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Non-gravitational forces

acting on small bodies

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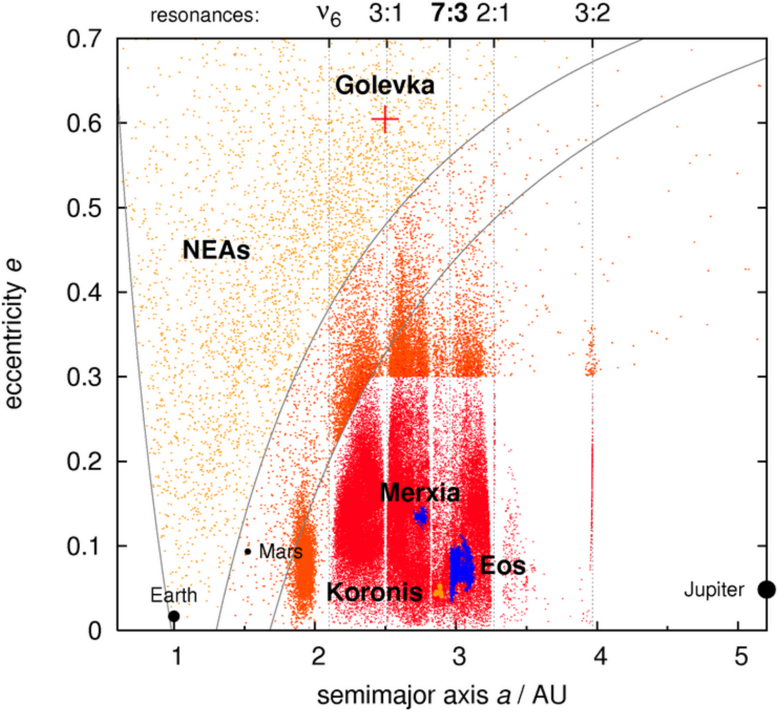
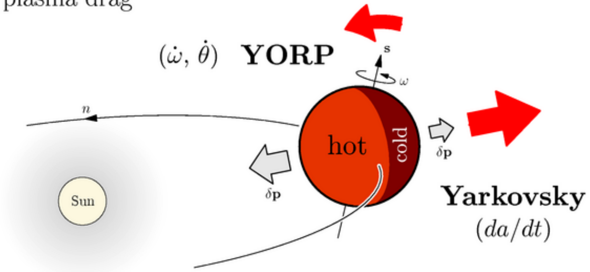

resonances:
ν6
3:1
7:3
2:1
3:2
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Golevka
NEAs
Merxia
Mars
Eos
Koronis
Earth
Jupiter
1
2
3
4
5
eccentricity e
semimajor axis a / AU

Accelerations in the size-range:

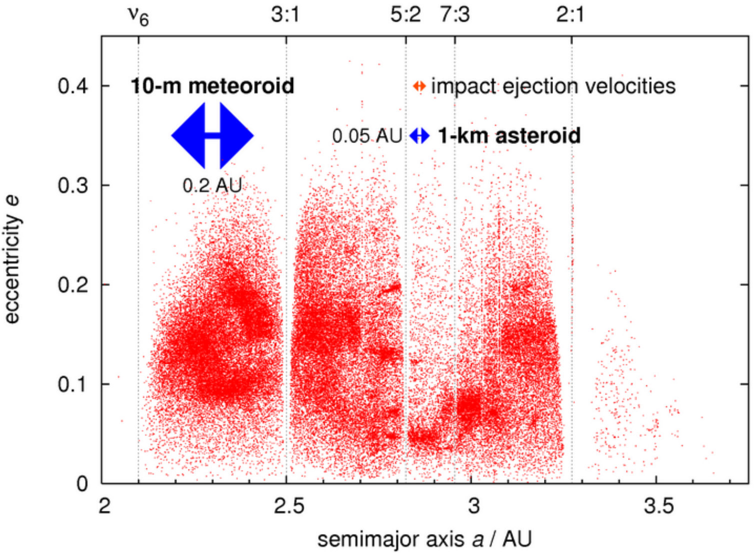
10 cm to 10 km

0. gravity $GM_\odot \simeq 1$ $GM_{\rm pl} \simeq 10^{-3}$ $GM_{\rm ast} \lesssim 10^{-9}$
1. Yarkovsky/YORP effect 10^{-7} to 10^{-11}
2. radiation pressure 10^{-6} to 10^{-11}
3. Poynting-Robertson drag 10^{-10} to 10^{-15}
4. solar wind "too small"
5. Lorentz force ⋮
6. plasma drag



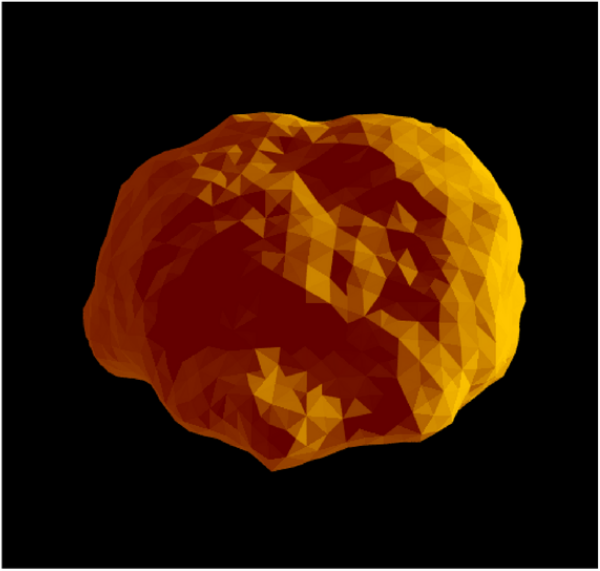
- radial pressure vs. drag & long-term accumulated effect

How much a body can move? (within its collisional lifetime)



- comparable to the distances between major resonances and sizes of asteroid families

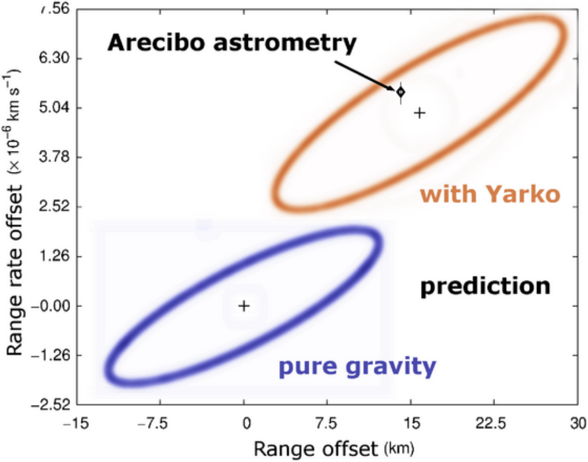
What do we need to calculate Yarkovsky/YORP?



- orbit, size and shape, spin axis orientation and period, mass, density of surface layers, albedo, conductivity, ...

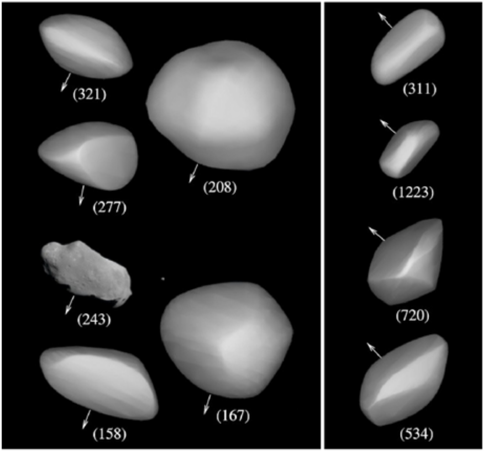
PART 1

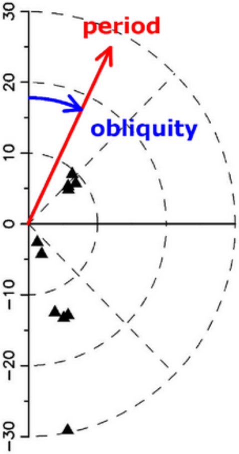
A directly measured semimajor axis drift (Chesley *et al.*, 2003): radar ranging to Golevka



- a more complex Yarko-model by Čapek & Vokrouhlický (poster P12.6)

Bimodal obliquity distribution in Koronis family **(Slivan *et al.*, 2003):**



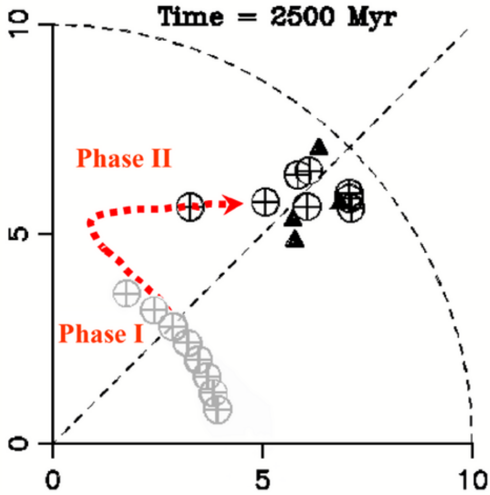


- prograde group: periods 7.5–9.5 h, obliquities 42°–50° and similar ecliptic longitudes within 40°
- retrograde group: $P < 5\,\mathrm{h}$ or $> 13\,\mathrm{h}$, $\gamma \in (154°, 169°)$

  $\Rightarrow$ collisions cannot produce this!

Spin state model (Vokrouhlický *et al.*, 2003):

- solar torques & YORP thermal torque



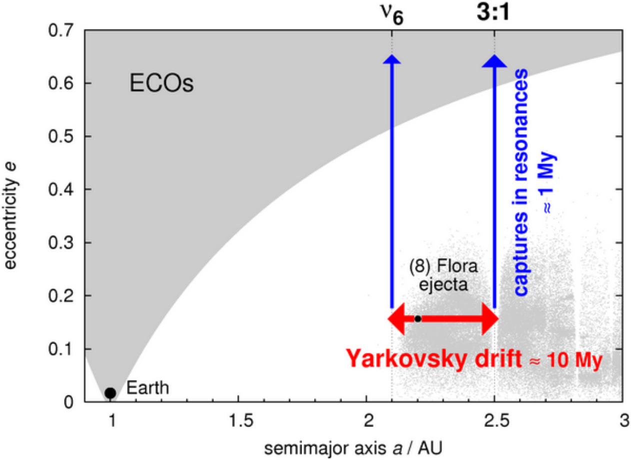
- prograde group: (I) YORP driven evolution to asymptotic state & (II) capture in spin-orbit resonance s_6 (precession rate $\simeq 26''/\mathrm{y} = -s_6$) $\Rightarrow$ paralelism in space

PART 2

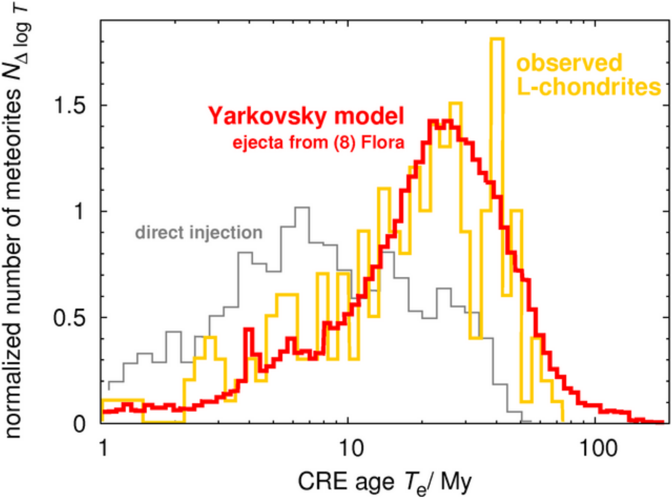
Meteorite transport from the Main Belt:

(Farinella *et al.*, 1998; Vokrouhlický & Farinella, 2000; Bottke *et al.*, 2000)

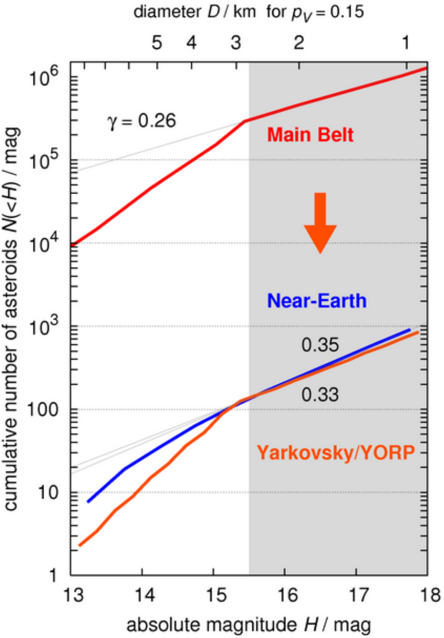
- motivation: long Cosmic Ray Exposure ages of meteorites



1. observed meteorite flux $\approx 3 \times 10^5$ kg/y
2. CRE ages > resonance residence times
3. CRE's of iron meteorites 10× longer than of stones
4. distribution of CRE's for stony meteorites
   (peaks ∼ stochastic events)

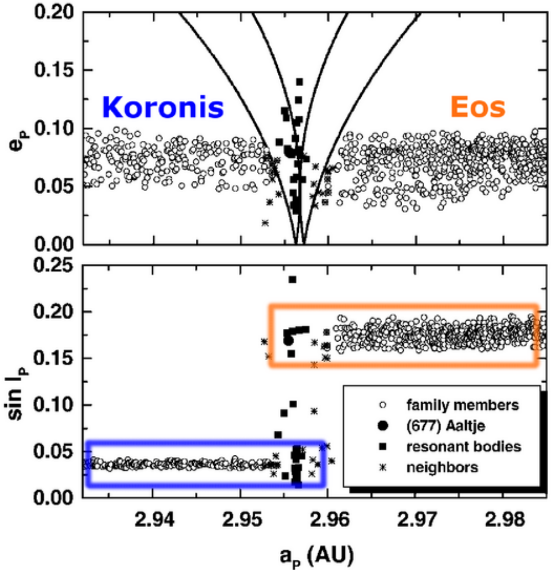


Delivery of Near-Earth Asteroids (Morbidelli & Vokrouhlický, 2003):



- observations of NEAs:
  1. removal rate: ∼200 bodies (>1 km) per My
  2. *H* distribution
- the same basic scenario as for meteorites:
  1. Yarko/YORP flux into the resonances: 150–200 My^{-1}
  2. slope change

J7/3 resonance, Eos and Koronis families (Tsiganis *et al.*, 2003):



- 22 resonant asteroids
- Yarkovsky drift $\Rightarrow$ steady state
- confinement of inclinations
- model for delivery into J2/1 MMR (Brož *et al.*, 2005; poster P12.4)

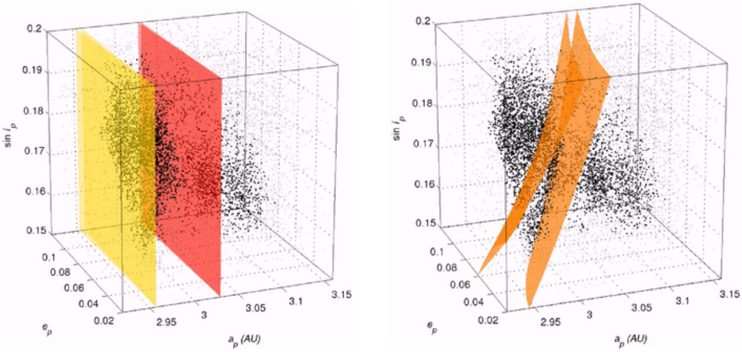
PART 3

Asteroid families:

(Bottke *et al.*, 2001; Vokrouhlický *et al.*, 2005)

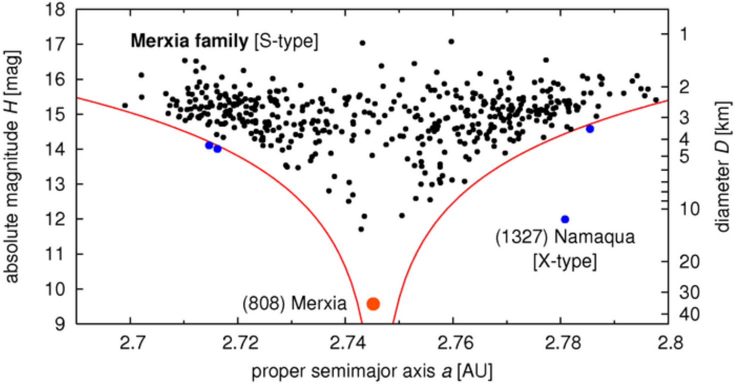
- "Bracketing" by resonances
- "Crossing" weaker MMRs
- "Trapping" in secular resonances

→ Eos family as an example



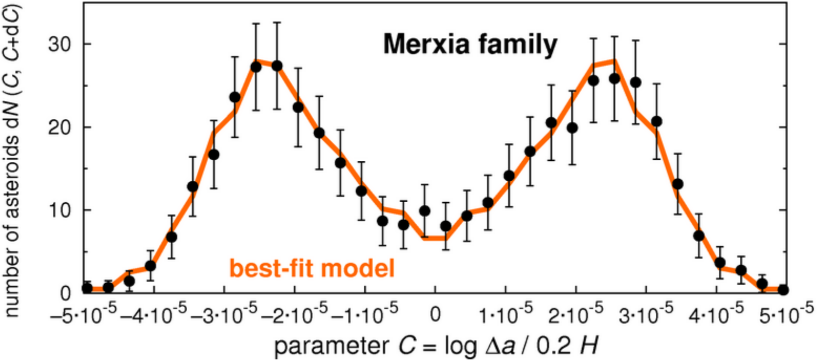
"Eared" families and a new method of family-age determination (Vokrouhlický *et al.*, submitted):

- 'V'-shape in the (a, H) plane
- outliers $\Leftrightarrow$ interlopers?

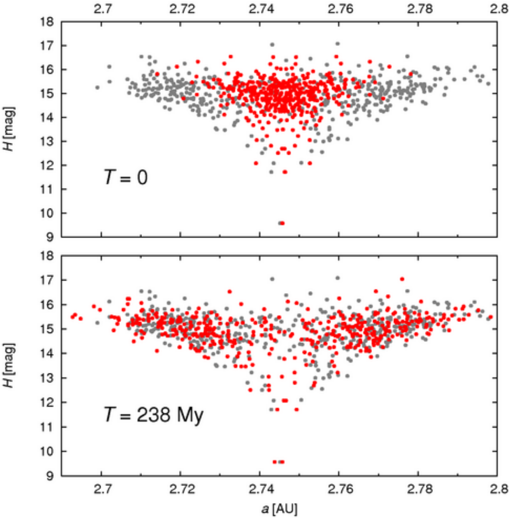


- problem: unknown *initial* spread
- "eared family" (overdensity of small members at extreme values of the semimajor axis) $\Leftarrow$ YORP effect fingerprint?!

- family evolution model: isotropic ejection (random P, θ), Yarkovsky drift, YORP effect, collisional reorientations
- free parameters:
  - initial velocity dispersion V of 5-km fragments
  - YORP "strength" $c_{\rm YORP}$
  - family age T
  - surface thermal conductivity K

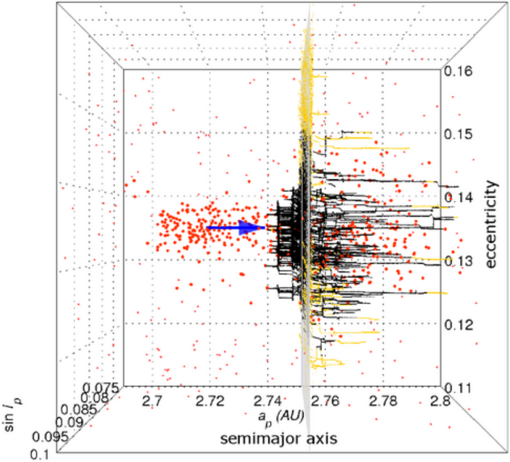


- the best fit:
- initial dispersion $\sim 1/2$ of observed
  (in agreement with a statistical argument of dell'Oro *et al.*, 2004)



– $V = 24^{+6}_{-12}\,\mathrm{m/s}$ $\Rightarrow$ small velocity
– $c_{\mathrm{YORP}} = 0.6^{+1.4}_{-0.4}$ $\Rightarrow$ YORP important
– $T = 238^{+52}_{-23}\,\mathrm{My}$ $\Rightarrow$ young age
– $K = 0.005\,\mathrm{W/m/K}$ $\Rightarrow$ regolith

- independent contraint: uneven dispersion in (a, e) plane
  $\Leftarrow$ Yarkovsky transport across the 3J−1S−1 resonance



- the method does not work for
  "too young" or "too old" families
- fresh clusters, like Karin and Veritas,
  were discussed by David Nesvorný (review R9.2)

Conclusions and future work:

- routine Yarkovsky detection by precise radar astrometry (Vokrouhlický *et al.*, 2005a,b)
  or future optical astrometry (with GAIA)
- direct detection of YORP?
  (by ground-based photometry or by space missions)
- systematic ages of all asteroid families,
  including large and old ones

– measurement of thermal-related parameters
  (masses, sizes, shapes, albedos, conductivity)

– modelling of several subsequent YORP cycles

- YORP origin of slowly rotating tumblers,
  binaries created by asteroid fission