Institut de Mécanique Céleste et de Calcul des Éphémérides

Test of GR & ref. frames linking from Gaia obs. of asteroids

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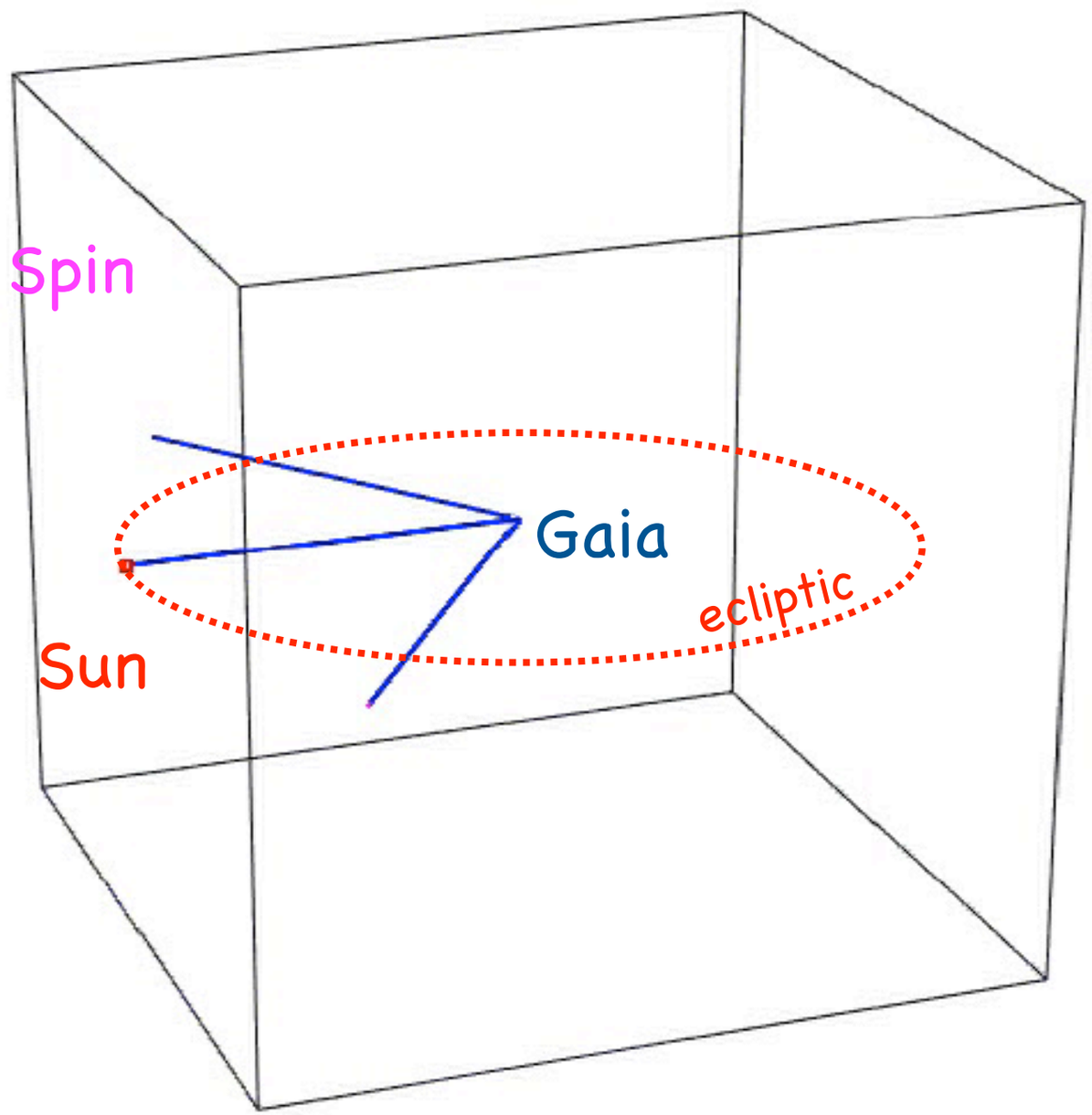
Outline

- The Gaia mission and observations of asteroids
- Orbit improvement — Variance analysis
  - ★ Asteroid mass
  - ★ Tests of GR
  - ★ Reference frames
- Results and prospective

Gaia Mission

- Launch - end 2011 ; operation - 5 years at L2 point
- Scanning the whole sky (≈60 obs./SSO target)
  no input catalogue
- Instruments
  - ★ spectroscopy (V<17)
  - ★ photometry (V<20)
  - ★ astrometry (V<20)
- About 300,000 asteroids (satellites, comets)

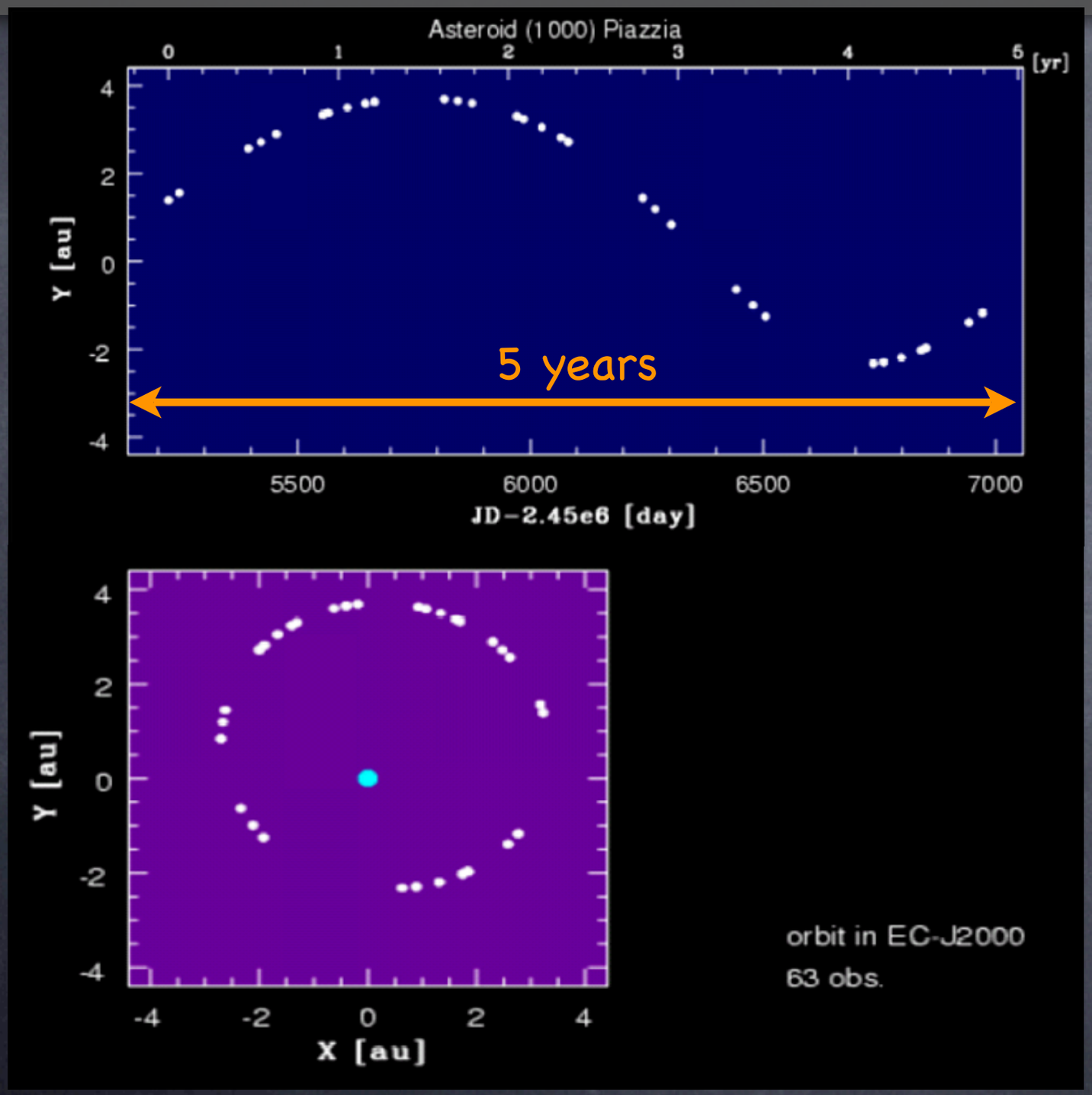
Gaia Mission



(L. Lindegren)

- 1 sky coverage after 6 months
- global astrometry

Gaia Mission



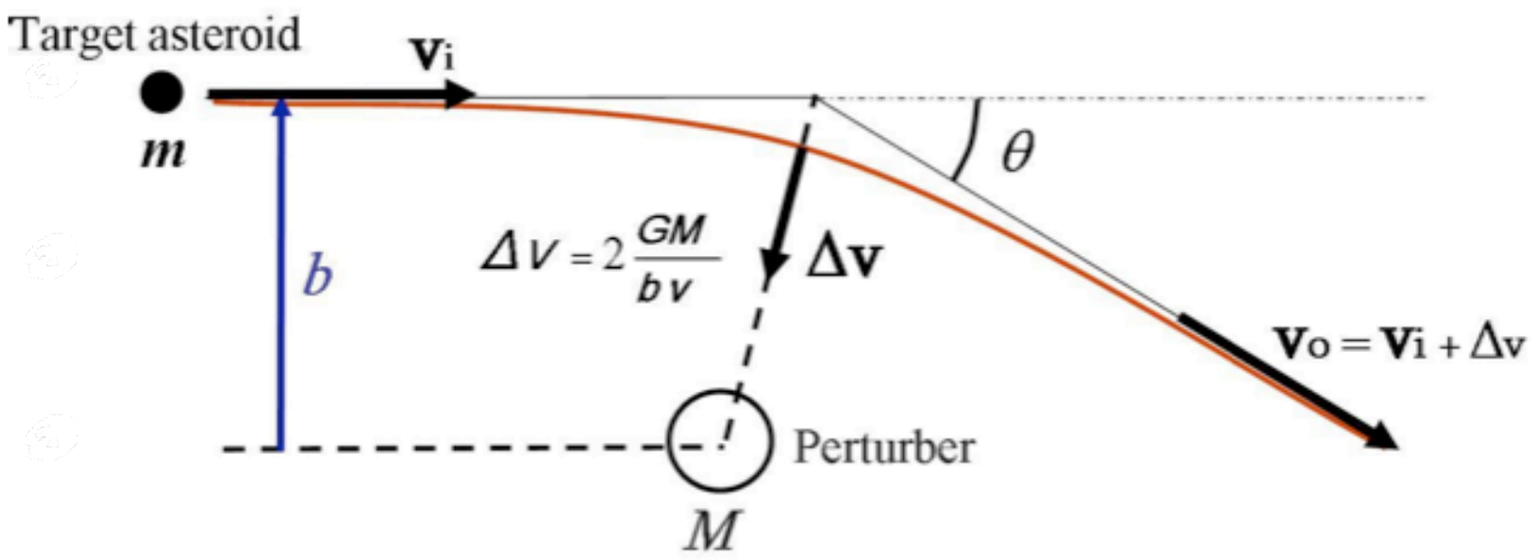
- Time and space distribution of observations
- A typical main-belt asteroid
- Not the same for all NEAs or Centaurs

Observations of asteroids

- Essentially one dimensional astrometry λ on osc. great circle ; precision ≈ 0.3—3 mas (restrictive)
- Observations in a homogeneous frame tied to QSOs (kinematically non-rotating)
- Observations down to low elongations (45°)
- **¡ GAIA not optimised for asteroids or NEOs !**

Asteroids Mass

- Binary asteroids (resolved)
- Close encounter ; deflexion



$$\tan\frac{\theta}{2} = \frac{G(m+M)}{v^2 b}$$

Fig. 10. Impulse approximation of a small target asteroid perturbed by a larger one. v_i and v_o are respectively the incoming and outgoing velocity vector. The effect of the perturbation is expressed by the vector Δv.

Asteroids Mass

- Binary asteroids (resolved)
- Close encounter ; deflexion
- Selection of perturbers/targets
- All perturbers and targets treated together
- ≈50 asteroids with $\sigma(m)/m \leq 10\%$
- Comparison to taxonomy ; porosity
- Influence on dynamics and ephemerides of Mars

Asteroids Mass

(simulation **with only** 20.000 asteroids — 544 perturbers)

N° Name	σ(m)	Mass m	σ(m)/m
4 Vesta	9.29E-14	1.3 E-10	0.07
1 Ceres	3.50E-13	4.5 E-10	0.08
14 Irene	1.03E-13	2.6 E-11	0.40
27 Euterpe	5.14E-14	1.0 E-11	0.51
10 Hygiea	3.25E-13	4.7 E-11	0.69
52 Europa	2.19E-13	2.4 E-11	0.91
2 Pallas	1.28E-12	1.3 E-10	0.98
15 Eunomia	2.79E-13	3.0 E-11	1.86
46 Hestia	2.25E-14	1.2 E-12	1.88
511 Davida	6.17E-13	3.0 E-11	2.06

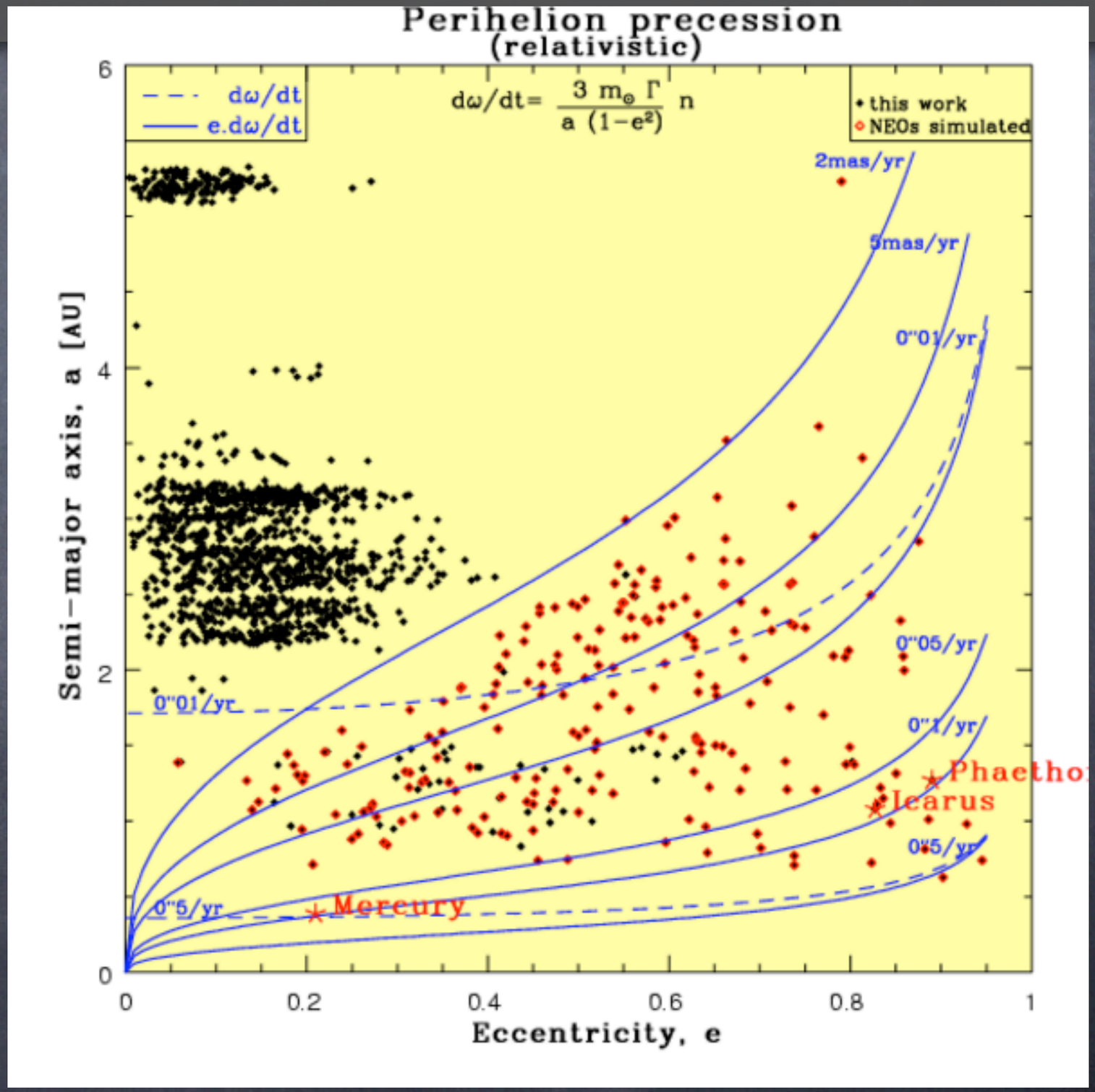
σ < 0.1 %

σ < 1 %

Presently unknown

Test GR

- NEOs
- Orbit sensitivity
- Precession of ω
  - ★ Solar J2
  - ★ PPN β
- Catalogue NEOs not complete
  => 3 sets A,B,C



Test GR

Gaia ≈850 NEOsim	β global	J_2 global	correl. global
set A	4E-4	.5E-8	0.85
set B	4E-4	1.1E-8	0.11
set C	5E-4	1.3E-8	0.68

- J_2 to 1.E-8 (≈10%) β to 5.E-4 separately

Reference Frames

- optical ICRF
  - ★ short time series
  - ★ homogeneous North-South
- asteroids
  - ★ observed in Gaia 'opt. ICRF' wrt Earth
  - ★ computed in dynamical wrt barycenter
- O-C = f rotation Ω and rotation rate $d\Omega/dt$

Reference Frames

	$\dot{G}/G$ [yr^{-1}]	$\Omega_{x\text{-}y\text{-}z}$ [μas]	$d\Omega/dt$ [μas/yr]
Gaia (20,000 obj.)	5.6E-12	12-12-31	3-3-12
Gaia (350,000 obj.)	2E-12	5-5-14	1-1-5
LLR (Williams et al. 2004)	9E-13	—	100
`Radar' (Pitjeva et al. 2005)	5E-14	—	—

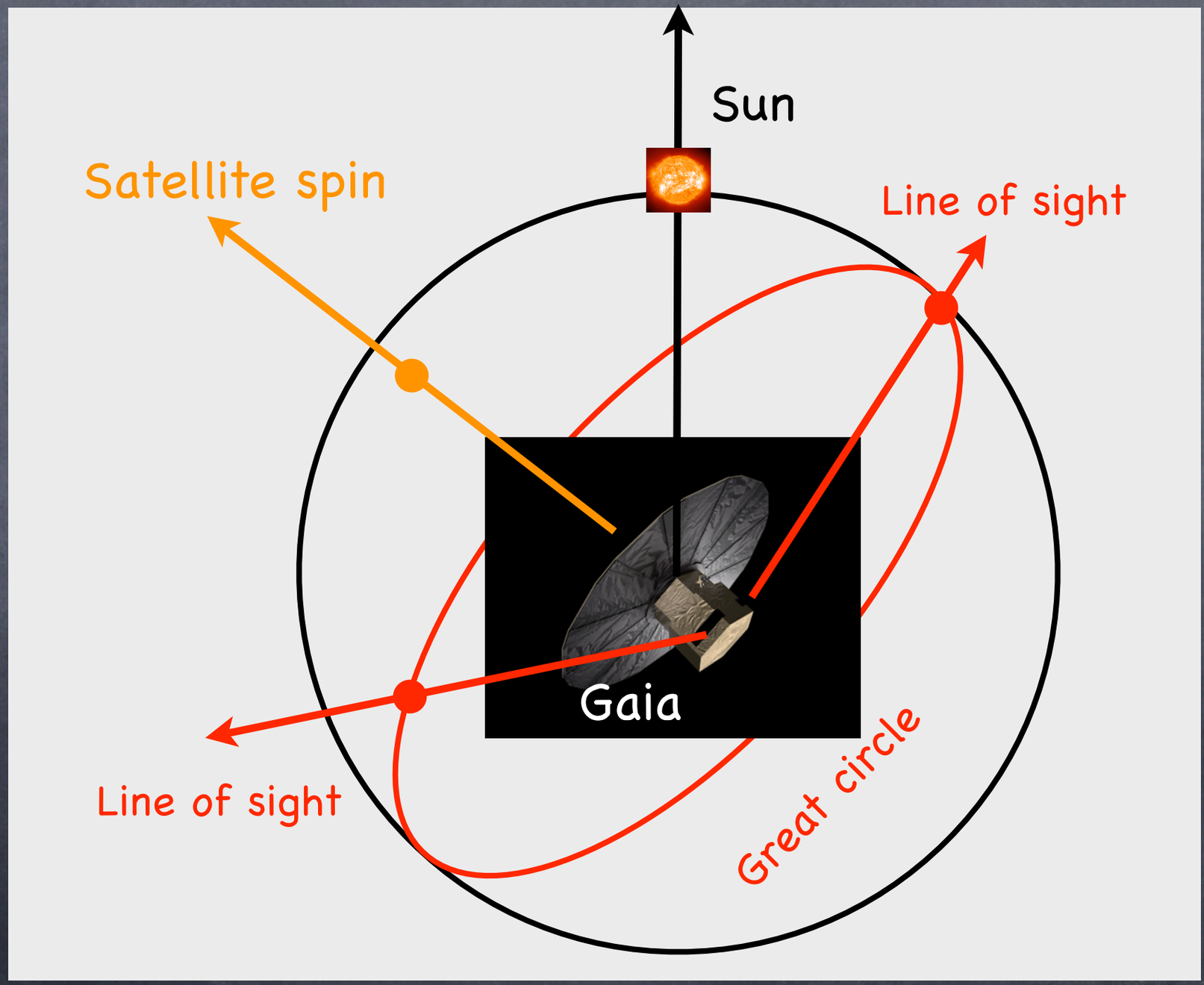
1 μas/yr ≈ 5.E-12 rad/yr

Results & Perspective

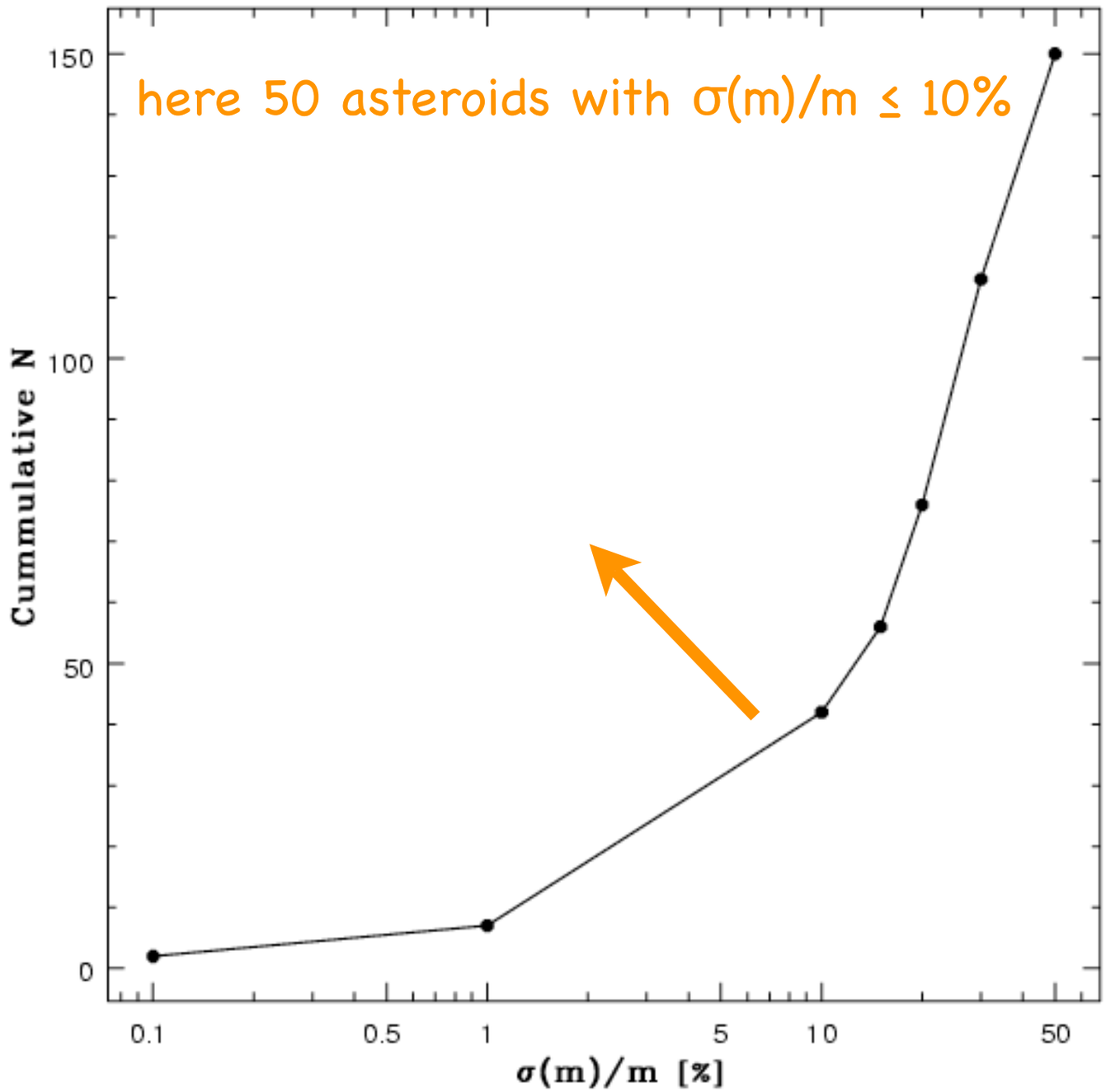
- Ephemerides of the Earth (for orientation of the ecliptic, not rotation rate)
- Non gravitational effects, and other systematic effects (observation and model)
- Possible test of SEP and varying PPN
- Larger set of targets for mass; Effects on Mars

Acknowledgements: Gaia teams CU2-3-4

Gaia Mission



Asteroids Mass



- 20,000 asteroids 544 perturbers
- 300,000 ast.
  => 3x more targets

Masses from Gaia

(simulation 20.000 asteroids)

Number of perturbers	
Total	544
$\sigma(m)/m < 0.1\%$	2
$\sigma(m)/m < 1\%$	7
$\sigma(m)/m < 10\%$	42
$\sigma(m)/m < 15\%$	56
$\sigma(m)/m < 20\%$	76
$\sigma(m)/m < 30\%$	113
$\sigma(m)/m < 50\%$	150

- Currently 35 asteroids at <50%
- M & R => density ρ to ≈ 20-30%

Test GR

Gaia ≈850 NEOsim	β alone	J_2 alone	β global	J_2 global	correl. global
set A	2 E-4	.3 E-8	4 E-4	.5 E-8	0.85
set B	4 E-4	1 E-8	4 E-4	1.1 E-8	0.11
set C	3 E-4	.9 E-8	5 E-4	1.3 E-8	0.68
$INPOP_{06}$ (Fienga)	β<0.1 E-4	—	β<1 E-4	6 E-8	—
LLR-EMP (Williams; Pitjeva)	2 E-4	—	1 E-4	3 E-8	—

- J2 to 1E-8 (≈10%) β to 5.E-4 separately