# A six-part collisional model of the main asteroid belt

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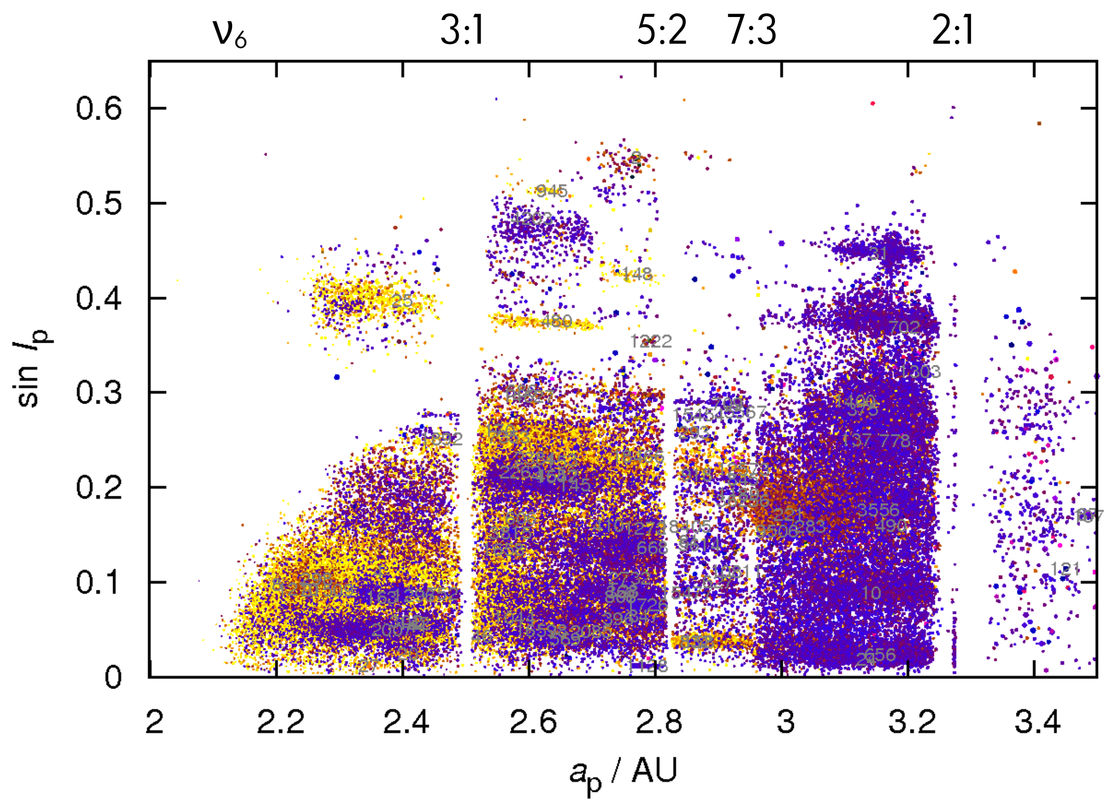
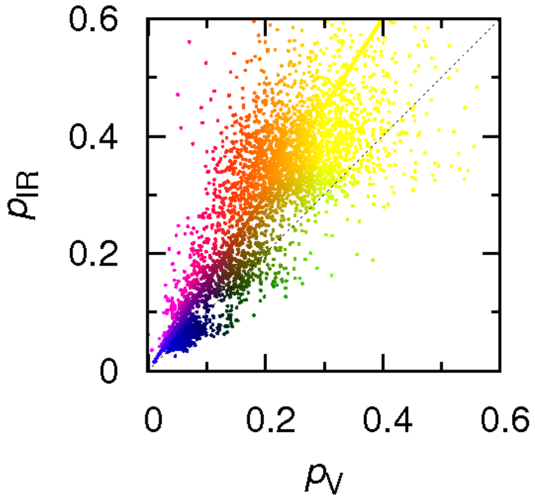
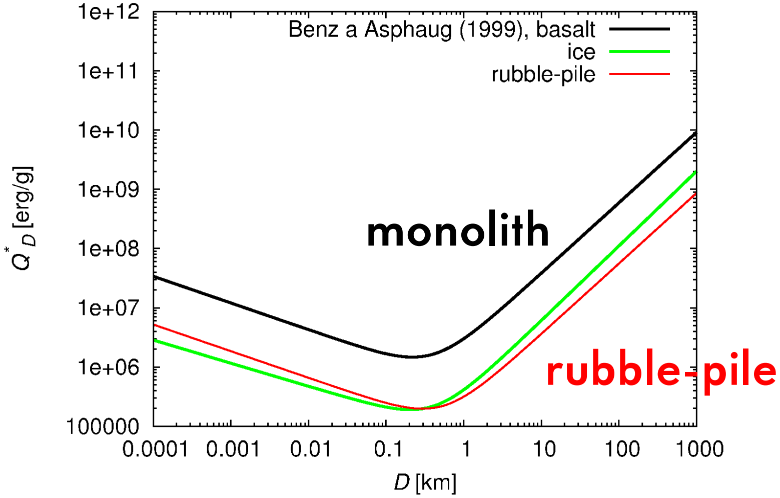


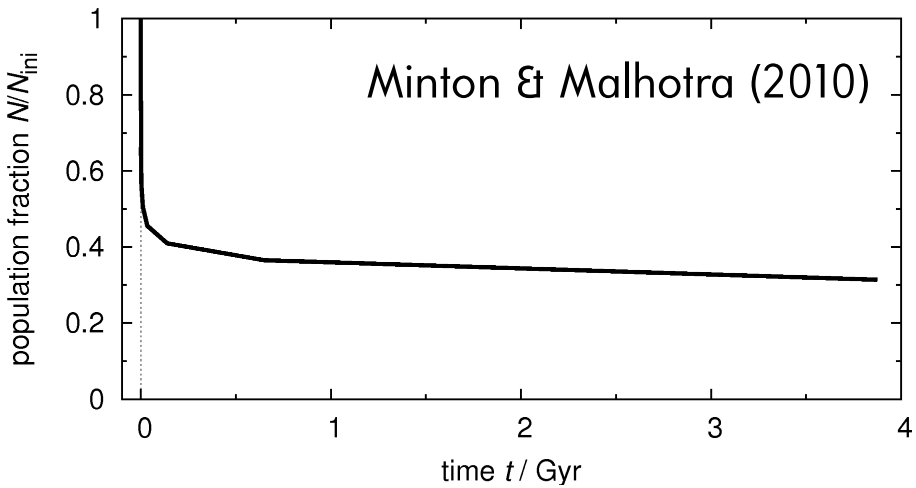

Milani & Kneževic (2003)
Masiero et al. (2011)



# Motivation

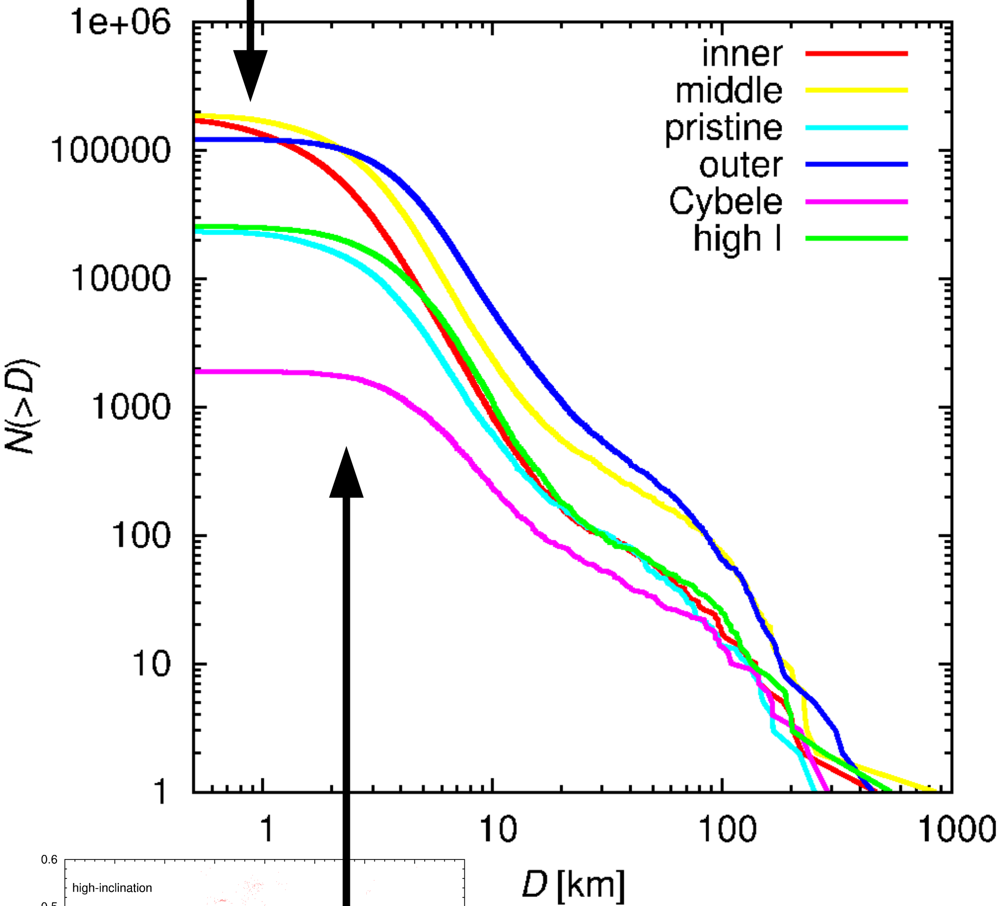
- *new* data (albedos and diameters for 129,750 asteroids) from the WISE satellite (Masiero et al. 2011)
- test if a *single* scaling law can be used for the whole main belt (Benz & Asphaug 1999)
- to decide if asteroids are rather *monolithic* or *rubble-piles*? (simulations from Durda et al. 2007, Benavidez et al. 2012)
- we focus on the last ~3.85 Gyr *only* (i.e. post-LHB)!

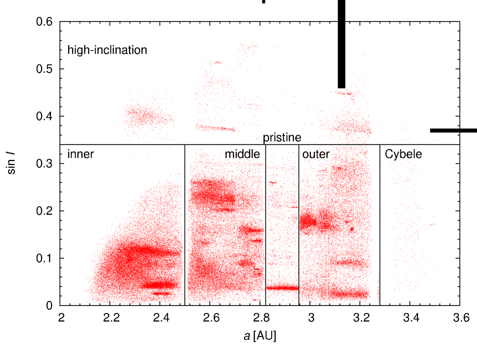


# Observational data from WISE

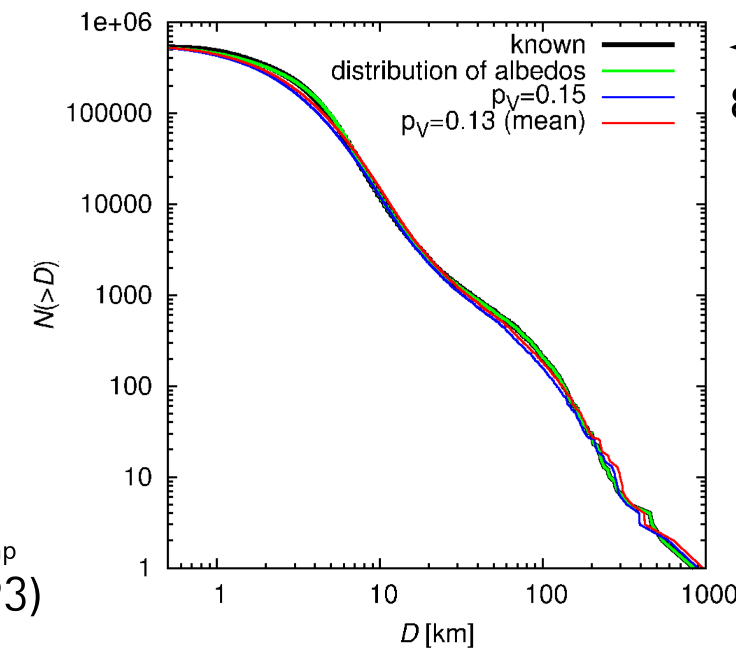
observational bias




we also computed intrinsic probabilities $p_i$ and impact velocities $v_{imp}$ (Bottke & Greenberg 1993)

- 6 parts of the MB: inner, middle, `pristine', outer, Cybele, high-inclination
- reconstruction of the SFDs for 535,630 asteroids (a Monte-Carlo method)




& verification

# Observed asteroid families

- we use the list of 82 families from Brož et al. (2013), with a few additions (Walsh et al. 2013)
- essentially compatible with lists of Masiero et al. (2013), Nesvorný (2012)
- we need also *physical* parameters ($D_{PB}$, $M_{LR}/M_{PB}$ ratio) to distinguish catastrophic disruptions (methods of Durda et al. 2007, Tanga et al. 1999)

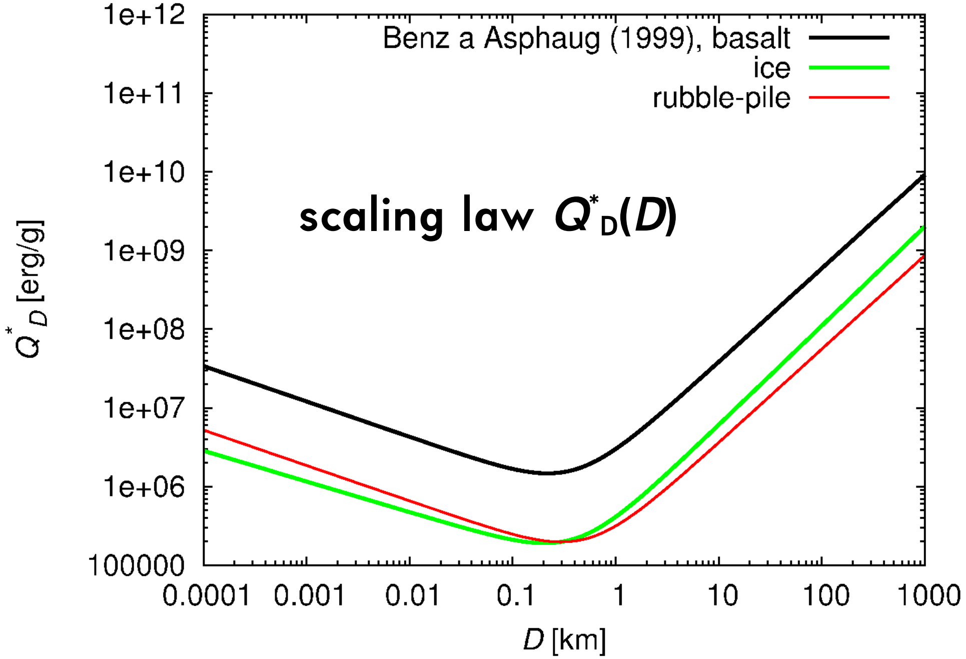


**Table 1.** A list of asteroid families and their physical parameters.

cont. below↓

| | Designation | $v_{cutoff}$ m/s | $N$ | $p_V$ | Tax. | $D_{PB}$ km | $D_{Durda}$ km | LR/PB | $v_{esc}$ m/s | $q_1$ | $q_2$ | Age Gyr | Notes, references |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Juno | 50 | 449 | 0.250 | S | 233 | ? | 0.999 | 139 | −4.9 | −3.2 | <0.7 | cratering, Nesvorný et al. (2005) |
| 4 | Vesta | 60 | 11 169 | 0.351w | V | 530 | 425! | 0.995 | 314 | −4.5 | −2.9 | 1.0 ± 0.25 | cratering, Marchi et al. (2012) |
| 8 | Flora | 60 | 5284 | 0.304w | S | 150c | 160 | 0.81–0.68 | 88 | −3.4 | −2.9 | 1.0 ± 0.5 | cut by $\nu_6$ resonance, LL chondrites |
| 10 | Hygiea | 70 | 3122 | 0.055 | C,B | 410 | 442 | 0.976–0.78 | 243 | −4.2 | −3.2 | 2.0 ± 1.0 | LHB? cratering |
| 15 | Eunomia | 50 | 2867 | 0.187 | S | 259 | 292 | 0.958–0.66 | 153 | −5.6 | −2.3 | 2.5 ± 0.5 | LHB? Michel et al. (2002) |
| 20 | Massalia | 40 | 2980 | 0.215 | S | 146 | 144 | 0.995 | 86 | −5.0 | −3.0 | 0.3 ± 0.1 | |
| 24 | Themis | 70 | 3581 | 0.066 | C | 268c | 380–430! | 0.43–0.09 | 158 | −2.7 | −2.4 | 2.5 ± 1.0 | LHB? |
| 44 | Nysa (Polana) | 60 | 9957 | 0.278w | S | 81c | ? | 0.65 | 48 | −6.9 | −2.6(0.5) | <1.5 | overlaps with the Polana family |
| 46 | Hestia | 65 | 95 | 0.053 | S | 124 | 153 | 0.992–0.53 | 74 | −3.3 | −2.0 | <0.2 | cratering, close to J3/1 resonance |
| 87 | Sylvia | 110 | 71 | 0.045 | C/X | 261 | 272 | 0.994–0.88 | 154 | −5.2 | −2.4 | 1.0–3.8 | LHB? cratering, Vokrouhlický et al. (2010) |
| 128 | Nemesis | 60 | 654 | 0.052 | C | 189 | 197 | 0.987–0.87 | 112 | −3.4 | −3.3 | 0.2 ± 0.1 | |
| 137 | Meliboea | 95 | 199 | 0.054 | C | 174c | 240–290! | 0.59–0.20 | 102 | −1.9 | −1.8 | <3.0 | old? |
| 142 | Polana (Nysa) | 60 | 3443 | 0.055w | C | 75 | ? | 0.42 | 45 | −7.0 | −3.6 | <1.5 | overlaps with Nysa |

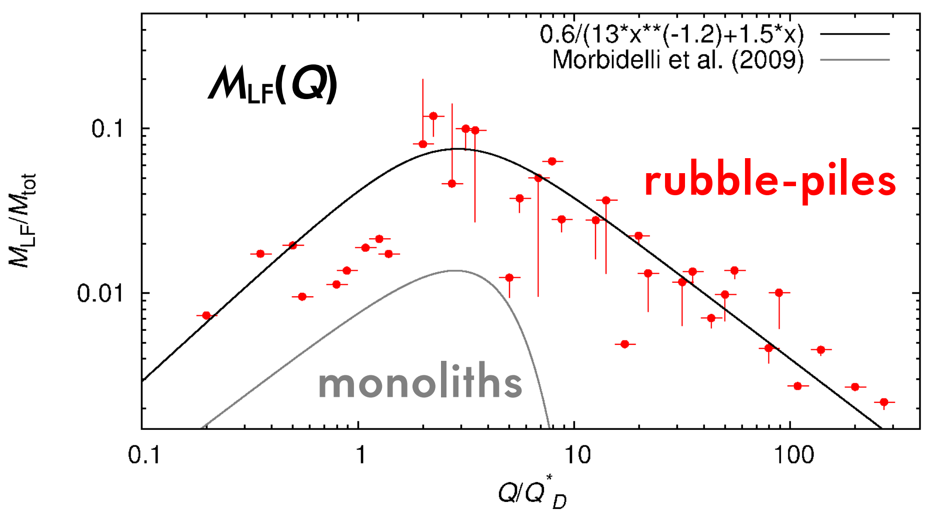
# The scaling law and fragment SFDs

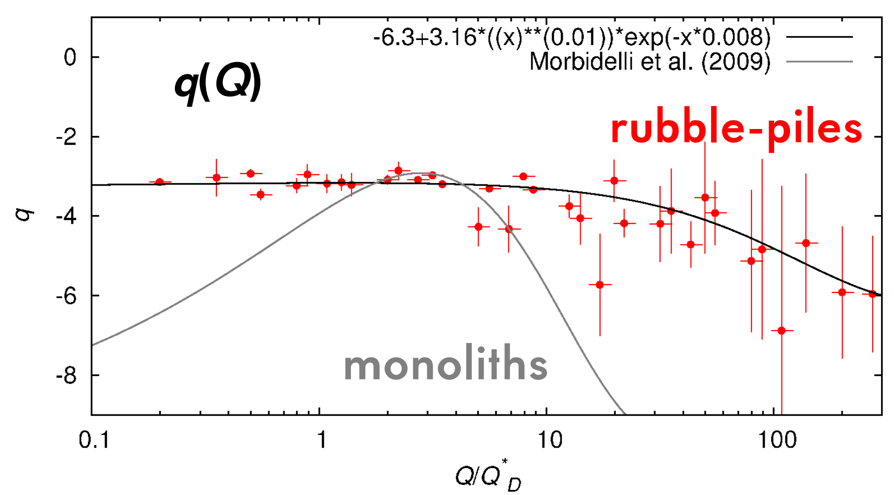



- scaling law expressed as:

$$Q^*_D = \frac{1}{q_{factor}} \left( Q_0 r^a + B \rho r^b \right)$$

- we need also parametric relations describing outcomes of disruptions: largest fragment mass $M_{LF}$ and SFD slope $q$ vs $Q/Q^*_D$



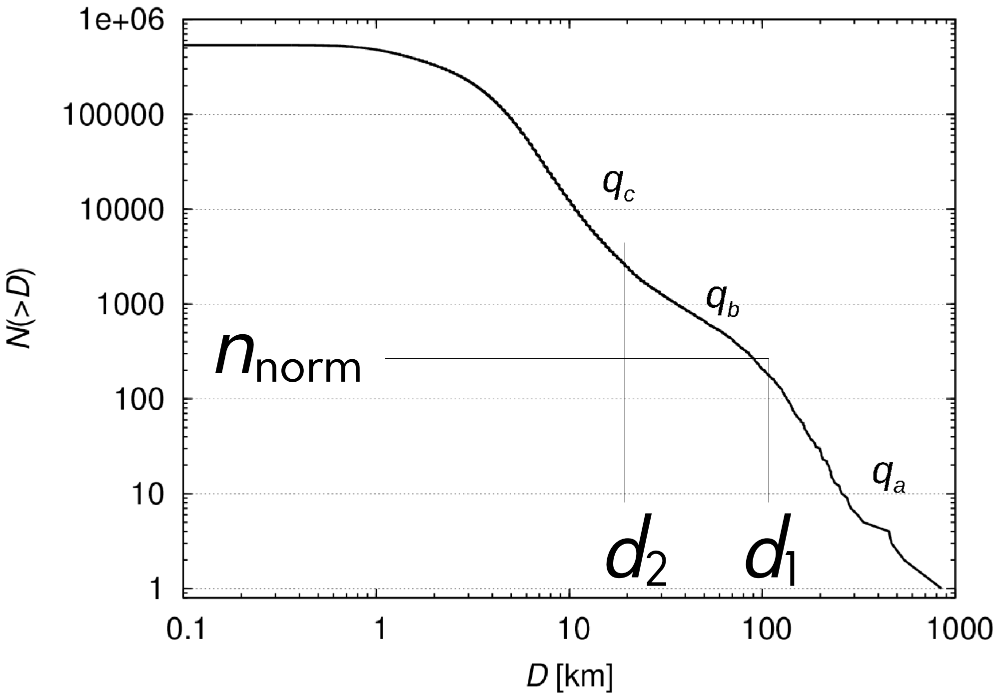
# Model, parameters, $\chi^2$ metric

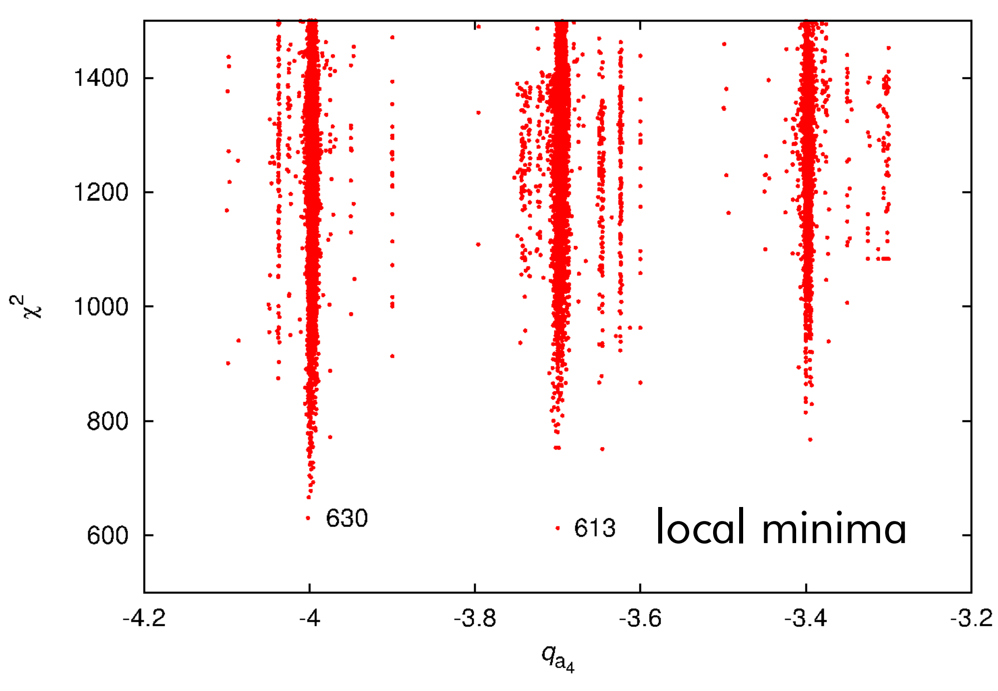
- Boulder code (Morbidelli et al. 2009), particle-in-a-box + SPH
- 36 free parameters: initial SFD slopes, ranges, normalization
- fit for SFD's @ $t_{end}$ = 4 Gyr and the # of families:

  *syn*, *obs* ... either $N(>D)$ or $N_{fam}$

  weighting $w_{fam} = 10$

$$\chi^2 = \sum_{i=1}^{N=96+6} \frac{(syn_i - obs_i)^2}{\sigma_i^2}$$

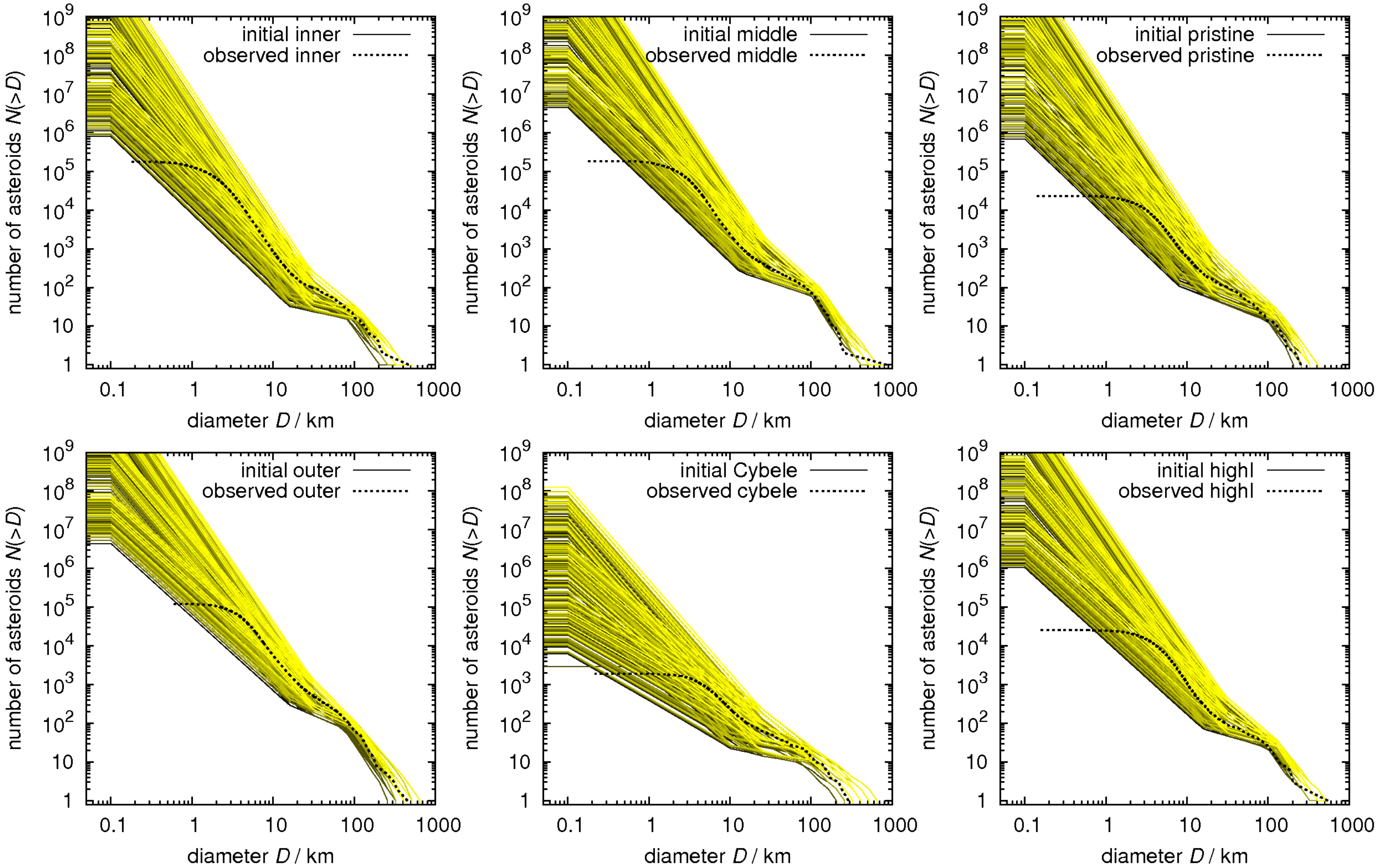


a wide range of

# Initial conditions (for simplex)

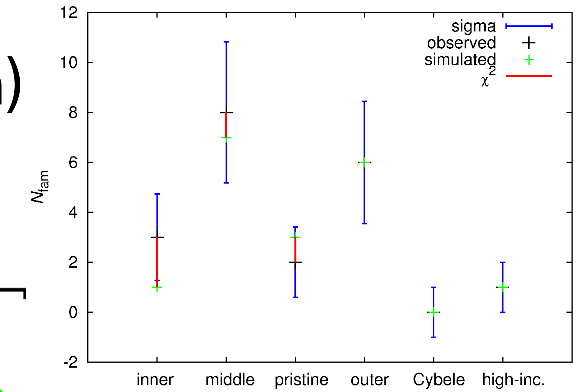
- 729 different SFDs * 300 iterations = 218,700 simulations
- convergence to a local minimum is difficult ← stochasticity!



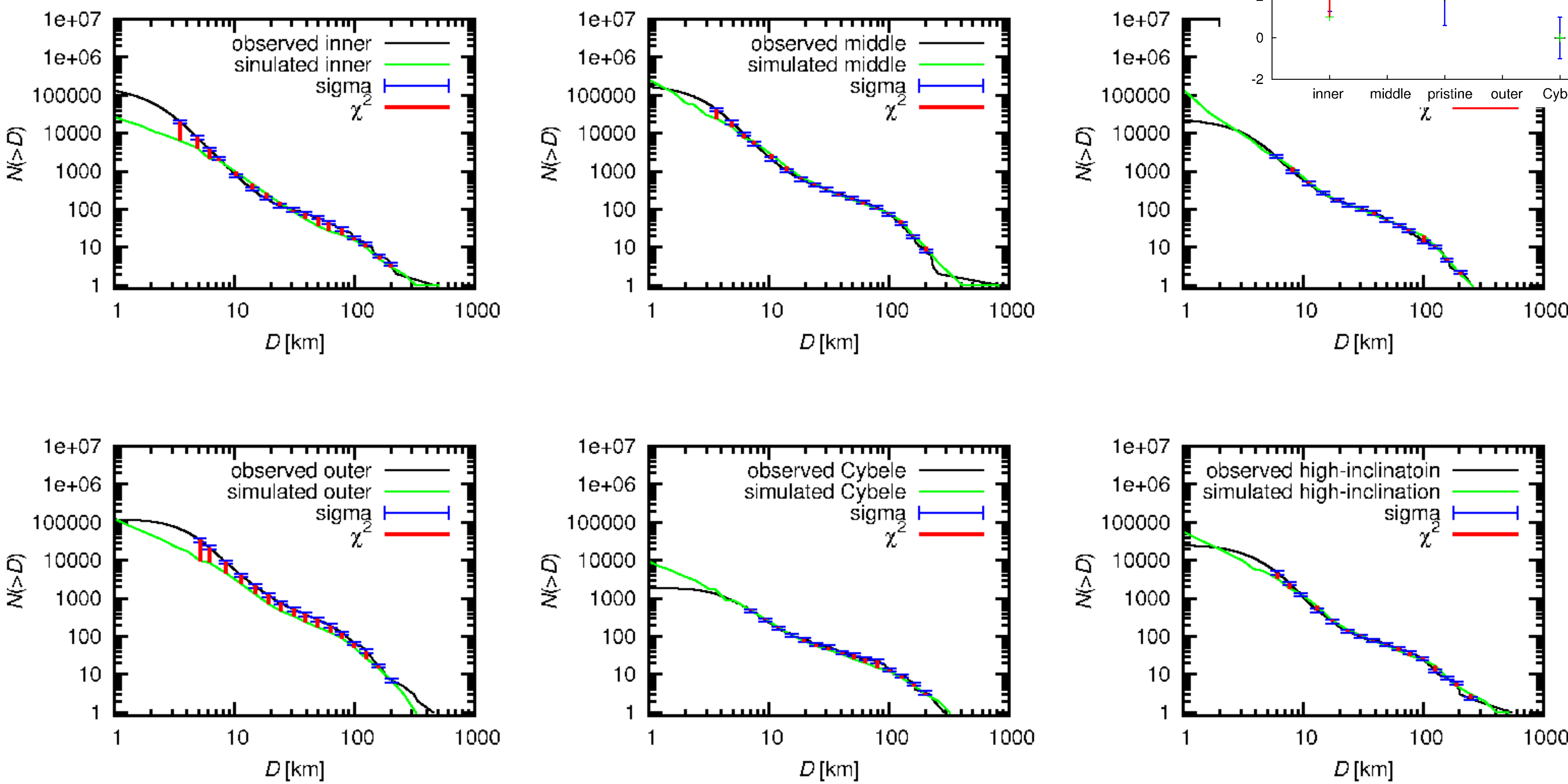

disruptions of large PB depend on the random seed

# Results for monoliths

families are OK



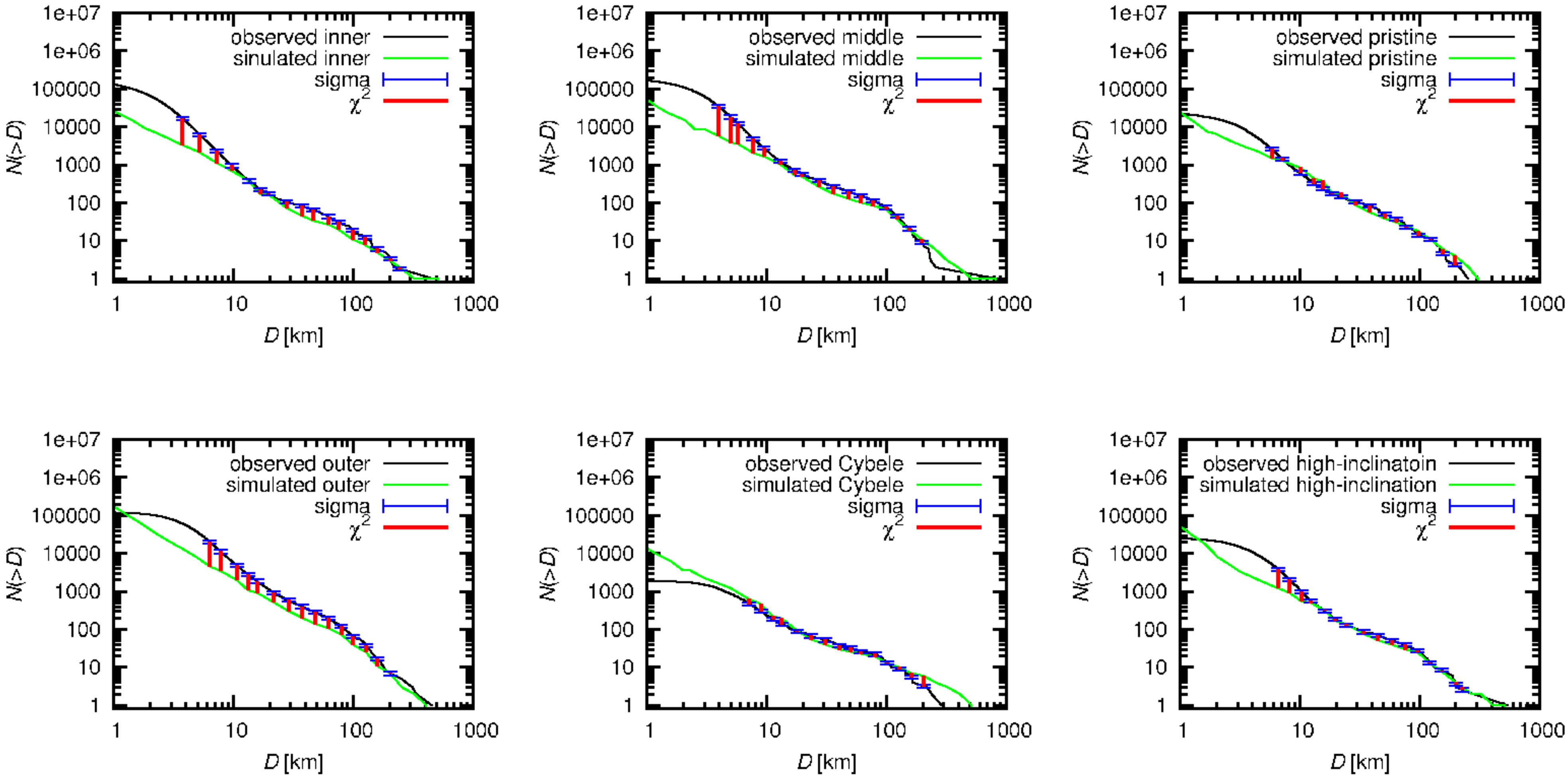

- problems with *some* SFDs! (for $D$ = 1 to 10 km)
- the best fit $\chi^2$ = 613, or 512 after a detailed analysis



# Results for rubble-piles

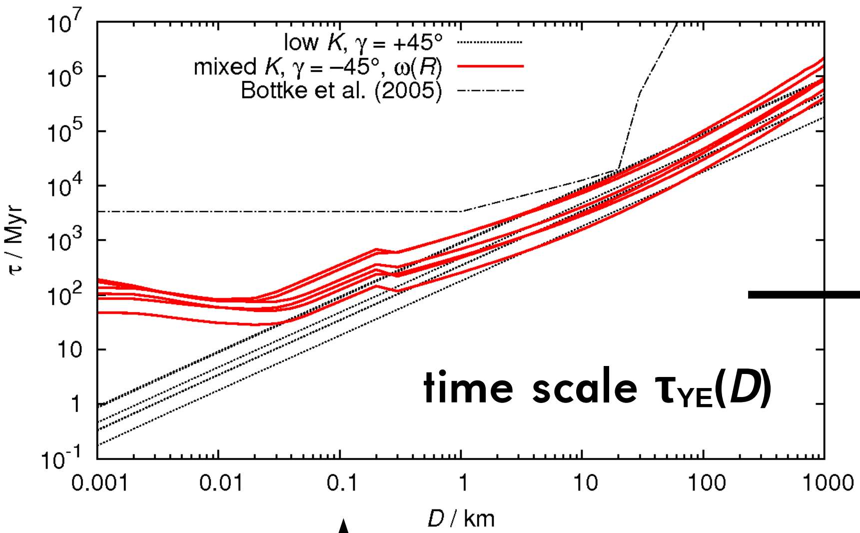
and the same set of iniconds...

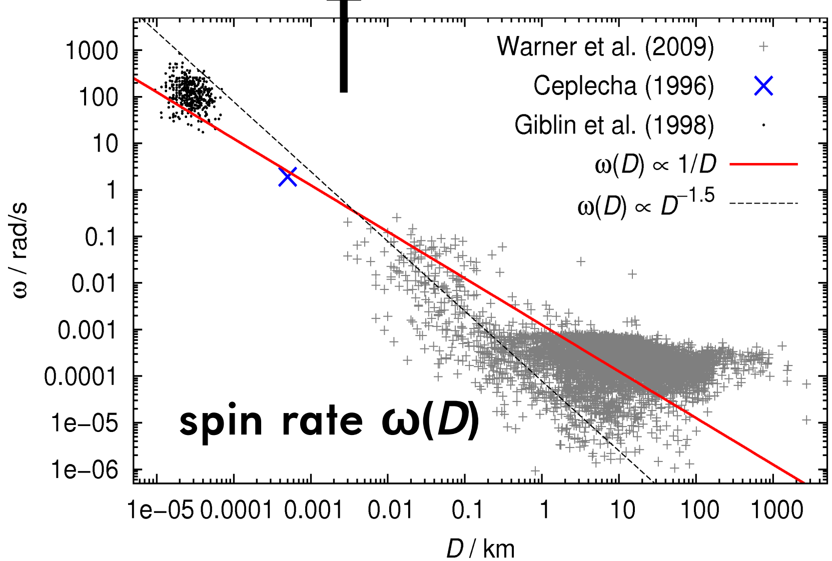
- the `best' fit $\chi^2$ = 1602 only, i.e. much worse than for monoliths!
- the main belt is *not* composed of (pure) rubble-piles?



Possible

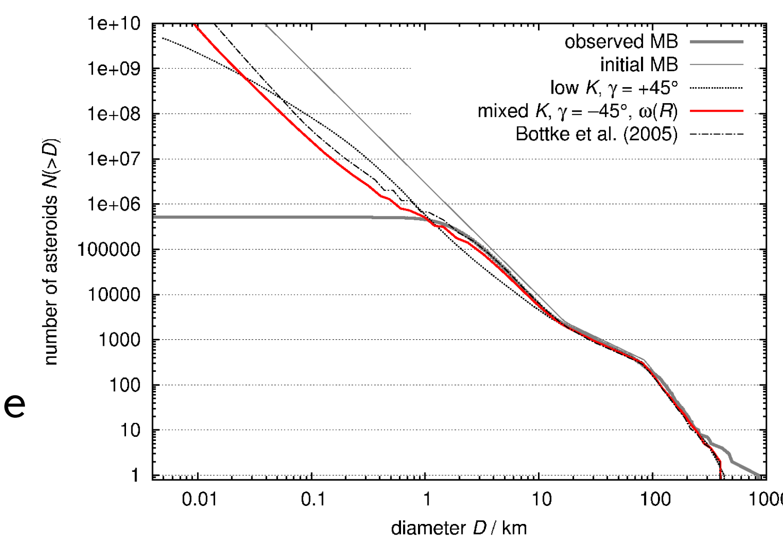
# Improvements of the model?




- use a longer SFD 'tail' ($D_{\min} = 0.01$ km)
- account for the Yarkovsky effect dynamical decay $N(t+\Delta t) = N(t)\exp\left(\frac{\Delta t}{\tau_{YE}}\right)$
- optimize *sequentially* the 6 parts of the MB
- none of these works!

a test for a single MB: we can exclude low $K$ & $\omega$



a lot of

# Conclusions and future work

- indeed different scaling laws for different parts of the MB?
- improve the scaling of $D_{PB}$ = 100 km disruptions?
- the evolution is too stochastic ($N \sim 10^0$) → prescribe large disruptions (i.e. a deterministic model)?
- improve the YE model (using N-body simulations)?
- some of $v_{imp}$ > 5 km/s → use a velocity-dependent scaling law? (e.g. Leinhardt & Stewart 2012)
- family lists are strongly biased? (Walsh et al. 2013)
- etc.?

2B disrupted