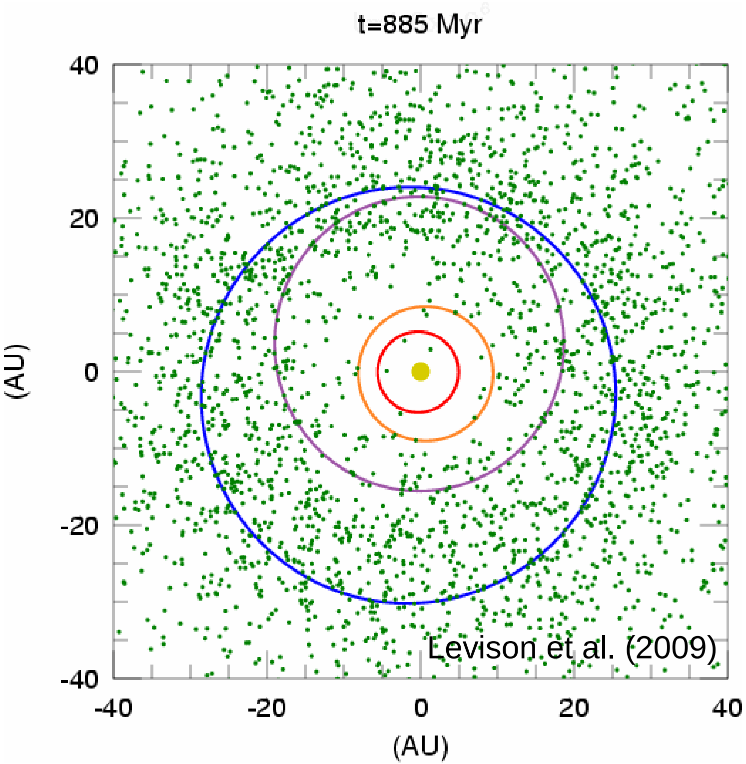
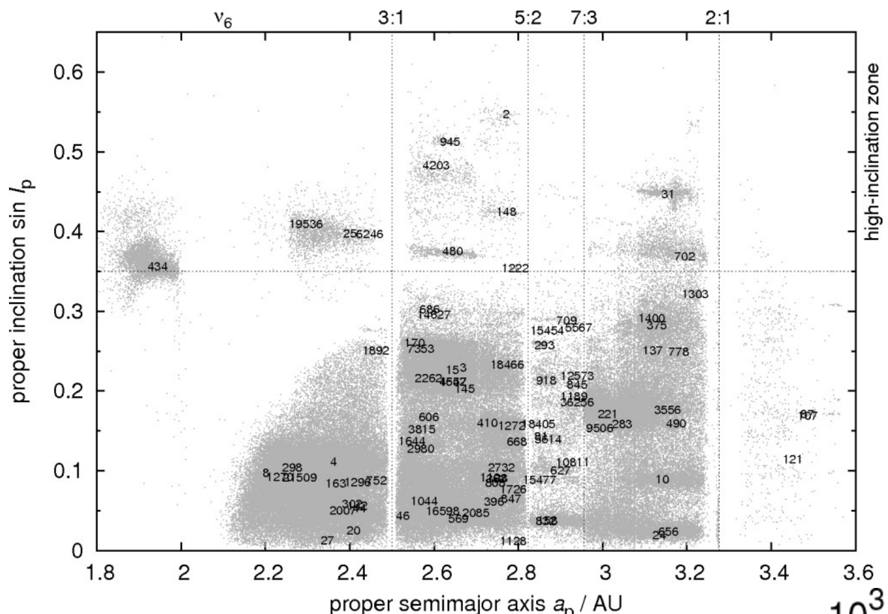
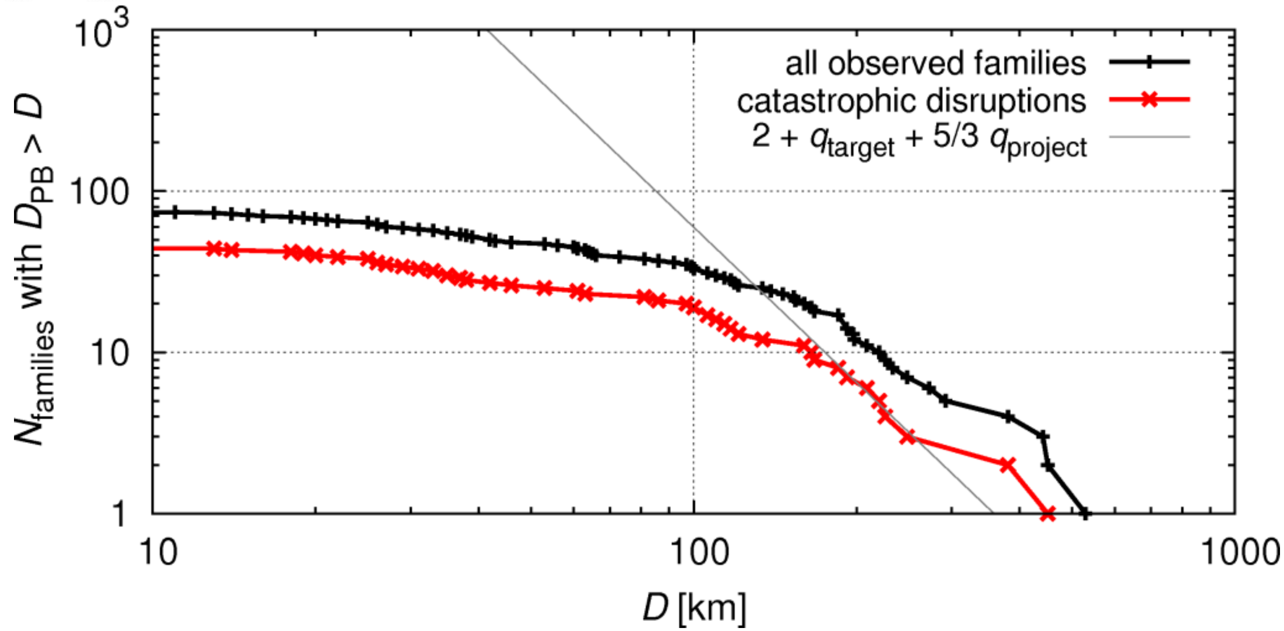


Asteroid families



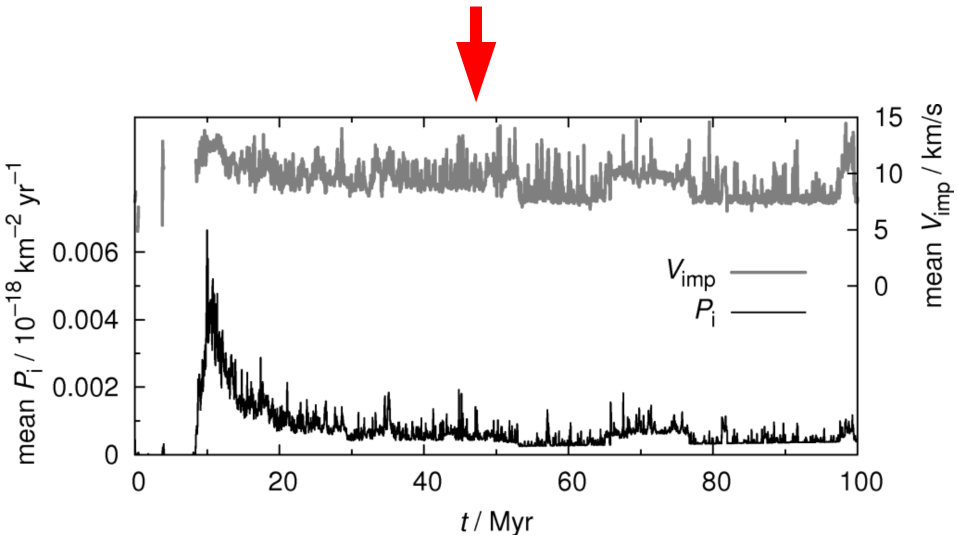
- synthetic proper elements (Kneževic & Milani 2003), identification by the HCM & SDSS colours
- physical properties for 82 families (D_{PB}, LF/PB, age)

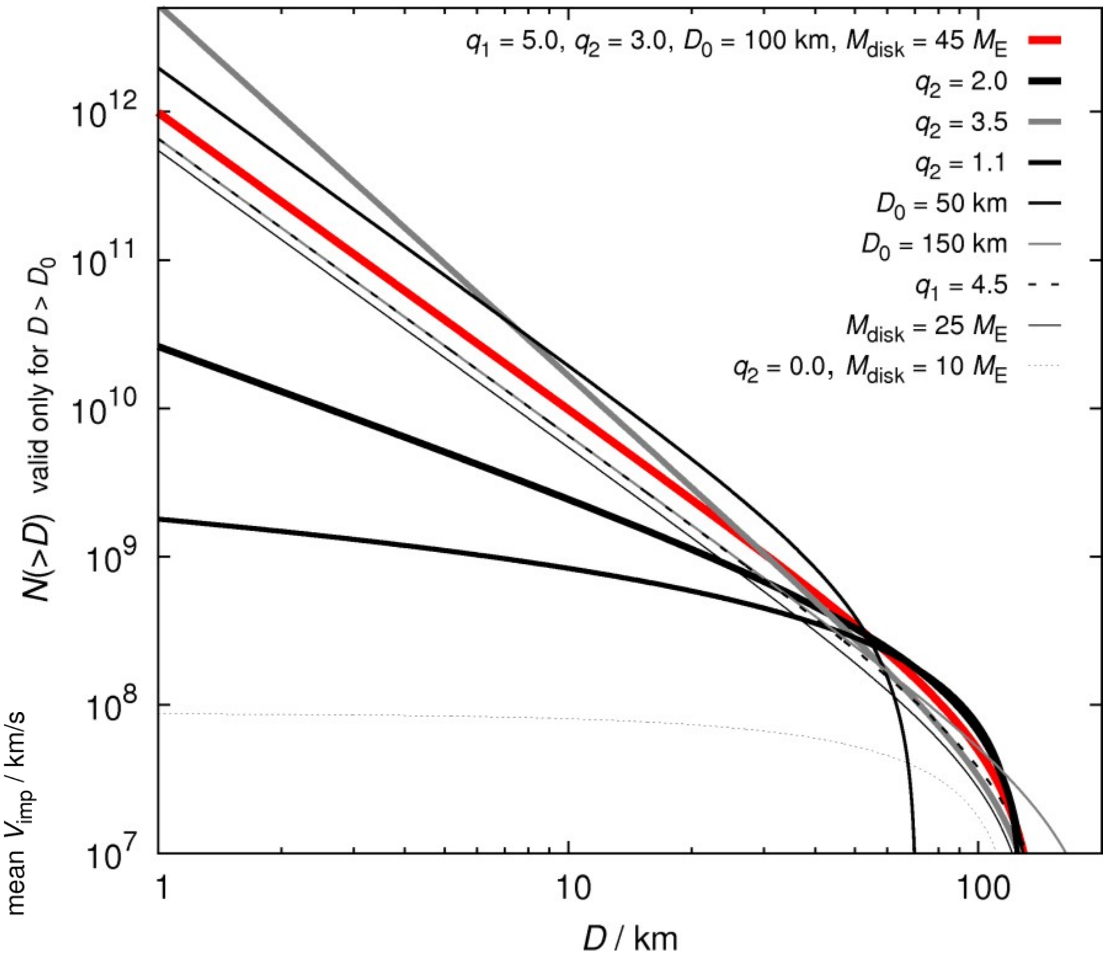
- PB sizes from Durda et al. (2007)
- definition of the “production function” $N_{families}$ with $D_{PB} > D$



The Late Heavy Bombardment

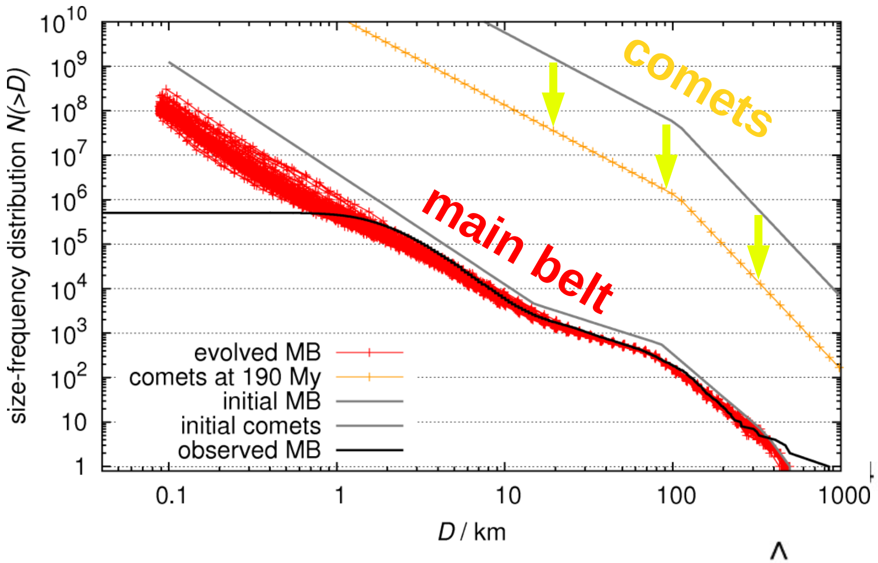
- the Nice model relates the LHB to an instability of the cometary disk beyond Neptune
- the evolution of intrinsic collisional probabilities and impact velocities





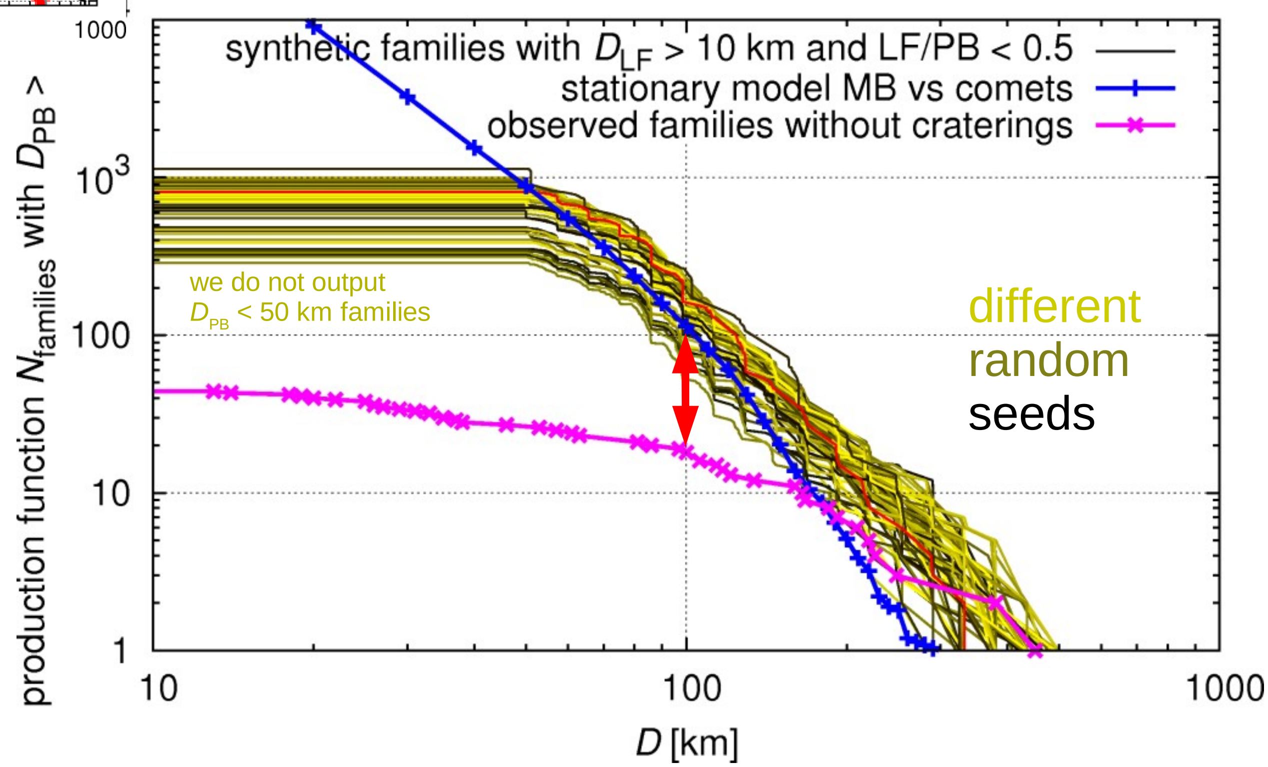
- what was the SFD of the cometary disk?

Collisional model of the MB vs comet population



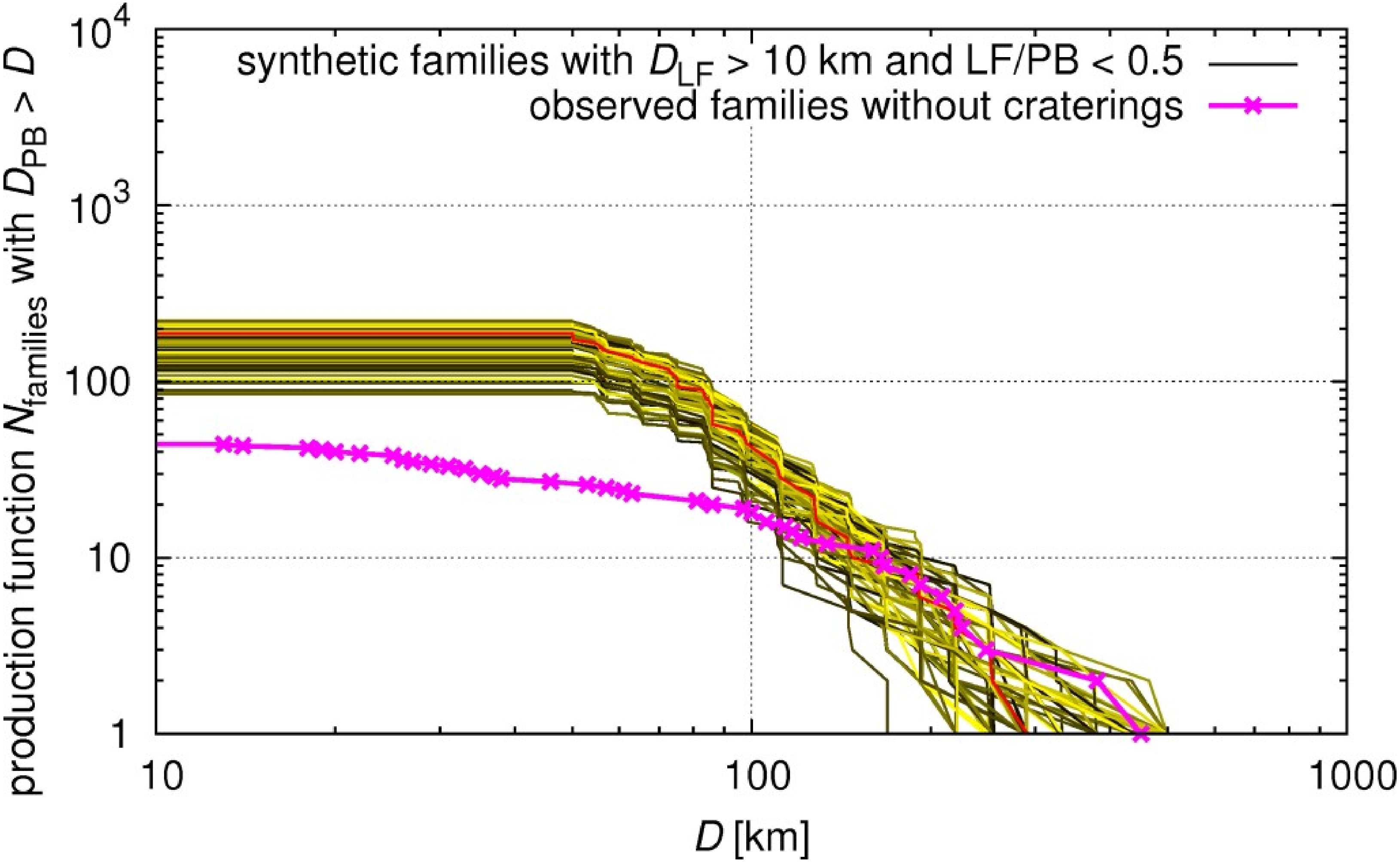
- Boulder collisional code (Morbidelli et al. 2009)
- Q_D of Benz & Asphaug (1999)
- we fit the observed SFD of the main belt

- ~ 10 families with D_{PB}> 200 km (OK)
- we usually obtain ~ 100 families (!)
- with D_{PB}> 100 km



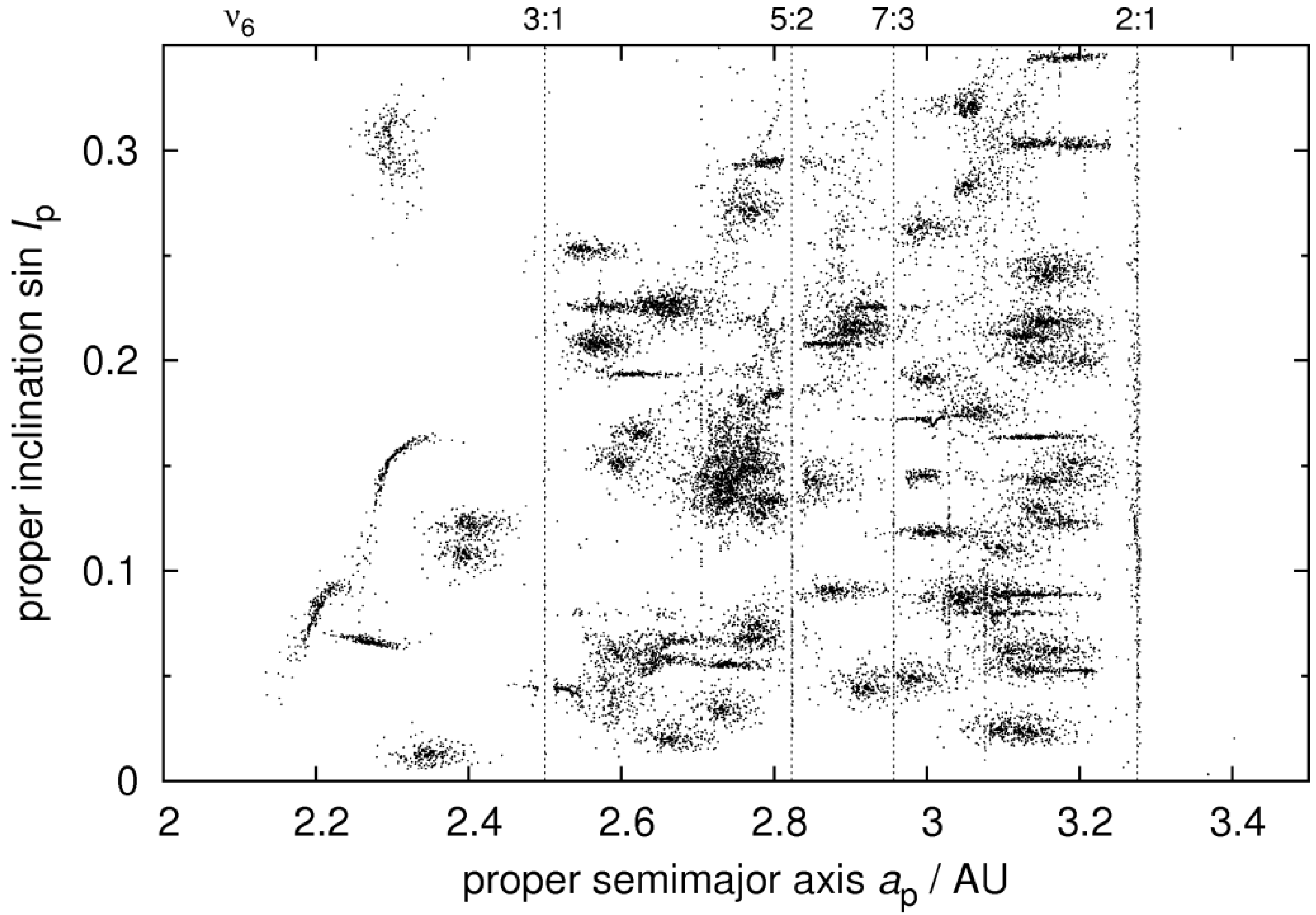
Physical lifetime of comets?

- if comets disrupt immediately below q_{crit} = 1.5 AU, the number of D_{PB} = 100 km families drops down to ~ 30



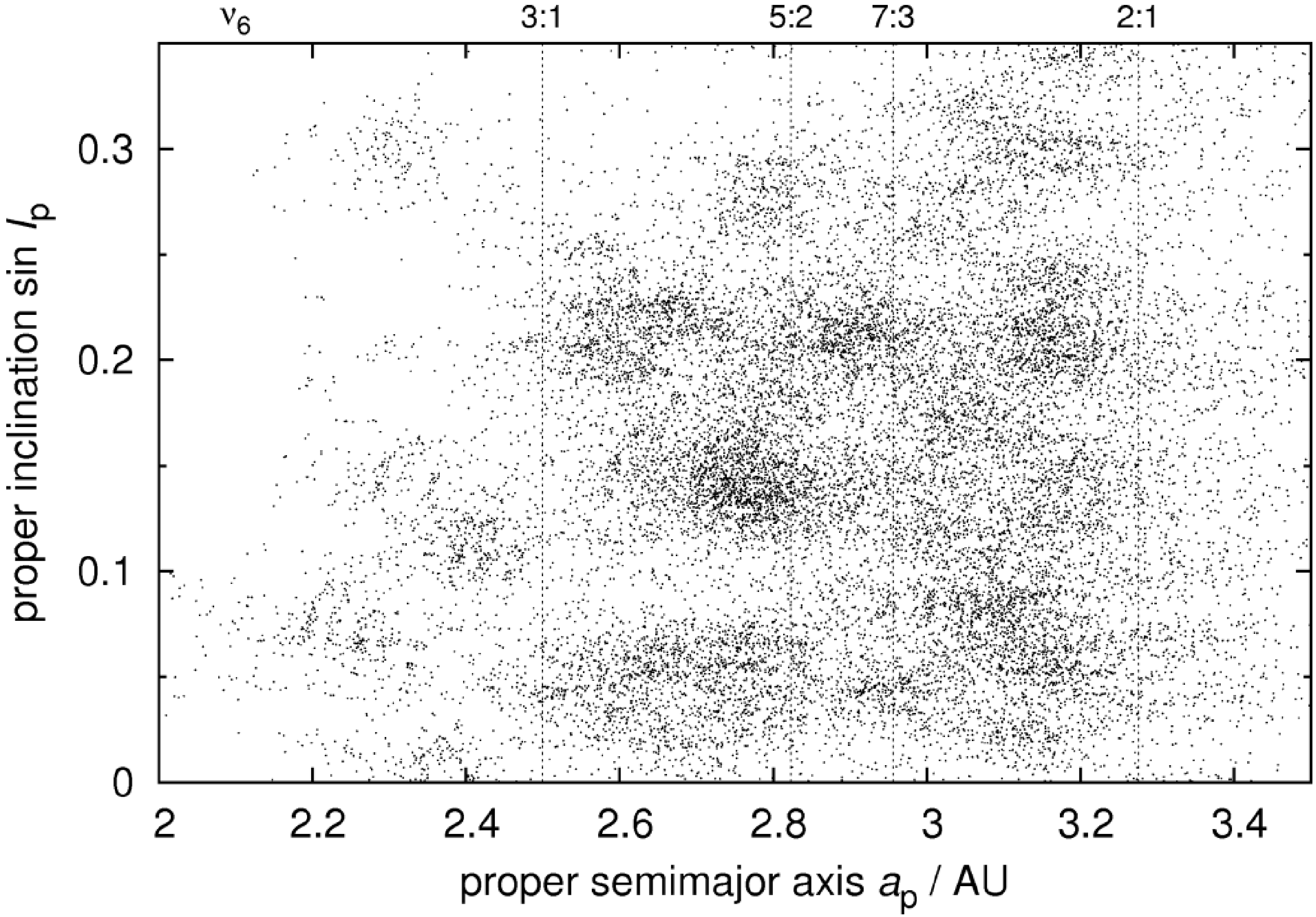
Can families overlap initially?

- 100 synthetic families with D_{PB}= 100 km - proper elements
- no! the families are too compact after the disruption

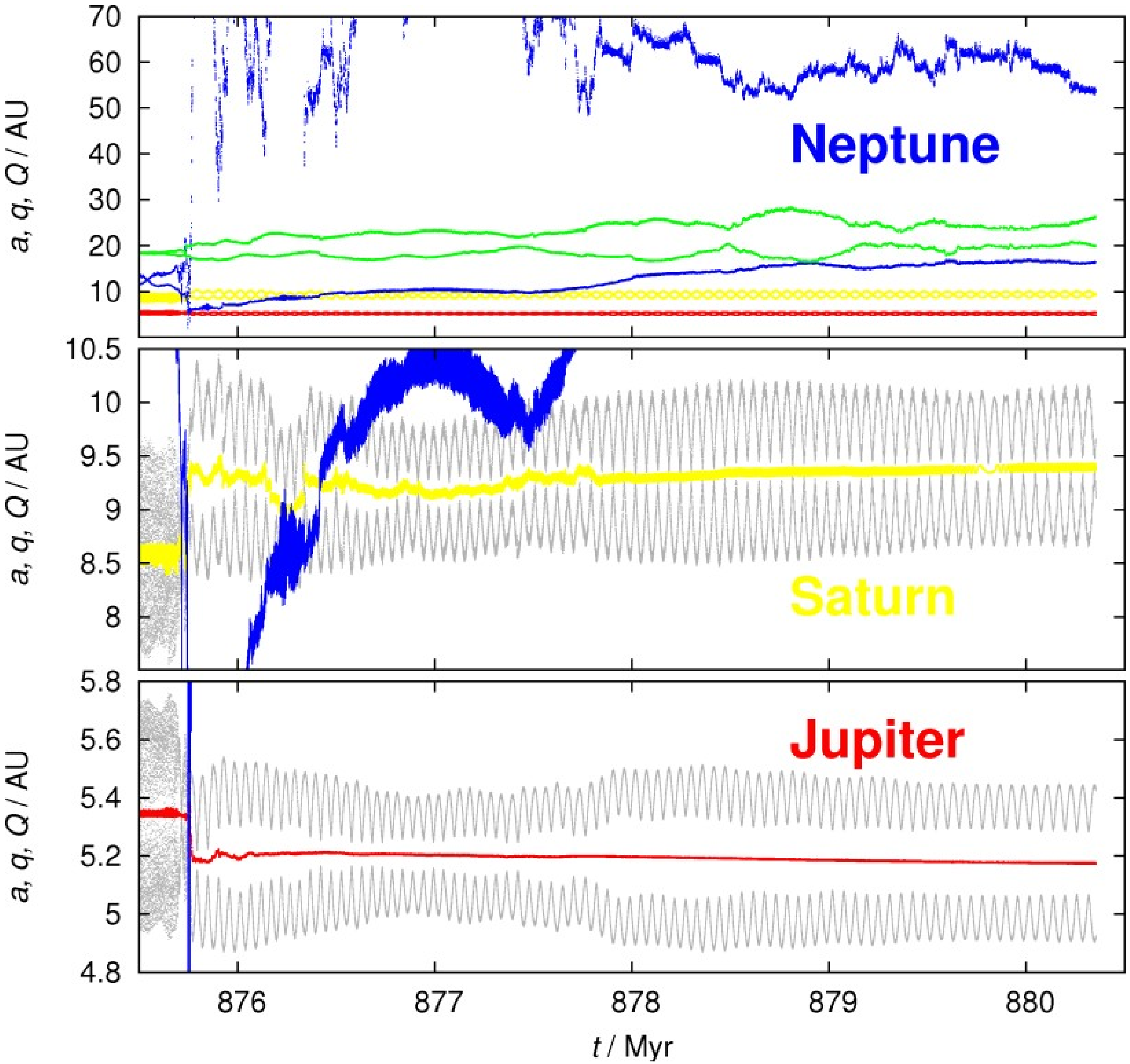


Can families be dispersed by the Yarkovsky effect?

- SWIFT integrator & MC model - the evolution over 4 Gyr
- partially! there are persistent structures in inclinations



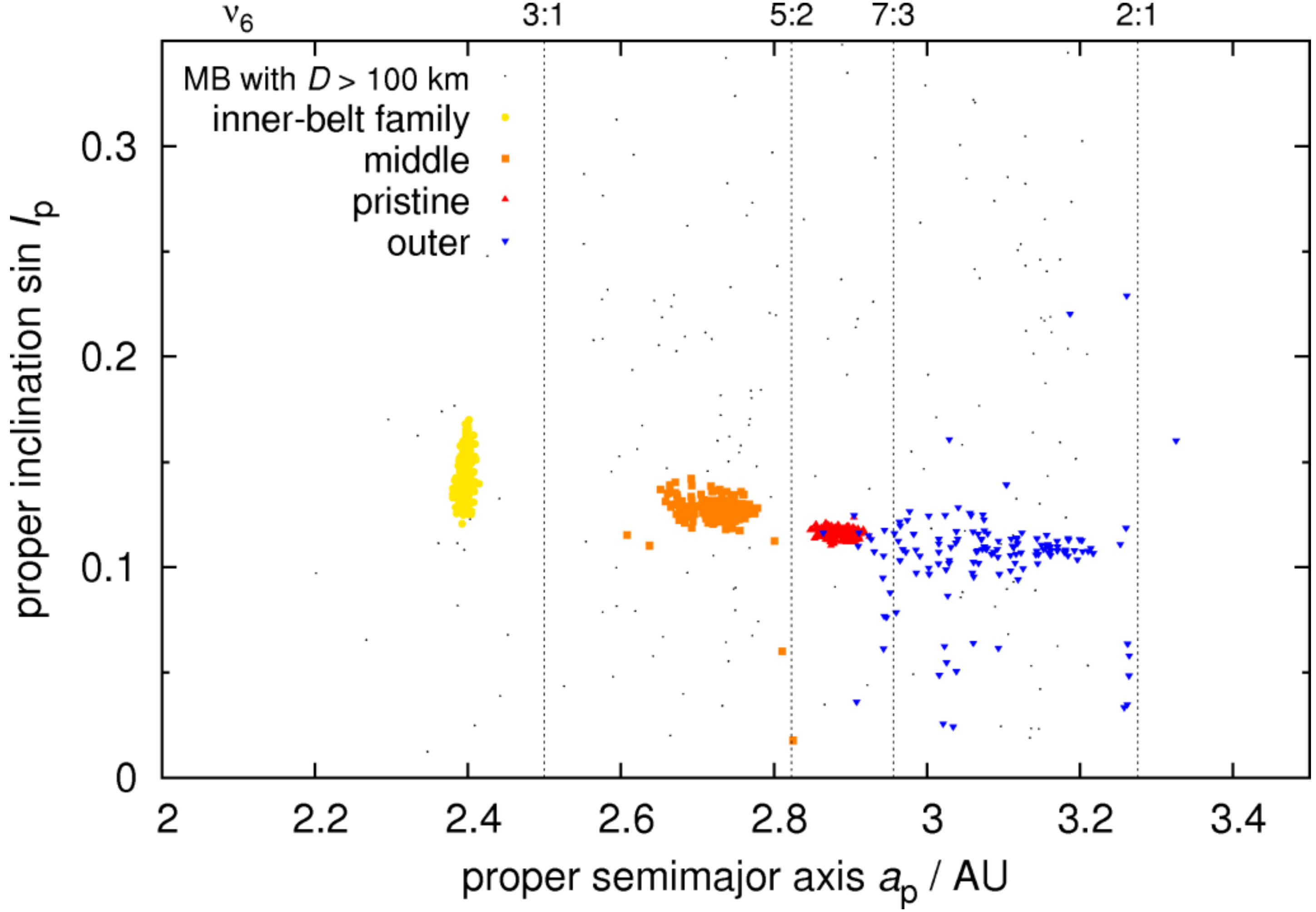
A jumping-Jupiter scenario



- Morbidelli et al. (2010)
- close encounters between planets
- fast migration of Jupiter & Saturn

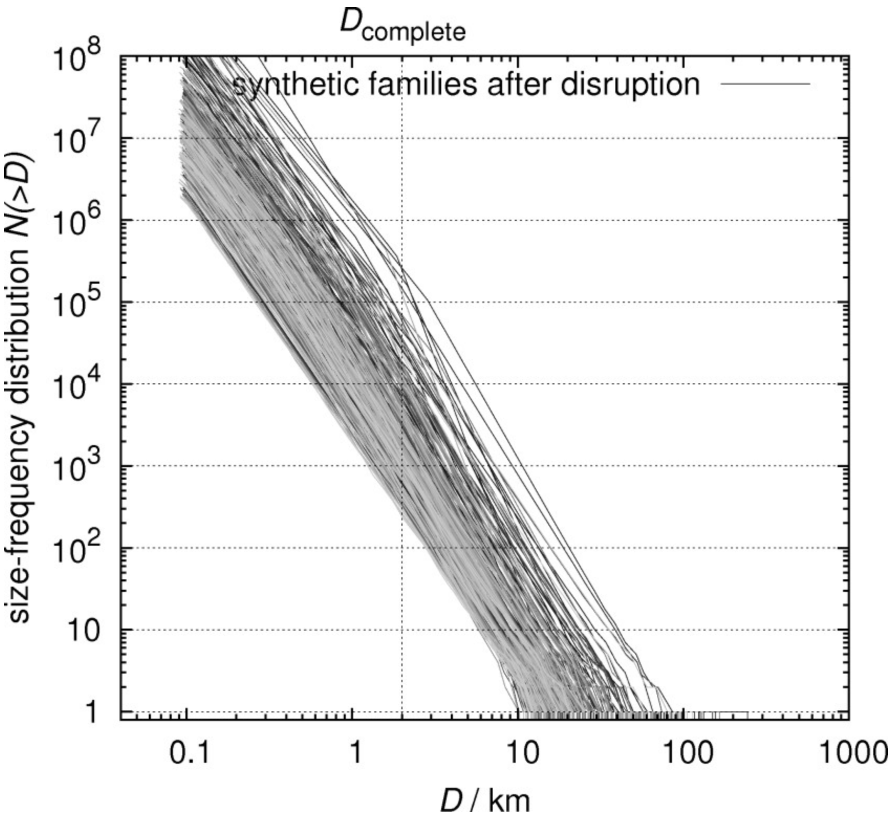
Perturbation by migrating planets?

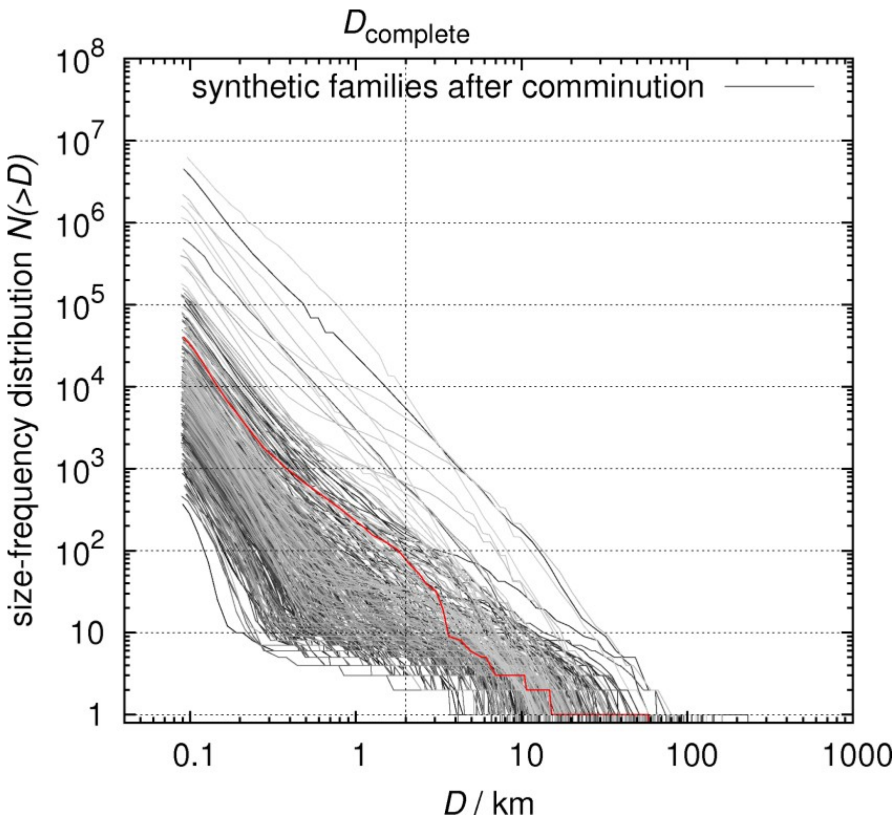
- “jumping-Jupiter” scenario (Morbidelli et al. 2010)
- no! inclinations cannot be perturbed sufficiently



Comminution of asteroid families

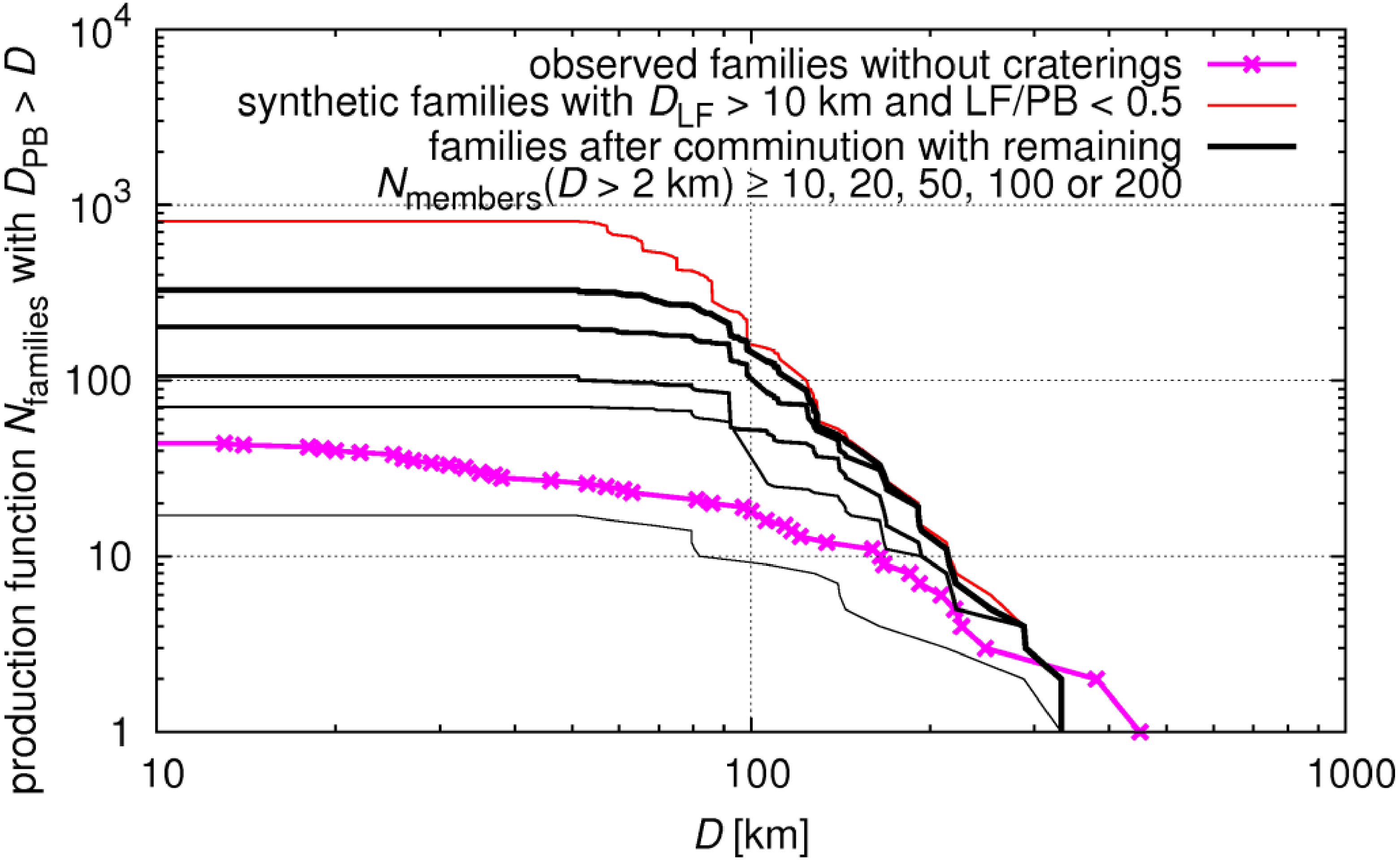
- initially steep SFD (Durda et al. 2007) become very flat after cometary bombardment and 4 Gyr of evolution





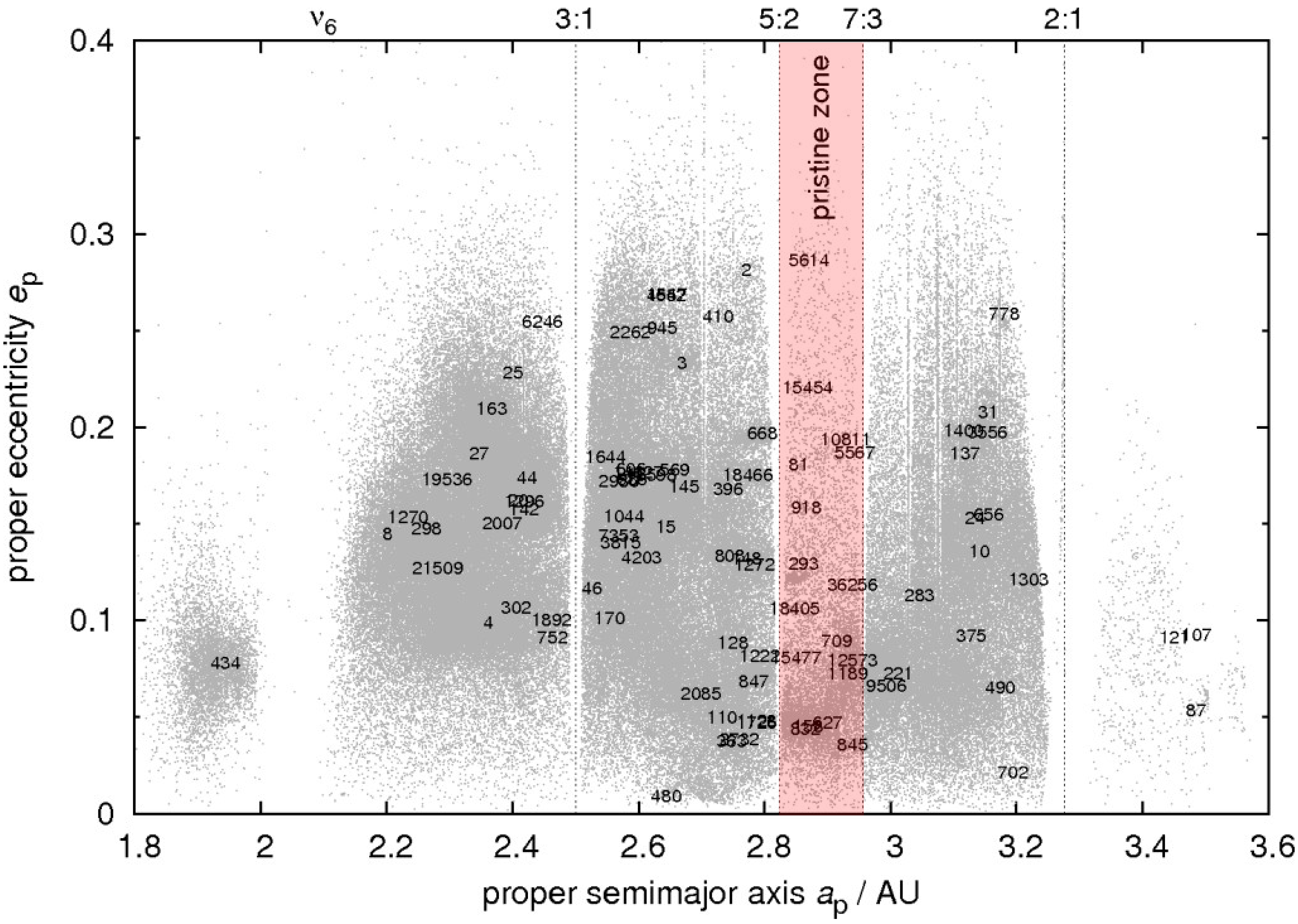
Comminution of asteroid families

- yes! comminution (together with the YE dispersal) can explain the paucity of D_{PB}= 100 km families

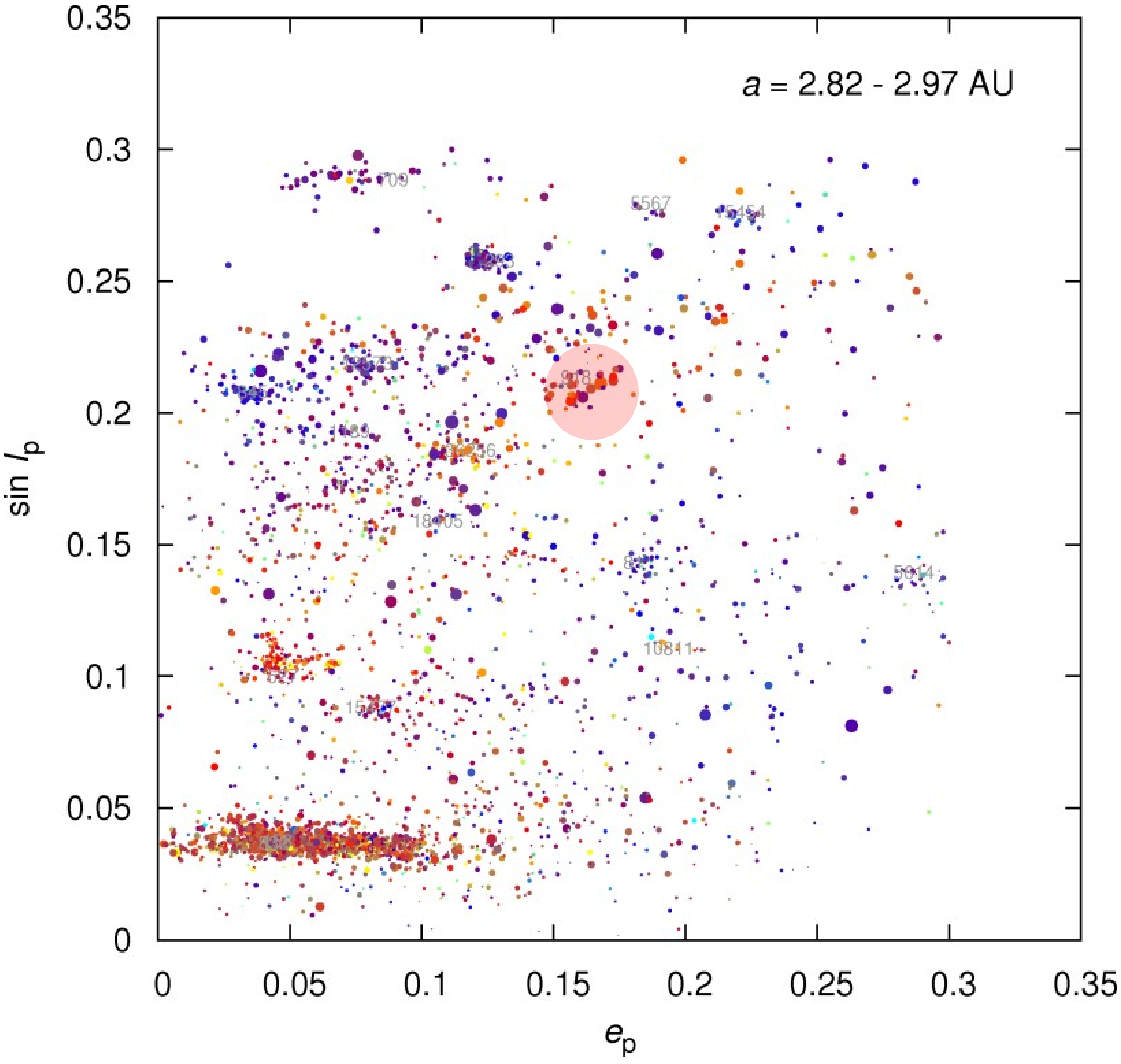


“Pristine zone” between 2.82 and 2.97 AU

- bounded by resonances, only one big family (Koronis)



"Pristine zone" between 2.82 and 2.97 AU



- the "small" families, e.g. 918 Itha, 5567 Durisen, 12573 1999 NJ_{53}, 15454 1998 YB_3, have very flat SFDs
- are they remnants of old D_{PB}= 100 km families affected by comminution?!

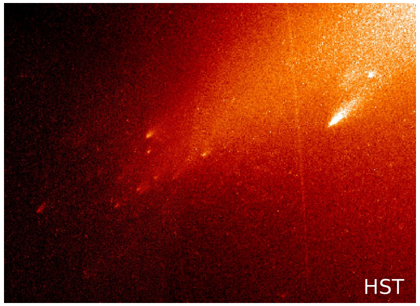
Conclusions and future work

- the LHB as predicted by the Nice model would create ~ 100 families DPB > 100 km in the main belt which are not observed, because:

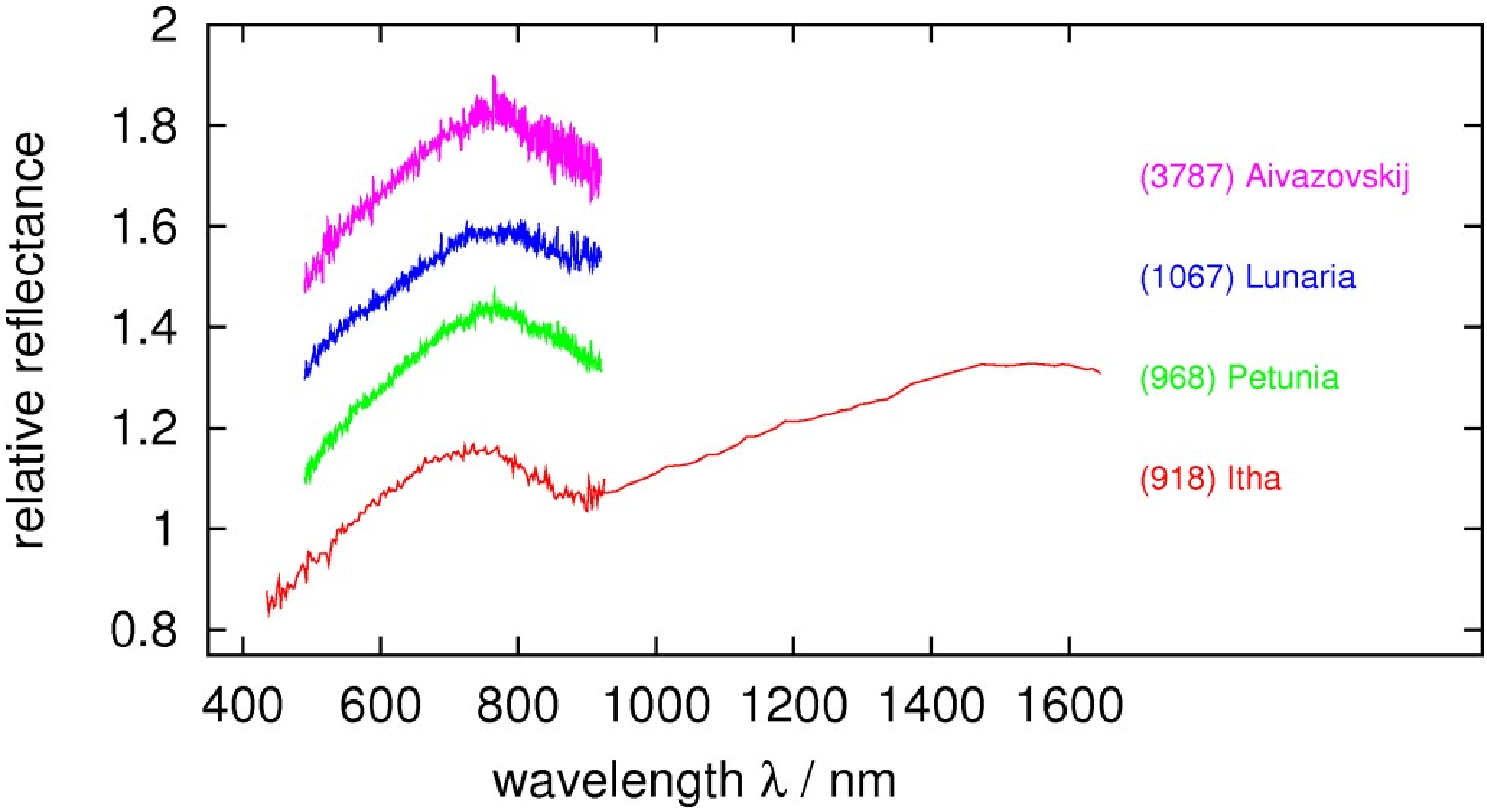
1. comets disrupt frequently below q_{crit}= 1.5 AU,
2. families are almost destroyed by comminution, or
3. the SFD of comets was shallow with D_0 ~ 150 km.

- there may exist remnants of D_{PB} = 100 km families in the "pristine zone" (a = 2.82 to 2.97 AU)?

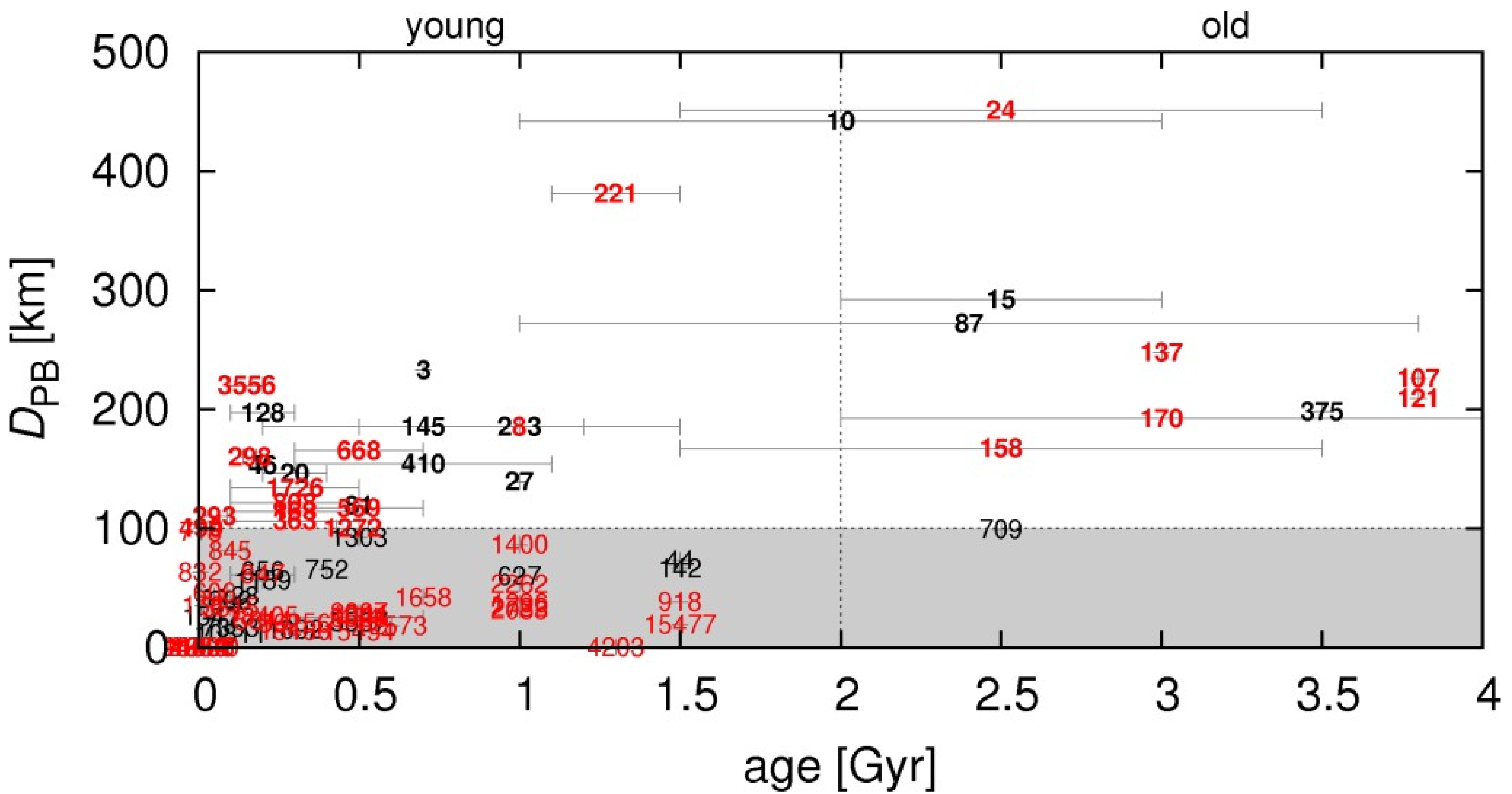
- a motivation for studies of high-velocity collisions between **hard** targets (asteroids) and **very weak** projectiles (comets)



(918) Itha family spectra



Family D_{PB} vs age distribution



Trey et al.: Vesta cratering

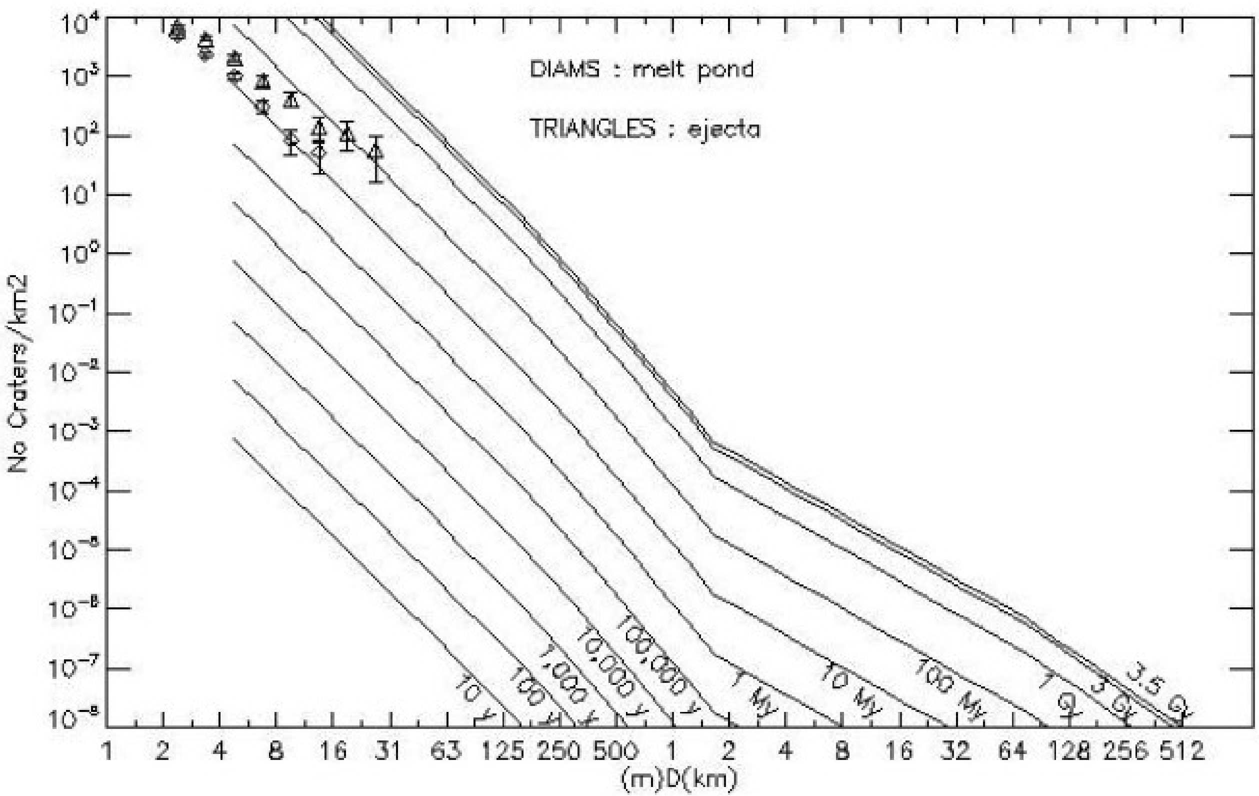
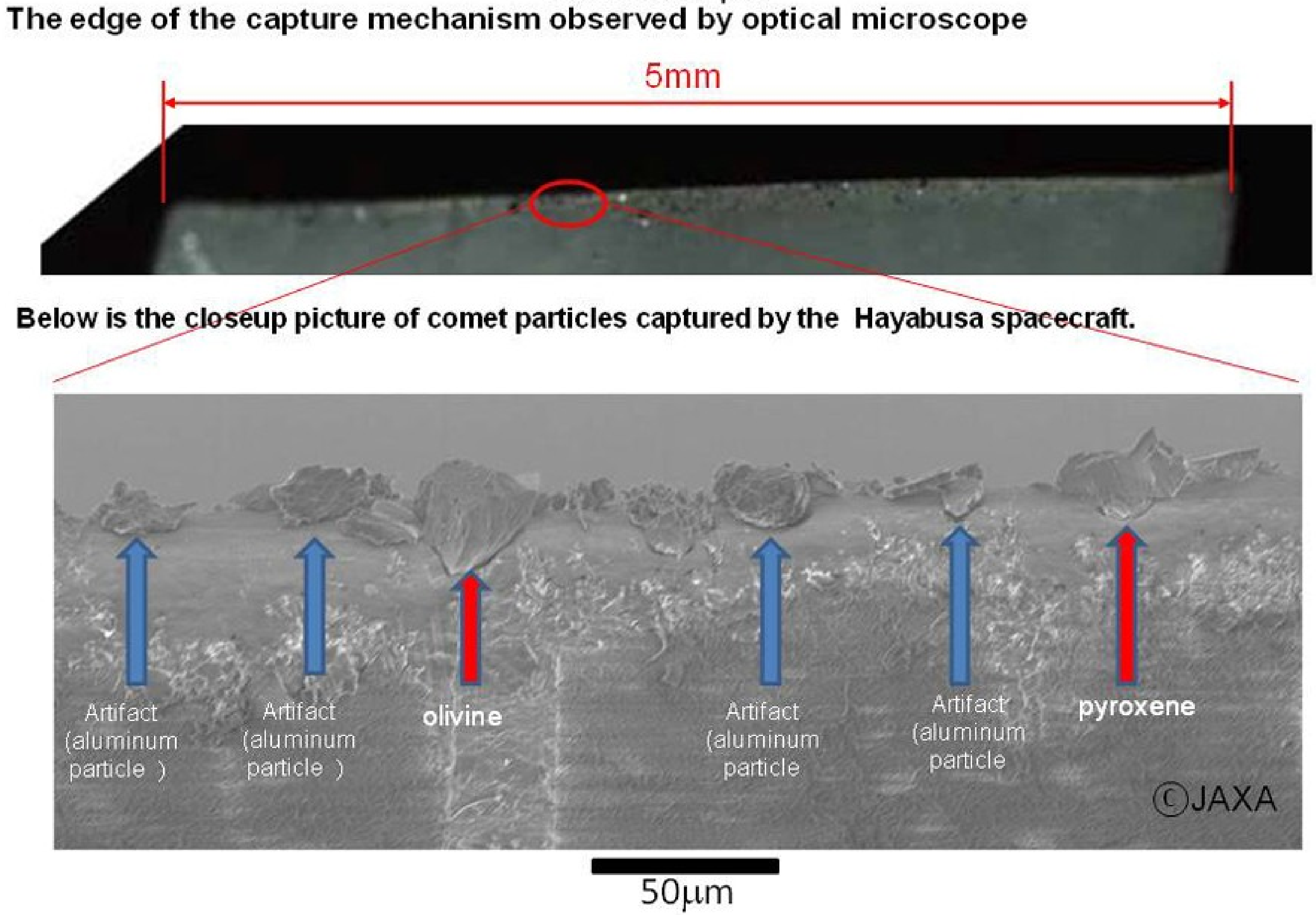


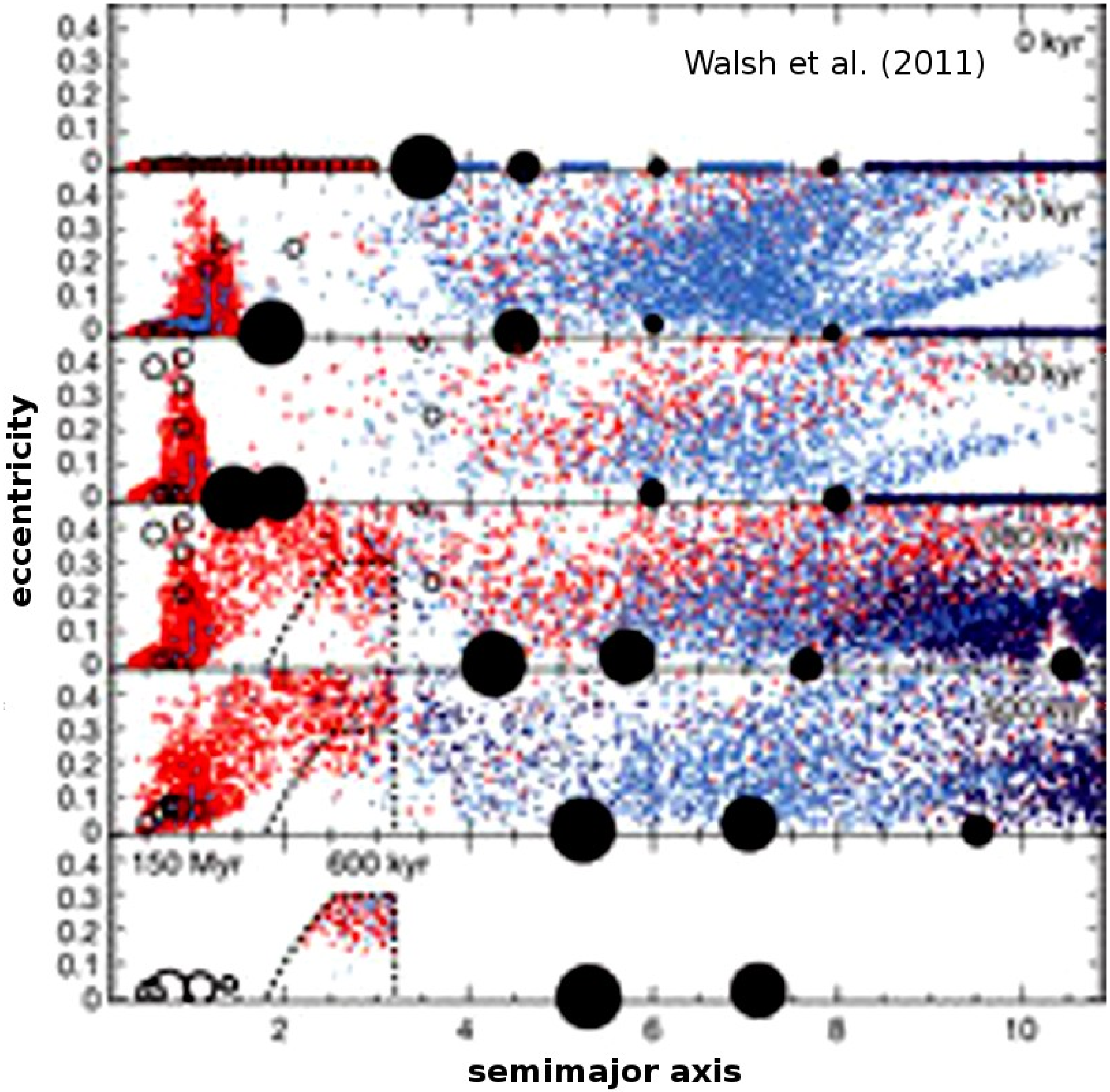
Figure 2: Comparison of craters size distribution on the melt pond (image LROC NA N°M122291425) and on the ejecta (image LROC NA N°M119943483). For both counts, the counted surface is ~70 000 m².

Hayabusa: particles from Itokawa

The spacecraft's special spatula observed by a scanning electron microscope

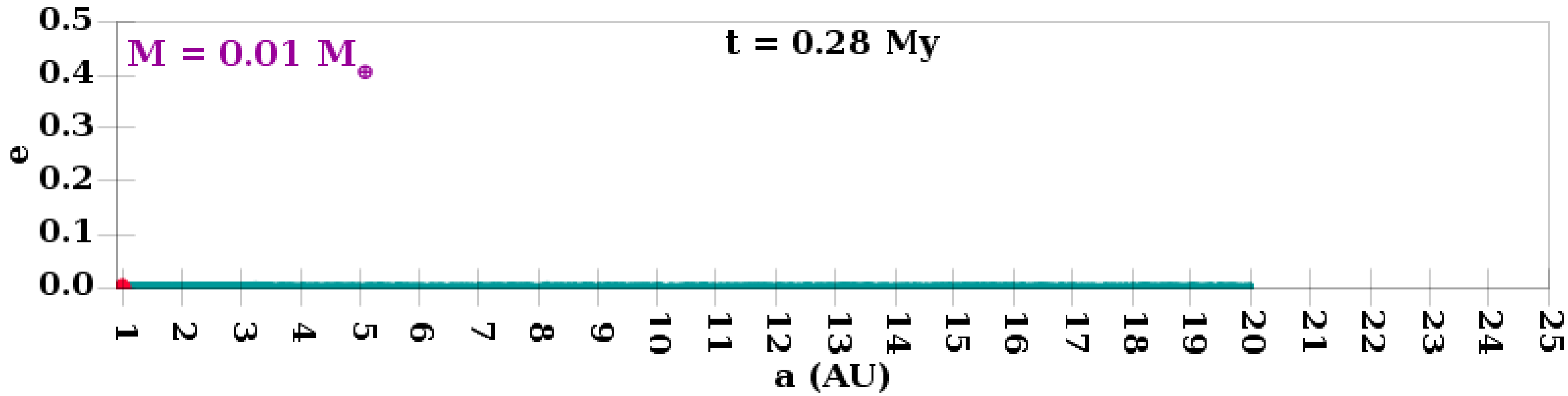


Walsh et al.: Grand-tack scenario



An EXTREME Case of Planetesimal-Driven Migration

- Embryo takes off:



- Grows like mad.
  - Stirring timescale slower than migration timescale $\Longrightarrow$ disk is dynamically cold.
  - We get large embryos (giant planet cores?) at $a > 5$ AU.
  - In the above example with $2.5\times$ MMSN:
    - Core is $5M_\oplus$ at 5.4 AU after $900,000$ yr.
    - Core is $14M_\oplus$ at 15 AU after $1,000,000$ yr.
  - Takes less time than growing something at 5 AU $\Longrightarrow$ Indeed, it solves a long-standing timescale problem.

Levison et al. (2011)

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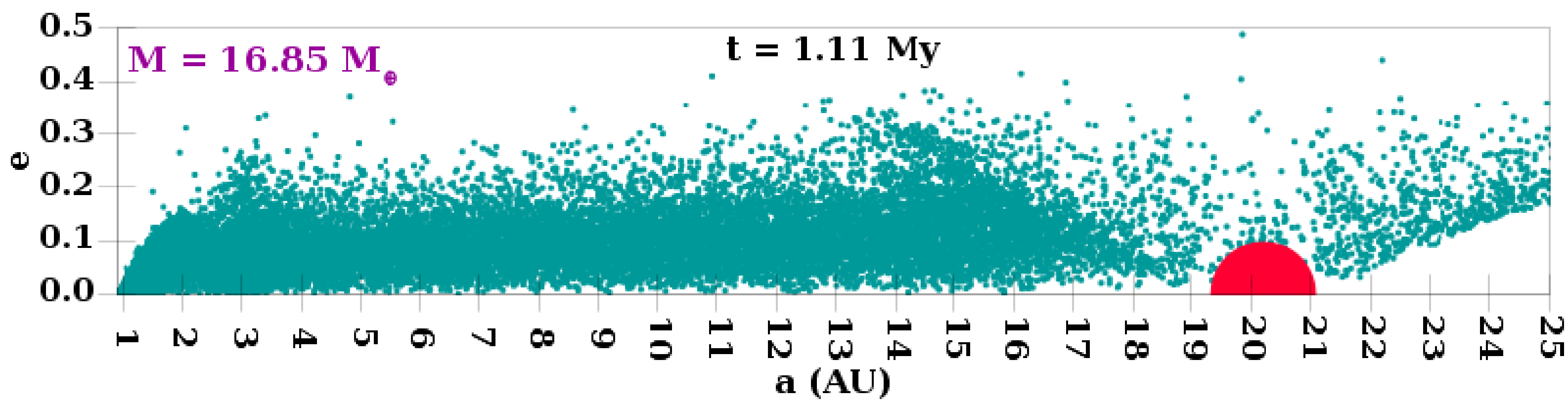

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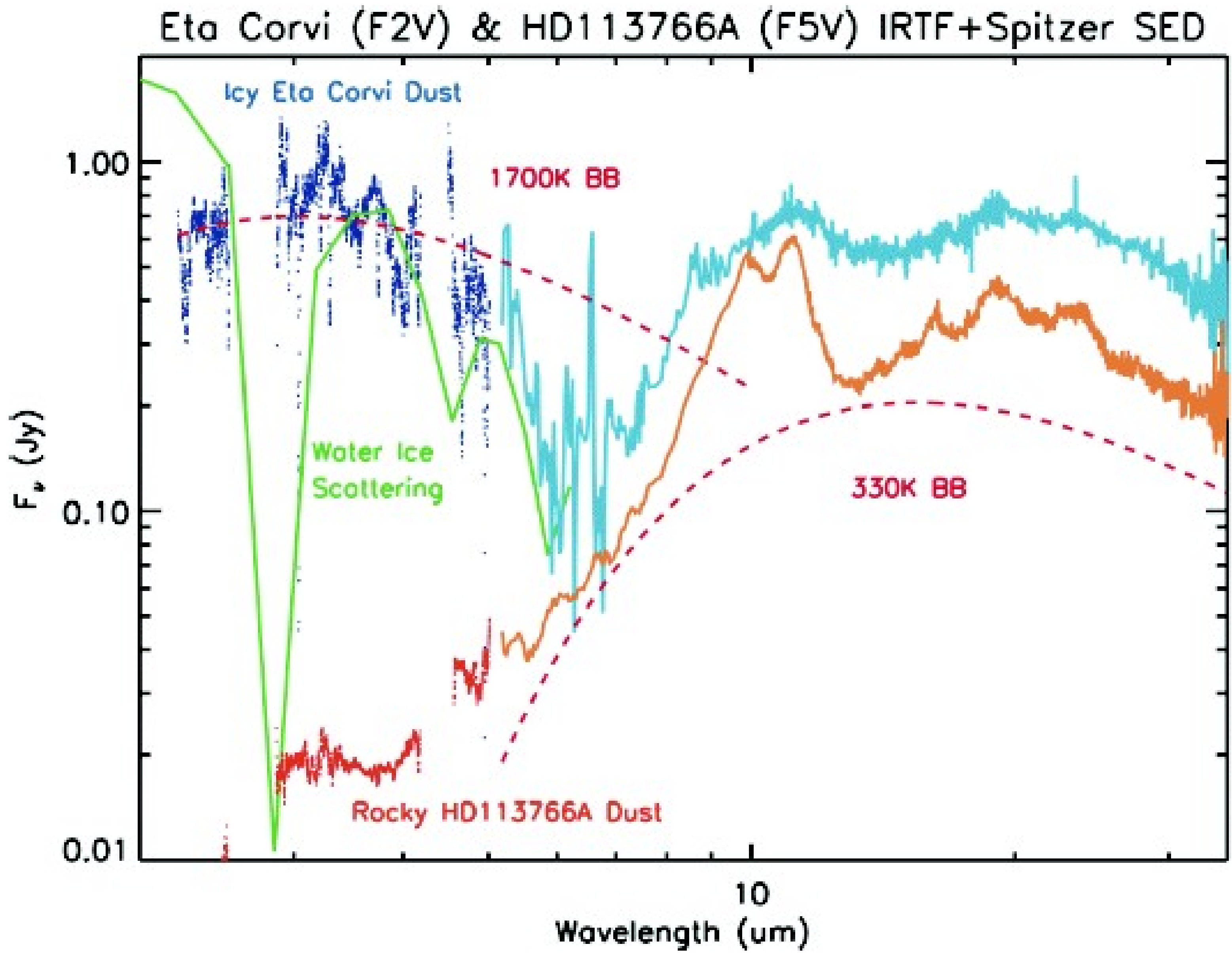
- Process:
  1. Planets start to grow near 1 AU.
  2. Outer embryo migrates to > 5 AU.
     - Grows $\sim 10M_{\oplus}$.
     - Excites disk $\Longrightarrow$ stops migration.
  3. If gas is gone $\Longrightarrow$ DONE.
  4. Disk cools (damps) due to aerodynamic drag.
  5. goto 1
- This occurs 4 times before the disk goes away.
  - See Dave Minton's poster for how Mars fits in.
- Possible implications:
  - Neptune is the oldest planet in the Solar System.
  - Jupiter forms just as the gas is going away.
  - Predicts (?) increasing core mass with heliocentric distance.
- But, we have yet to study the multi-planet case.

This talk can be found at www.boulder.swri.edu/~hal/talks.html
We thank NSF and NASA's NLSI and Origins for support.

Lisse et al.: LHB in the η Corvi system?



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