Gaia and the ground-based observations of the Solar System Objects

W. Thuillot (1) , P. Tanga (2) and D. Hestroffer (1)

(1) IMCCE, Observatoire de Paris
(2) Cassiopée, Observatoire de la Cote d'Azur

Why ground-based observations ?

www.oca.eu/tanga/GaiaEarthBased

- Solar System Objects = important part of the Gaia mission

- GB observations combined with the space observations: a unique support for completing the Gaia data.

- Workshop in Beaulieu/mer (Nice) in October 2008 :
26 participants (France, Russie, Ukraine, Turkey, Czech rep., Poland)

- Different aspects of the ground-based observations

WORKSHOP PROGRAMME

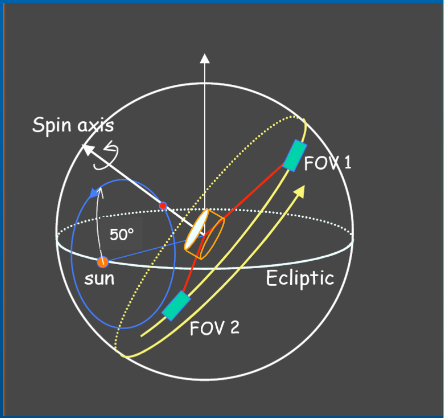
1. Introduction: the Gaia mission - need of ground-based support
2. Ongoing activities - short presentations and reports
3. Dynamics and ground-based astrometry
4. Physical properties
5. Stellar occultations
6. Satellites
7. Comets
8. Discussion: campaigns, coordinated actions

Asteroids

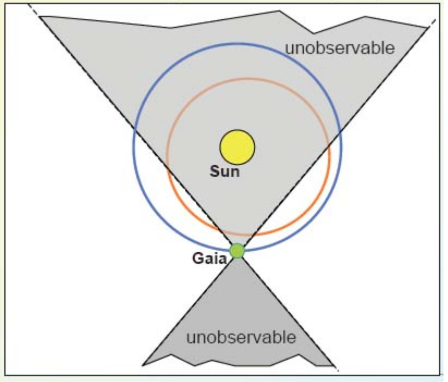
Gaia Solar System Observations

P. Tanga

- Gaia data for asteroids (prec. Singl meas.: 0.1-1 mas)
- 250 000 asteroids (most known)
- including several NEAs, Trojans, Centaurs
- Comets
- Small natural satellites



- Low Solar elongations 45 deg.
- IEAs (Inner Earth Objects)



Gaia Solar System Observations

P. Tanga

Gaia + GB observations (before, during, after)

- Masses determination

  40 σ<60% (Mouret et al. 2007) → 100 σ<15%

  GB obs. → +25

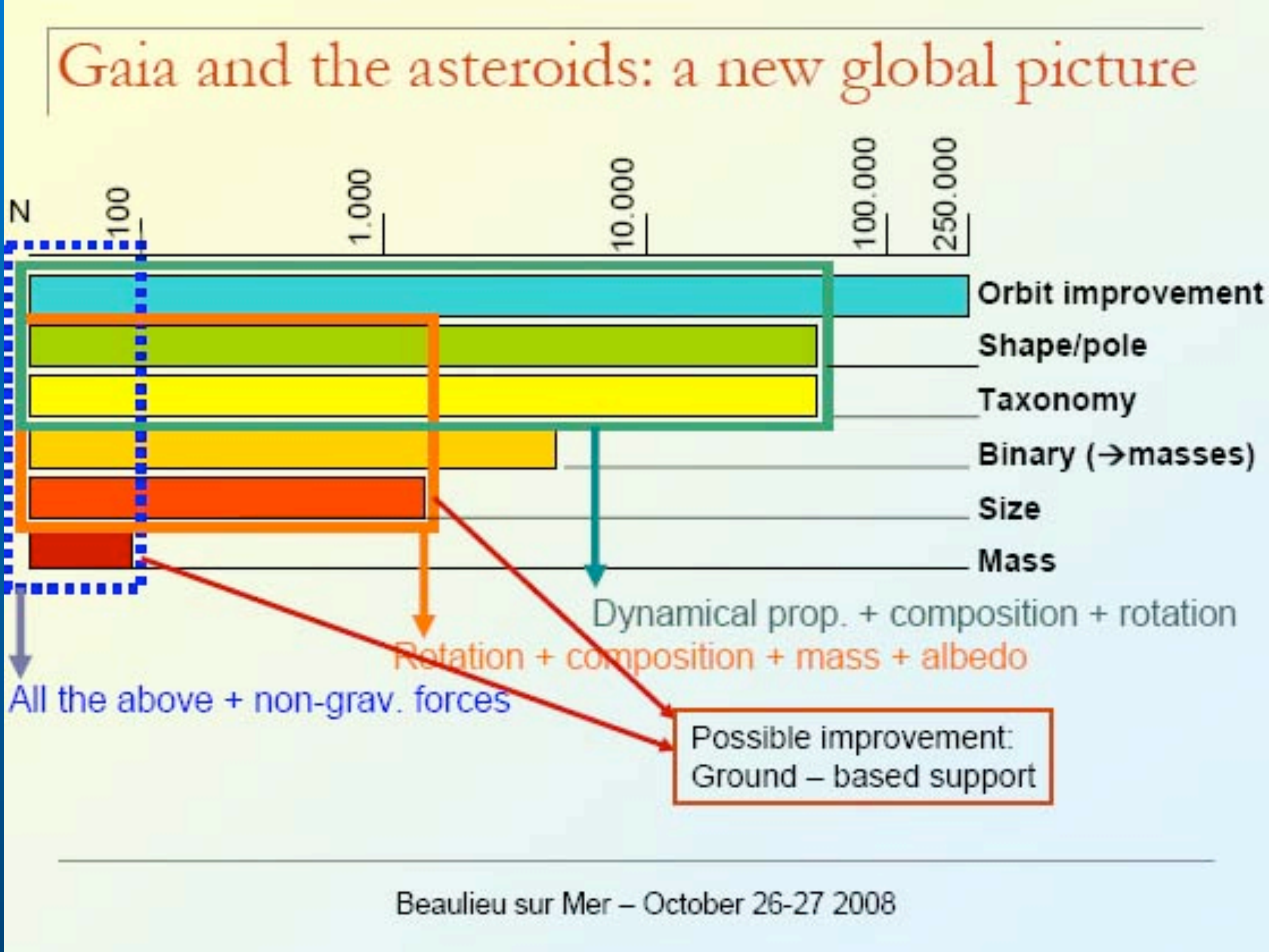
- Bulk density

  Gaia + HAR (interf./ AO)

- Yarkovsky acceleration :

  0.1 mas

  ~ 50?



Gaia and the asteroids: a new global picture

Dynamical prop. + composition + rotation

Rotation + composition + mass + albedo

All the above + non-grav. forces

Possible improvement:
Ground – based support

Beaulieu sur Mer – October 26-27 2008

Observations of NEOs from the ground

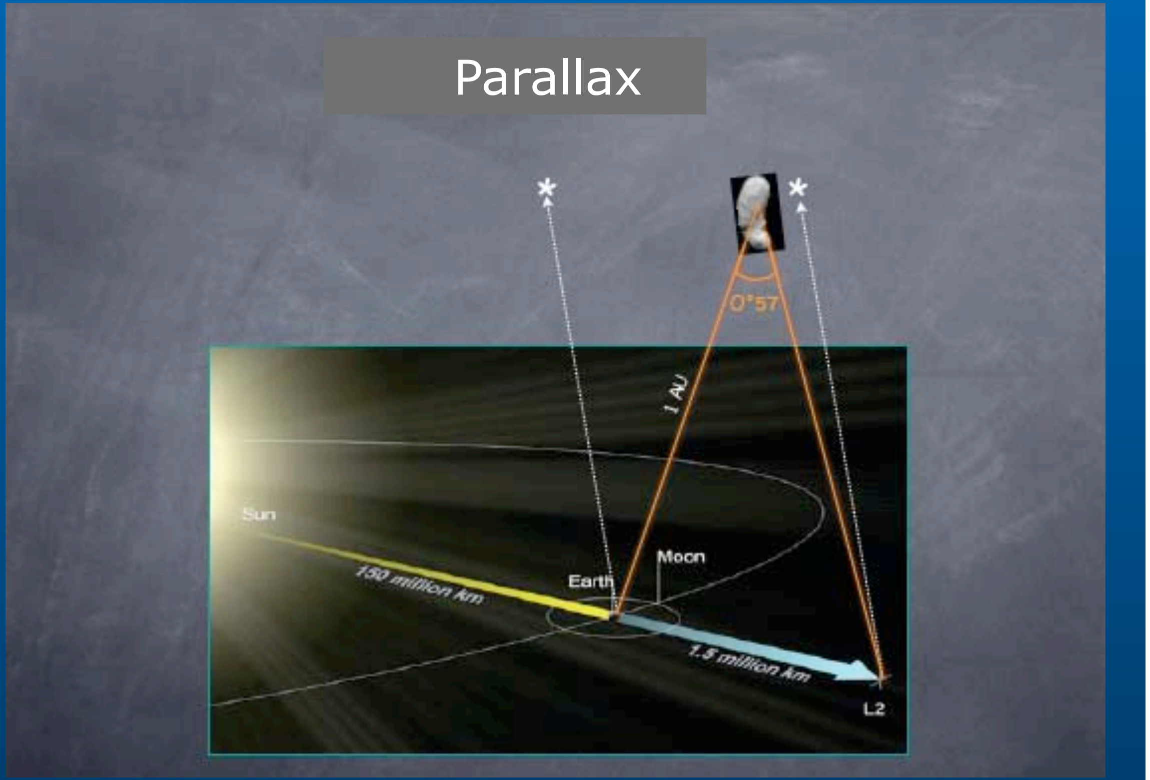
D. Hestroffer et al.

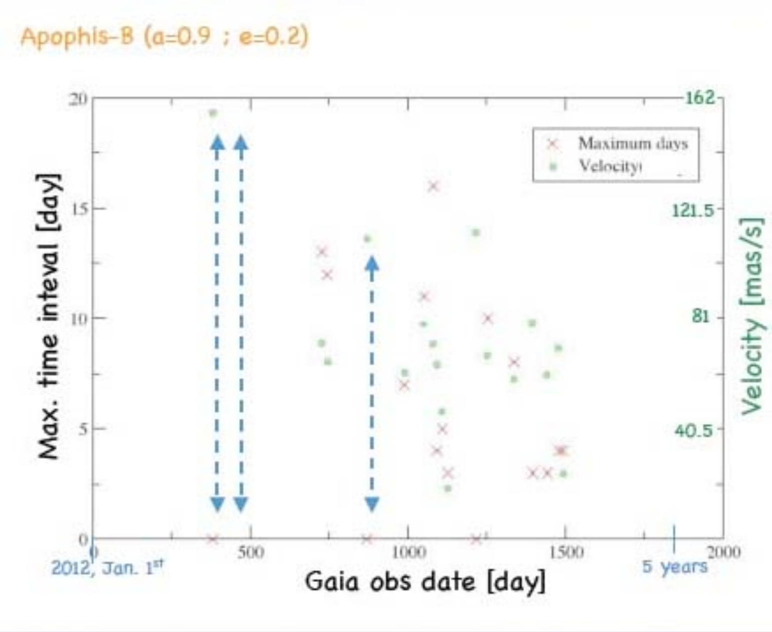
Limiting mag. 20, high excentricity, mean interval between two Gaia obs : 30 days,…

→ GB obs. necessary

- Exploring the problem of the parallax effect to retrieve a NEO from the ground

- First attempts by J. Frouard, new approach by D. Bancelin (IMCCE)



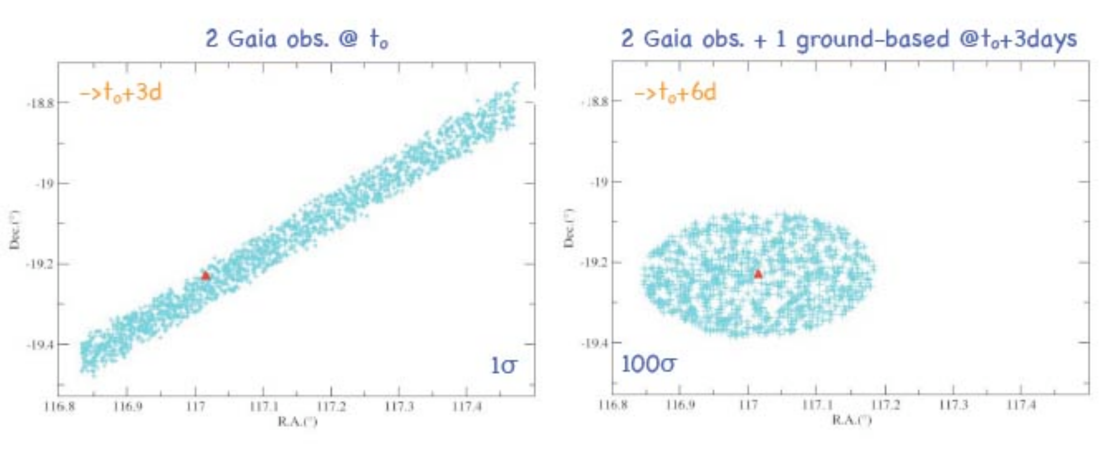


- sample of Gaia observations clone of Apophis (e= 0.2 a=0.9AU)
- parallax correction → geoc.

- 4 days = mean duration when uncertainty > 14 arcmin

- Orbital prediction with low number of observations
- Väissälä statistical ranging

- GB obs can reduce uncertainties for next observations after detection

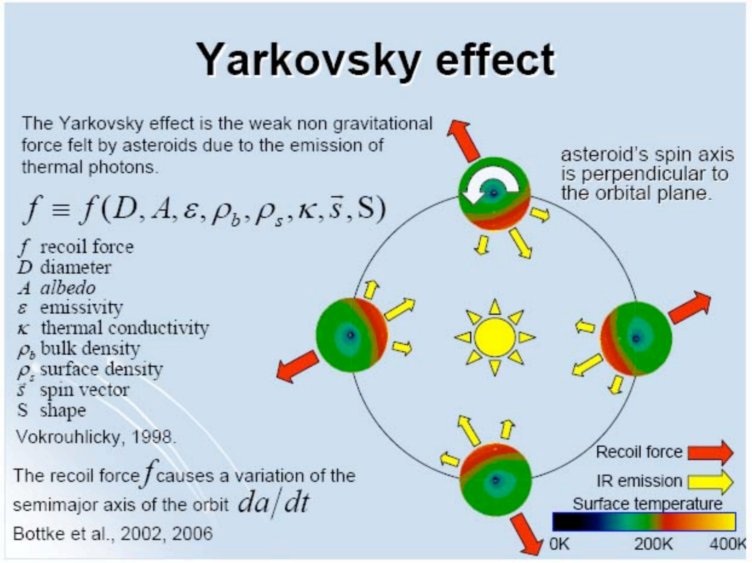


The Yarkovsky effect on Near-Earth asteroids with Gaia

M. Delbo et al.

- Yarkovsky effect depends on the size, spin vector, thermal properties, …

- Direct detection:
  (6489) Golevka
  1992 BF



Yarkovsky effect

The Yarkovsky effect is the weak non gravitational force felt by asteroids due to the emission of thermal photons.

$$f \equiv f(D, A, \varepsilon, \rho_b, \rho_s, \kappa, \bar{s}, S)$$

f recoil force
D diameter
A *albedo*
ε emissivity
κ thermal conductivity
ρ_b bulk density
ρ_s surface density
$\bar{s}$ spin vector
S shape

Vokrouhlicky, 1998.

The recoil force f causes a variation of the semimajor axis of the orbit da/dt

Bottke et al., 2002, 2006

asteroid's spin axis is perpendicular to the orbital plane.

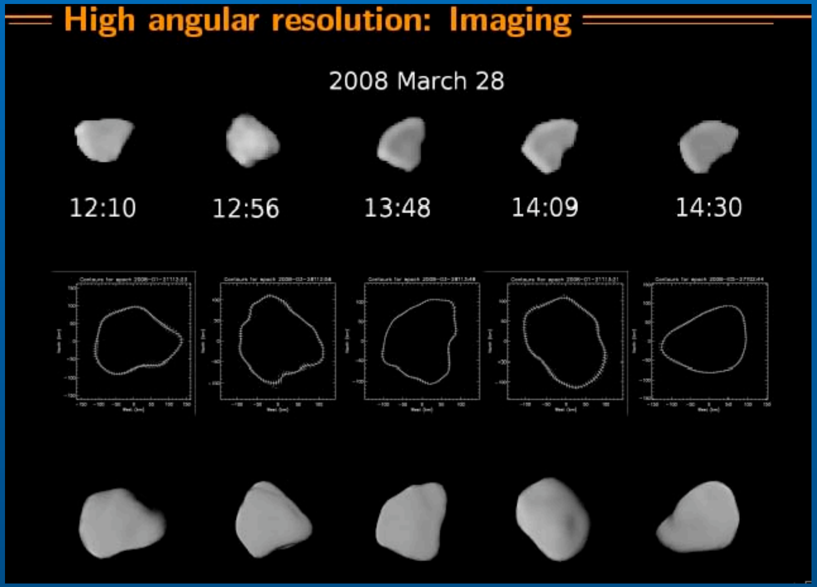
- Gaia astrom. will allow the detection of the YE for ~ 30-50 NEAs
- Gaia+ Radar astrometry: + 60 NEAs
- Size measurements (HRA observations,…) give access to bulk density and internal structure

High Angular Resolution observations support to Gaia mission

B. Carry

- HAR Imaging (ESO-VLT, 50 mas)
- Calibration (tailles)
- Photocenter offset / Barycenter

- 57 targets (Gaia mass determ.)
- density measurement
- taxonomy/density
- albedo distribution
- duplicity

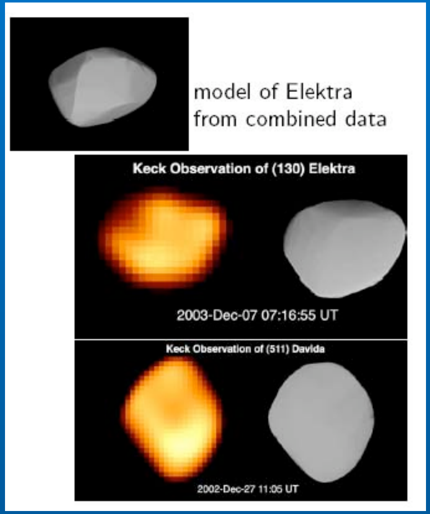


High angular resolution: Imaging

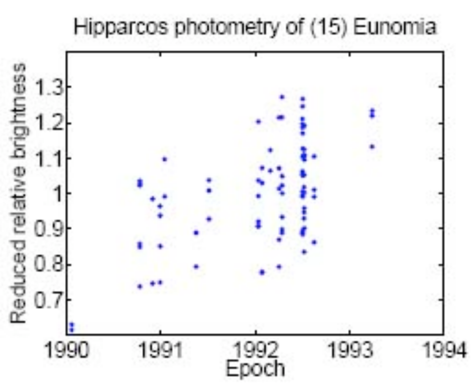
2008 March 28

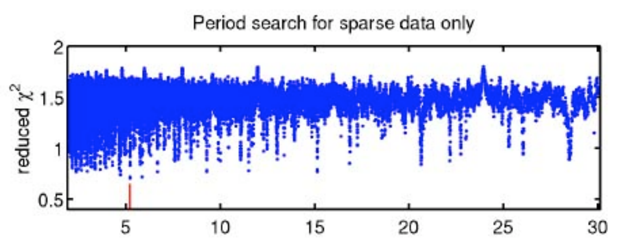
Asteroids models from Gaia photometry and complementary data

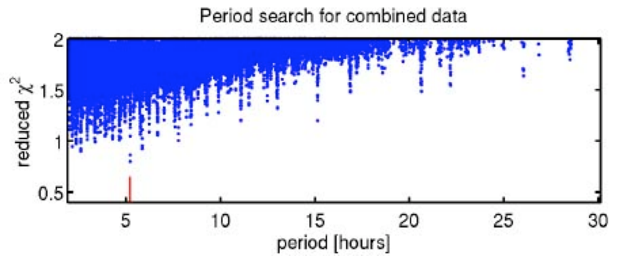
J. Durech


model of Elektra from combined data

- Inversion problem
- Gaia photometry : small number of derived models of asteroids
- Sparse data : need of complementary data from GB observations for inversion process
- sub-critical number of data, pole ambiguity, improvement of the model,…





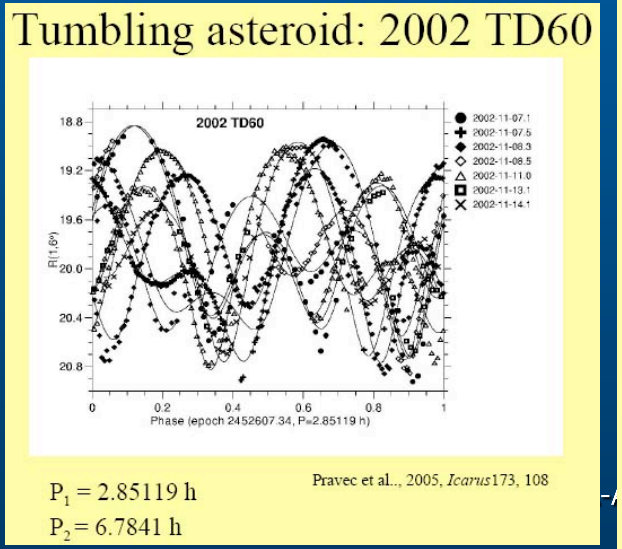


Asteroids with unusual lightcurves-photometry from Gaia and ground-based telescopes

T. Michalowski

- case of double asteroids and tumbling asteroids

- use of GB data for the interpretation of unusual lightcurves photometry

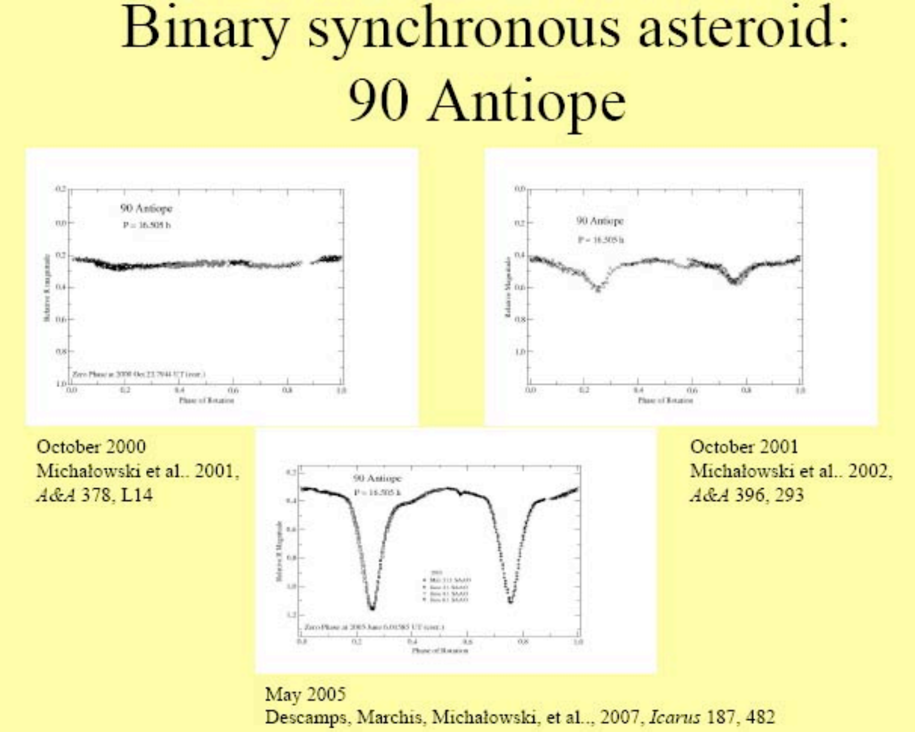


Tumbling asteroid: 2002 TD60

$P_1 = 2.85119$ h

$P_2 = 6.7841$ h

Pravec et al.., 2005, *Icarus* 173, 108



Binary synchronous asteroid: 90 Antiope

October 2000
Michałowski et al.. 2001,
A&A 378, L14

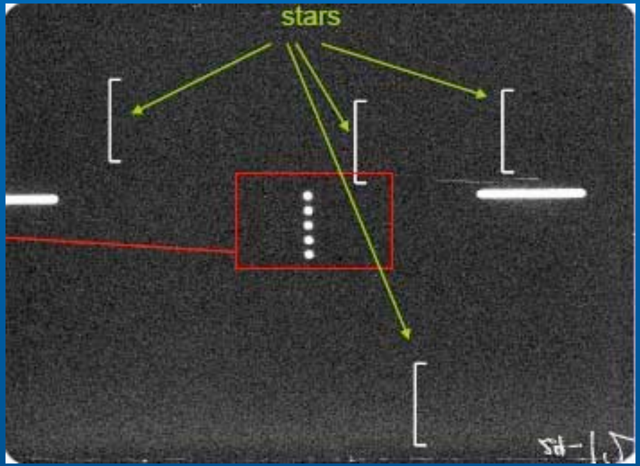
October 2001
Michałowski et al.. 2002,
A&A 396, 293

May 2005
Descamps, Marchis, Michałowski, et al.., 2007, *Icarus* 187, 482

Natural satellites

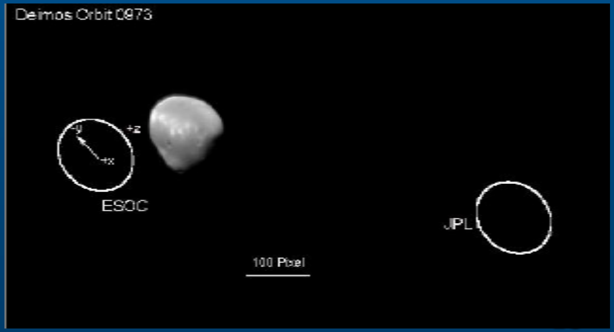
Natural satellites dynamics: what Gaia will bring

V. Lainey



- Gaia stellar catalogue / Gaia satellites observations

- Extended period of accurate re-reduced positions: better determination of tidal effects, planetary precession,…(Jupiter, Saturn)

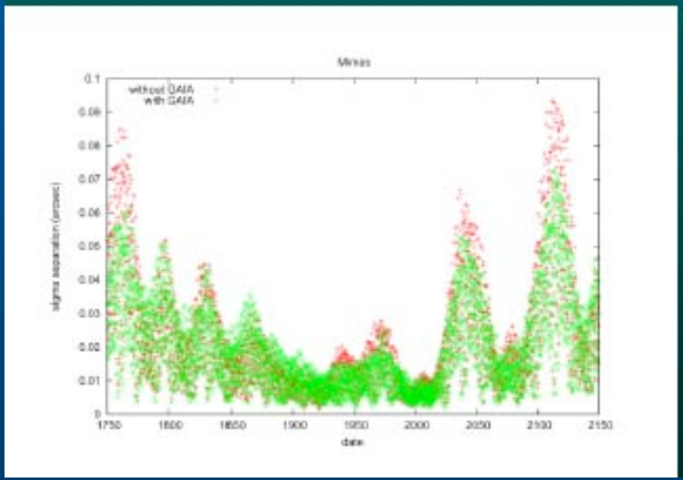


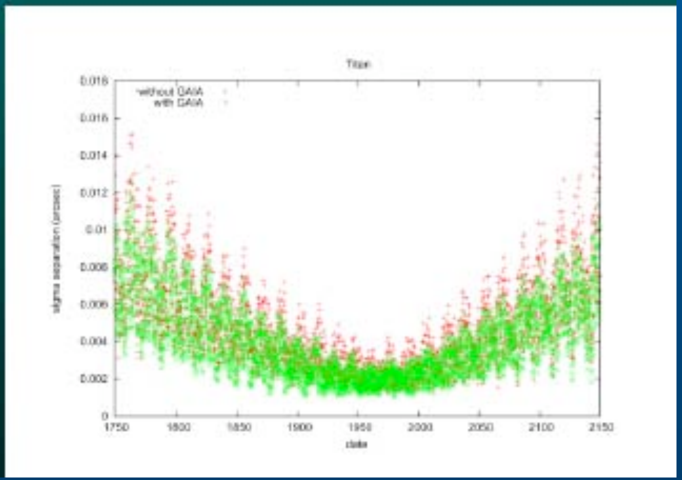
- Gaia astrometry of Martian, Uranian moons combined with other space data (MXpress, Cassini, Voyager): improvement of the dynamical parameters

What observations are to be made with gound-based telescopes in the framework of Gaia

J. Desmars, J.E. Arlot

- Natural satellites : Mimas,Titan (130 000 GB obs >1874@600mas)
- Study of the propagation of error
- Simulation of Gaia obs. on the 2012-2017 period (50@1mas)
- Modest improvement of precision of the model
- Too short interval of time vs. inequalities to modelize



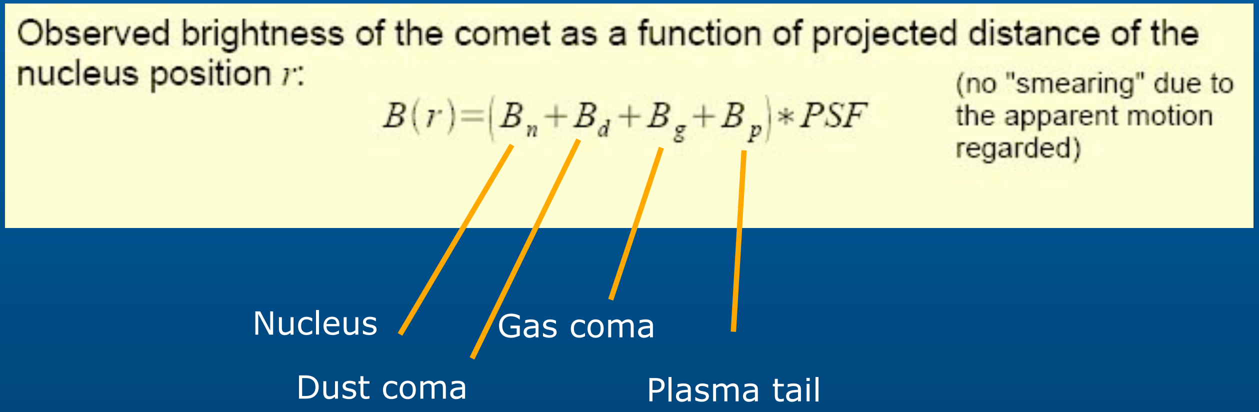


Comets

Comet simulations for Gaia

M. Weiler

- Gaia potentially will observe the comets currently discovered
- Gaia comet observations need to be simulated
- A simple but physical model is basically available
- The model will soon be available for simulations with GIBIS



Observed brightness of the comet as a function of projected distance of the nucleus position r:

$$B(r)=(B_n+B_d+B_g+B_p)*PSF$$

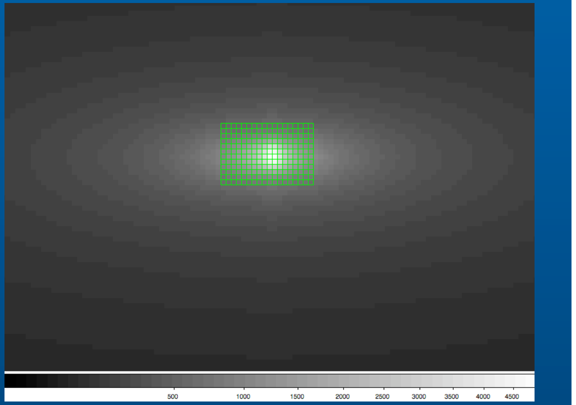
(no "smearing" due to the apparent motion regarded)

Nucleus

Dust coma

Gas coma

Plasma tail



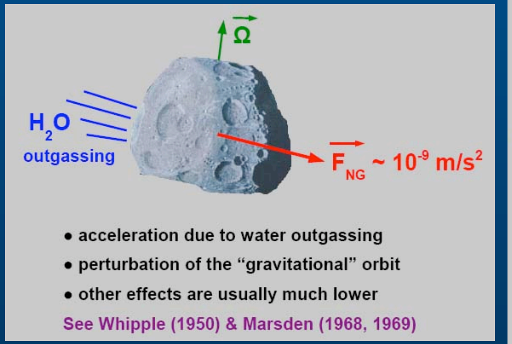
Non gravitational forces in comets

F. Colas et al.

- Gaia is not well suited for comets

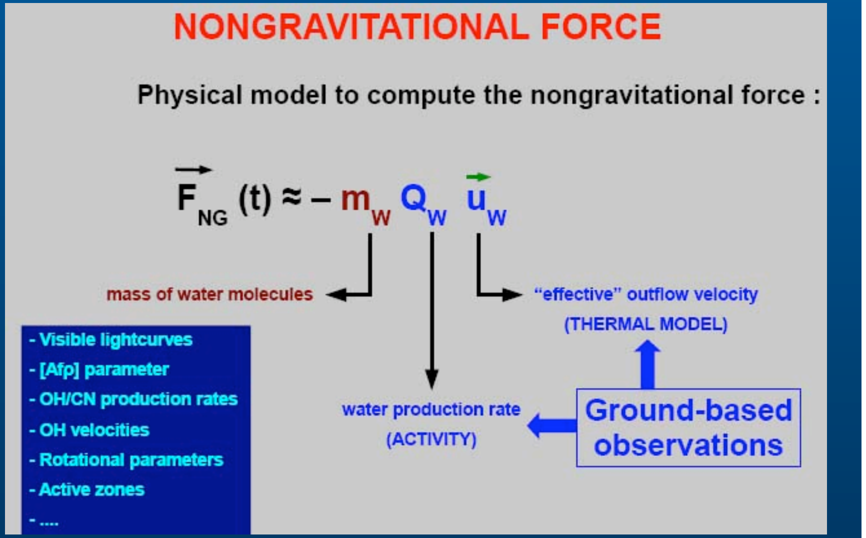
- If Gaia can give accurate astrometry, ground-based obs. are necessary to compute the NG forces

- Mass can be deduced from the measurement of NG forces



- acceleration due to water outgassing
- perturbation of the "gravitational" orbit
- other effects are usually much lower

See Whipple (1950) & Marsden (1968, 1969)



NONGRAVITATIONAL FORCE

Physical model to compute the nongravitational force :

$$\vec{F}_{NG}(t) \approx -m_W\, Q_W\, \vec{u}_W$$

mass of water molecules

"effective" outflow velocity (THERMAL MODEL)

water production rate (ACTIVITY)

Ground-based observations

- Visible lightcurves
- [Afp] parameter
- OH/CN production rates
- OH velocities
- Rotational parameters
- Active zones
- ....

Stellar occultations

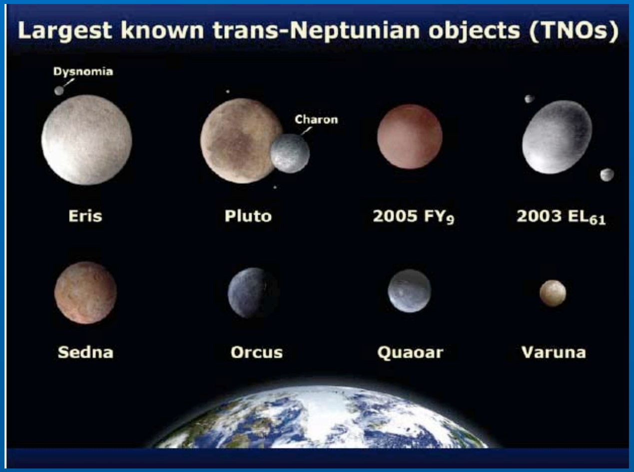
(TNOs, asteroids, satellites)

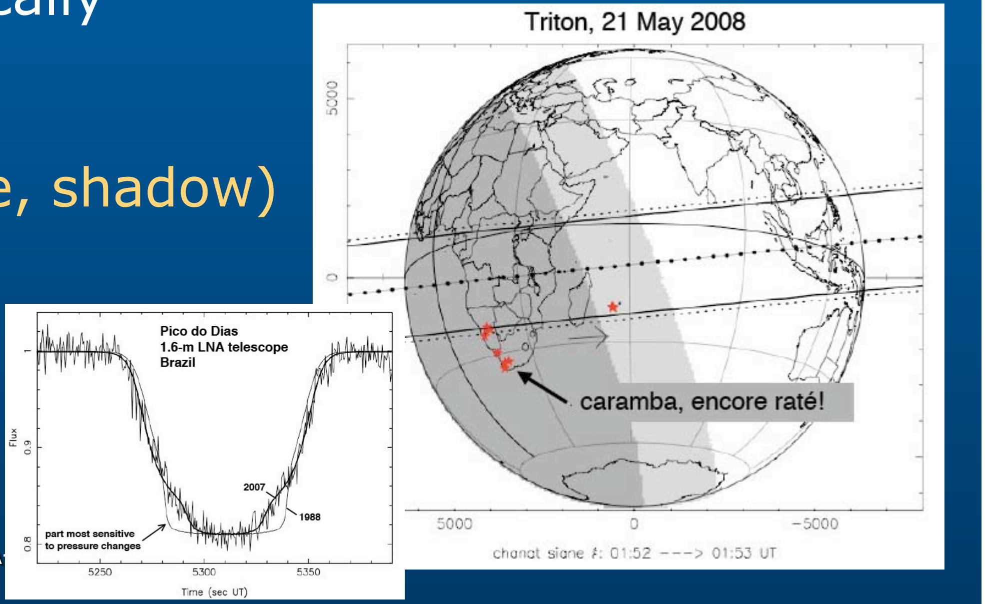
Probing remote Solar System bodies with stellar occultations

B. Sicardy

- Occultation : powerful method
- Planetary atmospheres
- Size, shape
- Natural satellites, Pluto, TNOs (100mas diam.)

- Gaia stellar catalogue will drastically improve the predictions:
  - ✓At 90% level for large TNOs
  - ✓Deployment of stations (edge, shadow)
  - ✓TAC: access faint stars
  - ✓Increase number of events

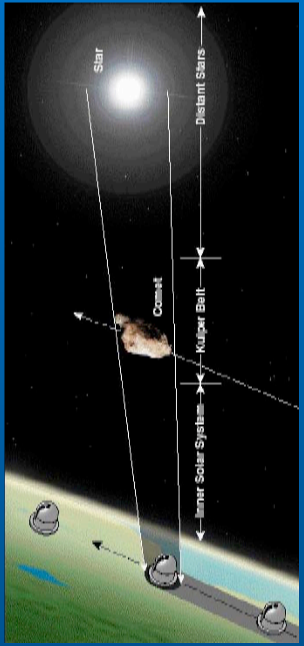


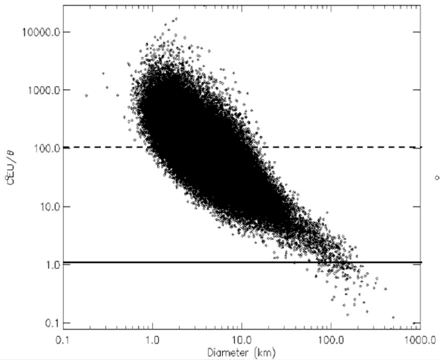


Stellar occultations after Gaia

P. Tanga

- Stellar occultations by asteroids
- Today poor predictability for objects < 50km

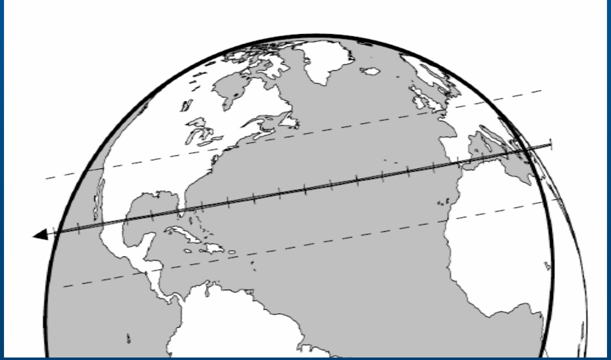




Predictions using the Gaia stellar catalogue

- 1m telescope: ensure 20-40 events/year for 20km diam.

- Network: completness of diameters>20km in a few year



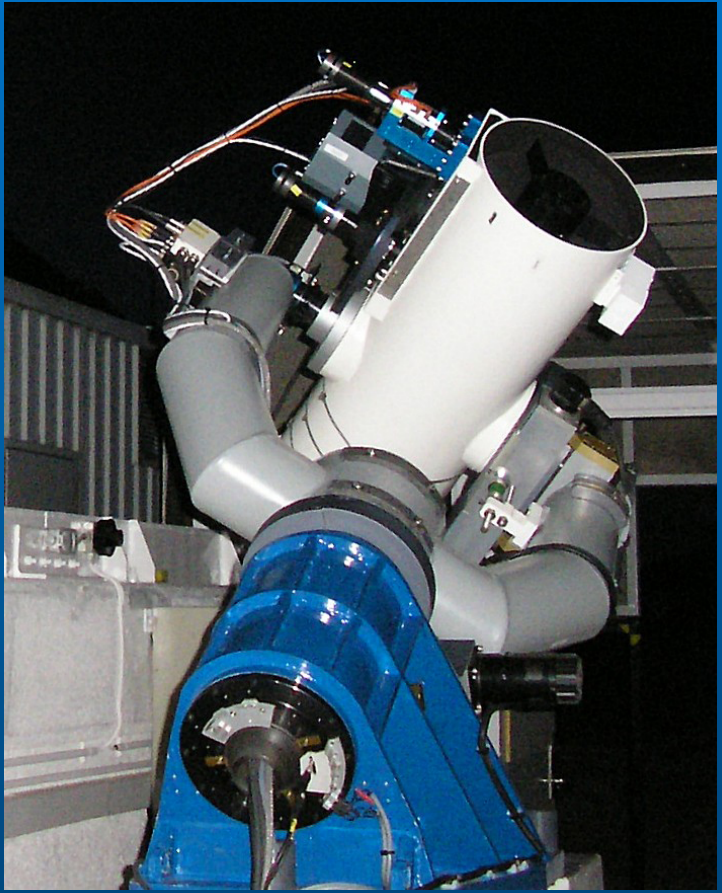
Ground-based facilities

Experiences in Automated Observing

A. Klotz, CESR

- Automatic/Robotic telescopes
- TAROT 1, TAROT2
- Network of rob. Tel.

✓ GRB
✓ RR Lyrae
✓ Eclipsing stars
✓ Stellar occultations
✓ Asteroids: characterization
✓ NEAs



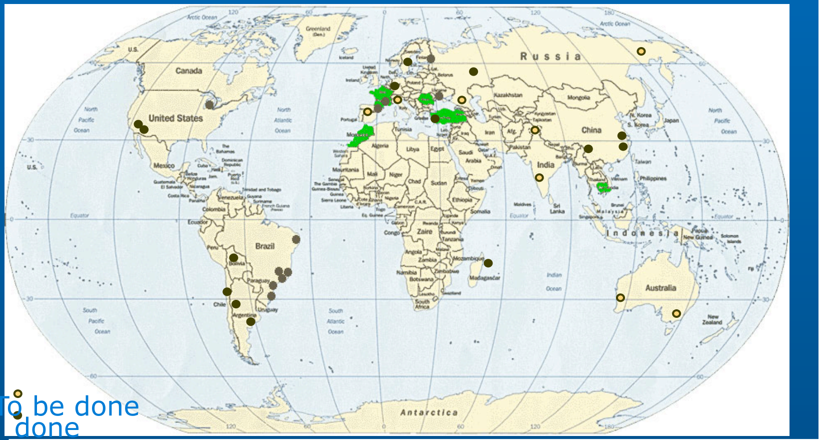
An alert network for supporting Gaia asteroid observations

W. Thuillot

CU4-DU 459 GB follow-up network

1. to avoid to loose an object
2. to follow up an object with critical behaviour

- to ensure observations on alert
- to ensure astrometric precision
- to apply a GB strategy after detection from space
- to ensure a coordination



○ To be done
● done

- 24 candidate sites
- 32 telescopes (0.25 to 2.4 m)

Workshop conclusions

Thanks to GB observations: the estimate of physical and dynamical parameters of Minor Bodies will be improved:

- Asteroid astrometry : mass, dynamical effects, follow-up of Gaia discov.
- Photometry: shape determination from inversion of lightcurves - ambiguity context (pole orientation)
- High Angular Resolution (AO) and Stellar occultations: sizes and shapes for bodies with mass determined by Gaia. Access to the bulk density and estimate of Yarkovsky effect.

- Robotic telescopes and meter-class tel. are well suited for astrom. and photom. for some complementary obs. Anf follow-up

- The Gaia stellar catalogue will have an important impact on: astrometric meas. of ancient obs. of natural satellites, stellar occultation predictions :

strong interest to access intermediate releases

Earth-based support to Gaia Solar System science

Beaulieu sur Mer - October 27-28, 2008

Scientific Organizing Committee

P. Tanga	*OCA*
D. Hestroffer	*IMCCE*
M. Delbo	*OCA*
F. Mignard	*OCA*
W. Thuillot	*IMCCE*

Acknowledgements/Remerciements

- Action specifique Gaia
- CNRS
- Cassiopee, Observatoire de la Cote d'Azur
- IMCCE, Observatoire de Paris
- Equipes de gestion des laboratoires