Physical properties of minor bodies of the solar system from Gaia observations

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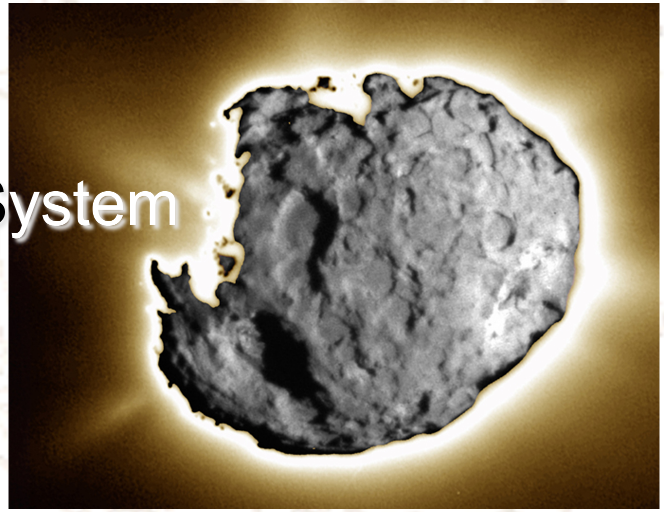
Gaia solar system objects harvest



- Asteroids (~250.000 – most known)
  - Mainly Main Belt Asteroids (MBA)
  - Several NEOs
  - Other populations (trojans, Centaurs,..)
- Comets
  - Primitive material from the outer Solar System
- Small planetary satellites
  - regular
  - irregular (retrograde orbits)
- Gaia will likely NOT observe «biggest» small bodies (θ_D>500 mas)
  - Main Planets, large satellites (Galilean, Titan..)

Small bodies of our Solar System

Physical properties and implication for their dymanics

Sizes (D)

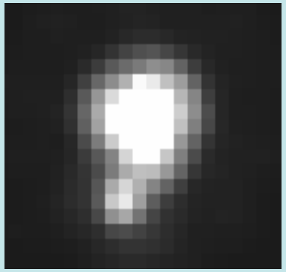
Asteroid size distribution

Collisional evolution

Formation of dynamical families

Earth impact risk assesment

Masses
Binary objects

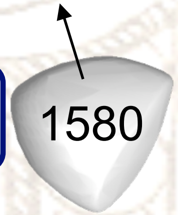


Bulk density → internal structure

Albedos (p_V)

Surface mineralogy
Constraints on the body's orgin

Shapes and spin vectors

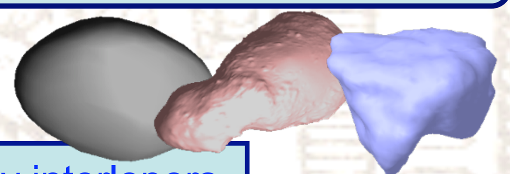


Collisional evolution

YORP -- radiation pressure effect able to spin up (and down) small asteroids

Yarkovsky effect -- radiation pressure effect able change the orbit of small asteroids

Spectroscopy of the surface



Identification of family interlopers

Space weathering processes

Link asteroids - meteorites

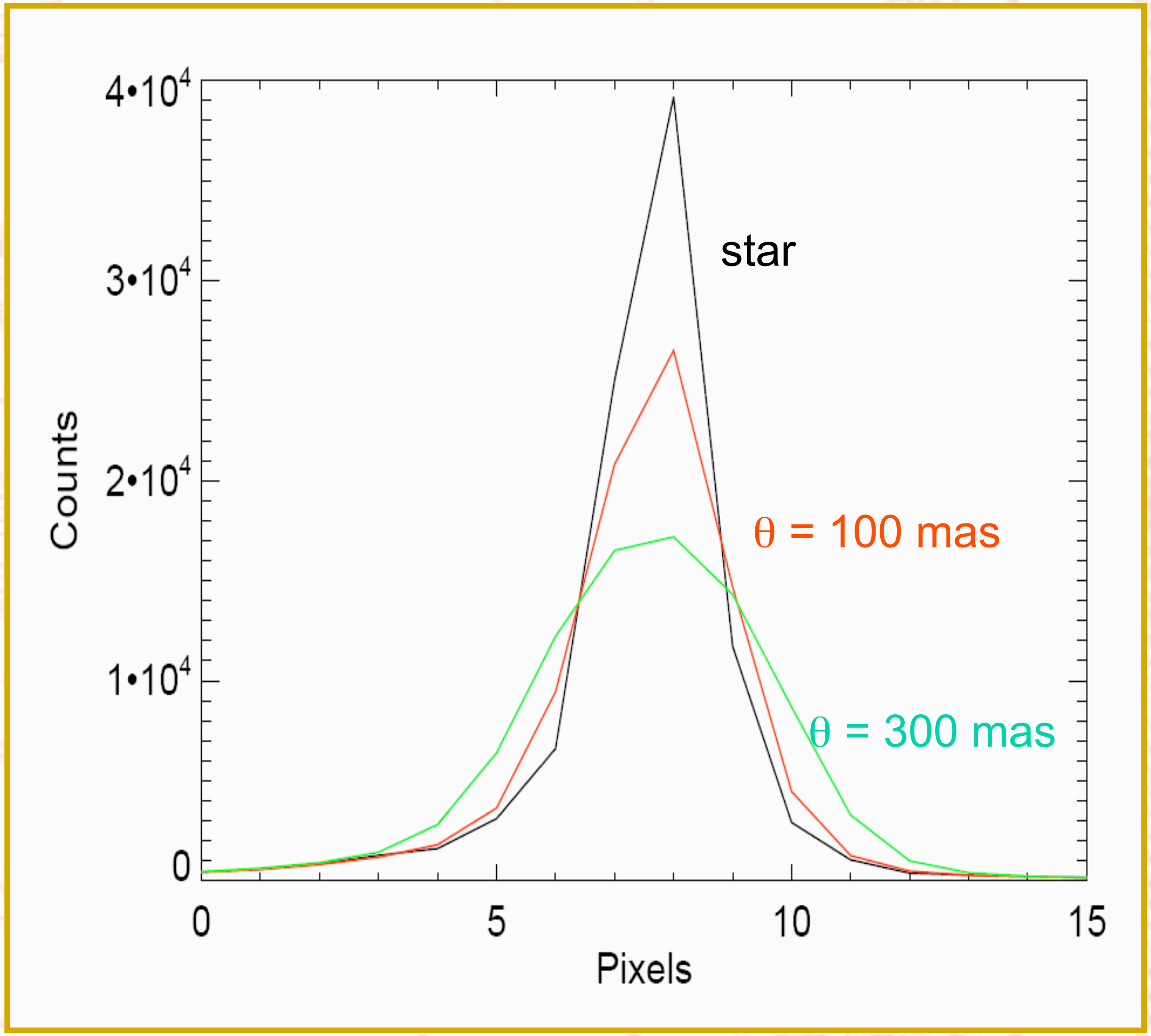
Limited knowledge and open questions

- ~350,000 known asteroids
- Sizes for ~2200 MBAs and ~80 NEAs from indirect methods (e.g. radiometry which makes use of thermal models)
- Shapes and spin vector states known for ~150 asteroids
  - (rotation periods for ~2000)
- Spectroscopy for 1500 asteroids
- Density, porosity known for a handful of objects

- Small members of dynamical families: how many? Sub-families?
- How many asteroids have satellites?
- How many asteroids are cohesionless rubble-piles? Size range ?
- Link with meteorites
- Asteroid – comet transition objects

Sizes of minor bodies

- Direct size determination for over 1000 asteroids
- Good quality sizes for D>40km; smallest measurable sizes D~20km (Main Belt)
- Object's size at different epochs (#70) → gross shape



AL signal measured by Gaia (AF) for different apparent sizes of the source.

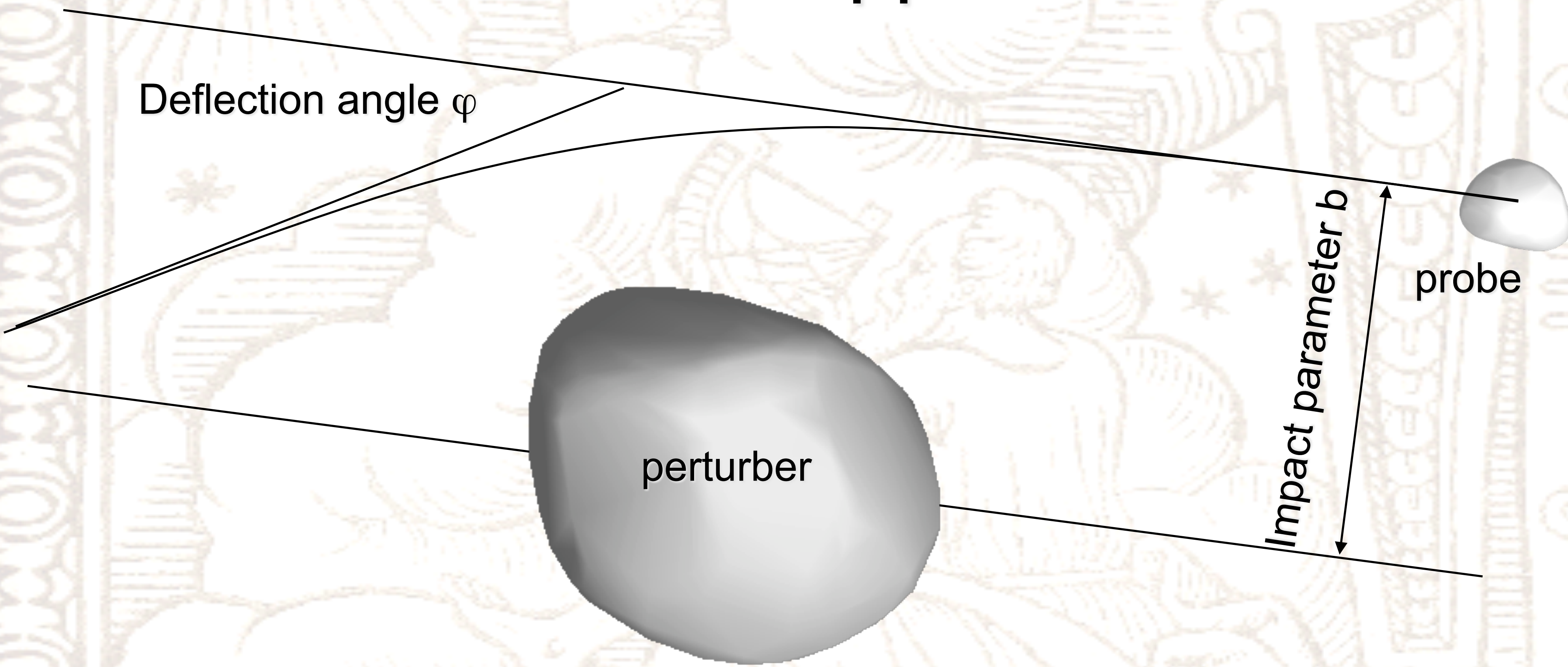
Asteroid masses: today

- Uncertainties (10-30% Ceres, Pallas, Vesta)
- ~40 asteroids at better than 60% (Mouret *et al.* 2007)

Asteroid	**Mass ($M_\odot$)**	**Reference**
10 Hygiea	$(4.7 \pm 2.3) \times 10^{-11}$	Scholl et al. 1987
	$(5.6 \pm 0.7) \times 10^{-11}$	Michalak 2001
11 Parthenope	$(2.6 \pm 0.10) \times 10^{-12}$	Viateau Rapaport 1997
15 Eunomia	$(4.2 \pm 1.1) \times 10^{-12}$	Hilton 1997
	$(1.2 \pm 0.4) \times 10^{-11}$	Michalak 2001

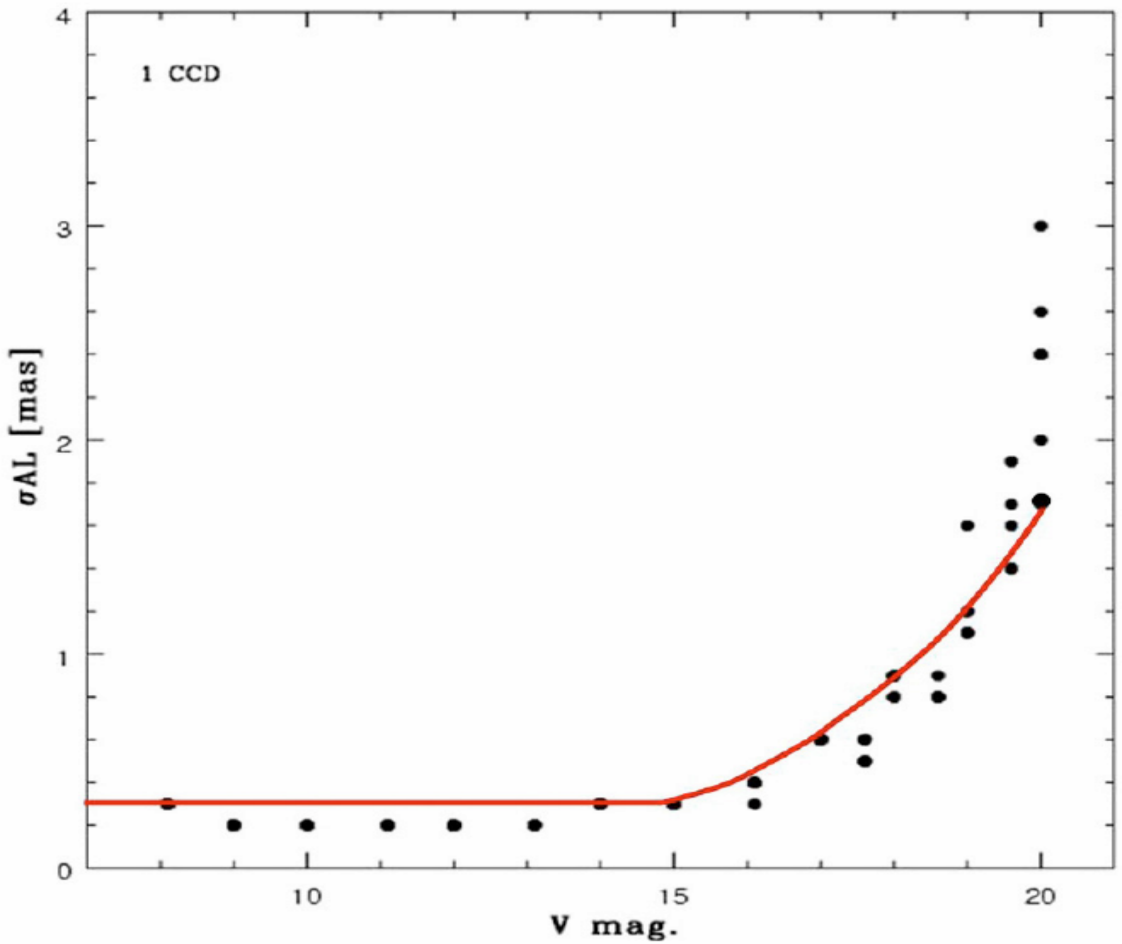
Unknown masses of the largest asteroids limit Solar System ephemeris:
Current accuracy : ~1 km/ 10 yr Earth, Mars (*Standish, Fienga 2001*)
~100 km / 10 yr for several NEOs

Determination of asteroids' masses from close approaches



$$\tan\frac{\varphi}{2} = \frac{G(M+m)}{bV^2}$$

Gaia astrometric accuracy



- *Improvement >100x in the accuracy of orbital elements*
- *Ephemeris position uncertainty < D for D > 20 km*

Statistics for mass determination

- More general approach: full N-body problem
- The mass M of the perturber is an unknown adjusted to yield best-fit to the observations:
- See Mouret 2007; Mouret et al, 2007

Number of perturbers	
Total	602
$\sigma(m)/m < 0.1\%$	2
$\sigma(m)/m < 1\%$	3
$\sigma(m)/m < 10\%$	36
$\sigma(m)/m < 15\%$	59
$\sigma(m)/m < 20\%$	75
$\sigma(m)/m < 30\%$	106
$\sigma(m)/m < 40\%$	135
$\sigma(m)/m < 50\%$	149

Masses of the ~100 larger perturbers
with accuracy better than 15% !!
→ General improvement of SS dyn. model

Mouret 2007
Mouret et al 2007

- Actually ~10 times more objects observed
- Problem (opportunity): several encounters occouring « before » and « after » Gaia

Accurate shape models (volume) are needed

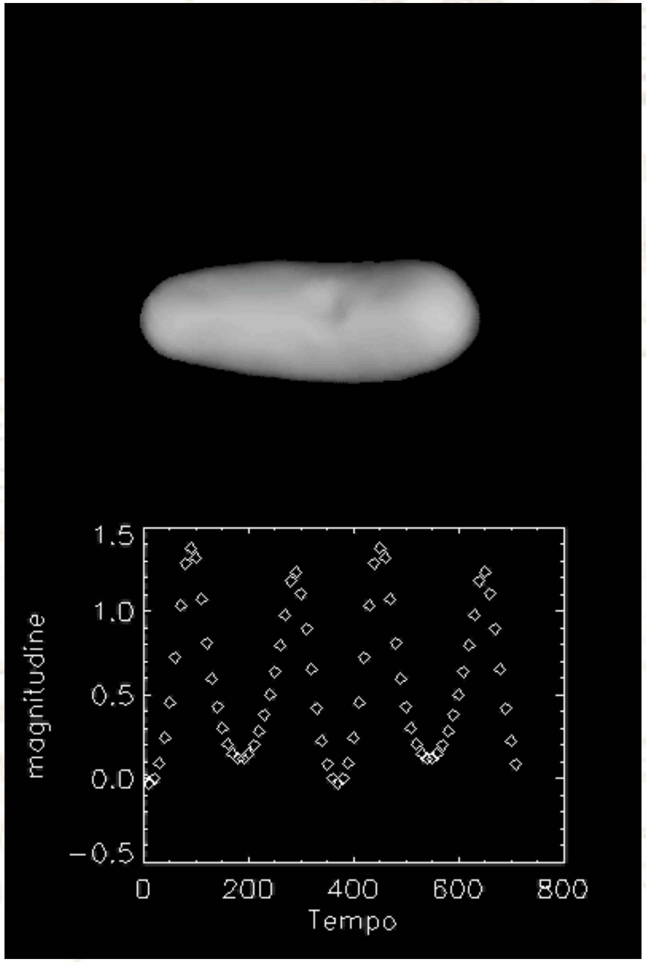
Gross shapes and spin states from inversion of the lightcurves

Different shapes → Different lightcurves

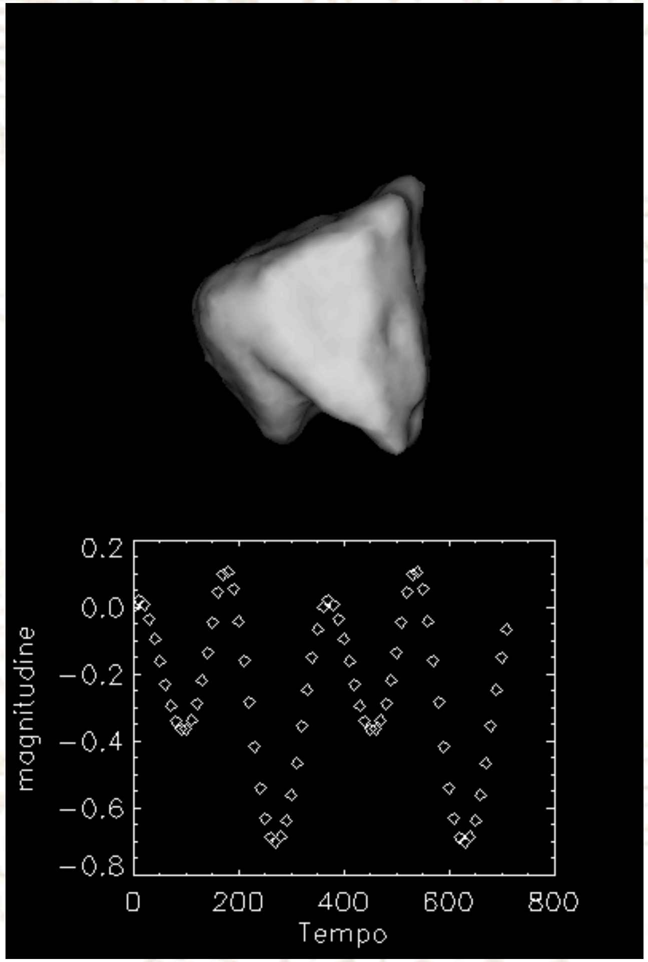
In general asteroid's visible magnitude is function of shape, rotation period, direction of the rotation axis (pole)

Determination of shape and spin state from lightcurve inversion is a well studied problem (Kaasalainen et al., 2002; see Mignard et al. 2007 for the case of Gaia)

433 Eros



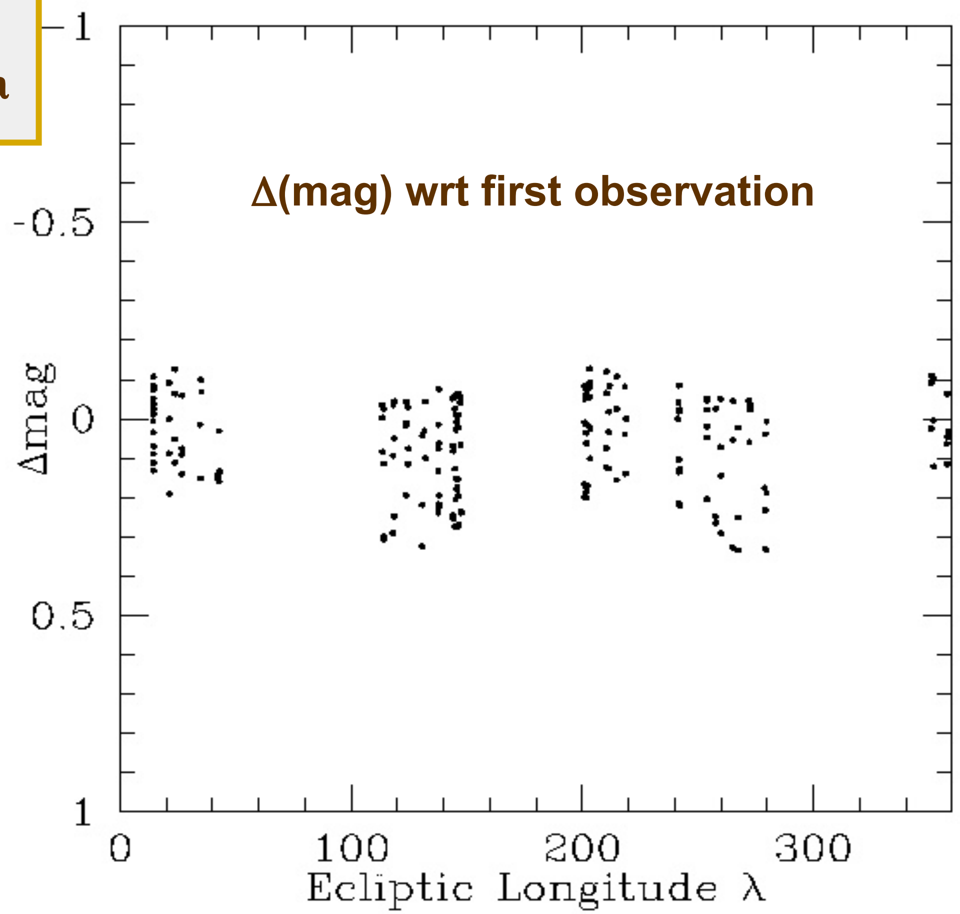
6489 Golevka



Shapes and poles from Gaia's photometry

Simulated GAIA observations

Orbit of 39 Laetitia



From lightcurve inversion: P = 7h.527

λ_p = 30; β_p = 60; b/a = 0.7; c/a = 0.5

PROBLEM

#60 - #70 observations
Over 5 years per asteroid
σ~0.01 – 0.02 mag

METHOD

Inversion of sparse photometric data possible
Kaasalainen 2004;
Durech et al 2006;

RESULTS

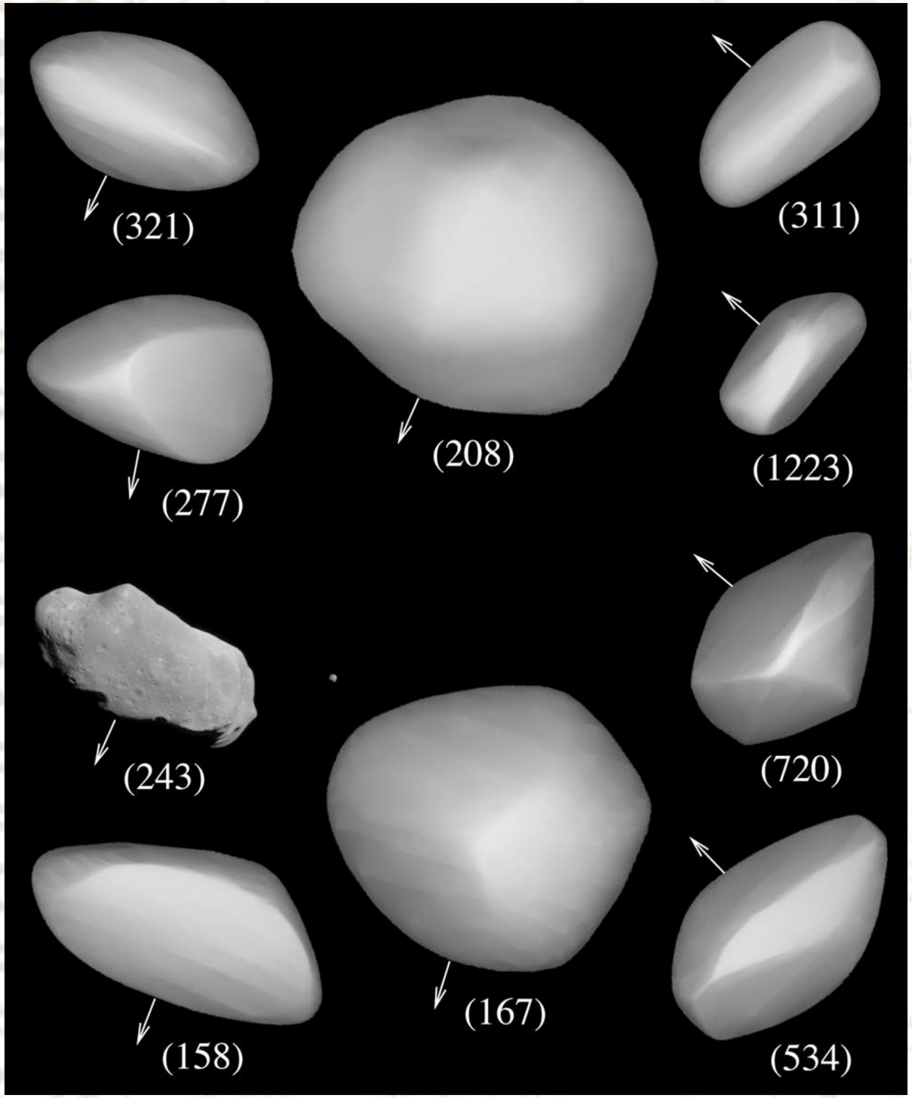
Shaps and pole solutions for

10,000

asteroids (Cellino et al)

#10,000 spin solutions: Implications

Spin vector alignement in the Koronis family



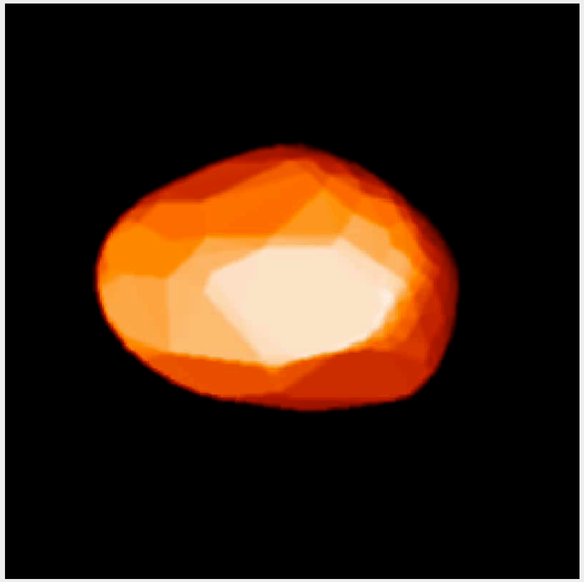
Slivan (2001); Vokrouhlicky et al. (2003)

- Spin properties: constraint to models of the collisional evolution of Main Belt asteroids.

Important applications:

- existence of preferential alignments of the spin axes of family members.
- Study of the strength of the YORP effect.

YORP: spin-up, spin-down and spin vector polarization
Cause: torque due to thermal emission and light reflection



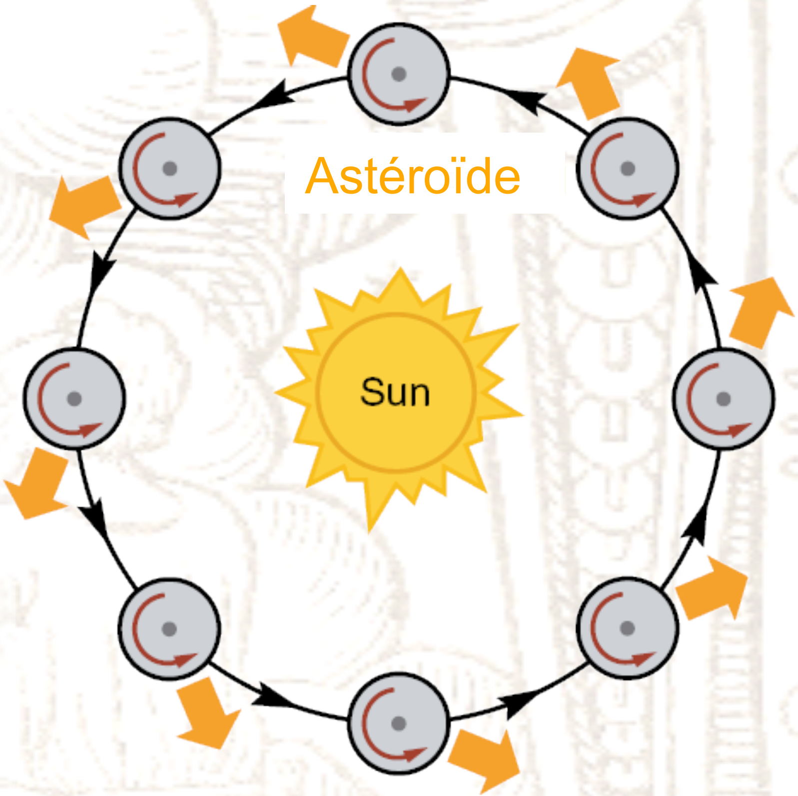
Link dynamics – physics of asteroids: Yarkovsky effect

***Yarkovsky* effect**

Force due to the thermal IR emission

⇓

Variation of the semimajor axis, *a*, of the orbit of an asteroid.



Size dependence of the Yarkovsky effect

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$da/dt \propto D^{-\xi}$, $0.6 < \xi < 1$

D = diameter

(Delbo & Tanga 08)

- Effects on the transport of near-Earth asteroids from the main belt

Delbo et al, 2007

Direct measurement of the Yarkovsky effect from **Gaia** asterometry for 15~30 near-Earth asteroids

Delbo, Tanga, Mignard 2008
Mouret et al. in preparation

Taxonomy of asteroids

Taxonomy classifies asteroids on the basis of visible and/or near-IR reflectance spectroscopy

In the Main Belt

C-type albedo ~ 0.05 - 0.10

S-type albedo ~ 0.10 - 0.25

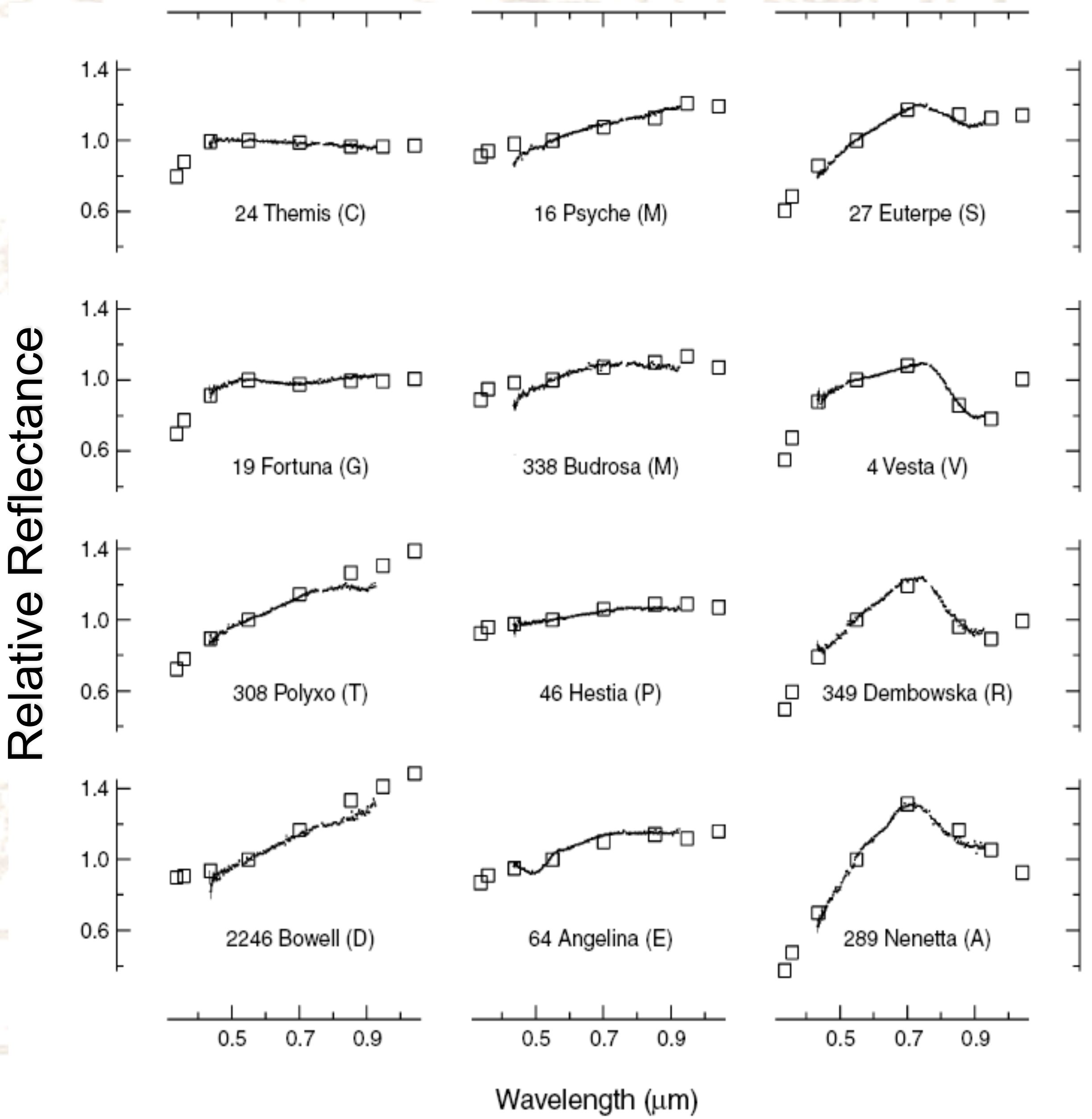
M-type albedo ~ 0.10 - 0.25

E-type albedo ~ 0.30 - 0.60

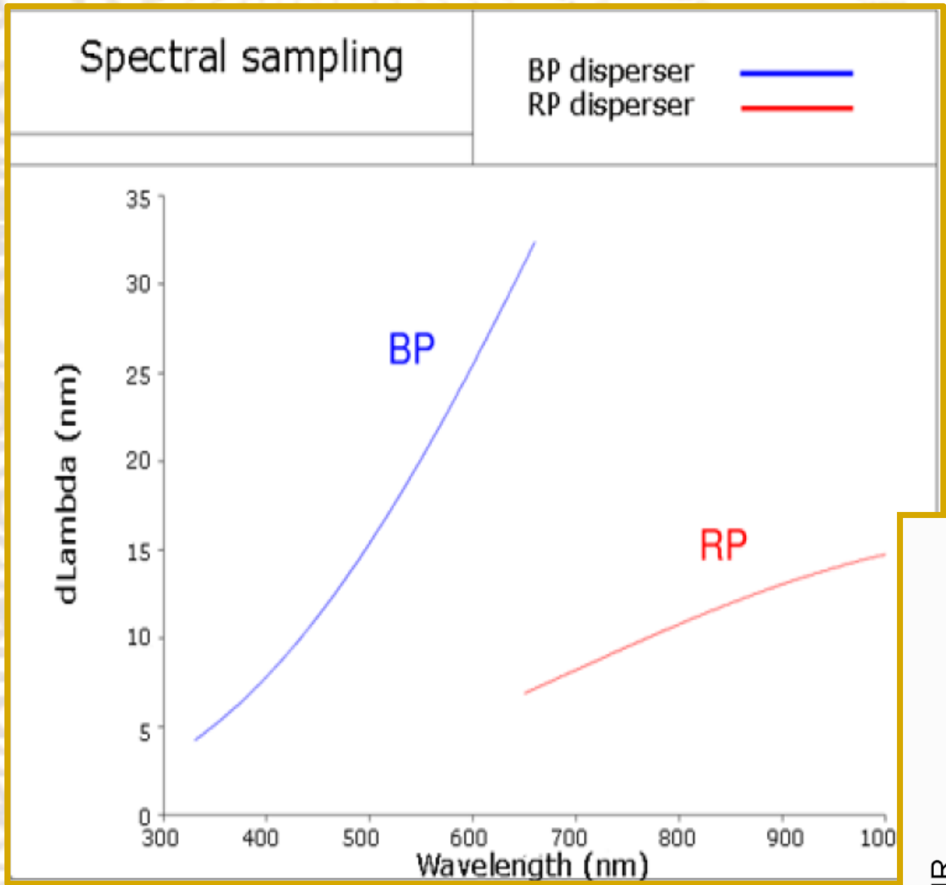
P-type albedo ~ 0.05 - 0.08

Link with meteorites

Bus & Binzel (2002) CCD spectra of 1500 asteroids

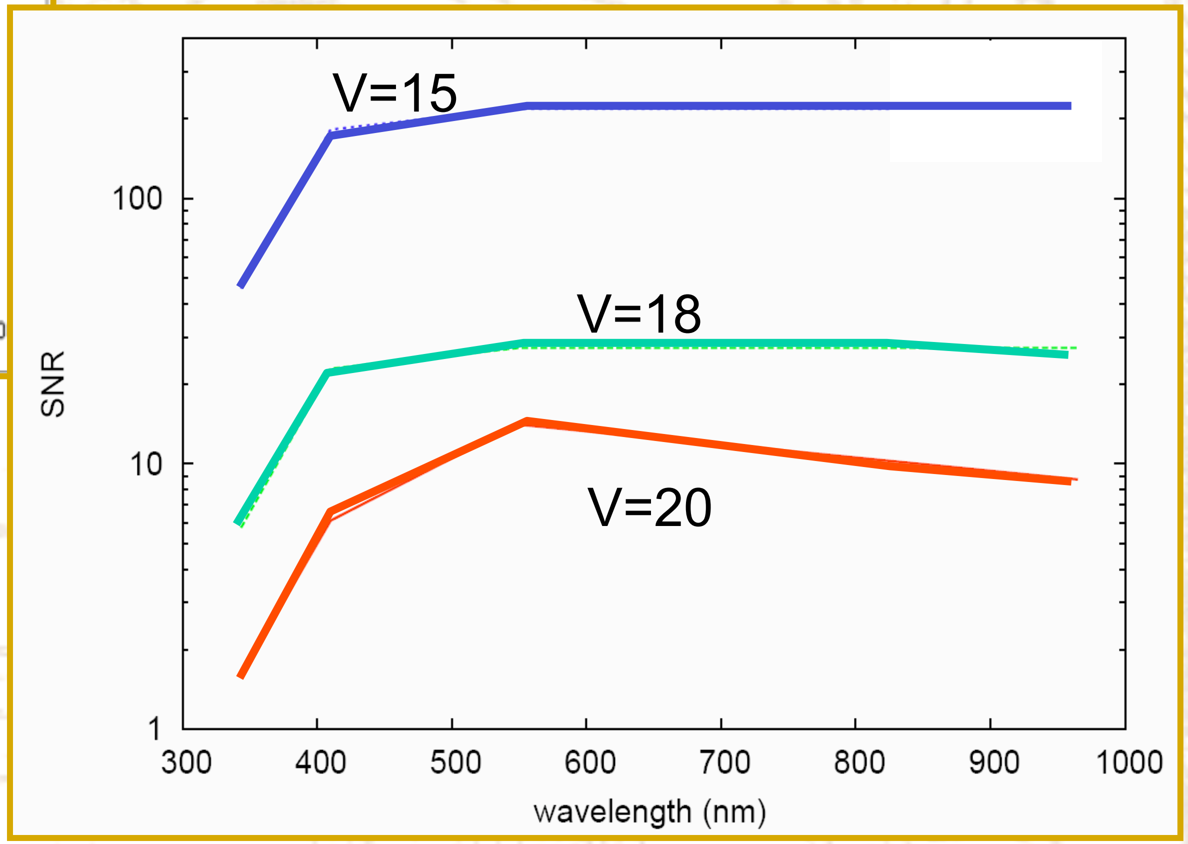


Gaia spectrophotometry: BP-RP



Gaia will obtain low resolution spectra of about 200,000 asteroids

Signal to noise ratio for Asteroid observations →



Conclusions

- 200,000 asteroids will be surveyed with repeated observations
- direct measurement of sizes for the largest 1,000 asteroids
- masses for about 100 bodies
- gross shapes and rotation states for 10,000 asteroids
- Spectroscopy → surface composition and space weathering effects

See the Review paper by

Mignard, F., Cellino, A., Muinonen, K., Tanga, P., Delbo, M., Dell'Oro, A., Granvik, M., Hestroffer, D., Mouret, S., Thuillot, W., Virtanen, J., 2008. The Gaia mission: Expected applications to asteroid science. Earth Moon Planets, Earth Moon and Planets 101, 97-125.