Julia asteroid family

↑ vs adaptive-optics observations of (89) Julia

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• ← this is (89) at 0.171 arcsec!

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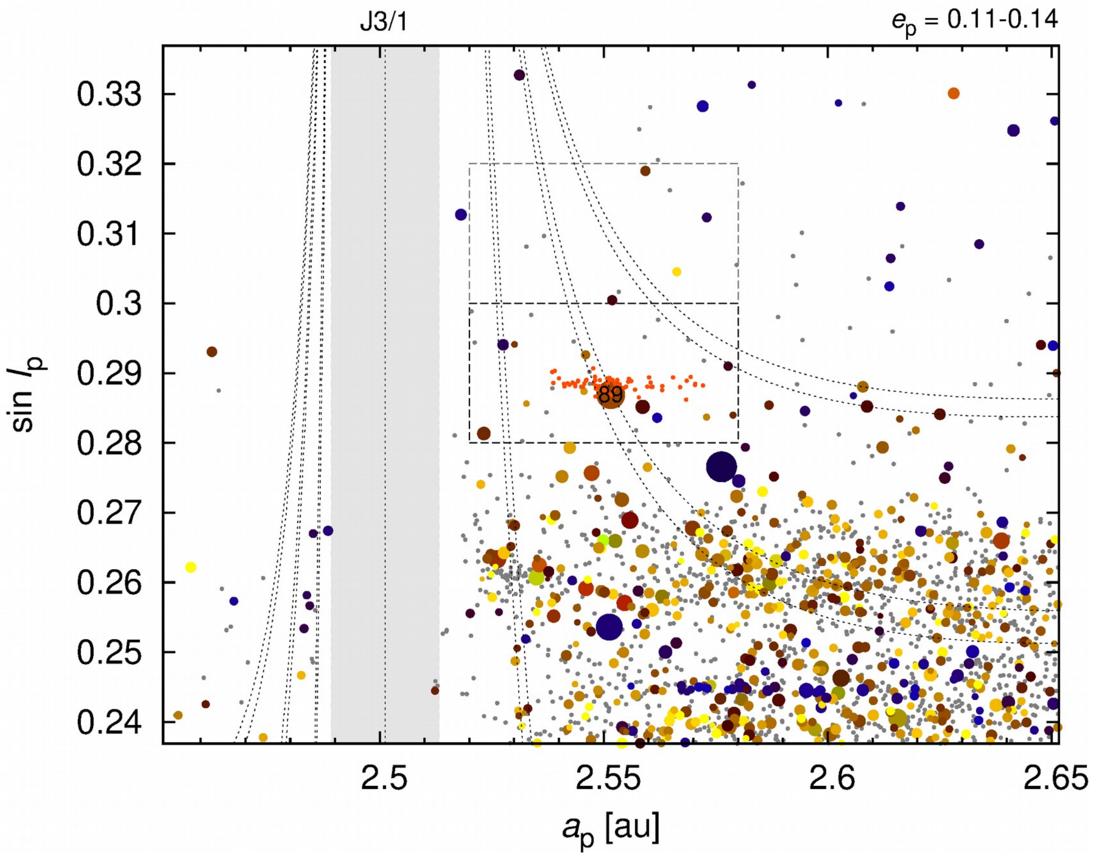
Julia family identification

- middle belt, high-I, low # of a. (Nesvorný etal. 2015)
- synthetic proper elements (Kneževic & Milani 2003)
- hierarchical clustering (Zappala etal. 1995) with $v_{\rm cut} = 80$ m/s → 66 members
- taxonomy **S** (or K?)
- albedo $p_V = 0.184$
- **LL chondrites** analogue (Vernazza etal. 2014) → $\rho_{\rm bulk} = 3300\ \mathrm{kg/m^3}$



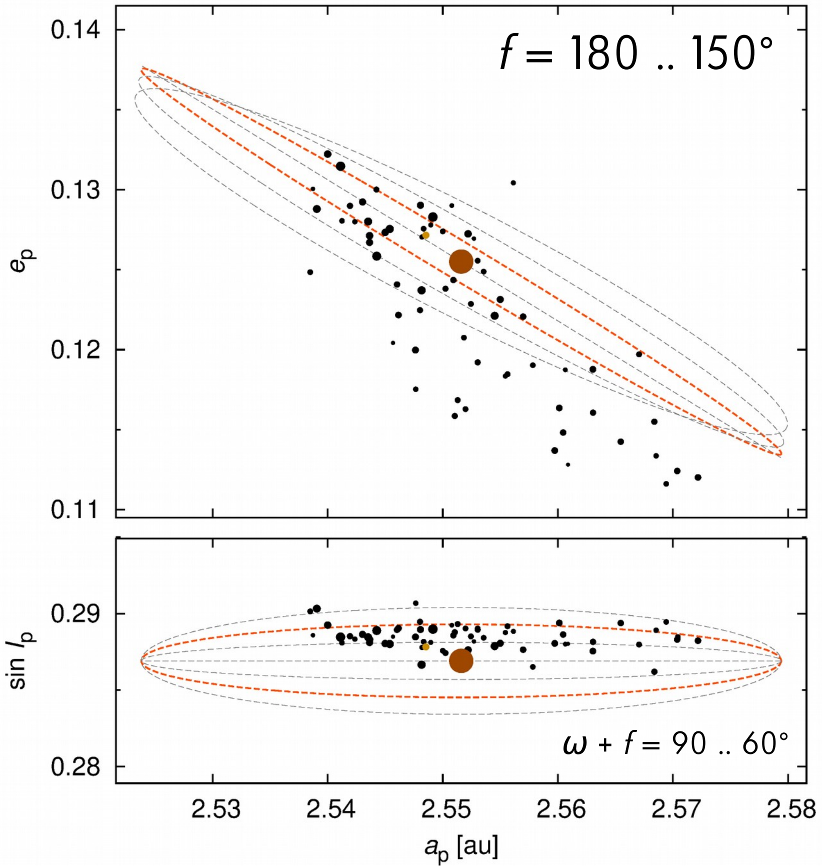
Preliminary analysis

- **escape velocity** $v_{esc} \doteq 115$ m/s
- ellipses due to **Gauss equations**:

$$\Delta a = \frac{2}{n\sqrt{1-e^2}}[\Delta v_T + e(\Delta v_T \cos f + \Delta v_R \sin f)]$$

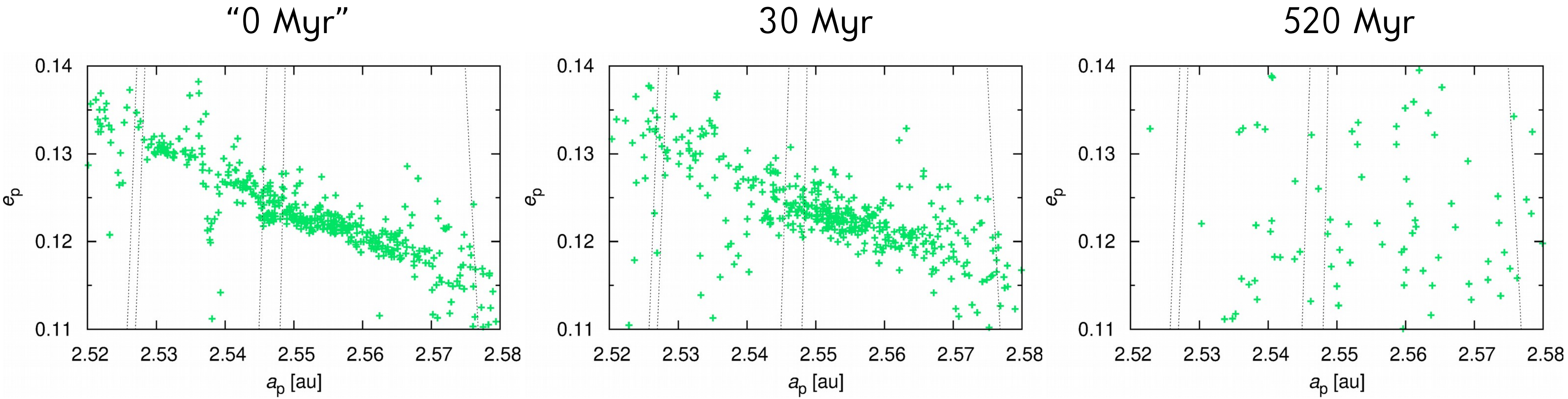
$$\Delta e = \frac{\sqrt{1-e^2}}{na}[\Delta v_R \sin f + \Delta v_T(\cos f + \cos E)]$$

- a cut at $a_p = 2.54$ au ← proximity to J3/1 resonance?
- a shift in $\Delta I_p = 0.002$ rad ← ejection into half-space?



1. N-body orbital simulation

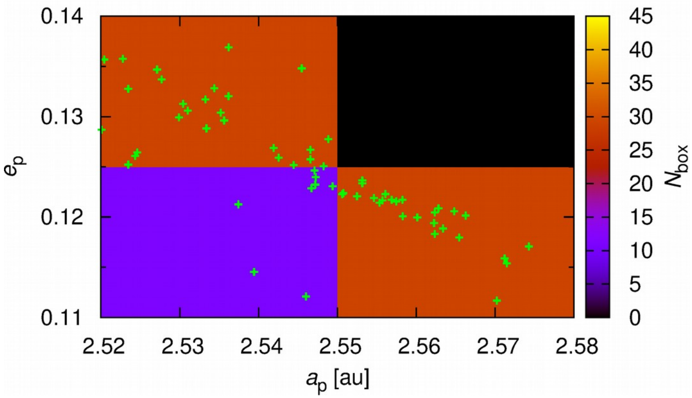
- dynamical model: Sun + 4 giant planets + (13) Egeria (Levison & Duncan 1994), Yarkovsky diurnal & seasonal effect (Vokrouhlický 1998), YORP effect (Čapek & Vokrouhlický 2004), collisional reorientations, mass shedding @ ω_{crit}
- 660 particles, v_{max} = 500 m/s, ρ_{surf} = 1500 kg/m^3, $K = 10^{-3}$ W/m/K, …



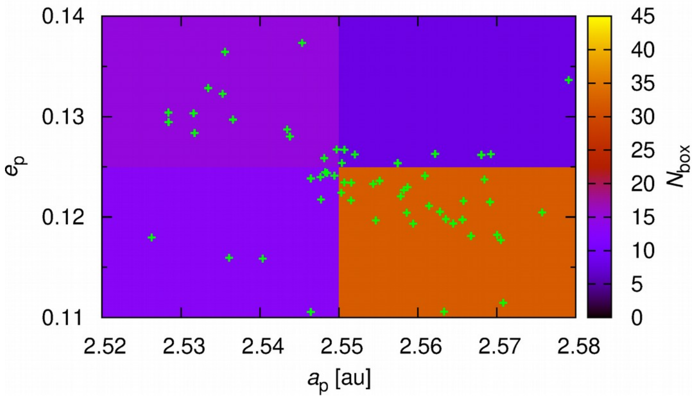
N-body (cont.)

- post-processing: (i) uniform background, (ii) match **SFD** @ every time step, (iii) random selection of orbits from ICs (see Brož & Morbidelli 2018)
- sorry for being so noisy, but 66 is low number...
- Julia family **age**: 10 to 120 Myr (i.e. both lower and upper limits)

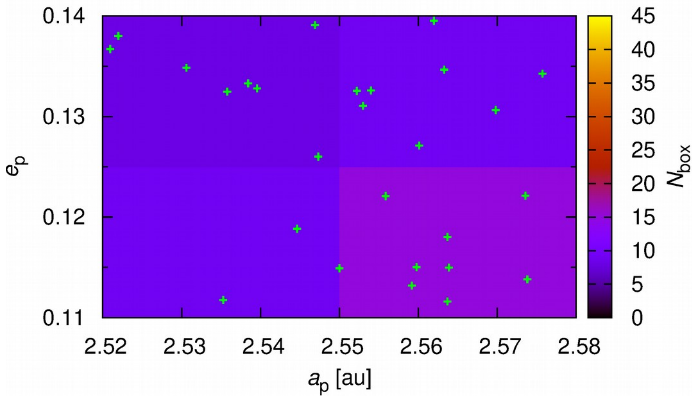
"0 Myr"



30 Myr



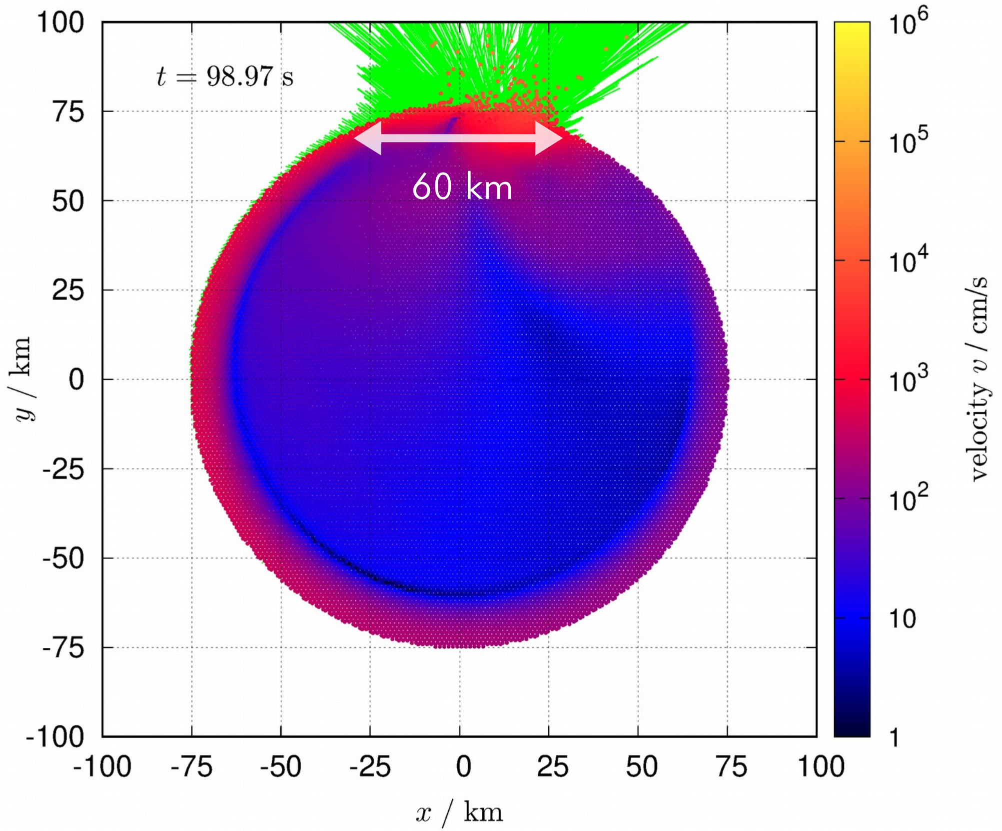
~~520 Myr~~



2. SPH break-up simulation

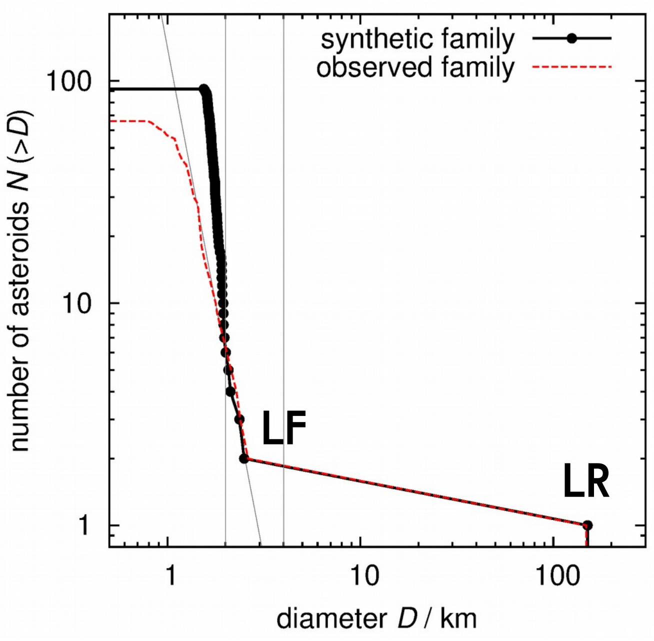
- fragmentation by SPH5 (Benz & Asphaug 1994), reaccumulation by Pkdgrav (Richardson etal. 2000)
- Tillotson (1962) EOS, von Mises yielding, Grady & Kipp (1980) fracture model, no porosity
- basalt material with $\rho_0 = 3300$ kg/m^3
- $N = 1.4 \cdot 10^6$ to resolve LF
- **IC**: d = 8 km, v = 6 km/s, θ = 75°, …
  → fragment SFD, v-field, **crater size**

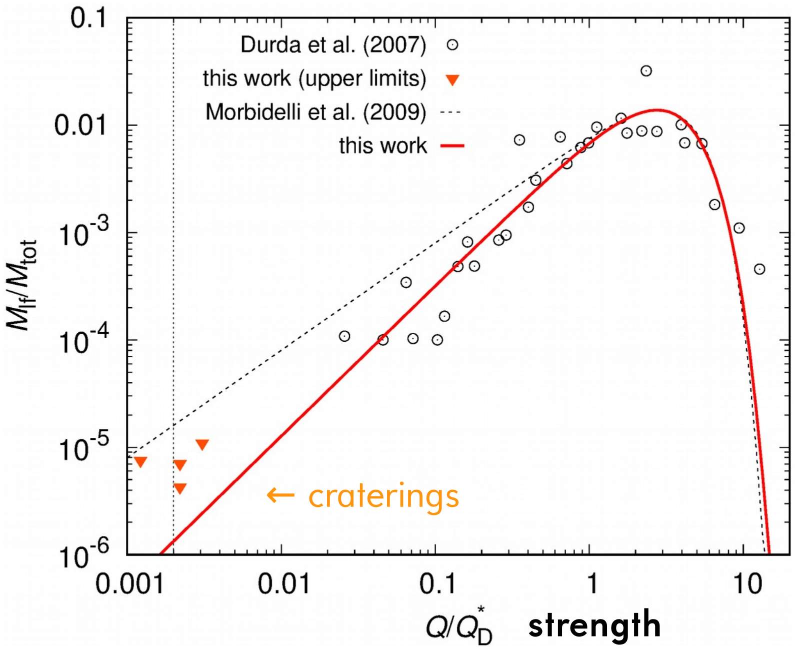
↑
transient



SPH (cont.)

- size-frequency distribution $N\,(>D)$ → barely resolved **LF** (slope unreliable)
- correction of M_{LF}/M_{tot} parametric relation from Morbidelli etal. (2009) ← important!

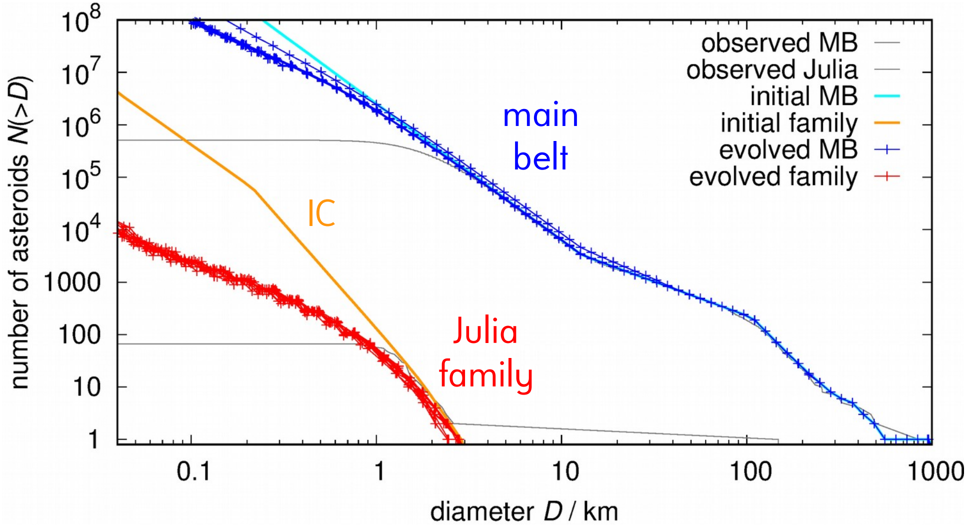




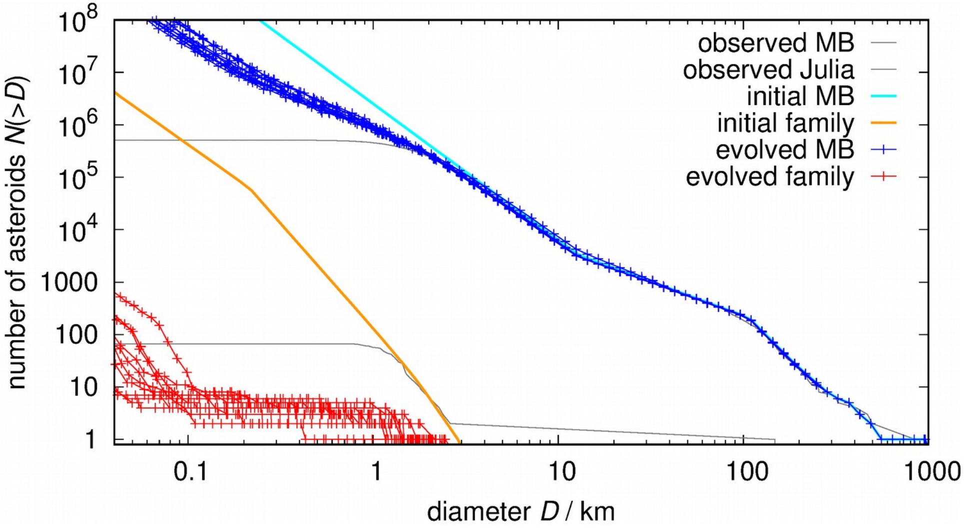
3. Monte-Carlo collisional simulation

- Boulder code (Morbidelli etal. 2009), scaling law of Benz & Asphaug (1999), …
- without (89) Julia (LR), i.e. only fragments → family lifetime ~ 100 Myr

30 Myr



~~520 Myr~~

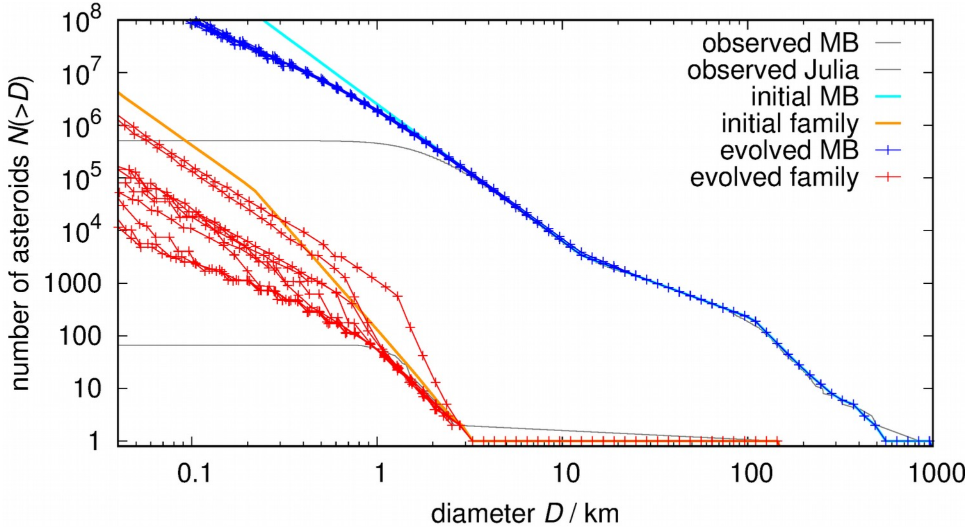


Monte-Carlo (cont.)

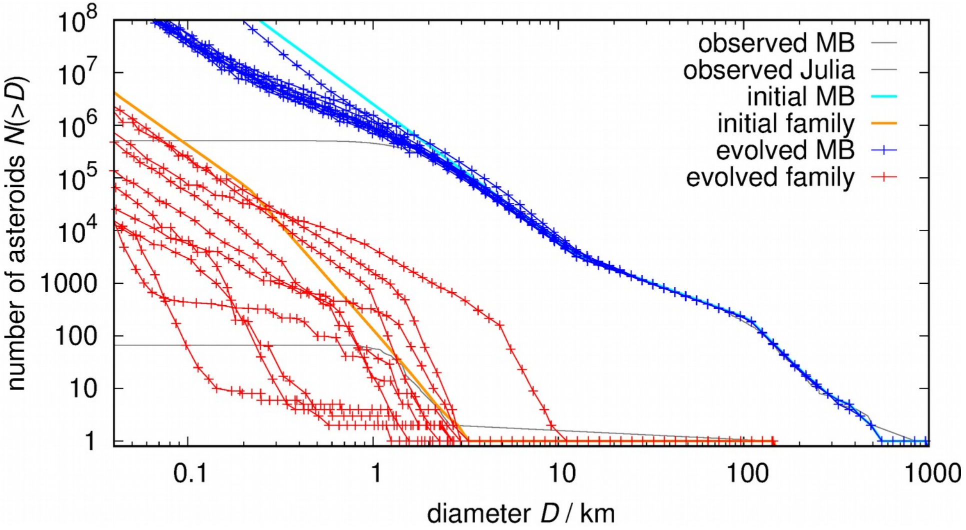
$D_{LF} \geq 2.6$ km

- the same with (89) Julia → number of events: **1 to 10** per 4 Gyr (100 MC runs)
- if ≫ 1 then possible **resurfacing**? irregular shape?

30 Myr

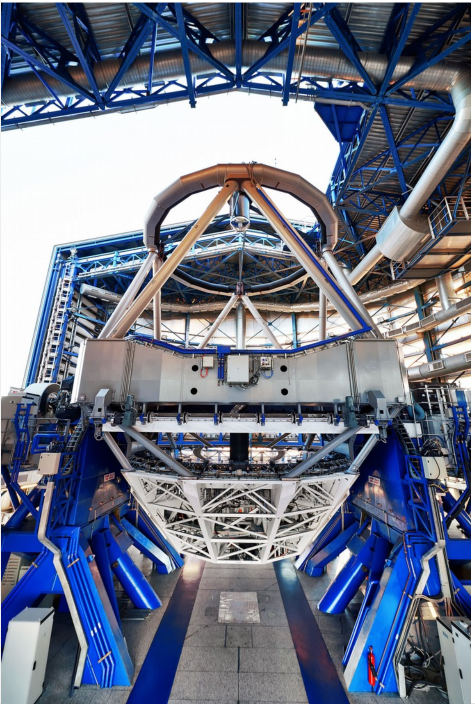


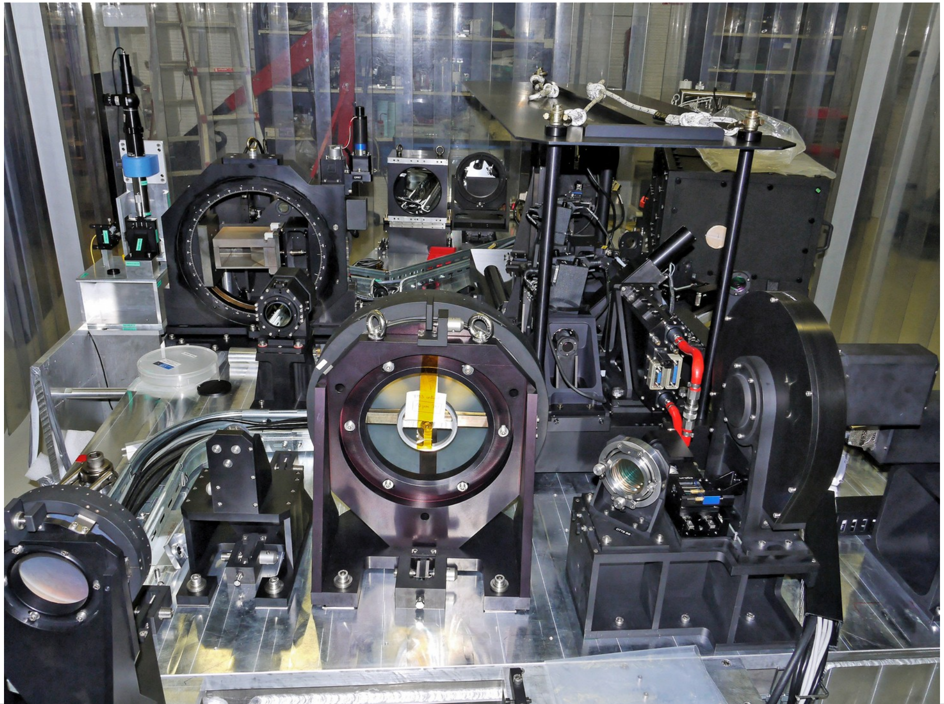
~~520 Myr~~



Adaptive Optics imaging of (89) Julia

- VLT/SPHERE/ZIMPOL instrument (Schmidt etal. 2018), N_R filter (645 ± 28 nm), Julia as NGS, nearby * as PSF, 5 series of 10-s exposures @ epoch





PSF

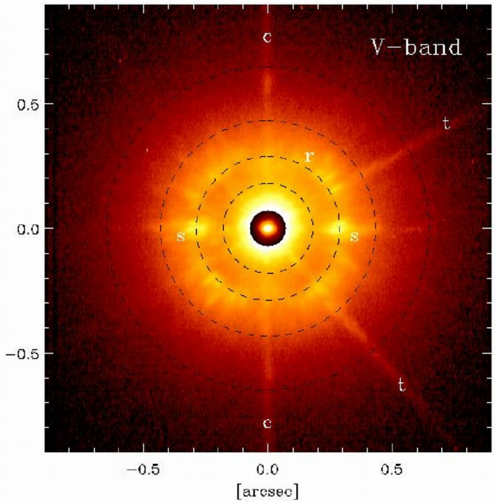
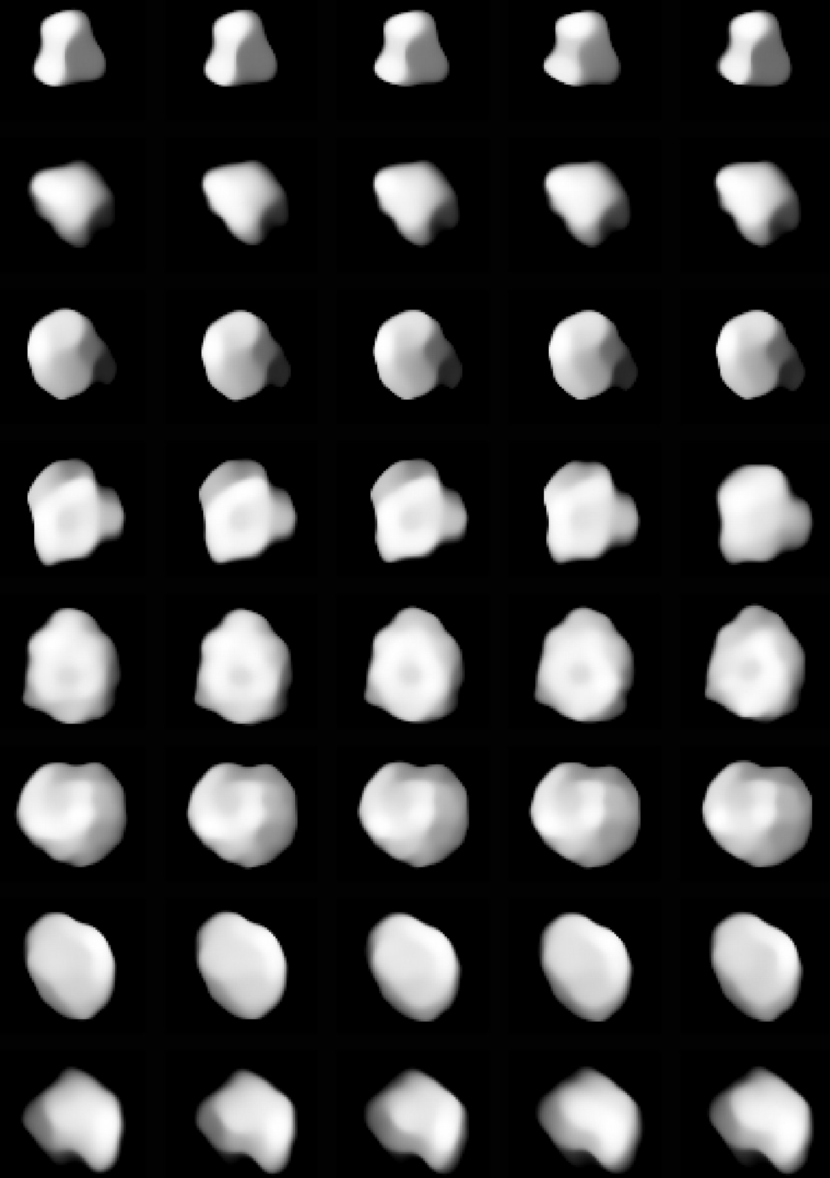
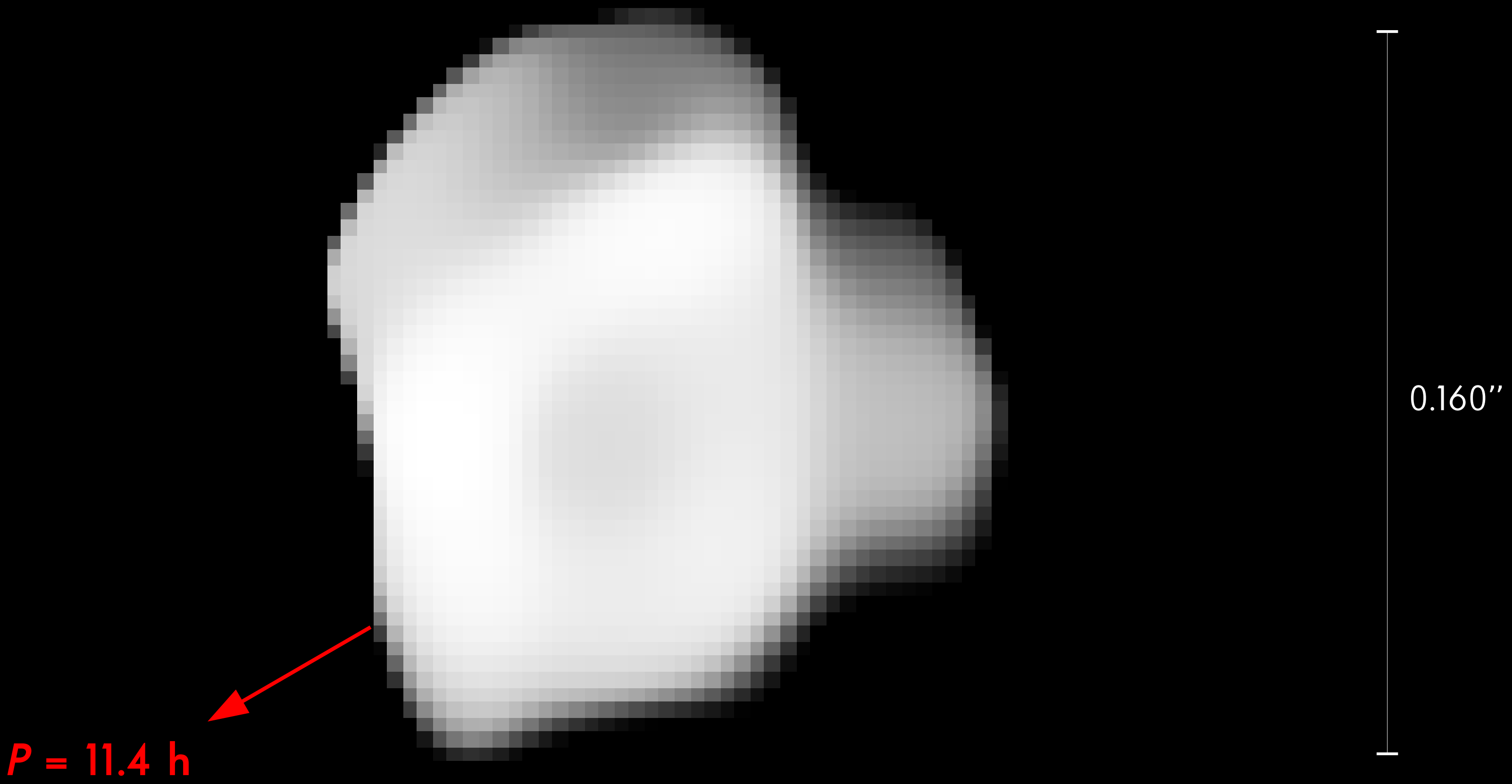


Fig. 8. Normalized PSFs of HD 183143 for the V-band (top) and the N_I-band (bottom) with the color scale reduced by a factor of 100 for the central peak within $r < 20$ pixels. Marked PSF features are the speckle ring near the AO control radius (r), strong fixed speckles from the AO system (s), two telescope M2 spider features (t), and the CCD frame transfer trail of the PSF peak (c). The dashed rings illustrate the location of the azimuthal cuts shown in Fig. 9.

8 epochs
Jul 7th - Oct 10th 2017
mypoic deconvolution
by MISTRAL algorithm
(Fusco etal. 2003)




P = 11.4 h
0.160''

Crater ("Nonza")

- 3D shape reconstruction by ADAM (Viikinkoski etal. 2015): AO + LC + regularisation
- crater visible at longitude 0° (def.) and latitude -32°

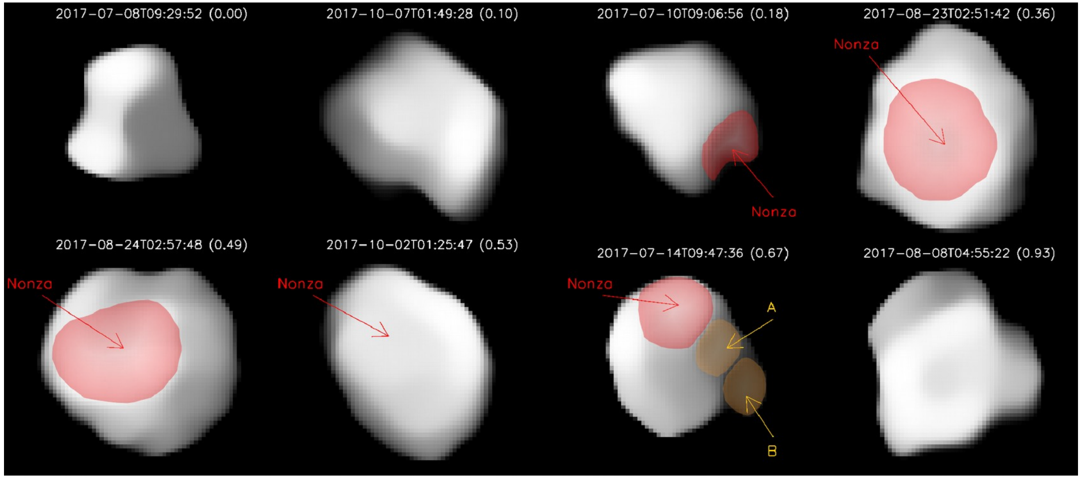
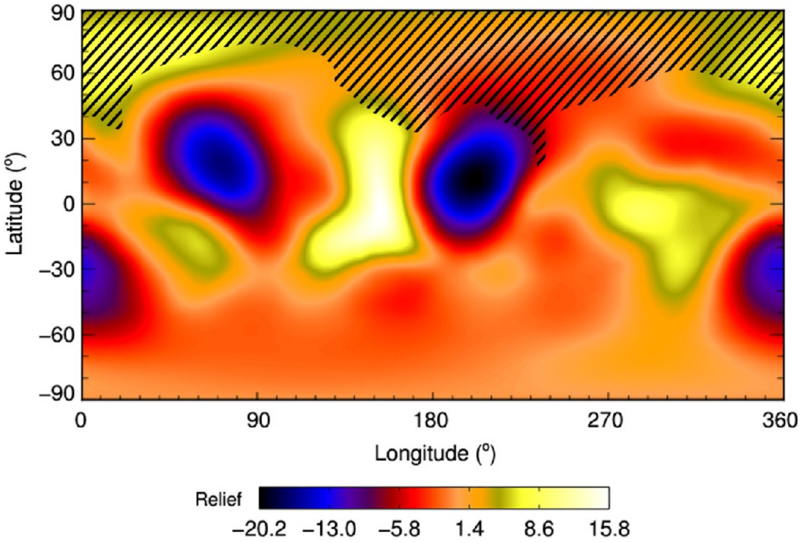


Fig. 3: Identification of the impact craters present at the surface of Julia. Besides the large impact basin Nonza, we identified two possible small craters (A and B) at rotational phase 0.67.



Crater size & position

- estimated crater size D = (74.8 ± 5.0) km (SPH: >60 km)
- **excavated** volume V_{ex} = (9800 ± 4900) km^3 (SPH: 7600 km^3)
- **ejected** volume V_{ej} = 176 km^3, i.e. $V_{\mathrm{ej}} \ll V_{\mathrm{ex}}$

- SPH: ejection velocity wrt. barycentre $v_{\mathrm{ej}} \doteq 100$ m/s → $\Delta I = 0.002$ rad, cf.

$$\Delta I = \frac{\Delta v_W}{na\sqrt{1-e^2}}\frac{r}{a}\cos(\omega + f)$$

- **obliquity** of Julia γ = -17°; for $\varphi = \gamma$, ejecta can fly the most above (or below)
- Nonza with **latitude** φ = -32° is in a suitable position!

Conclusions (optimistic)

- 20 yr after HST observations of (4) Vesta…
- **asteroid families ↔ craters identifications** possible from ground!
- 40-m class telescopes (ELT) will be used

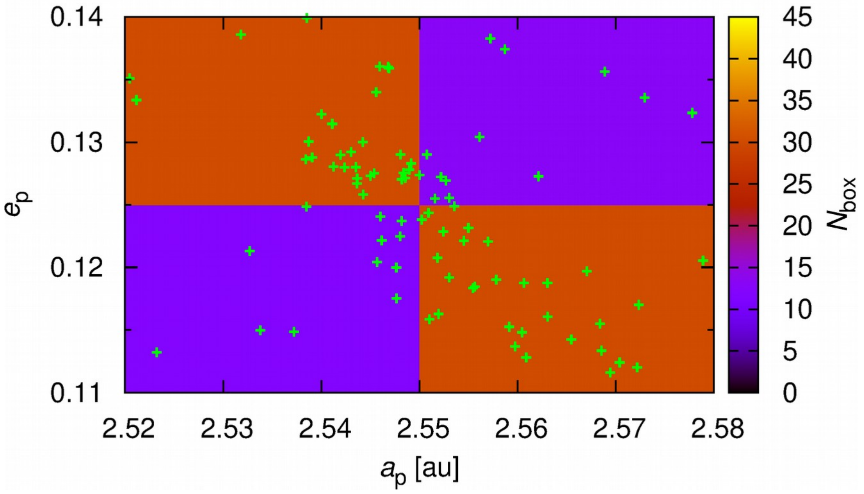
- Vernazza etal. (2018) A&A, forthcoming

Comparison of simulations & observations

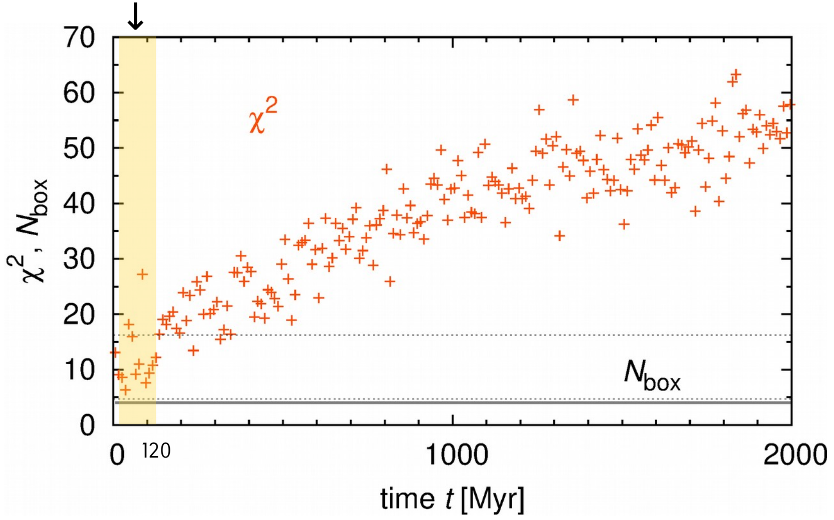
- # of a. in boxes in (a_p, e_p) space
- suitable χ^2 metric (Poissonian σ):

$$\chi^2 = \sum_{i=1}^{N_{\rm box}} \frac{(N_{{\rm syn}\,i} - N_{{\rm obs}\,i})^2}{\sigma^2_{{\rm syn}\,i} + \sigma^2_{{\rm obs}\,i}}$$

observed



age



2. SPH break-up simulation

- **IC**: d = 4.4 km, v = 6 km/s, θ = 15°