Investigation de la dynamique des astéroïdes avec Gaia

Orbites, masses, physique fondamentale

Serge Mouret,

F. Mignard, D. Hestroffer

AS Gaia, 18 décembre 2007

O - C principle

Input data:
positions of the asteroids,observation dates, precision of observations

$$O - C = A\,\Delta\mathbf{u}$$

Least-squares techniques

$$\Delta\mathbf{u} = (A^t A)^{-1} A^t (O - C)$$

$\sigma(\Delta\mathbf{u})$

Estimation of the error

Correction to the initial conditions at the reference time

Position-velocity

Masses of perturbers

Global parameters

(J2, β, γ, η, dG/dt)

Physical parameters of certain asteroids

Expected precisions

Realistic simulated data:
Observation dates, positions of the space probe, precision of observations

By F. Mignard, P. Tanga, F. Arenou and D. Hestroffer

↓

$$O - C = A\,\Delta\mathbf{u}$$

Computation of the partial derivatives matrix

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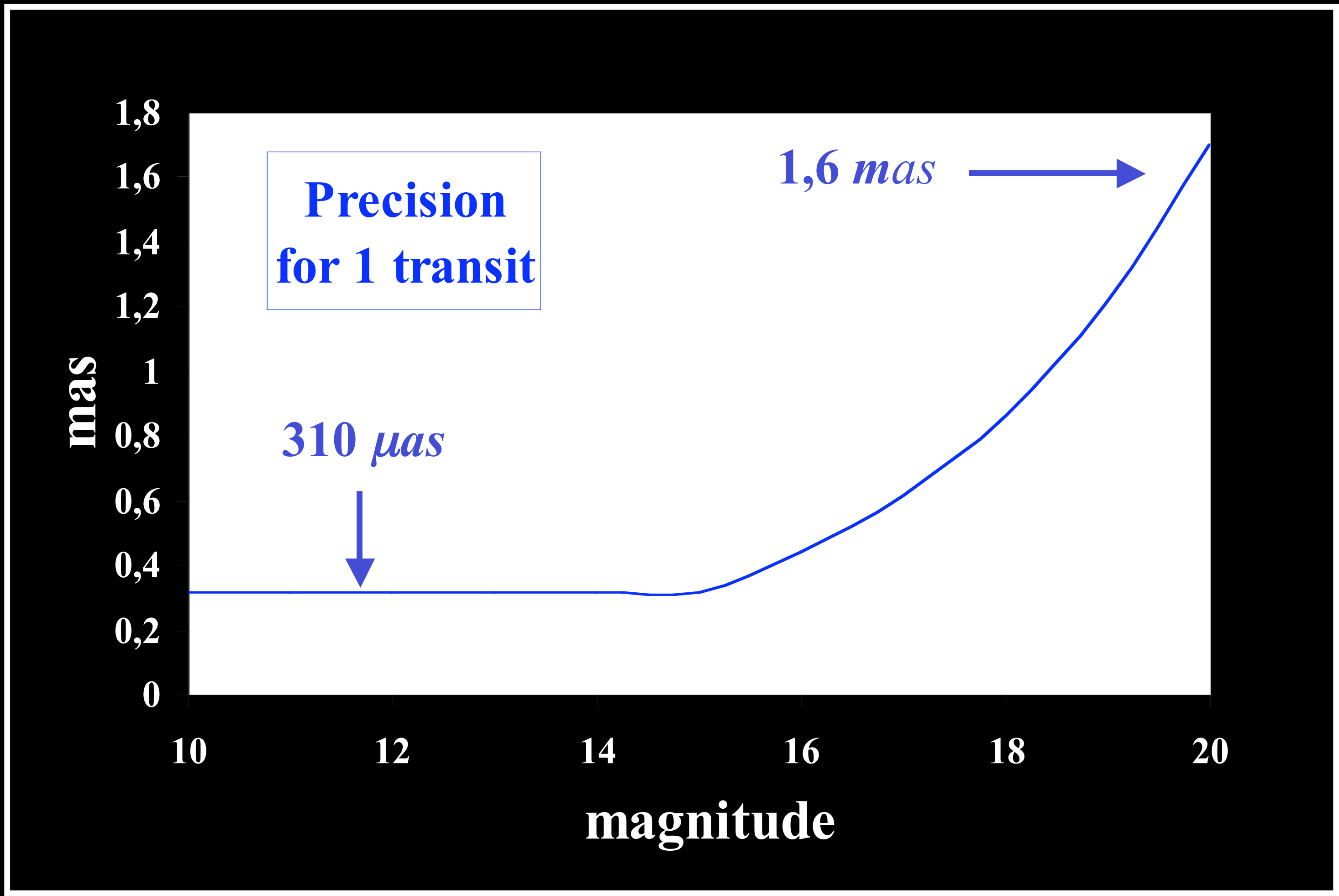
$\sigma(\Delta\mathbf{u})$: diagonal elements of $\sqrt{(A^t A)^{-1}}$

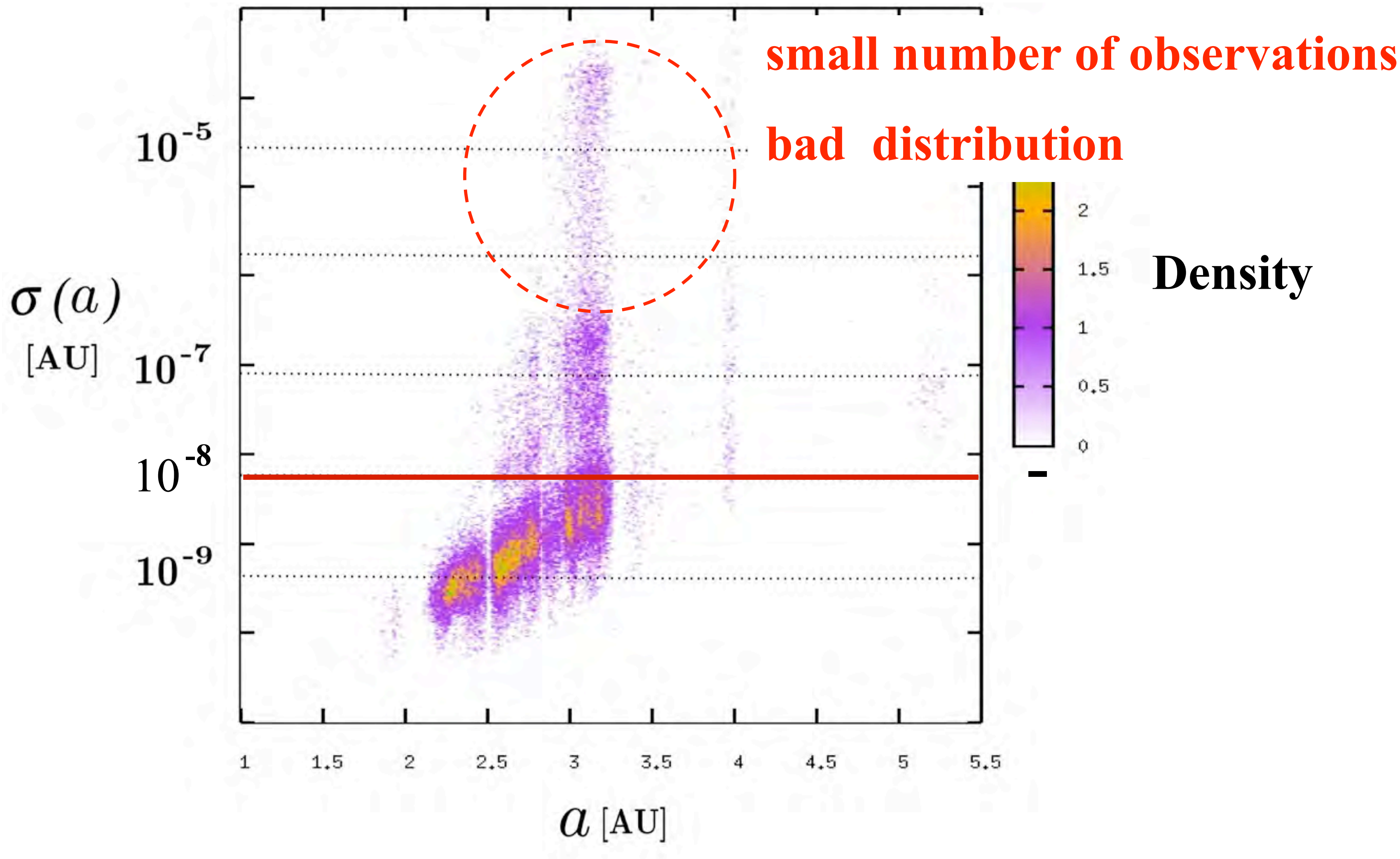
Precision of observations



From simulations of F. Arenou & D. Hestroffer

Orbits improvement

Expected precision on the semi-major axis



Specificities of mass determination

$$O\text{-}C = A\Delta u$$

Gaia specificity:

The number of valuable close approaches is very large and they involve many perturbers

Consequence:

Global solution for the perturber masses

by simultaneously handling

all perturbers and target asteroids

Mass determination

Selection of close approaches

Date:

2011 to 2016

Perturber:

∈ first 20,000

m > 10^{-13} Msun

Target:

∈ the first 350,000

Close approach retained if

b < 0.5 AU (impact par.)

Impulse approach

$$\text{deflection angle}: \quad \tan\frac{\theta}{2} \approx \frac{G(M+m)}{v_i^2\, b}$$

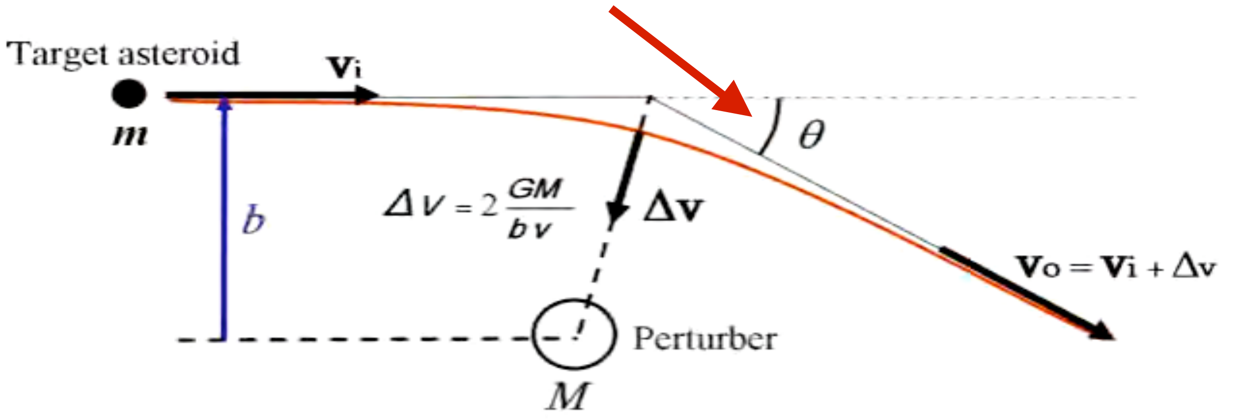


Fig. 10. Impulse approximation of a small target asteroid perturbed by a larger one. v_i and v_o are respectively the incoming and outgoing velocity vector. The effect of the perturbation is expressed by the vector Δv.

Results: expected precision on the masses

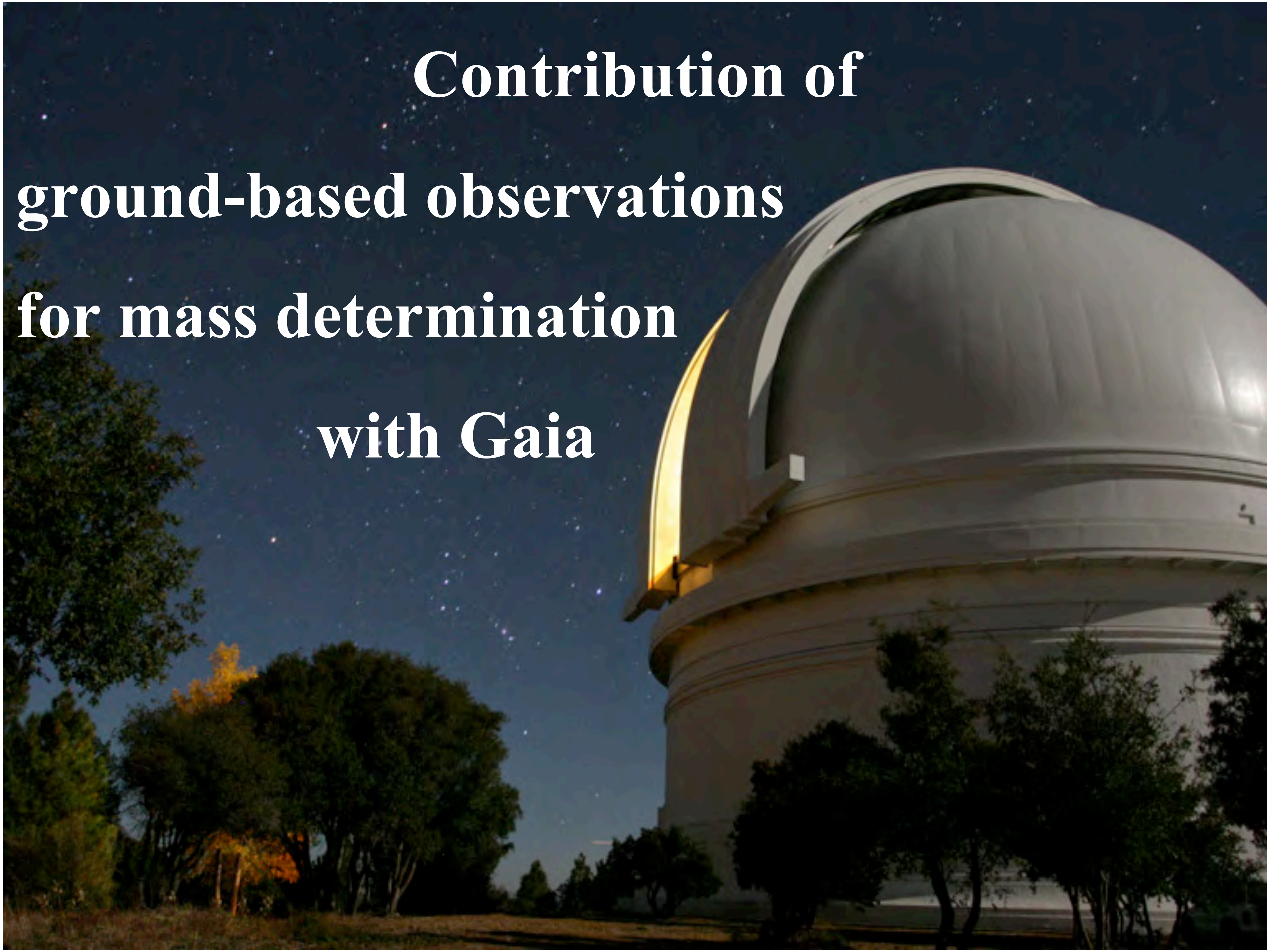
Number of masses	
Total	602
σ (m)/m < 0.1%	2
σ (m)/m < 1 %	3
σ (m)/m < 10 %	36
σ (m)/m < 15 %	59
σ (m)/m < 20 %	75
σ (m)/m < 30 %	106
σ (m)/m < 50 %	149

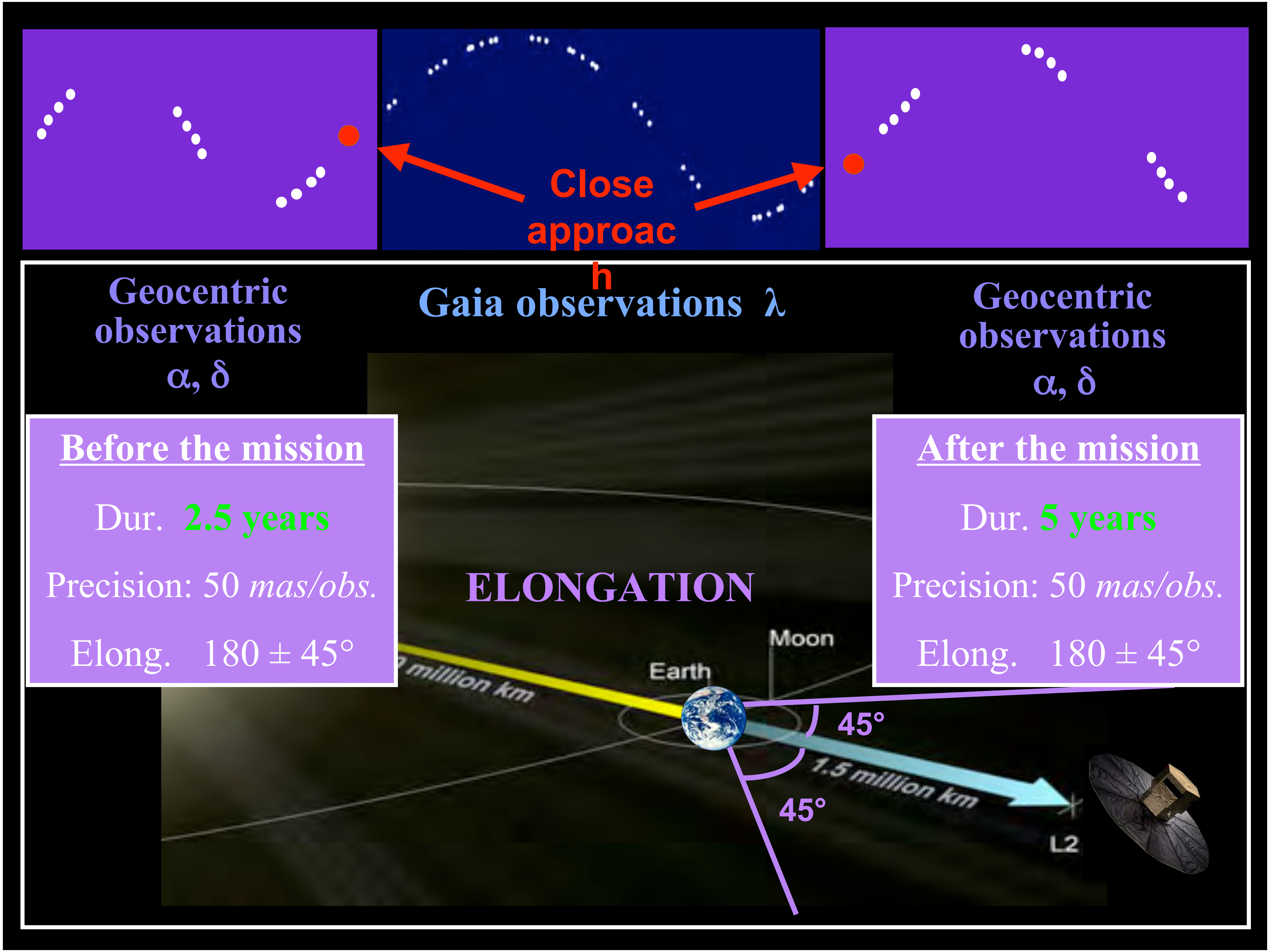
m is the reference mass of the perturber

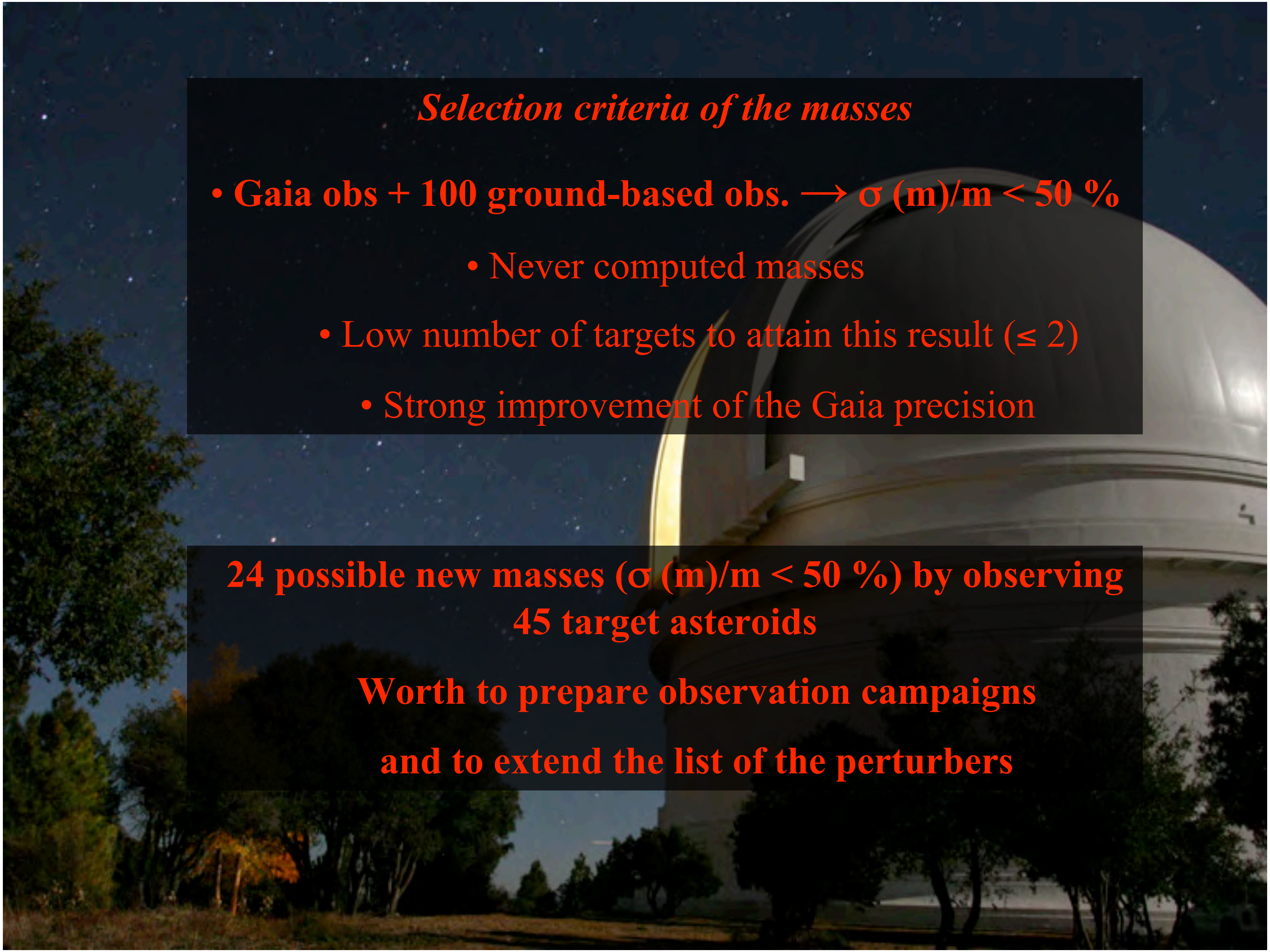
σ (m)/m is the relative precision

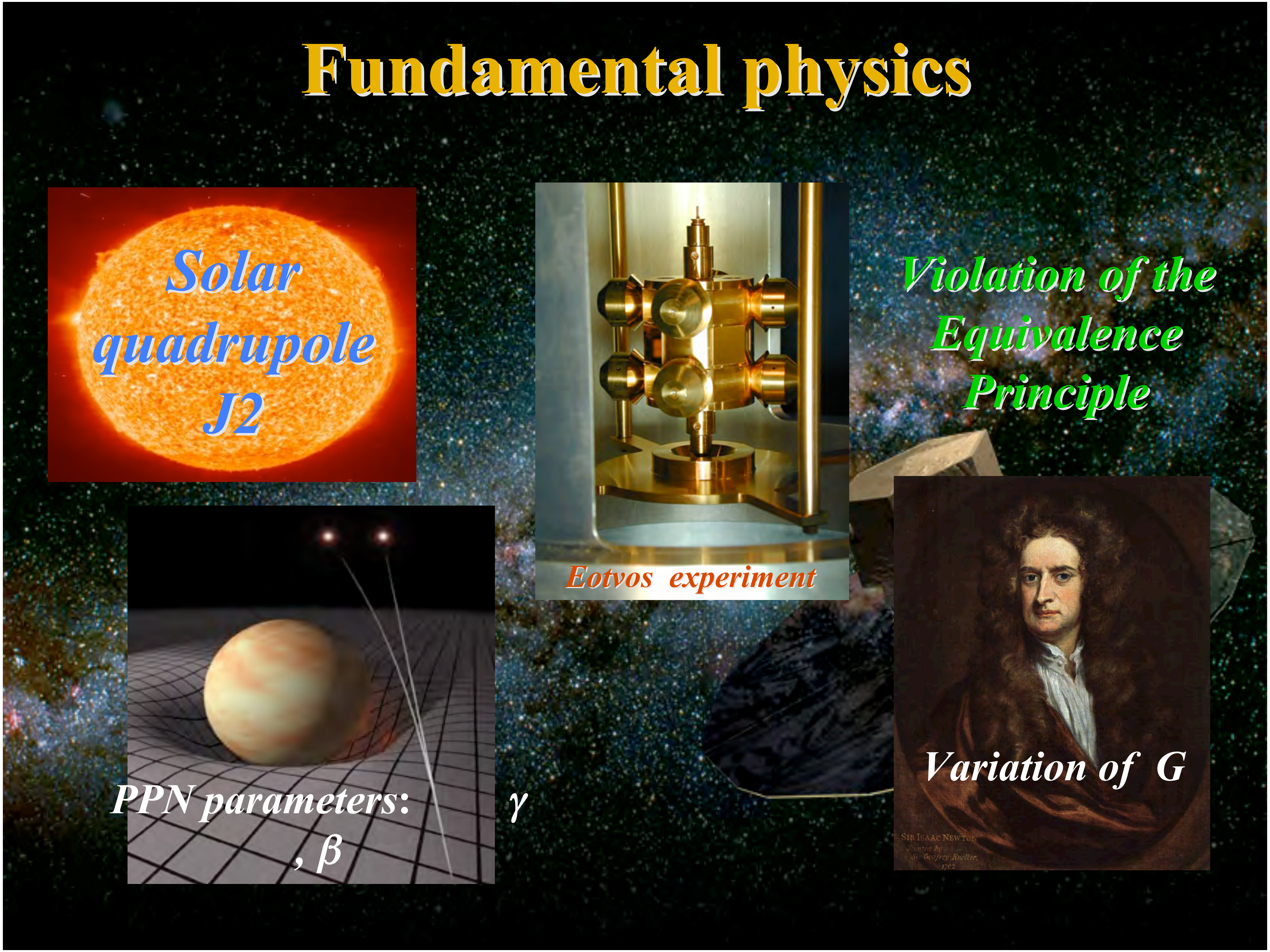
Current determinations:
21: σ (m)/m < 10%, 41: σ (m)/m < 50%
but the systematic errors much larger

These results depend on many things which are not yet fully known such as
- the exact start of the mission,
- the exact duration
- the scanning law
- the expected precision on the positions
- the initial mass etc …


Contribution of
ground-based observations
for mass determination
with Gaia


Close
approac
h
Geocentric observations
α, δ
Gaia observations λ
Geocentric observations
α, δ
Before the mission
Dur. 2.5 years
Precision: 50 mas/obs.
Elong. 180 ± 45°
ELONGATION
After the mission
Dur. 5 years
Precision: 50 mas/obs.
Elong. 180 ± 45°
million km
Moon
Earth
45°
45°
1.5 million km
L2


Selection criteria of the masses
• **Gaia obs + 100 ground-based obs. ⟶ σ (m)/m < 50 %**
• Never computed masses
• Low number of targets to attain this result (≤ 2)
• Strong improvement of the Gaia precision
24 possible new masses (σ (m)/m < 50 %) by observing 45 target asteroids
Worth to prepare observation campaigns
and to extend the list of the perturbers


Fundamental physics
Solar quadrupole J2
Eotvos experiment
Violation of the Equivalence Principle
PPN parameters: γ, β
Variation of G
Sir Isaac Newton

Fundamental physics

Input: > 200,000 asteroids

Parameters u	Theoretical values	Gaia precision (asteroids)	Current Precision	future missions
J2	2×10^{-7}	1.9×10^{-7}	$\sim 6 \times 10^{-9}$ (Helioseismology)	$\sim 10^{-8}$ (Bepicolombo)
β (PPN)	1	1.9×10^{-3}	$\sim 2.3 \times 10^{-4}$ (indirect η)	
γ (PPN)	1	1.1×10^{-3}	$\sim 2.3 \times 10^{-5}$ (time delay)	$\sim 10^{-6}$ - 10^{-7} (Gaia–bending of light)
η Nordtvedt	0	6.2×10^{-4}	4.5×10^{-4} (LLR)	
dG/dt	0	3.9×10^{-12}	9×10^{-13} (LLR)	

Non gravitational forces
Yarkovsky effect

General principle

Anisotropic re-emission of heat (thermal infrared photons) received from the Sun in the visible. The photons, leaving the asteroid, carry away momentum.

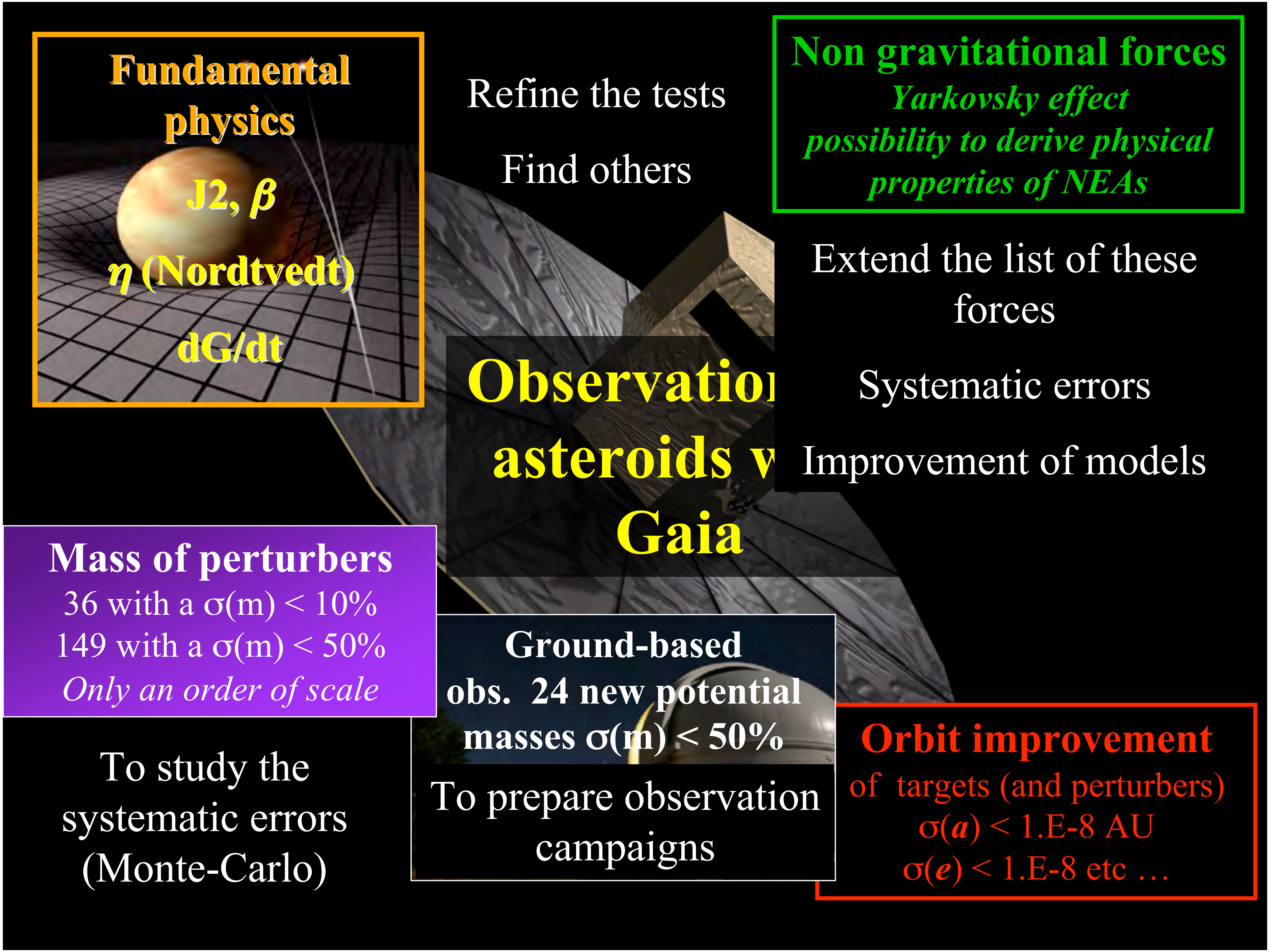
Work in collaboration with M. Delbo

The force was modelled from Vokrouhlicky papers by M. Havel and M. Delbo (Master 2 project)

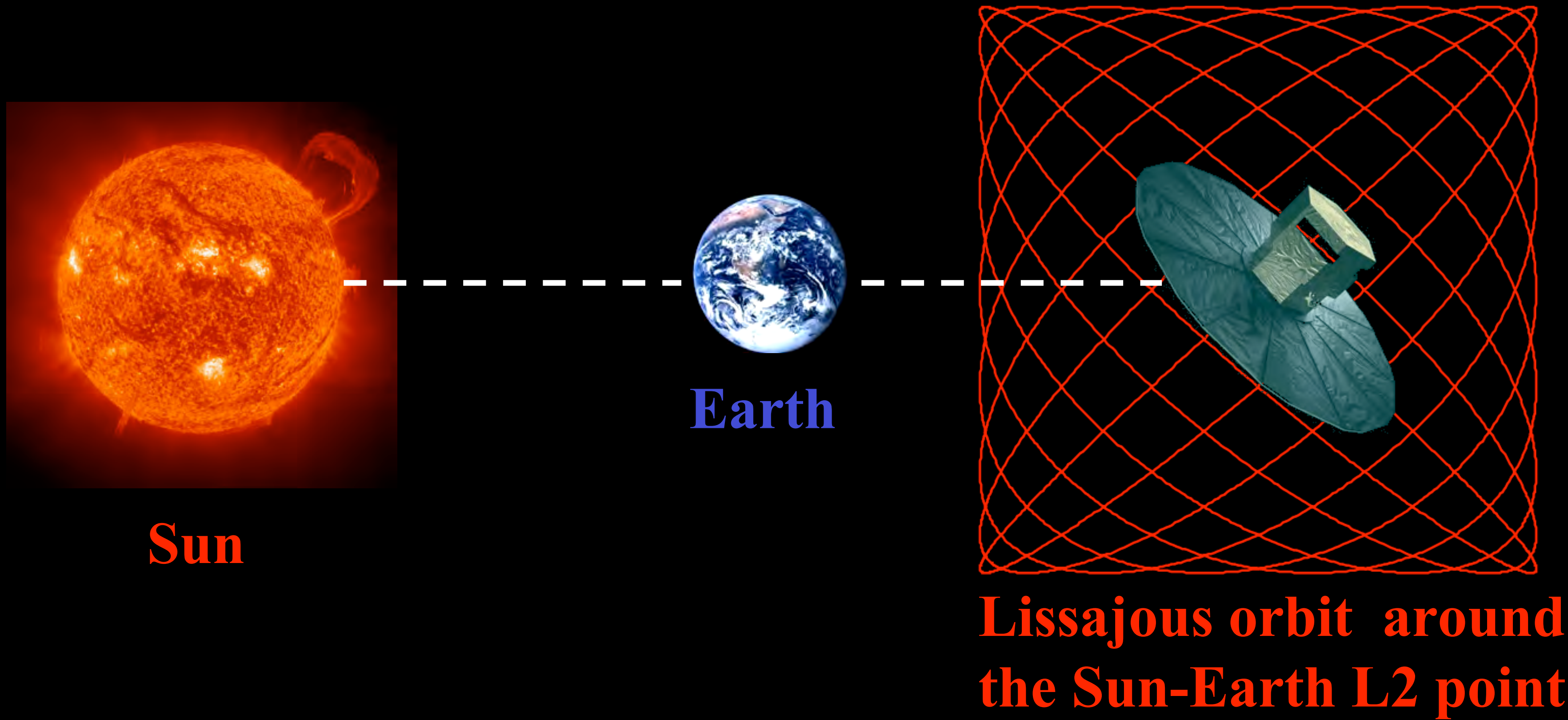
Input

1366 NEOs
Independent fit of some physical parameters
- diameter, thermal inertia, rotation parameters -

Simulations - RESULTS

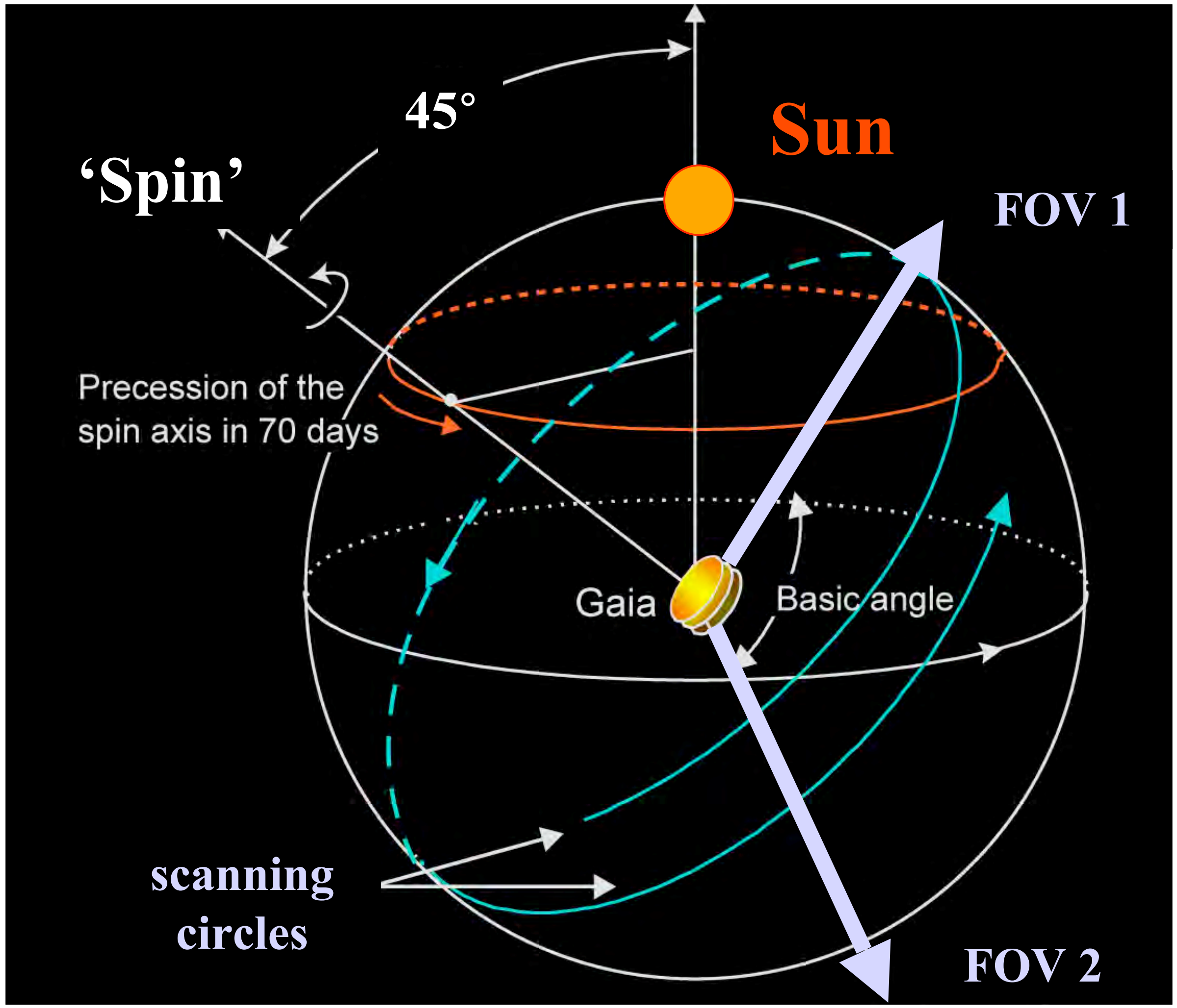

Fundamental physics
J2, β
η (Nordtvedt)
dG/dt
Refine the tests
Find others
Non gravitational forces
Yarkovsky effect
possibility to derive physical properties of NEAs
Extend the list of these forces
Systematic errors
Improvement of models
Observatio
asteroids w
Gaia
Mass of perturbers
36 with a σ(m) < 10%
149 with a σ(m) < 50%
Only an order of scale
Ground-based obs. 24 new potential masses σ(m) < 50%
To study the systematic errors (Monte-Carlo)
To prepare observation campaigns
Orbit improvement
of targets (and perturbers)
σ(a) < 1.E-8 AU
σ(e) < 1.E-8 etc …

Positions of Gaia



Modelled by F. Mignard

Observation dates of asteroids
- the scanning law -



Simualtions of P. Tanga and F. Mignard