Main Belt collisional evolution
in the context of AO observations of large asteroids

Miroslav Brož[1], in collaboration with P. Ševeček[1], P. Vernazza[2], L. Jorda[2], J. Hanuš[1], M. Marsset[4], A. Drouard[2], M. Viikinkoski[3], B. Carry[5], F. Marchis[6], R. Fetick[2], T. Fusco[2], M. Birlan[7], and the HARISSA (High Angular Resolution Imaging Survey of the Shapes of Asteroids) team; D. Richardson, E. Asphaug

(2) Pallas

Monte-Carlo model (*all* collisions)

(e.g. Boulder code, Morbidelli et al. 2009)

- Monte-Carlo approach
- number of disruptions
- parametric relations (from SPH)
- largest remnant
- largest fragment
- SFD slope of fragments
- dynamical decay

focussing

$$n_{ij} = p_{\mathrm{i}}(t) f_{\mathrm{g}} \frac{(D_i + d_j)^2}{4} n_i n_j \Delta t$$

$$M_{\mathrm{LR}} = \left[-\frac{1}{2} \left(\frac{Q}{Q_D^\star} - 1 \right) + \frac{1}{2} \right] M_{\mathrm{tot}} \quad \text{for } Q < Q_D^\star$$

$$M_{\mathrm{LR}} = \left[-0.35 \left(\frac{Q}{Q_D^\star} - 1 \right) + \frac{1}{2} \right] M_{\mathrm{tot}} \quad \text{for } Q > Q_D^\star$$

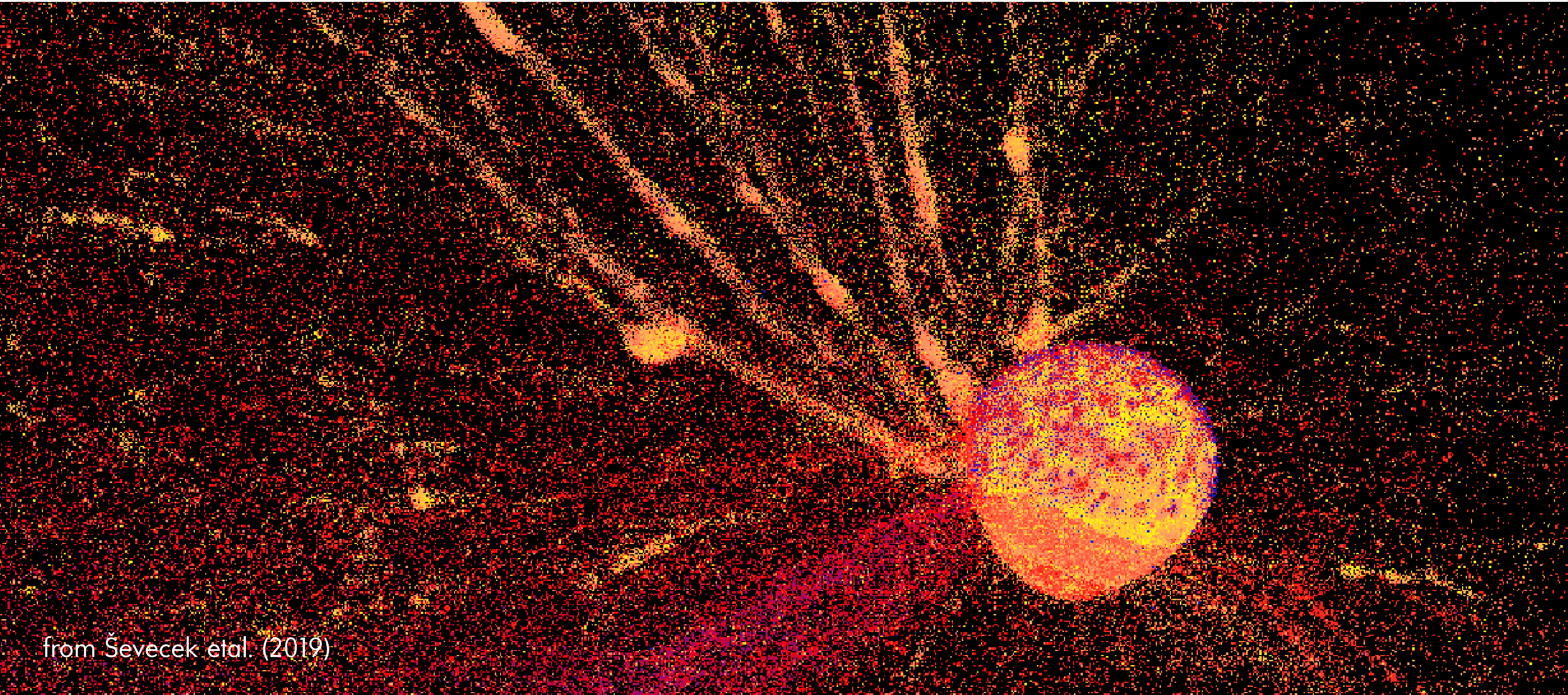
$$M_{\mathrm{LF}} = 8 \times 10^{-3} \left[\frac{Q}{Q_D^\star} \exp \left(- \left(\frac{Q}{4 Q_D^\star} \right)^2 \right) \right] M_{\mathrm{tot}}$$

pseudo-random-number generator for rare collisions

specific energy $Q = ½\, m_i v^2 / M_{\mathrm{tot}}$, $Q_{\mathrm{D}}{}^*$ ... scaling law

$$q = -10 + 7 \left(\frac{Q}{Q_D^\star} \right)^{0.4} \exp \left(-\frac{Q}{7 Q_D^\star} \right)$$

SPH model (1 collision)

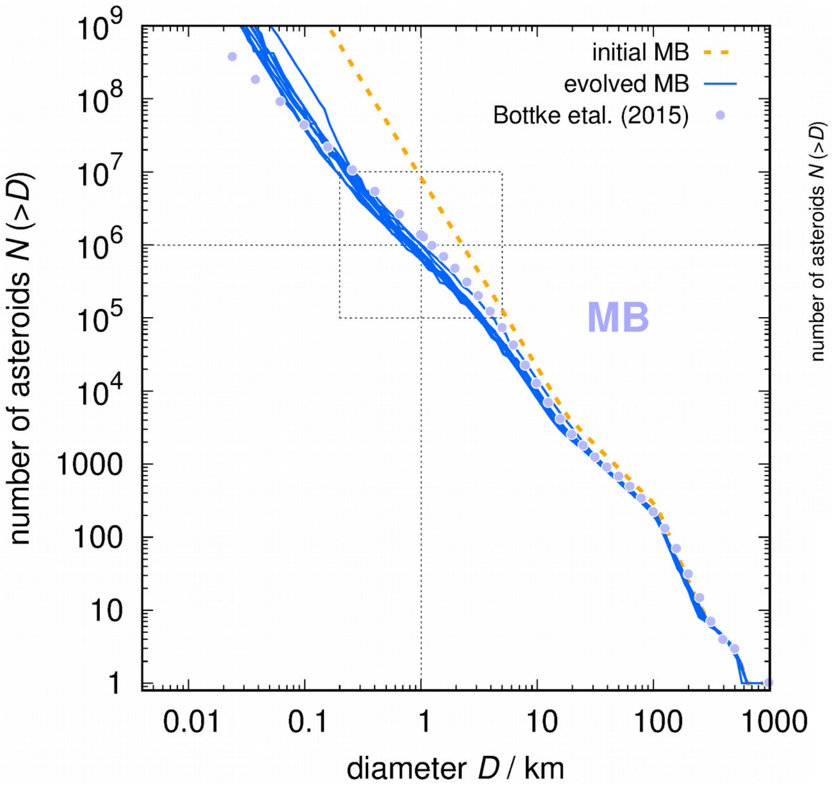


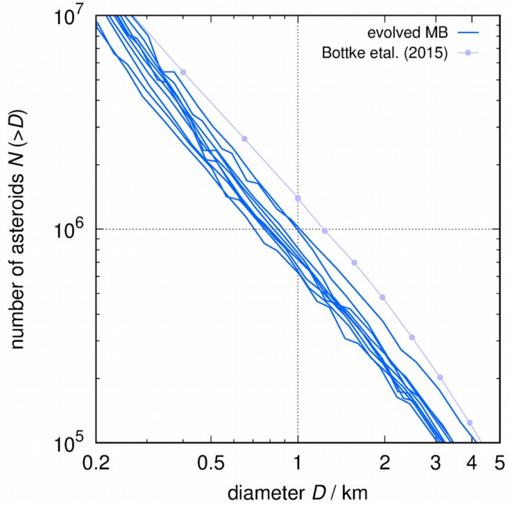
from Ševecek etal. (2019)

Standard MB collisional model?

- P_i, v_{imp} constant, but not N
- nominal time scale 4 Gy
- scaling: Benz & Asphaug (1999), monolith, basalt, …
- YE dynamical removal (Bottke etal. 2005)

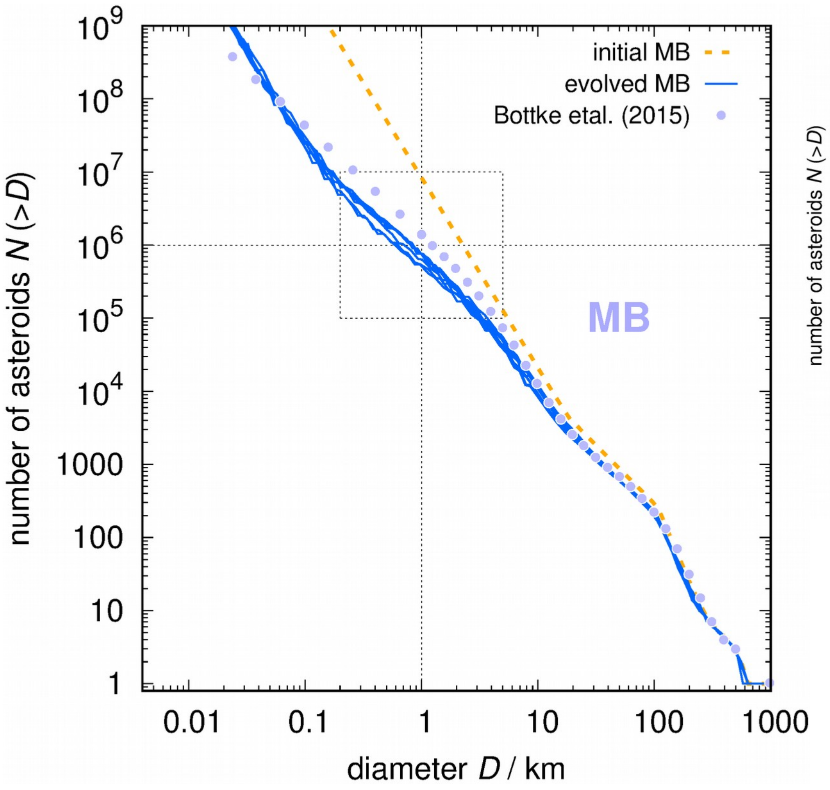
- usually, SFD $N_{syn} < N_{obs}$ for $D \simeq 1$ km bodies
- a trivial problem…

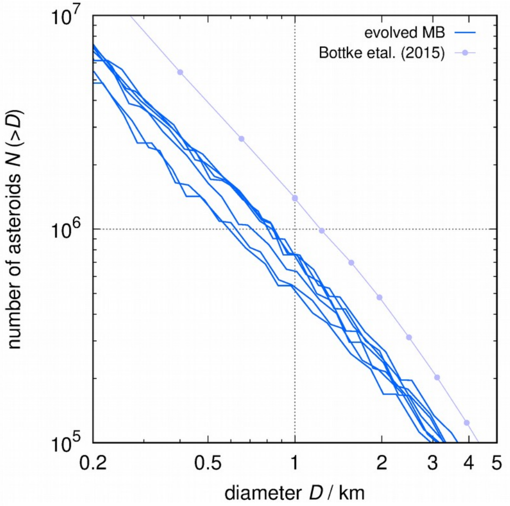




Test 1: 10-km parametric relations

- M_{LR}, M_{LF}, q relations (modified from Ševeček etal. 2017)
- linear interpolation for D = 10↔100 km
- but super-catastrophic impacts not computed
- not so trivial...

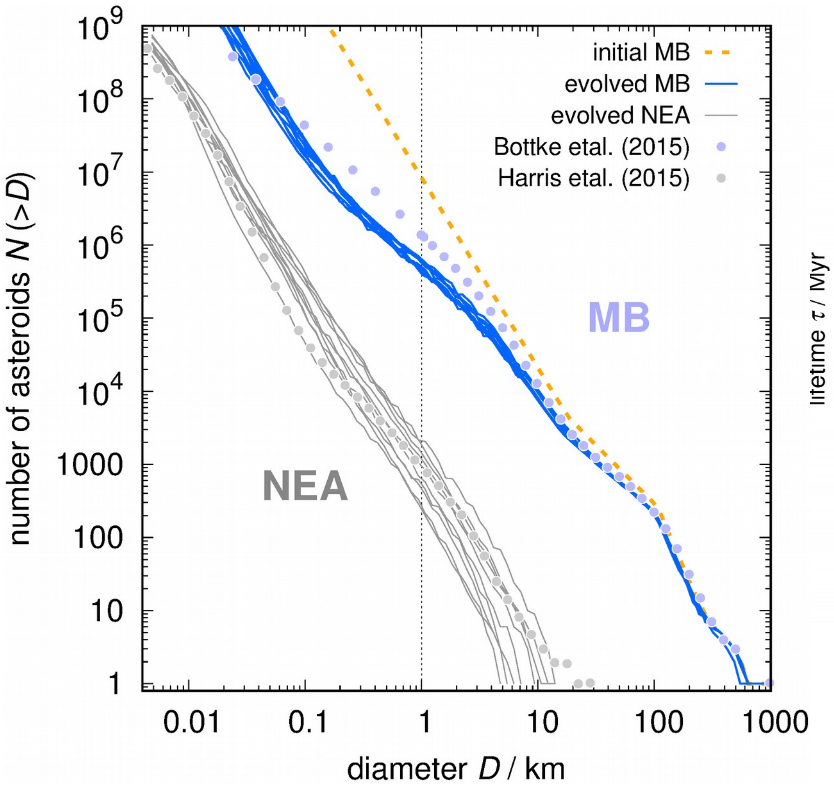


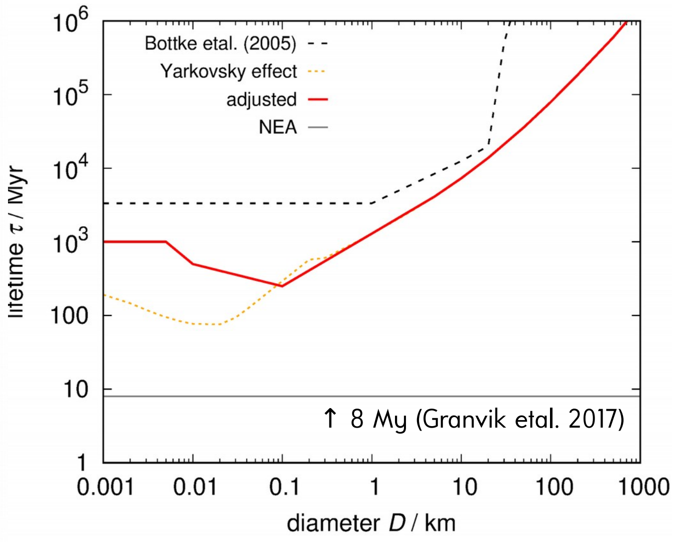


Test 2: Dynamical removal

- Yarkovsky effect
- ω, K … $f(D)$, or transitions (Delbo etal. 2007)
- YORP → YE
- must fit **NEA**!

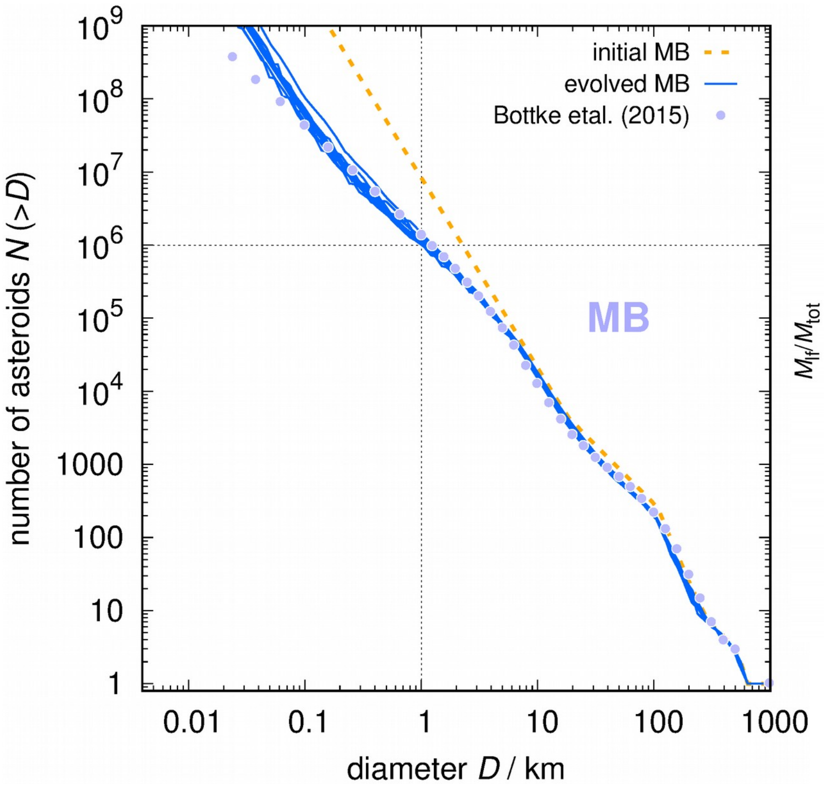
- alternatively, YORP disruptions? (Marzari etal. 2011, Jacobson etal. 2014)



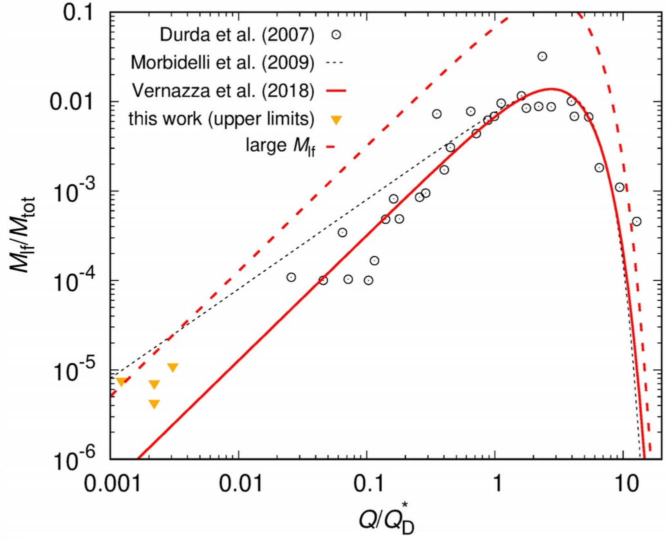


Test 3: SPH input (LF/PB mass)

- different rheology?
- cf. friction, crushing (Jutzi 2015)

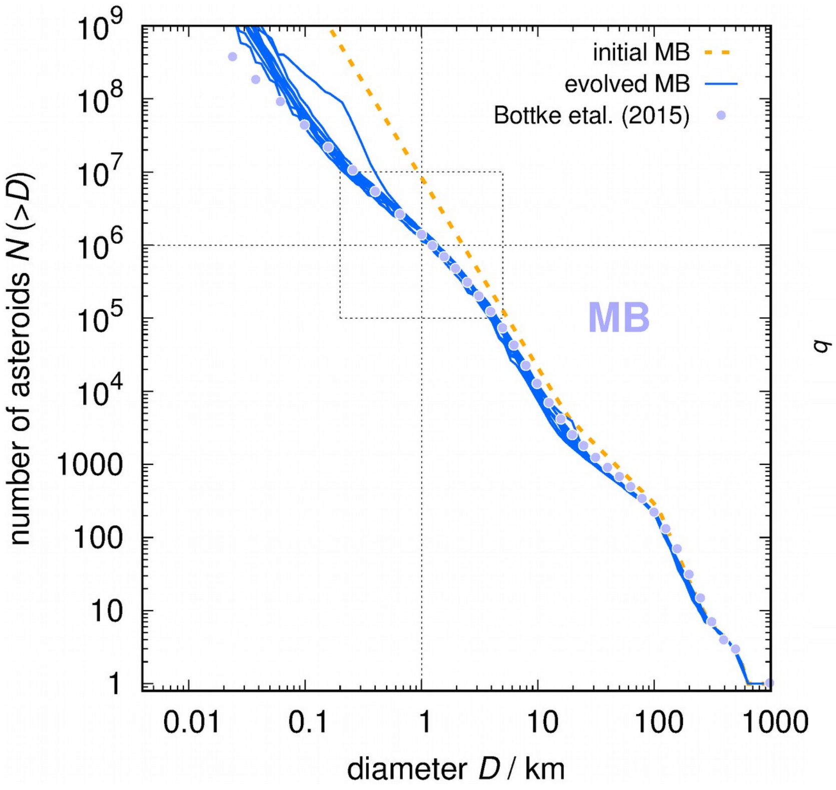


factor 10 in $M \rightarrow 2$ in D
i.e. 2nd largest fragment

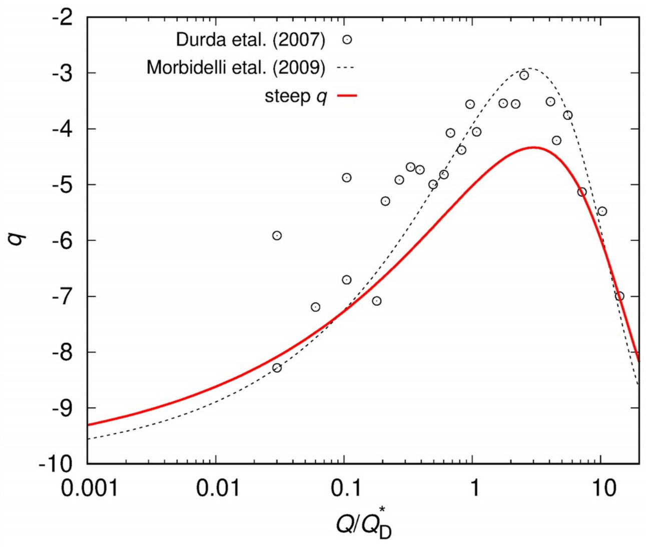


Test 4: SPH input (fragment slope)

- dtto

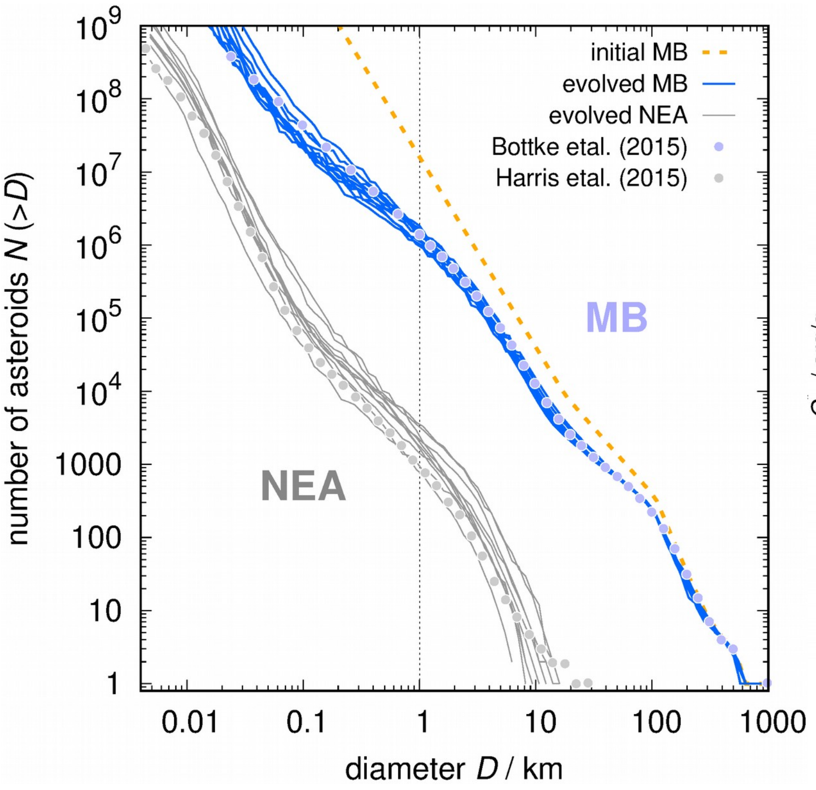


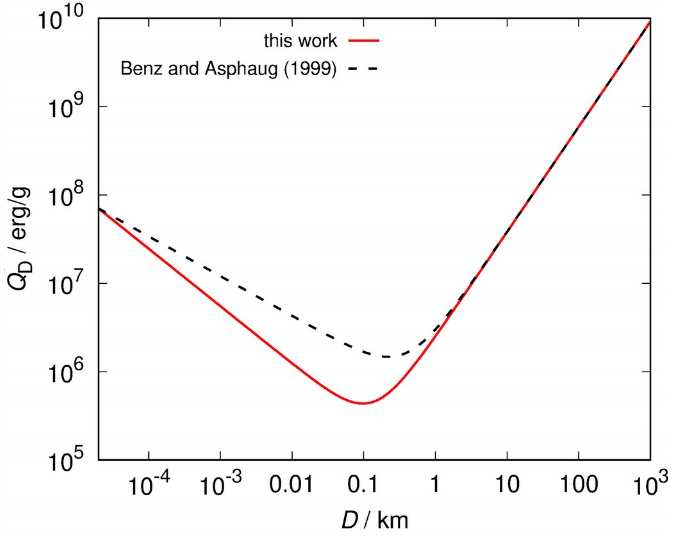
q steeper by −2



Test 5: Scaling law

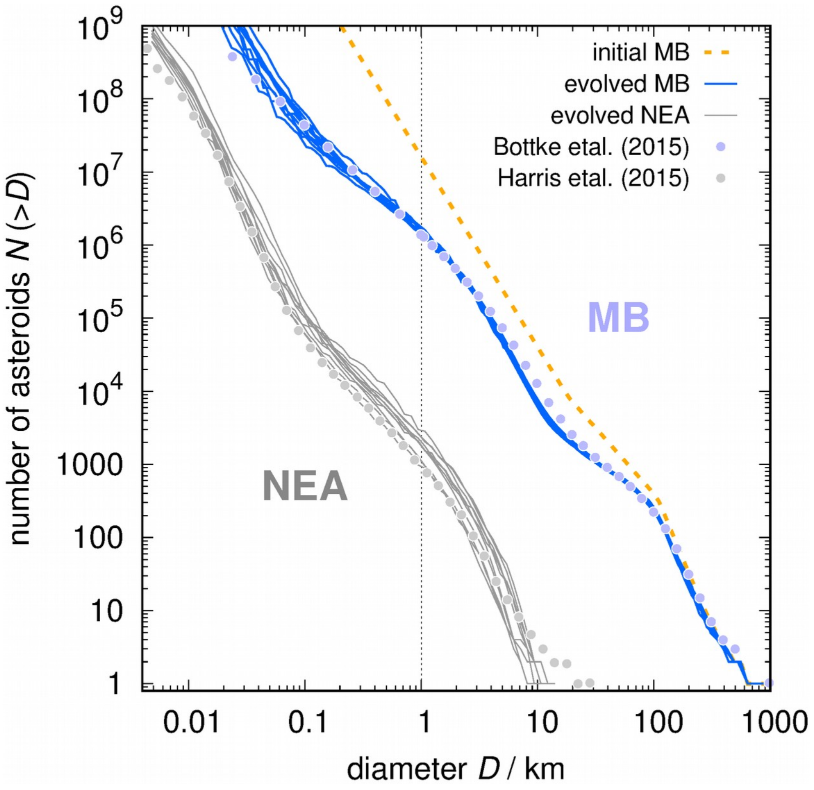
- lower strength, and a shift 200→100 m (O'Brien & Greenberg 2003)
- verify by SPH?
- alternatively, YORP

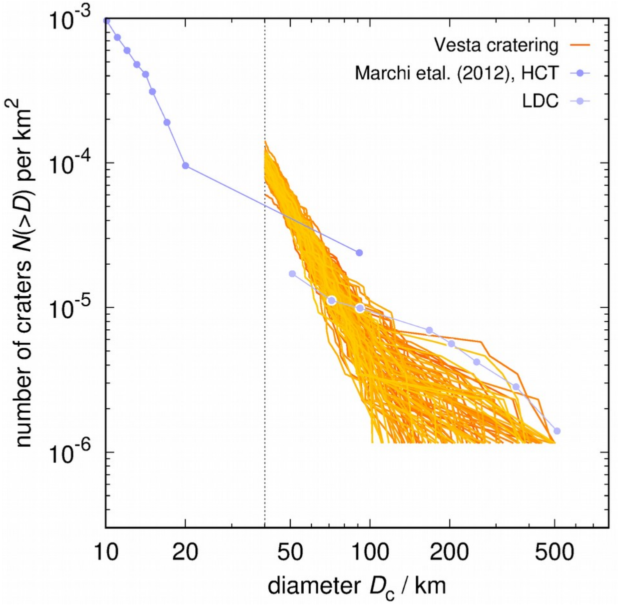




Test 6: Initial conditions

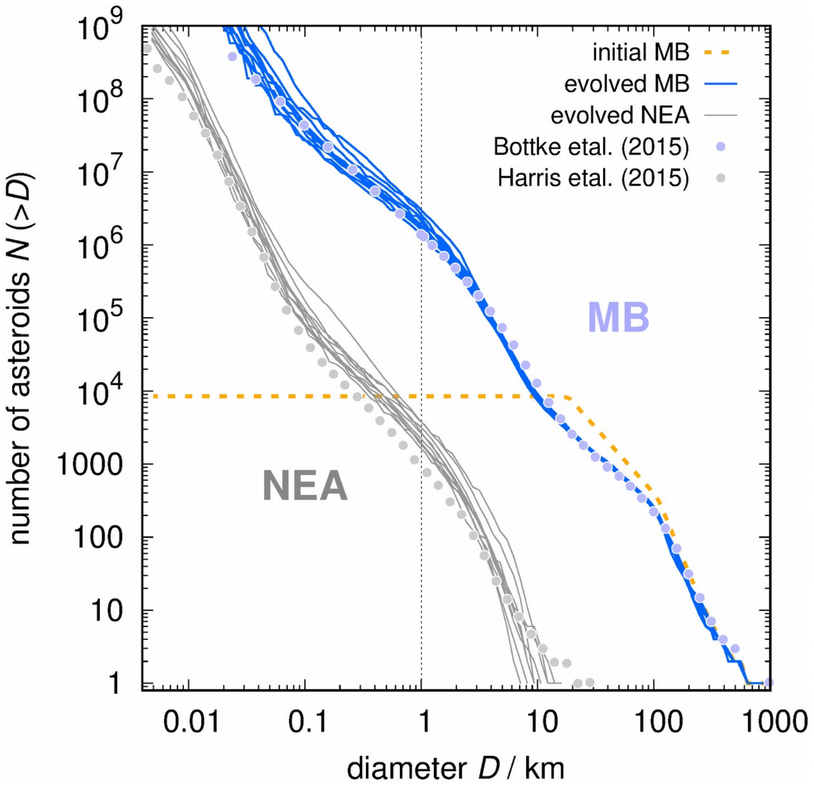
- e.g. Vesta cratering
- $\int \mathrm{d}t$ sensitive to the initial population! (Marchi etal. 2012)
- N_{syn} too steep, but...
- scaling law is also modified here
- crater erasure *not* included (O'Brien etal. 2006)

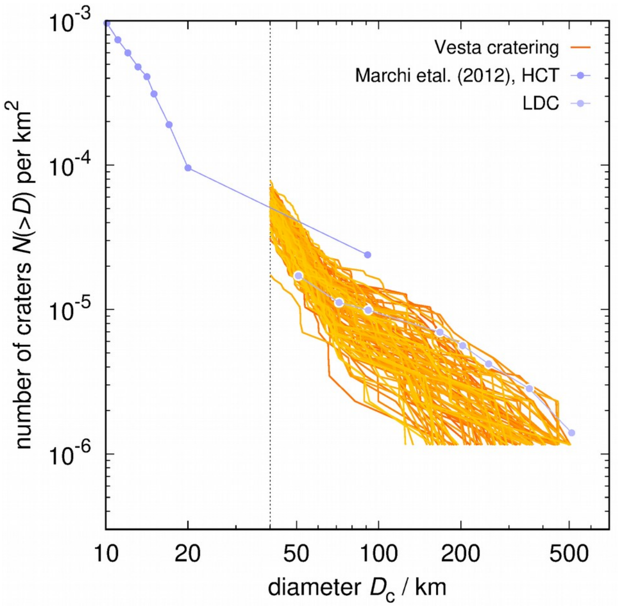




Test 6: Initial conditions

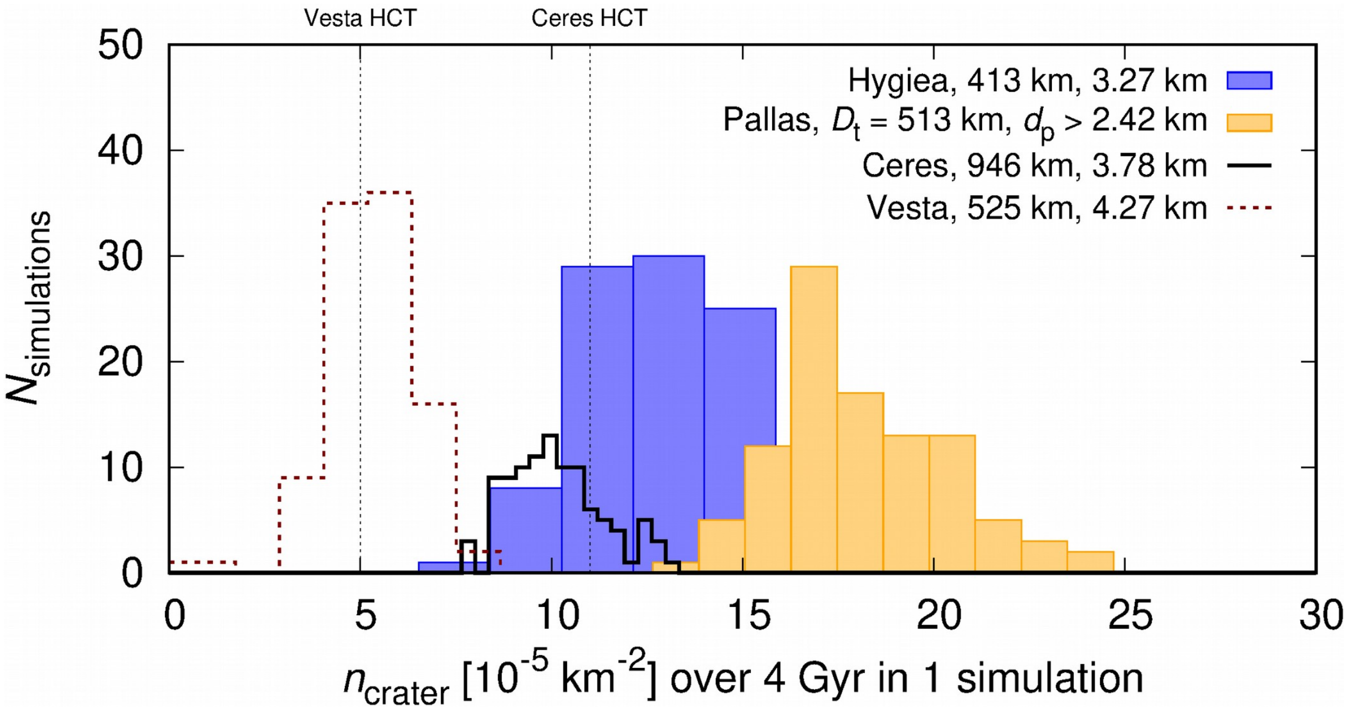
- flat SFD (a.k.a. Morbidelli etal. 2009, Marchi etal. 2012)
- N_{syn} shallow(er)





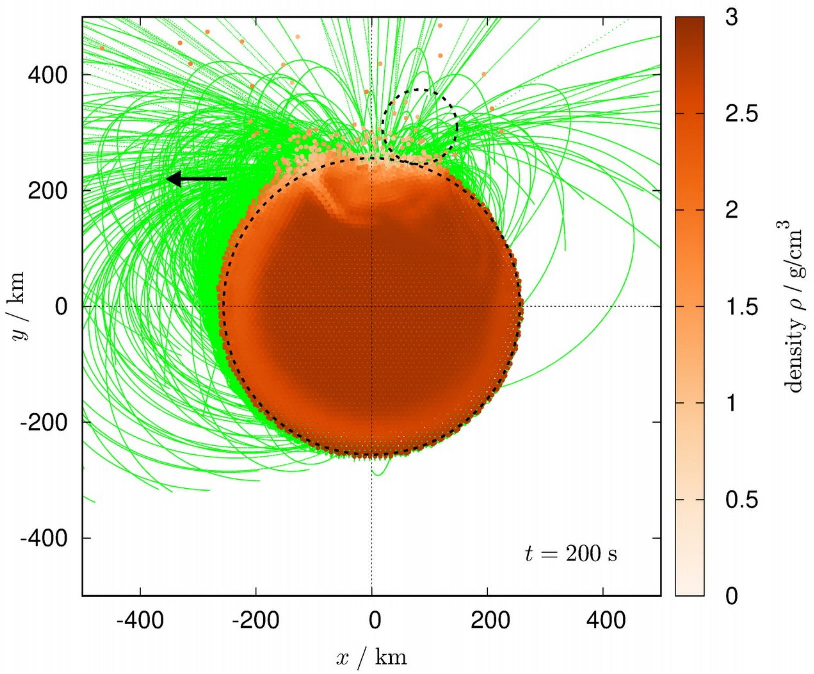
Collisional environment(s) in MB

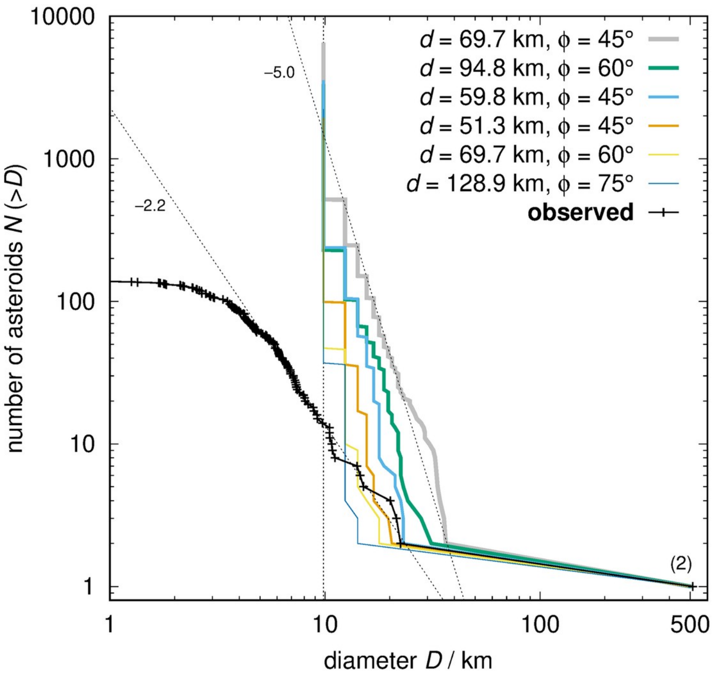
- Vesta, Ceres vs Hygiea, Pallas ← different P_i, v_{imp}, g, for π-scaling and $\boldsymbol{D_c > 40}$ **km**

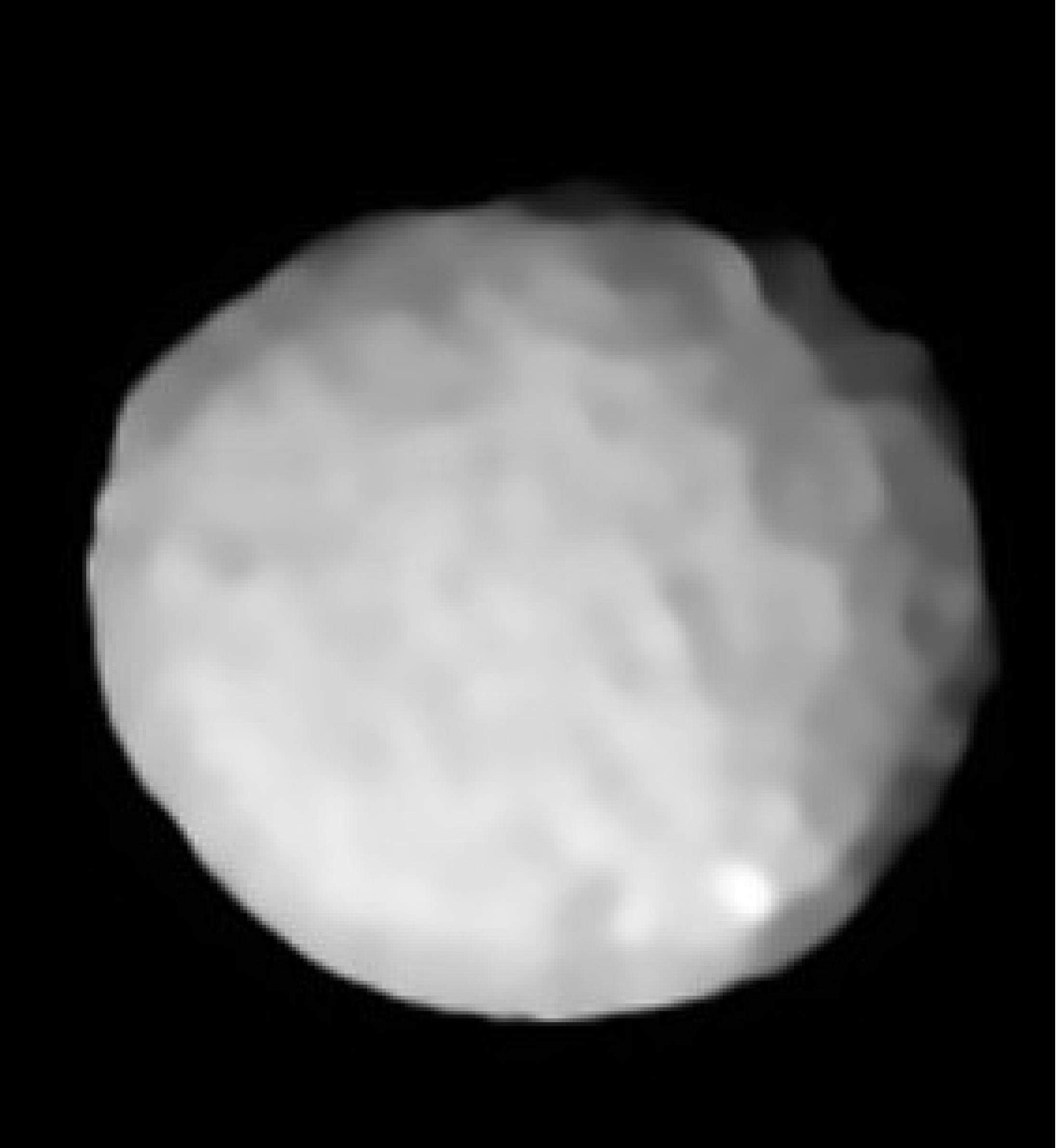


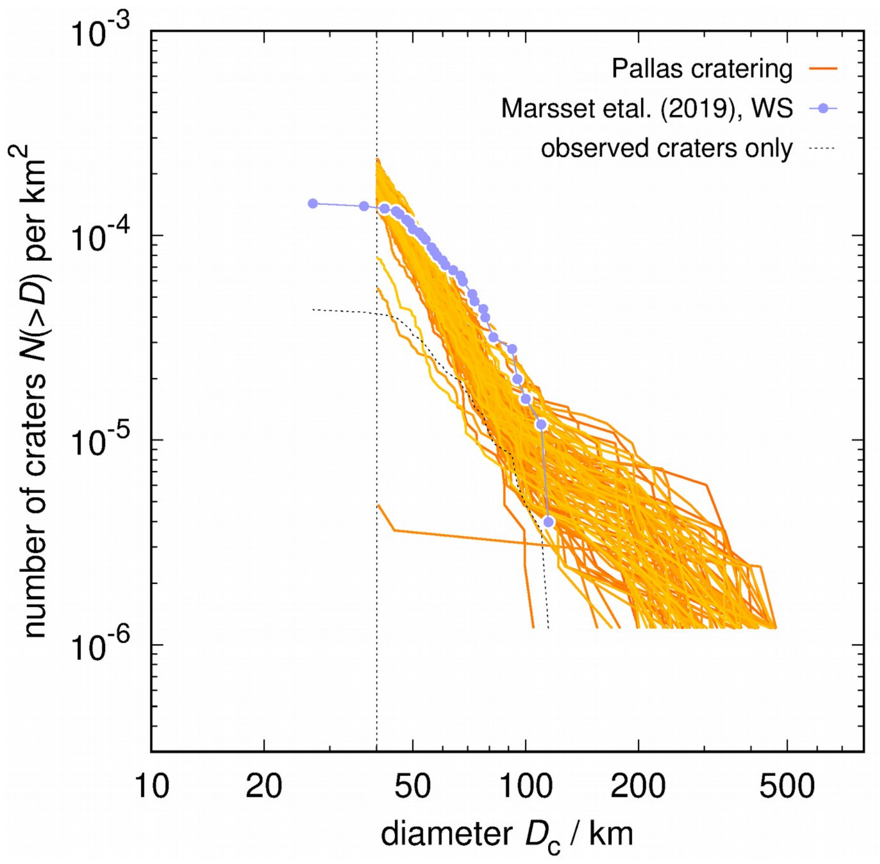
Pallas family origin

- SFD: Q/Q_D^* = 0.024 (↓) to 0.067 (cratering); *but* 2 features? (Marsset etal. submit.)
- N-body: dynamical age (1.6 ± 0.3) Gyr





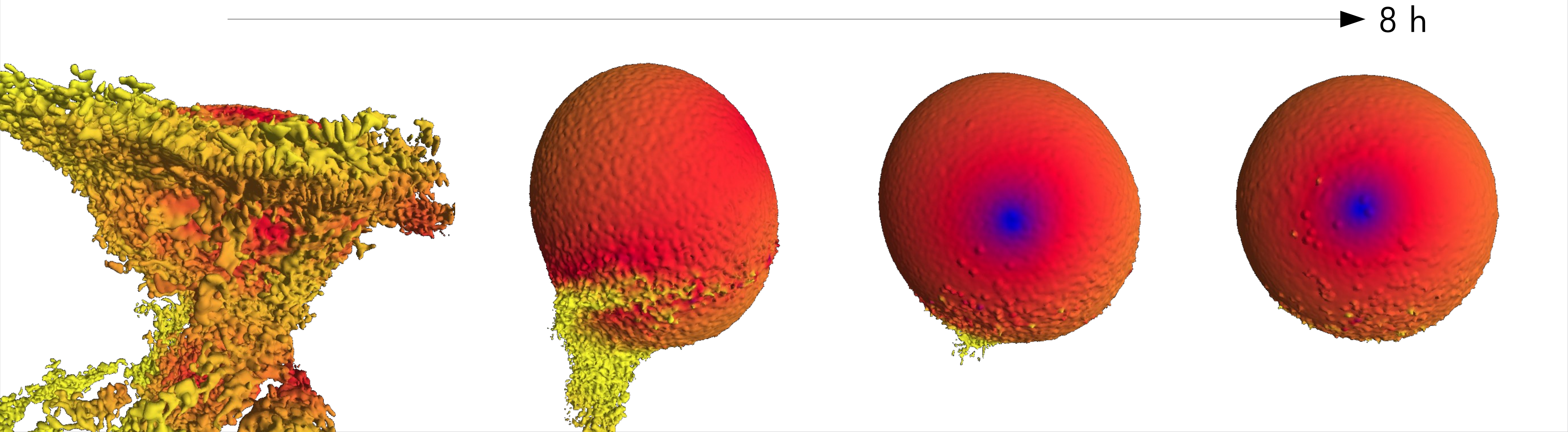


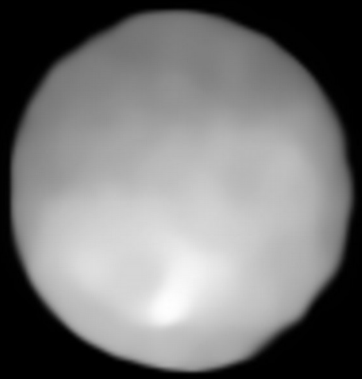


Pallas cratering
Marsset etal. (2019), WS
observed craters only
number of craters $N(>D)$ per km^2
10^{-3}
10^{-4}
10^{-5}
10^{-6}
10
20
50
100
200
500
diameter D_c / km

Hygiea family origin

- SFD: Q/Q_D^* up to ~0.3 to eject intermediate-size f., i.e. *reaccumulative* event
- friction-less material → (almost) spherical shape of LR → see...
- acoustic oscillation time scale 4 ± 1 h (cf. Riller etal. 2018 for Chicxulub)





Conclusions pessimistic & optimistic

- Problem 1: standard MB collisional model? well, not yet...
- Problem 2: no resurfacing model yet
- Problem 3: no rotation yet (Ševeček etal. 2019)
- Problem 4: no LHB; Moon cratering record?
- Problem 5: C-types (like Ceres, Hygiea) have too shallow topography for AO?
- Problem 6: development of deconvolution algorithms (ELT)

⋮

- # of records: Pallas, Iris, Gaspra, Ida, Mathilde, Eros, Lutetia, Itokawa, Bennu, Ryugu
- see: **516** (Carry), **1011** (Bin Yang), **1376** (Hanuš), **1971** (Vernazza), **B152** (Jorda), **B173** (Drouard), **B257** (Marsset etal.), ...