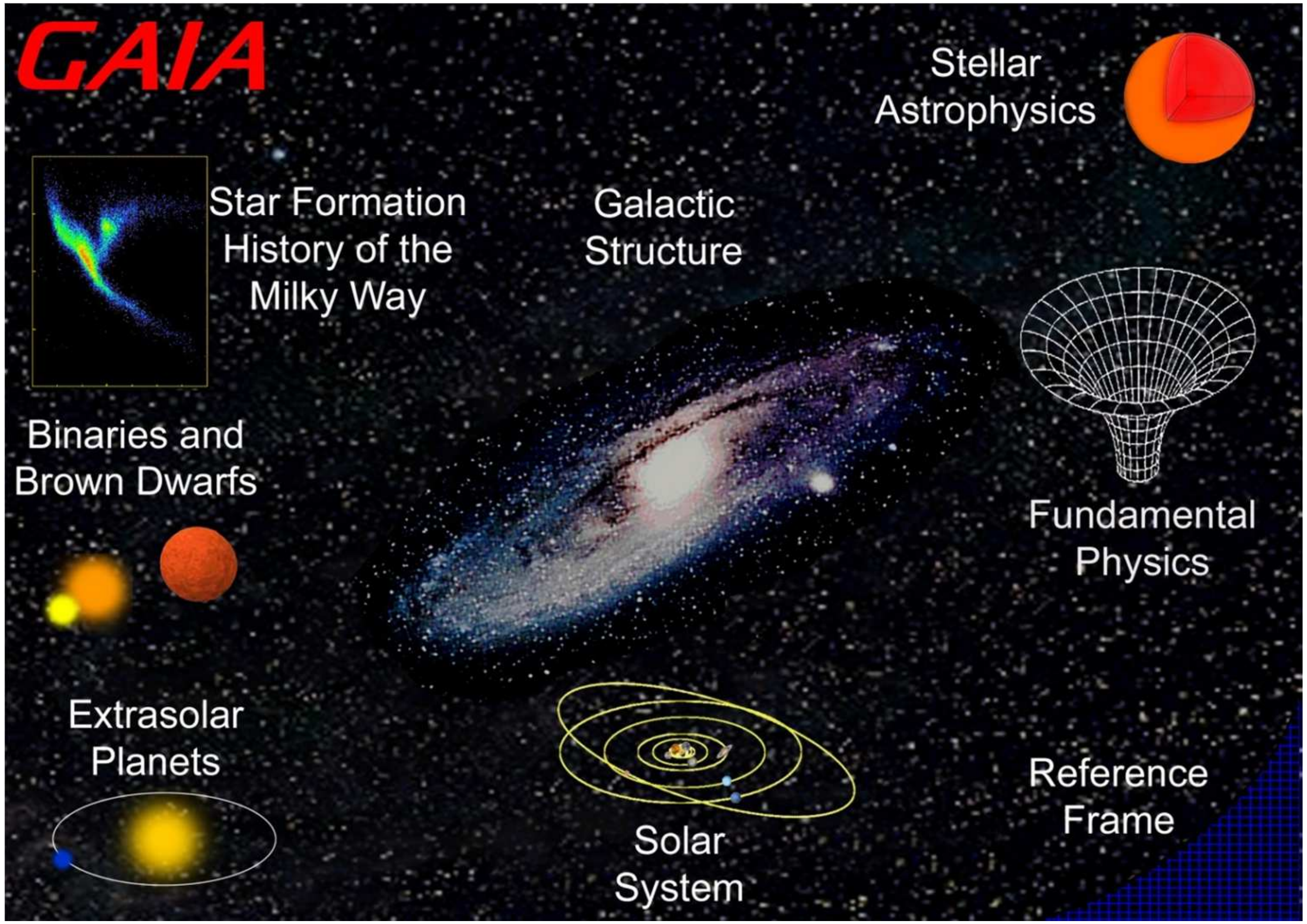
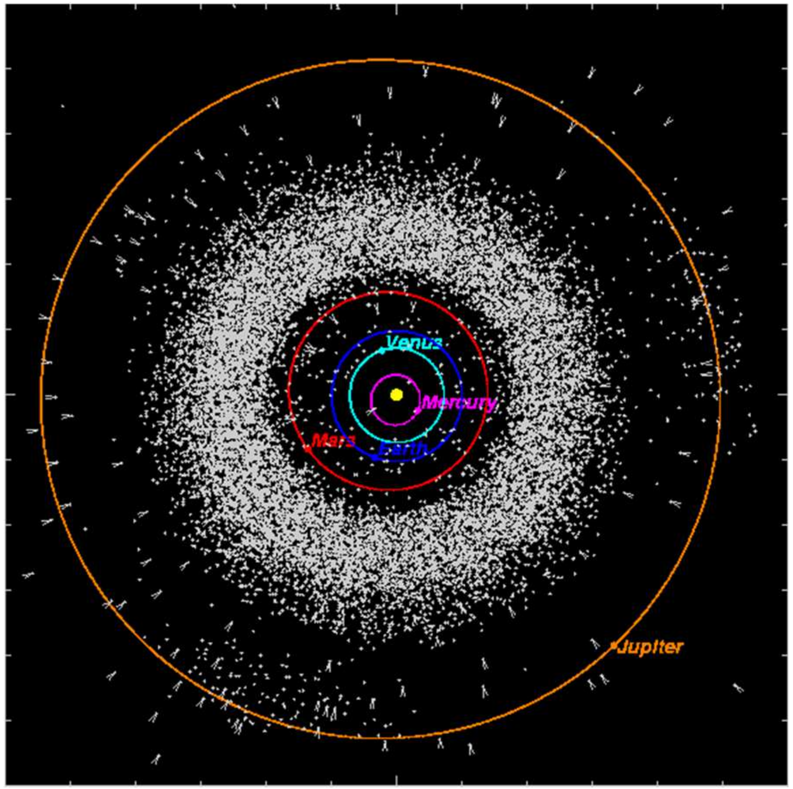
L’impatto di Gaia in Planetologia

Alberto Cellino, (INAF-OATO) – Roma, 14/02/2013



The impact of GAIA on Asteroid Science will be huge!



The challenge

- 1 source out of 2500 will be a Solar System Object (SSO)
- Transit frequency: ~ 1 SSO every 6 s
- Identification and data processing for moving sources:
  - Every single transit occurs in a different location in the sky
  - Normal procedures for stars not possible
  - Need of a catalog of orbits (but not all available orbits are of a sufficiently good quality)

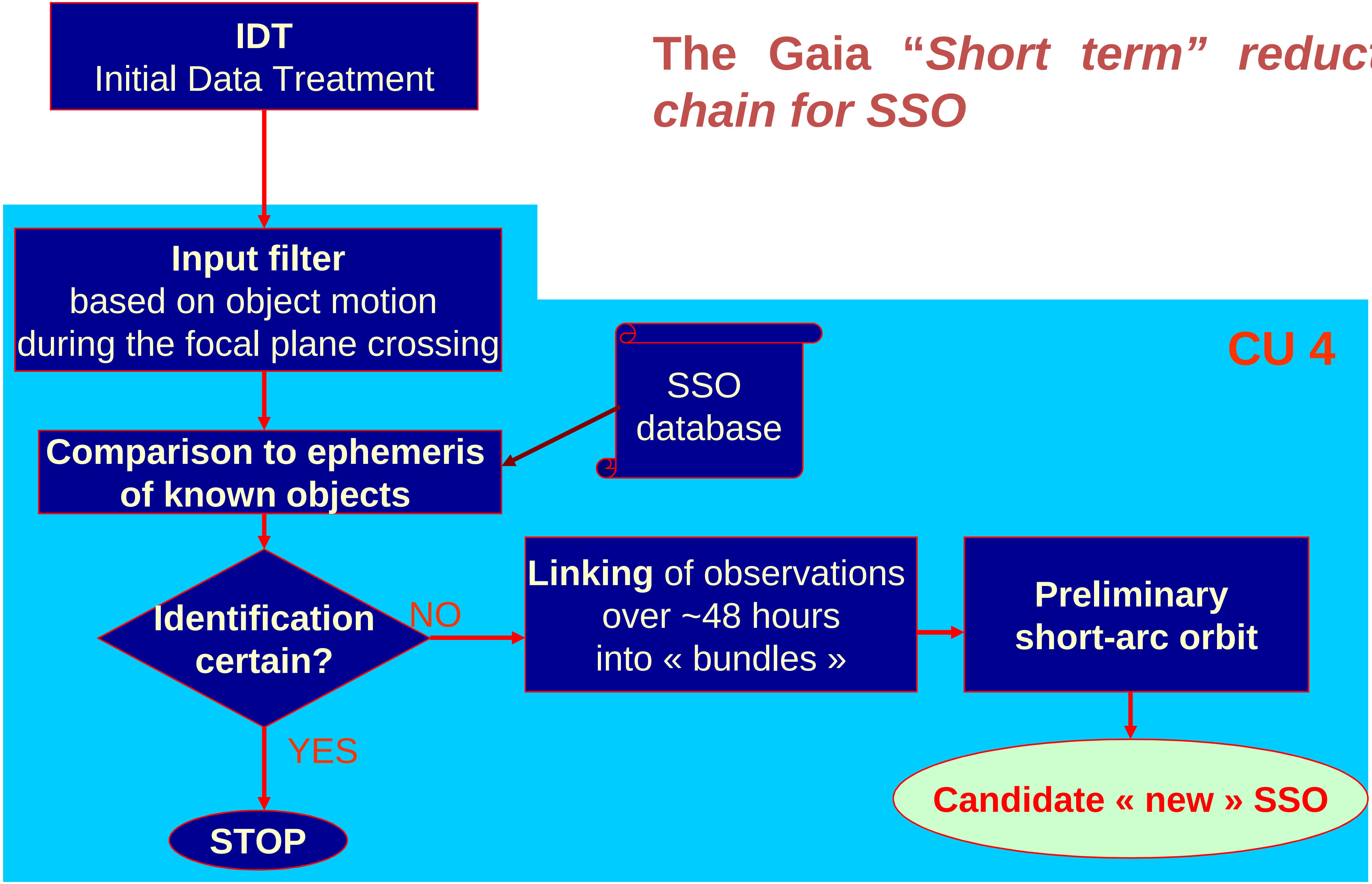
Problems

- Limits in astrometric accuracy due to apparent motion
- Ambiguous/wrong identifications → requires observation « threading »
- Orbit determination based on short arcs (2-3 transits).

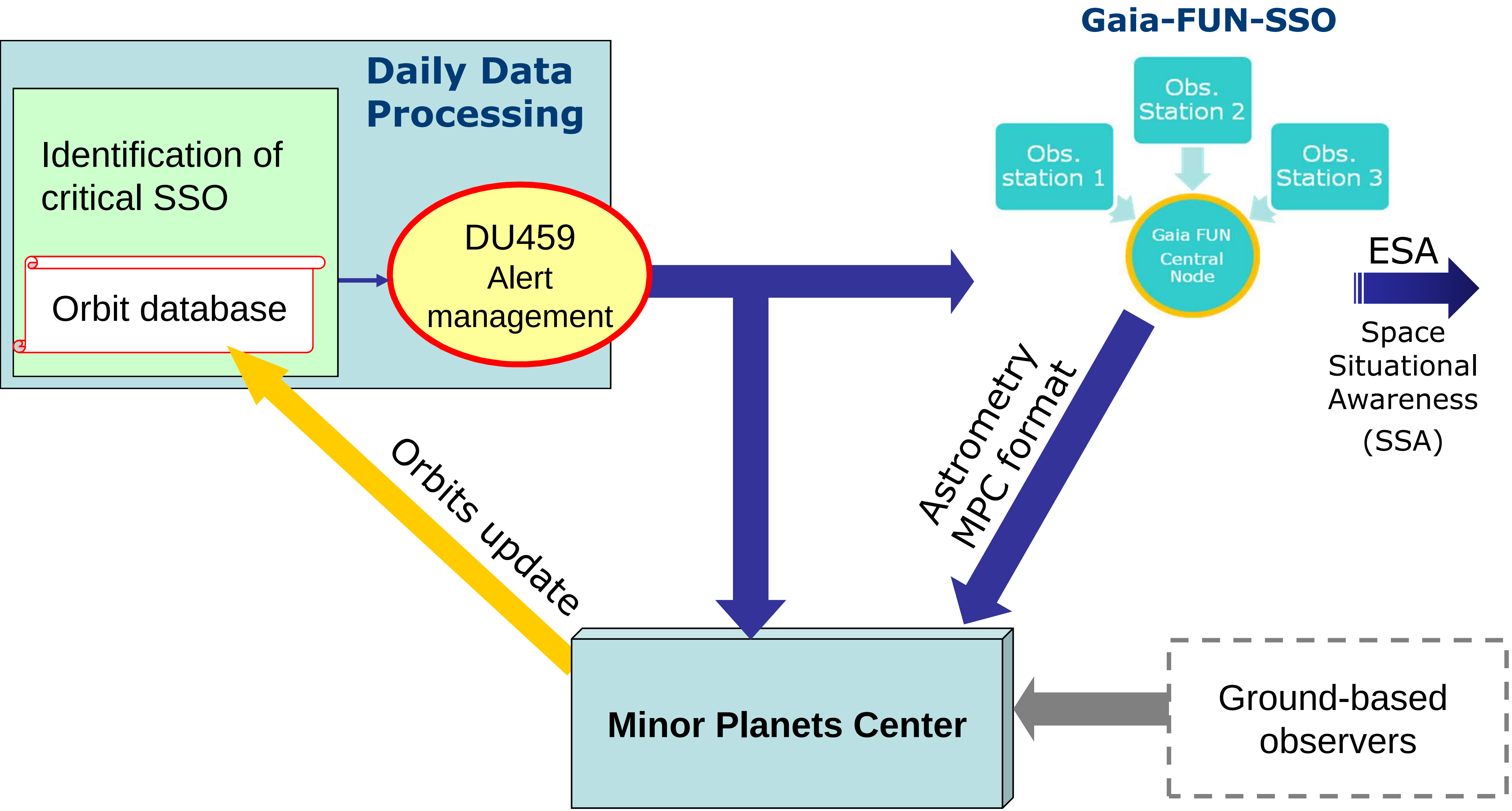
General considerations

- **Gaia will not observe “big” objects (>600 mas), thus *no planets, no large planetary satellites*.**
- **~400,000 asteroids will be observed (down to magnitude G=20).**
- **A few comets, a few Trans-Neptunian objects**
- **60-70 transits per object (during 5 years).**
- **“*Short Term*” reduction chain to process objects newly discovered by Gaia (mostly asteroids with orbits interior to the Earth’s). Data made public to allow prompt *follow-up* from the ground.**
- **“*Long Term*” reduction chain for all known objects.**

The Gaia *"Short term" reduction chain for SSO*

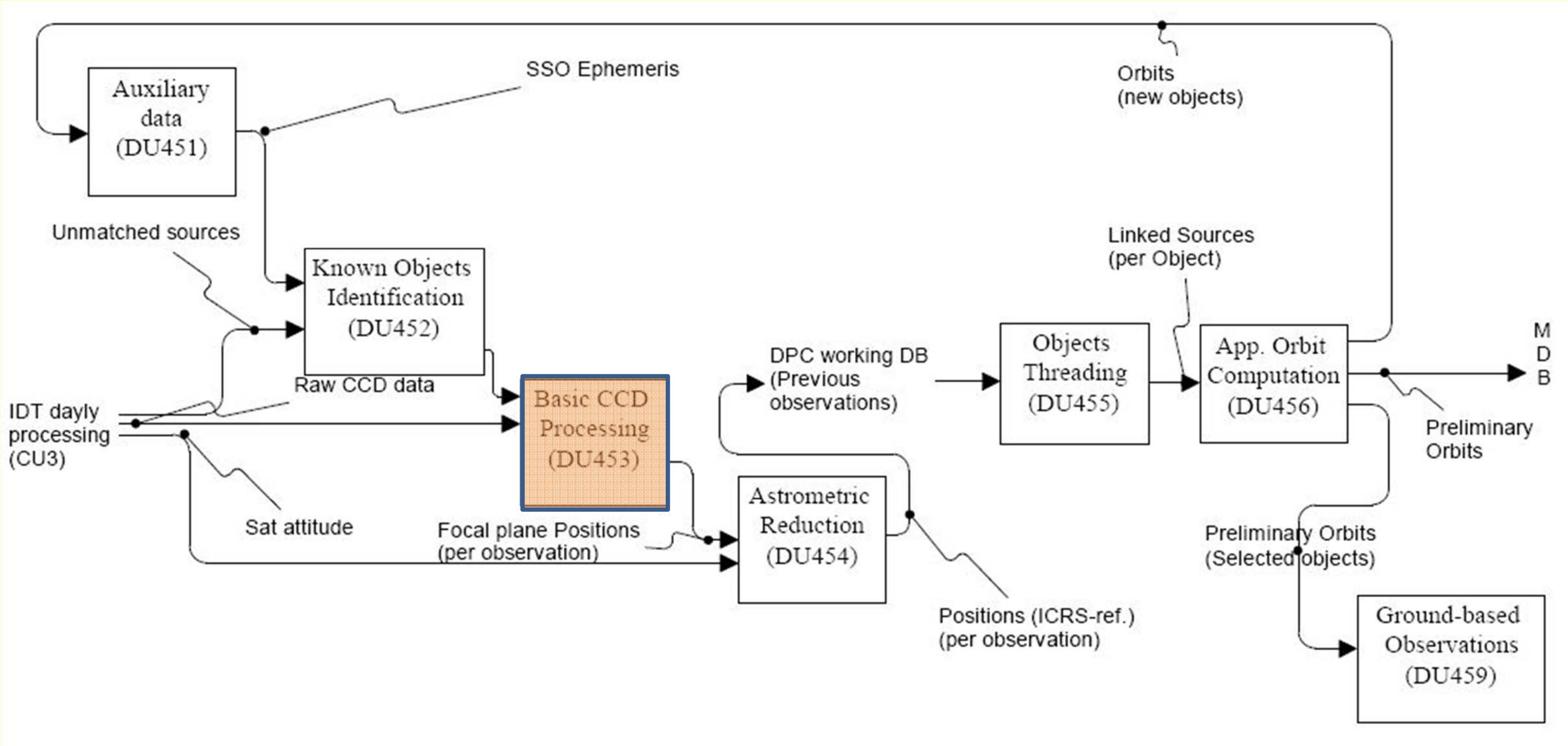


Follow-up Network for SSO



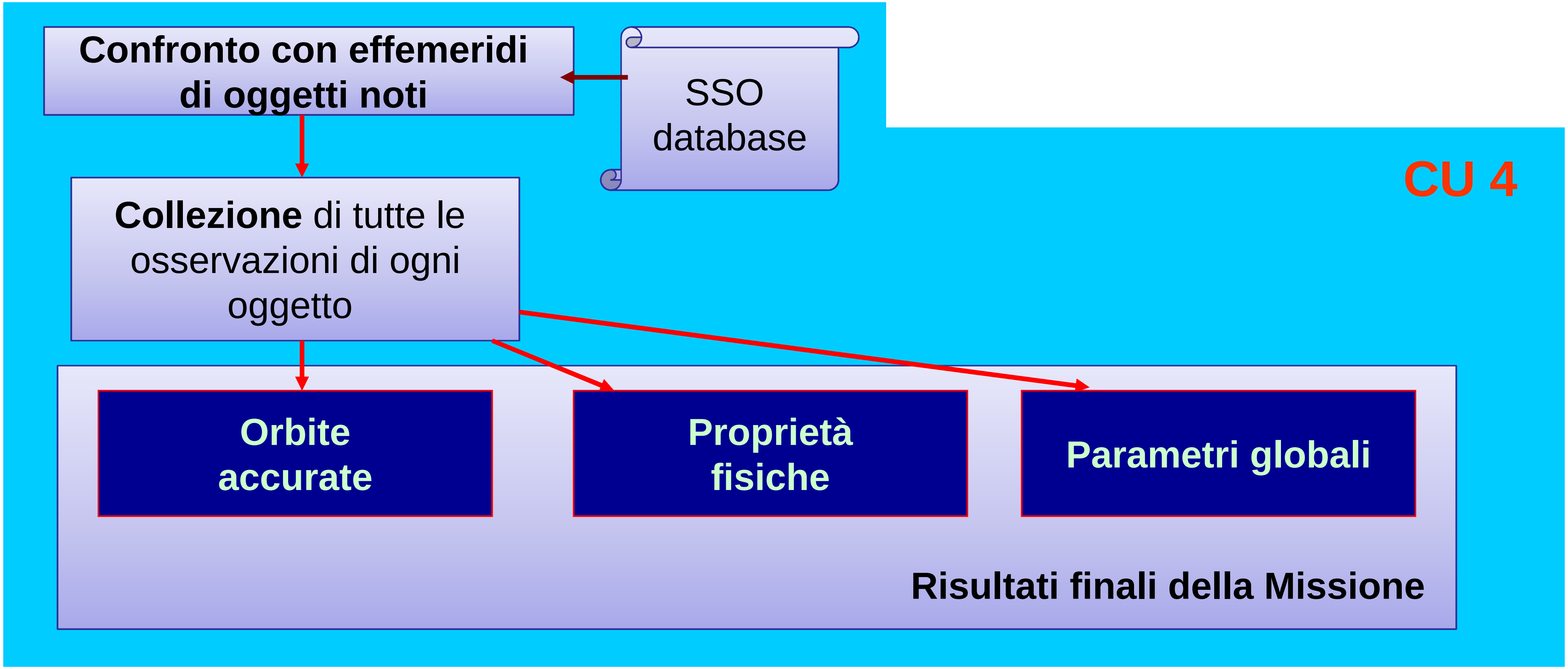
Problem: minimization of false alerts

Short-term chain: Italian responsibilities



DU453 Leader: A. Dell'Oro (OAA)

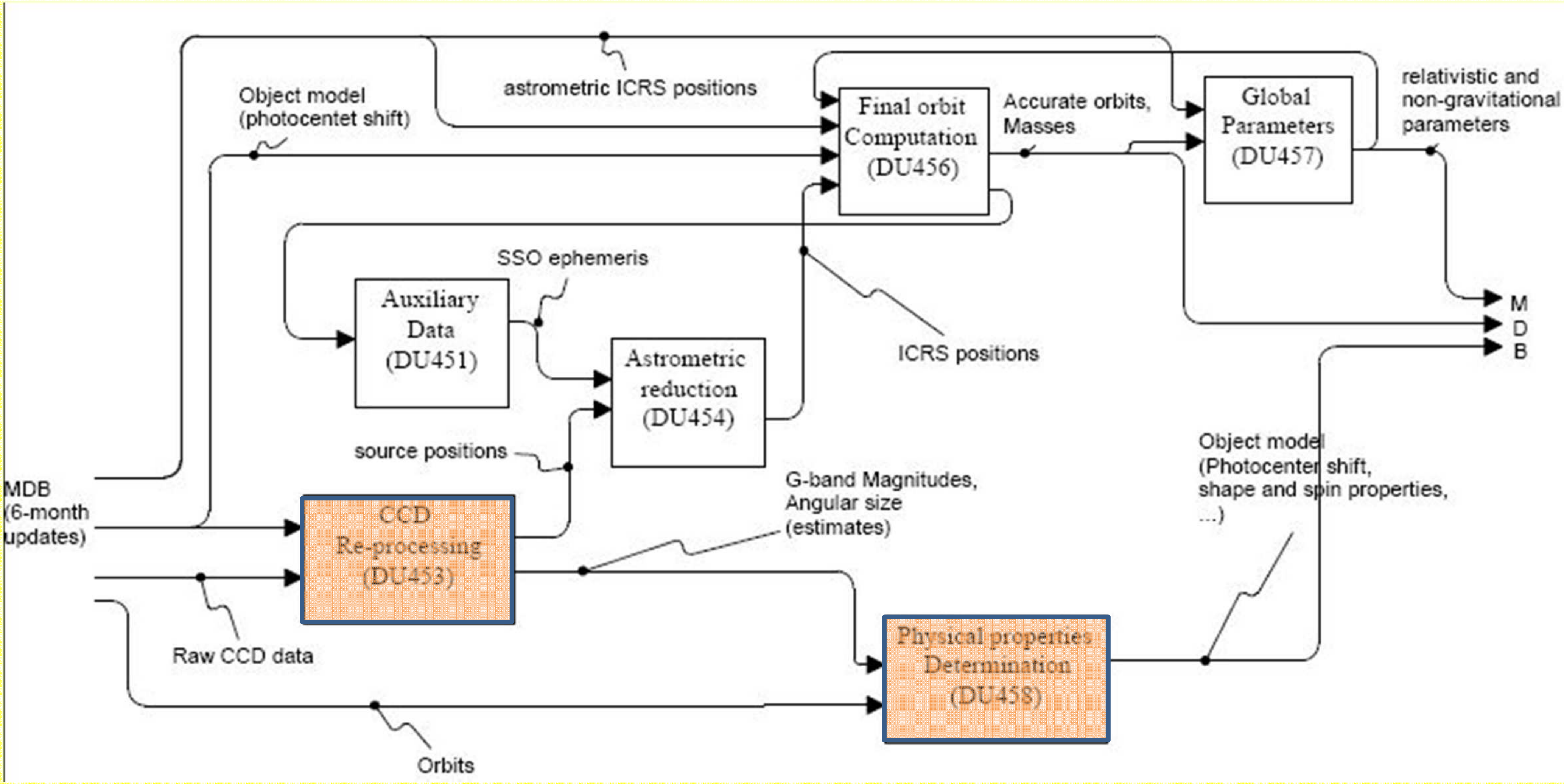
The Gaia « *Long term* » reduction chain for SSOs



Mostly end-of-missions tasks (+ intermediate runs)

Possibly, iterative processes

Long-term chain: Italian responsibilities



DU453 Leader: A. Dell'Oro (OAA)

DU458 Leader: A. Cellino (OATo)

Identified science goals

Astrometry

- Systematic survey - discoveries possible (in particular at low solar elongations)
- Orbits : X 100 improvement
- Perihelion precession for 300 planets : GR tests
- Masses from close encounters ~ 100 masses expected

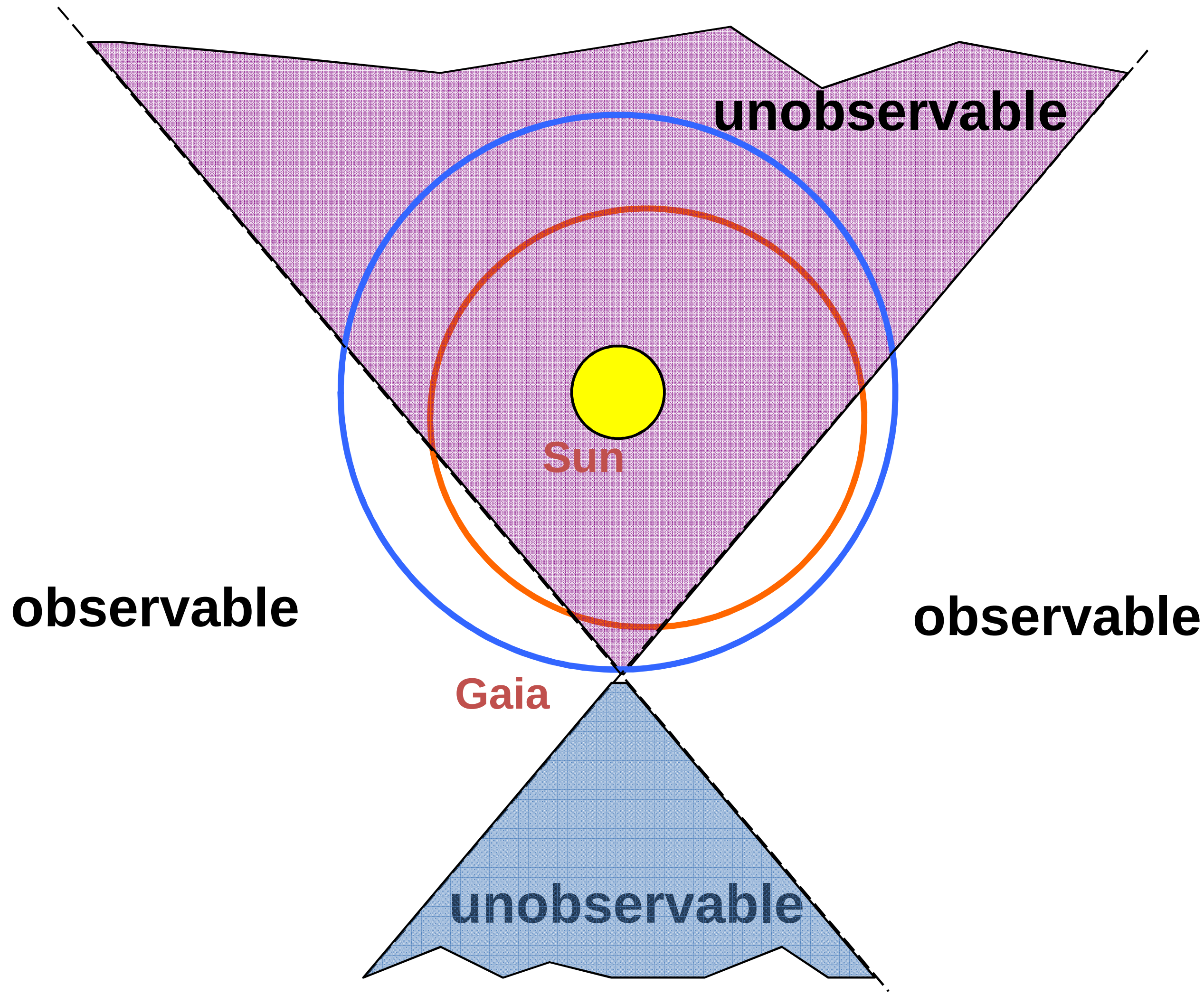
CCD signal

- Diameter for over 1000 asteroids (→ density)
- Binary asteroids

Photometry

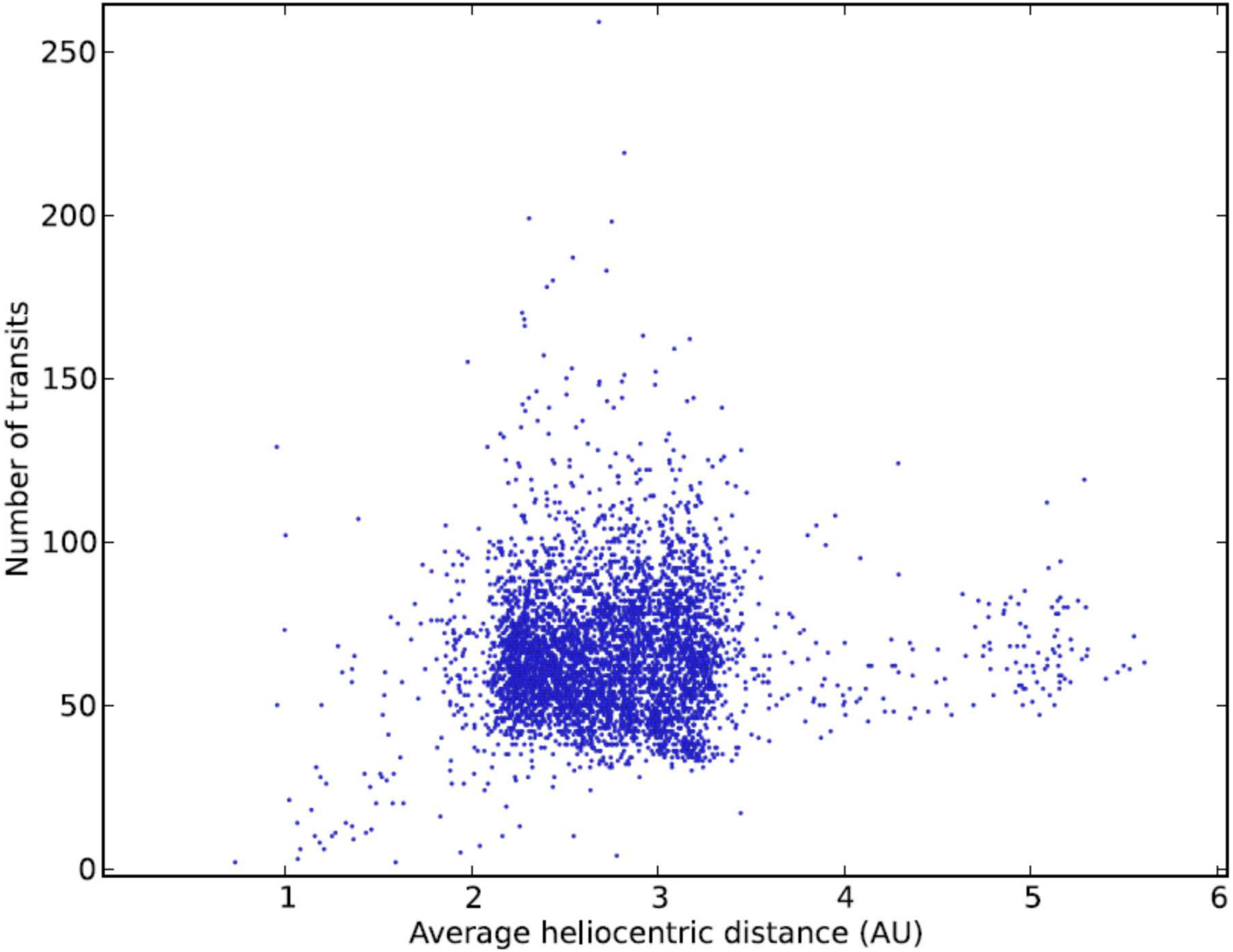
- Spectrophotometric data from B to R : reflectance spectra, taxonomic classification
- Sparse photometric data over 5 years : rotation, pole, shape.

Observable regions



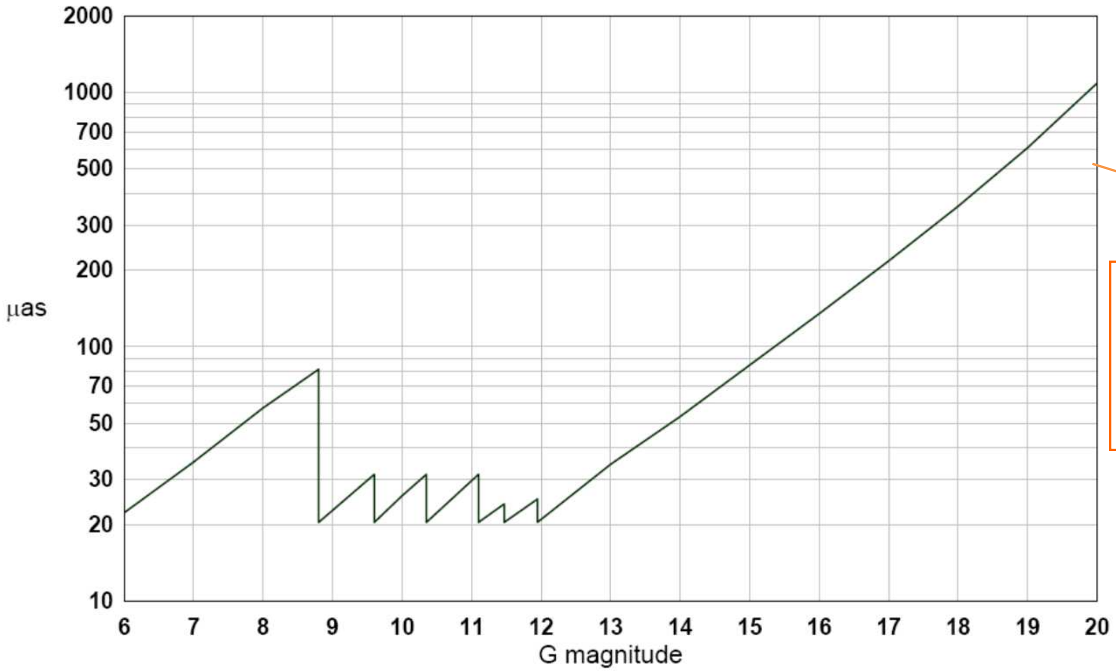
- Gaia's spin axis will always be oriented 45° from the Sun. At each rotation, sky regions at solar elongation angles between 45° and 135° will be observed
- Low solar elongations (~45-60°) suitable to detect Inner Earth Objects and other Near-Earth objects
- Main belt asteroids observable, but never at solar opposition

Number of single transits per object



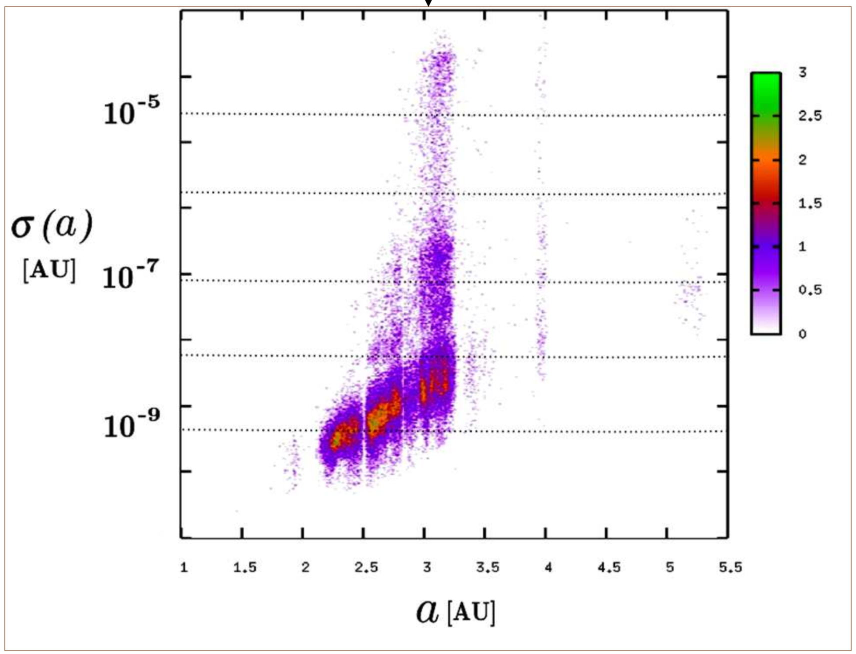
(Simulation limited to about 2000 objects, only)

Exploiting the unprecedented astrometric accuracy of Gaia:



Single transit

Improvement by a factor of 100 in orbital elements determination



Very weak dynamical effects will be measurable, making it possible to obtain mass measurements based on deflections produced by asteroid mutual close encounters

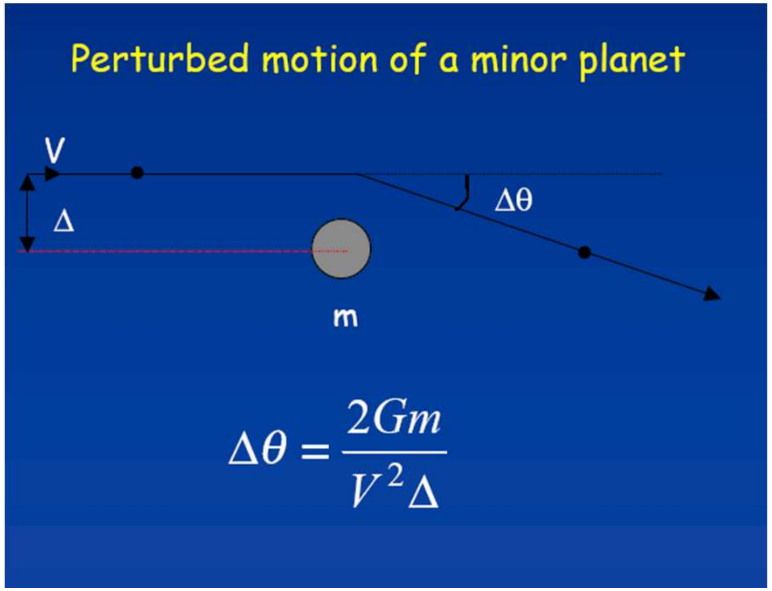
We basically do not know Asteroid masses, but they are sorely needed:

- To understand internal structure and evolution :

- The great unknowns : **density,** porosity…
- Gravitational aggregates or solid bodies?
- The origin of shapes
- The collisional history
- Impact risks and mitigation strategy

- To improve Solar System ephemerides

The measurement of asteroid masses from Gaia observations of asteroid mutual close encounters: current estimates



The most important close encounters will be those involving as perturbers some of the largest asteroids.

The expected Gaia *single encounter* accuracy on the mass is of the order of $\sim 10^{-12}\,M_{\odot}$

But :

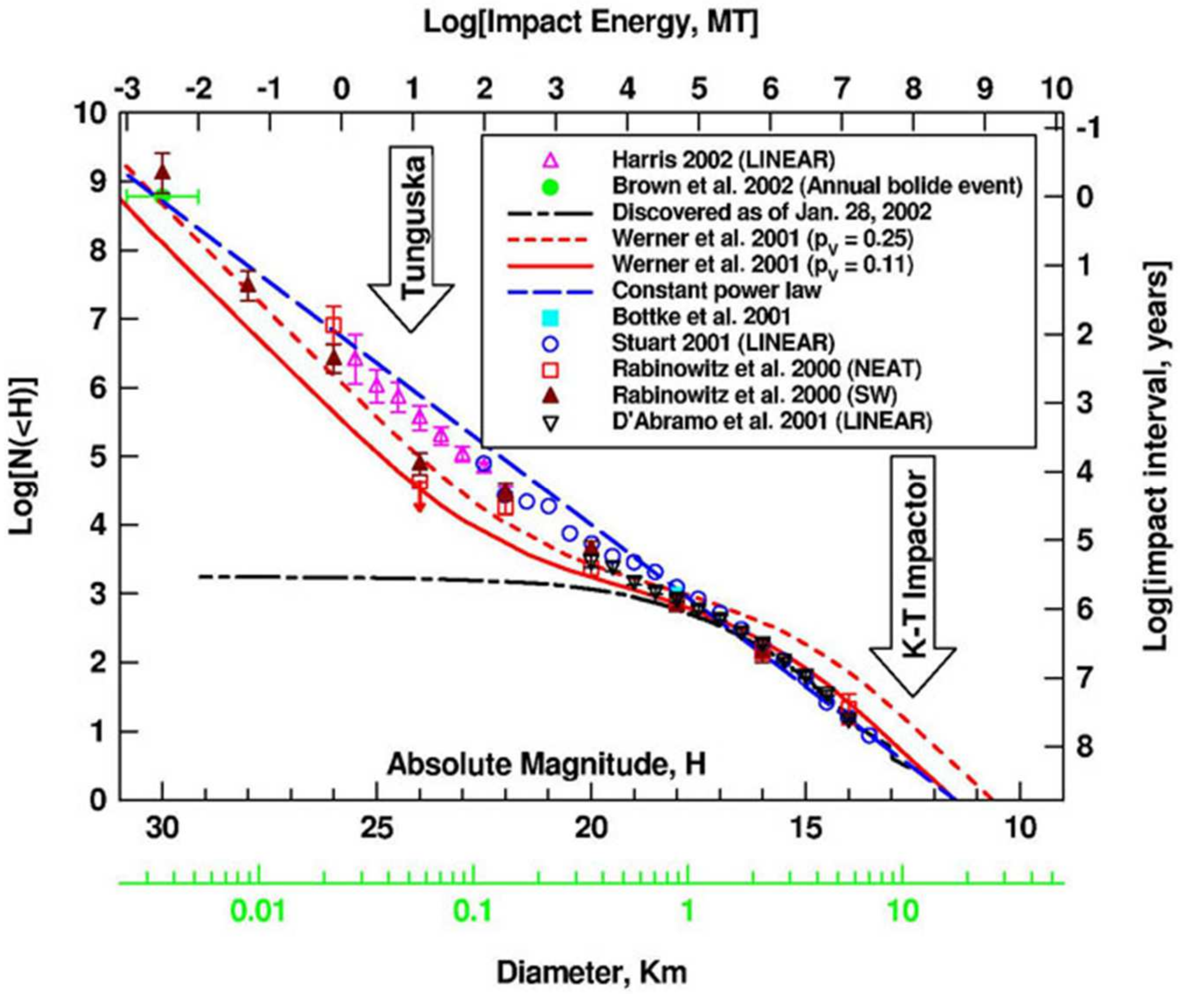
- ***There will be several close approaches* involving the same perturber**

According to simulations, a final accuracy down to $\sim 10^{-13}$ - $10^{-14}\,M_{\odot}$ is expected to be reached at least in some cases.

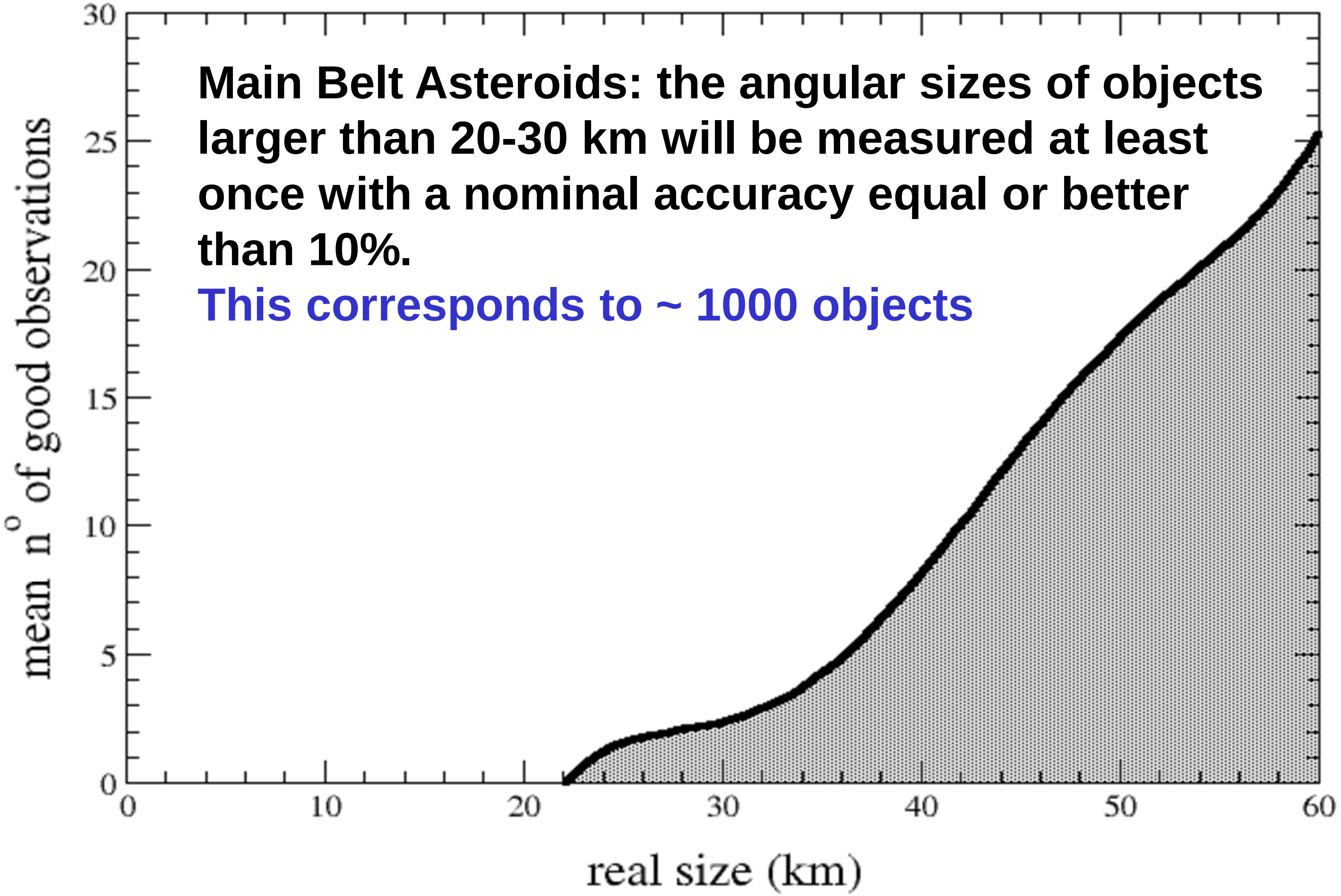
In the case of 1 Ceres this leads to a mass uncertainty of less than 0.1% !! (a huge improvement)

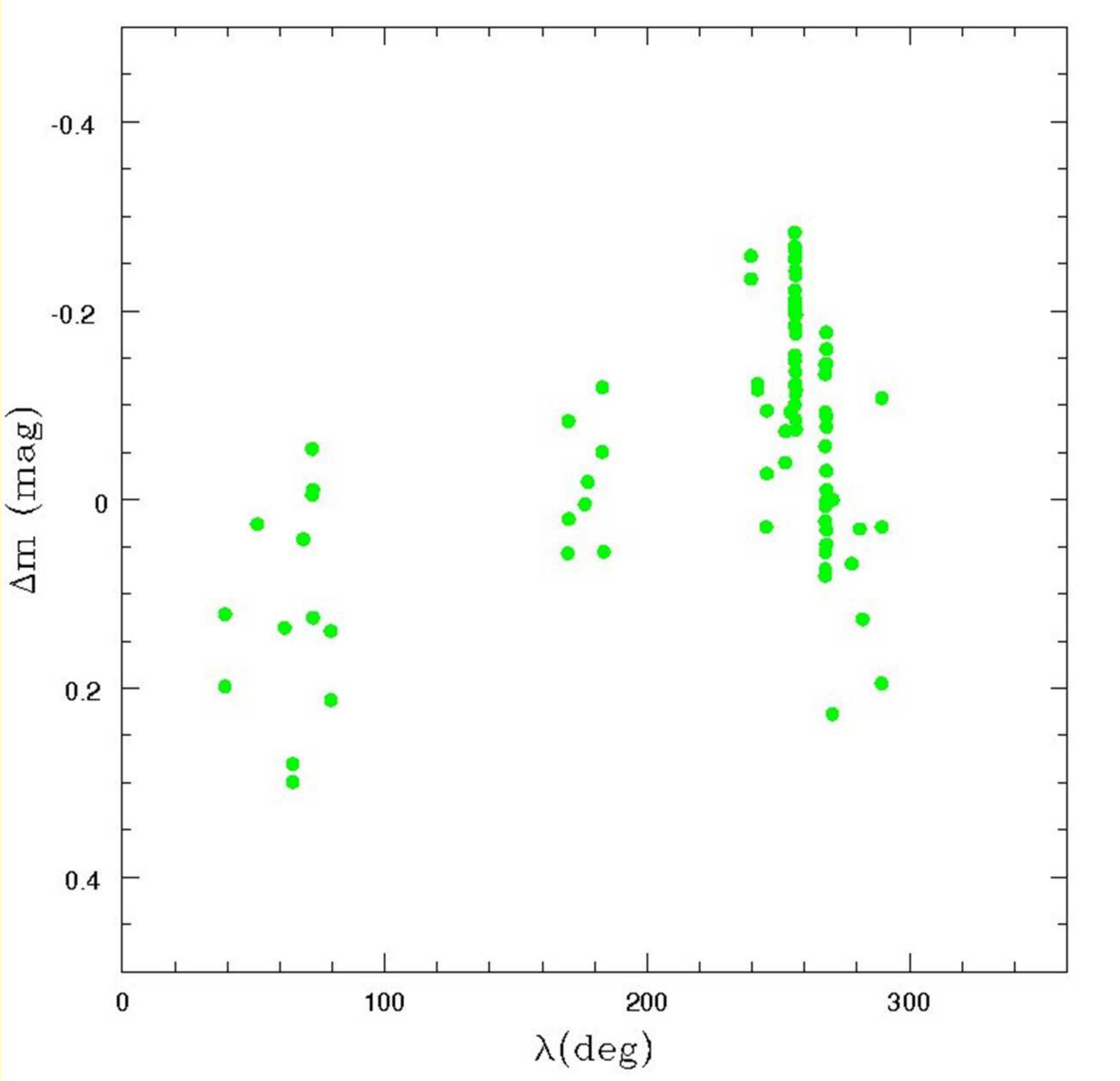
→ **Decent mass determination for about 100 asteroids**
σ(m)/m < 20% for ~80 objects

The size distribution of Main Belt asteroids is a major constraint for models of the collisional evolution of the asteroid belt. Moreover, sizes and shapes are needed to derive bulk densities when masses are known. However, asteroid size data are generally *not* known from direct size measurements!



Number of expected "good" Gaia transits per object as a function of diameter



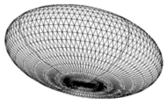


GAIA disk-integrated photometry

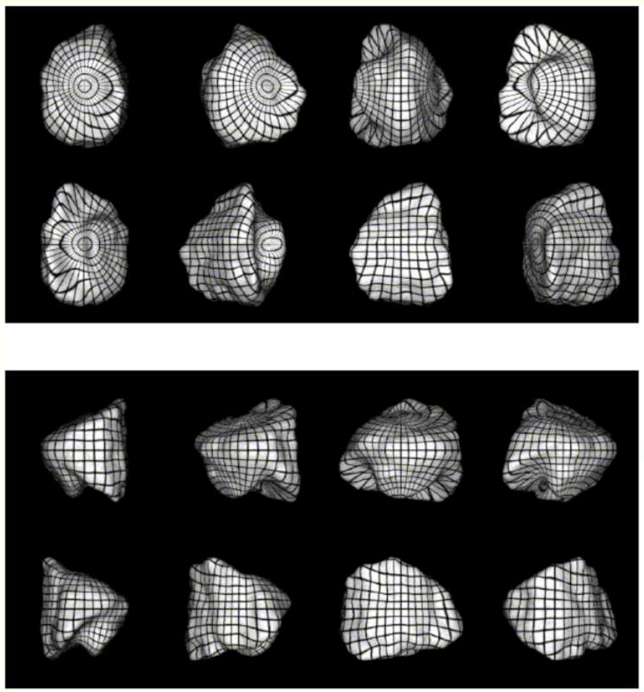
Sparse photometric data (no lightcurves)

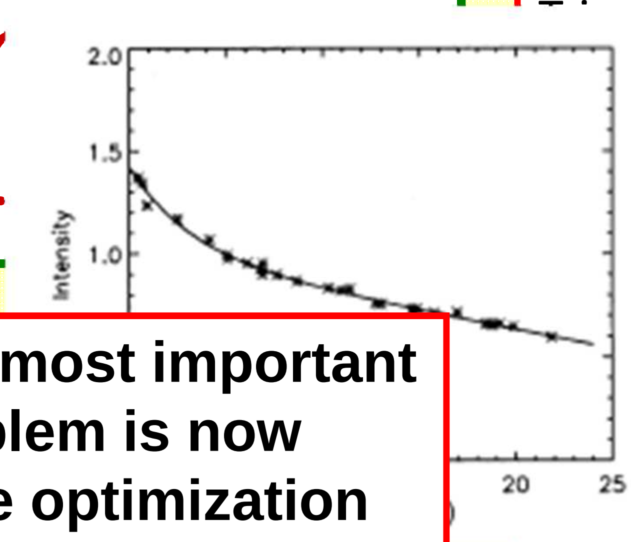
Good sampling of the variation of the aspect angle over five years of observations

Simulation of Gaia observations of the asteroid(15) Eunomia

The inversion problem: The objects are assumed to be triaxial ellipsoids.  A "genetic" algorithm is used to solve for the unknown spin period, spin axis direction, two axial ratios, rotational phase at t=0, and a phase-magnitude linear coefficient.

The effectiveness of th
method tested by means
numerical simulat





The most important problem is now code optimization to minimize the required CPU time

ellipsoid shapes
shapes: digital shapes of
omia, (6489) Golevka,
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t simulated orbits, spin
and poles

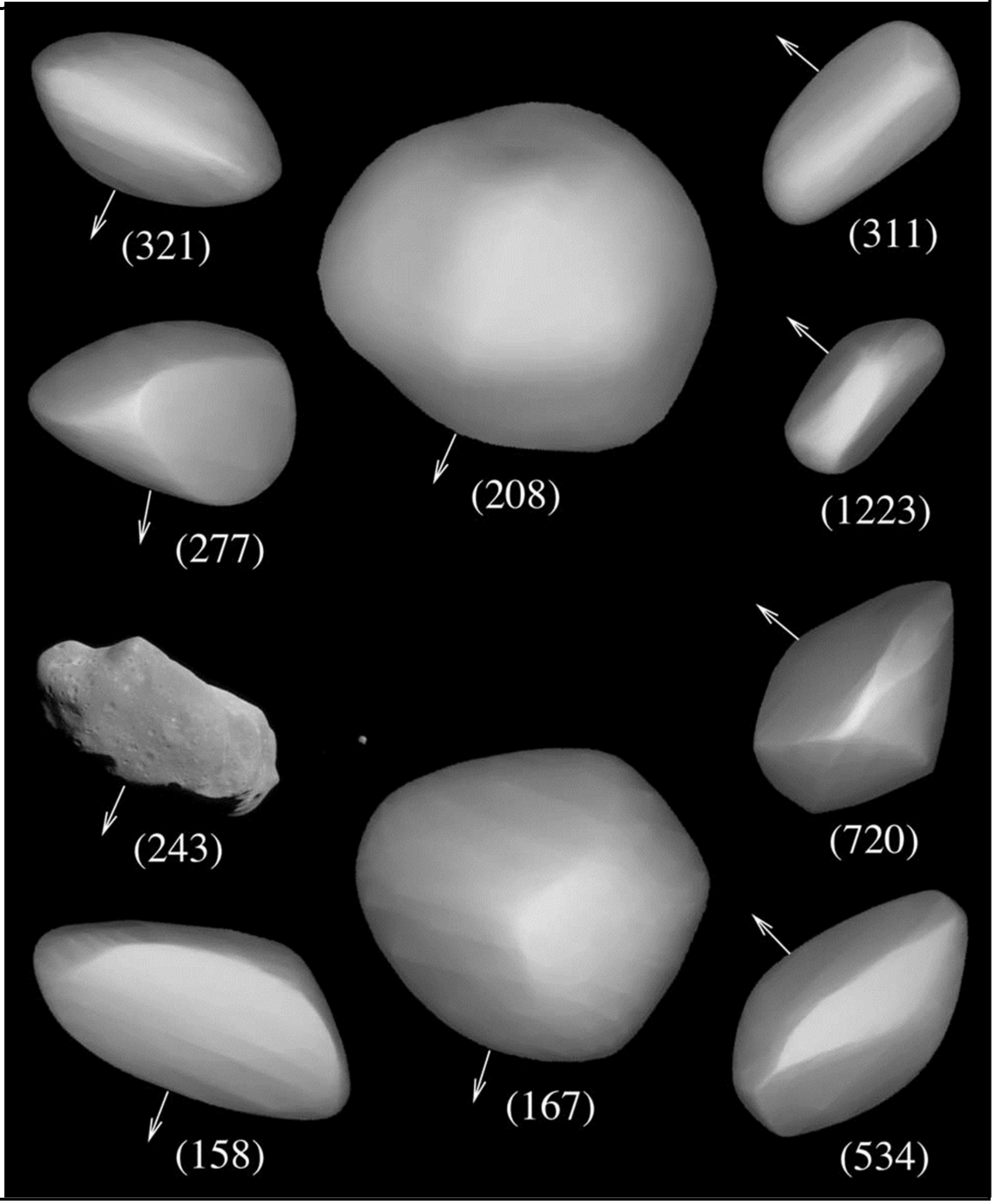
Application of the code to previous HIPPARCOS photometric data

The results are generally encouraging: Photometry inversion for a number of the order of 100,000 asteroids should be possible

We expect to find solutions (poles, periods and axial ratios) for a significant fraction of the asteroid population.

General application: Spin properties as a new, important constraint to available models of the evolution of the Main Belt population.

Other applications: test of the existence of possible preferential alignments of the spin axes among family members. Assessment of the "YORP" effect.



Spectrophotometric (BP/RP) data and taxonomic classification

Sampling of asteroid reflectance spectra from Blue to Red by means of BP/RP data .

This taxonomic classification will have two major advantages:

1. It will be homogeneous, being based on data collected by a single instrument;

2. It will include for most objects the Blue region of the spectrum (as opposite to taxonomic classifications based on ground based spectroscopic surveys carried out during the last decades).

The Blue part of the reflectance spectrum is a very important diagnostic tool to distinguish among different sub-classes of primitive, low-albedo objects (the typical targets of space missions like Marco Polo-R), including the objects belonging to the old and interesting F class identified many years ago.

Mass (astrometry + binaries)

Size + Shape

⇒ Bulk Density

Bulk Density

Taxonomy

⇒ Interpretation of taxonomy in terms of composition and internal structure

The Gaia revolution in asteroid science

Expected Post-GAIA scenario in Asteroid science: The big Revolution

- Masses and average densities measured for ~ 100 objects.

- Sizes directly measured for ~1,000 objects

- Spin properties and general shapes for many thousands of objects; spin as a constraint to collisional evolution models

- New taxonomy of a very big sample of the population. Implications for the original gradient in composition of the Solar System, and for dynamical diffusion and collisional mechanisms.

- New “spectroscopic” families.

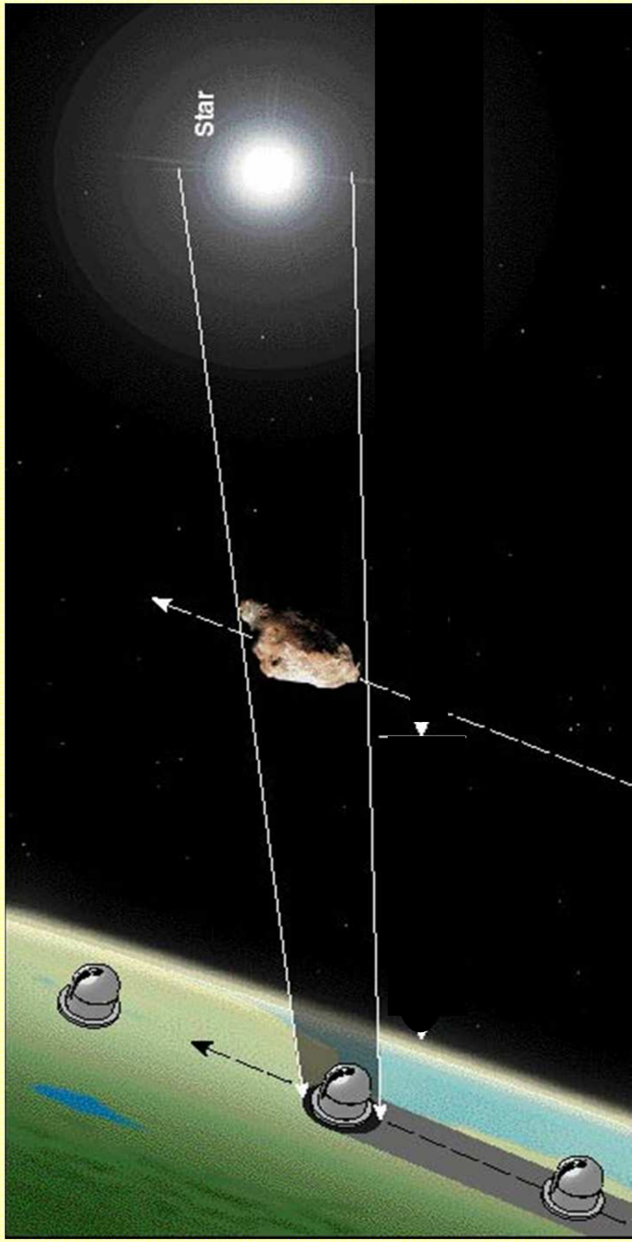
After Gaia : the occultation revival

Today

- poor predictability for objects <50 km
- bright Hipparcos/Tycho stars favoured
- ~0.1 events/object/year
- Current practical limit: 100 km at 10% accuracy

After Gaia (100 X orbit improvement):

- Uncertainty smaller than the asteroid at >20 km
- 1-m automated telescope(s):
  - Single site: 20-40 events/yr for any object of ~20 km
  - Network: completeness of diameters > 20 km in a few yr
- Derivation of projected shape
- Discovery of binary systems



Thank you