Gaia
and Solar System science

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Observatoire de la CÔTE d'AZUR

Gaia DPAC Data Processing & Analysis Consortium

Gaia and the Solar System…

- Gaia will NOT collect observations of « large » bodies (> 600 mas?)
  - Main Planets, large satellites
- Comets
- « Small » planetary satellites
  - « regular »
  - « irregular » (retrograde orbits)
- Asteroids (~600.000)
  - Mainly Main Belt Asteroids (MBA)
  - Several Near Earth Crossers (NEO)
  - Other populations (trojans, Centaurs,..)

…poorly known in general:

- >600.000 identified
- 50% « good » orbit; <1% rotation period; <0.1% approx. shape; <0.5% spectral type; <0.01% mass.

Context: other large surveys

- **Pan-STARRS (PS1 – 2010...)***
  - **V = 24, 5 Sloan bands** - **σ~63 mas** + parallaxes - whole sky 4 /month
  - 100,000 Jupiter Trojans (2900 now), 20,000 Kuiper belt objects (800)
  - Automated analysis and extraction of transient sources
  - Plans for **photometric inversion → « complex » shapes**

- **LSST (2015…)***
  - **V=24, 6 bands** **σ~9 mas + parallaxes** whole sky 8 /month
  - 30 TB each night, immediately public
  - **Plans for NEO search – not yet clear for other aims**

- **Wide-field Infrared Survey Explorer - WISE (completed)**
  - 4 bands (**3.3 – 23 μm**), 1000 x IRAS sensitivity (1983)
  - **~10 observations for 100,000 asteroids**
  - → **albedos, sizes**

…+ SPITZER (more objects, lower precision)

* data from E. Hog

The challenge

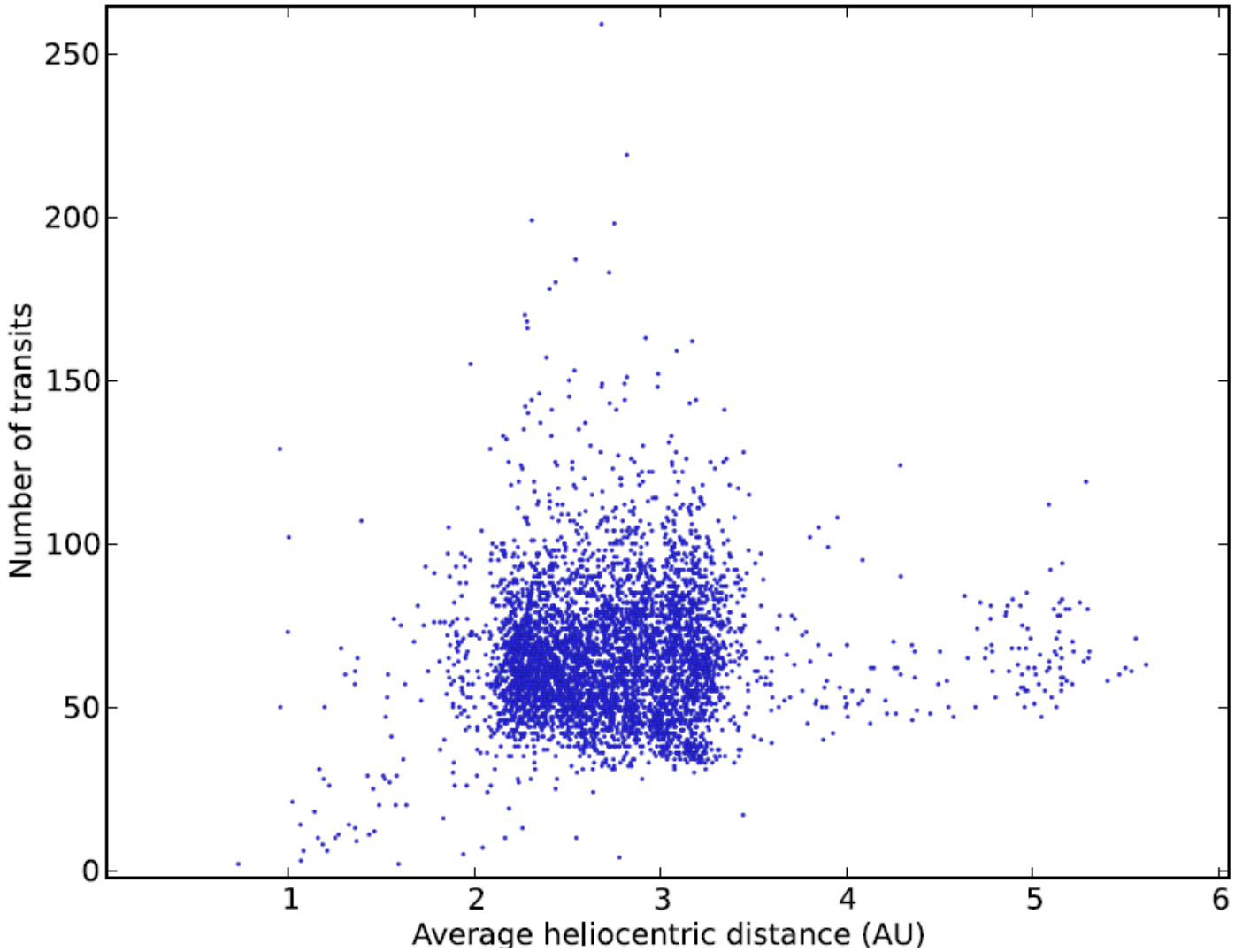
- 1 source out of 2500 is a SSO
- SSO rate: ~ 1 SSO / 6 s

- Moving objects identification:
  - cannot proceed as for the stars (cross - matching)
  - needs an orbit catalogue (but not all the available orbits are « good enough»)

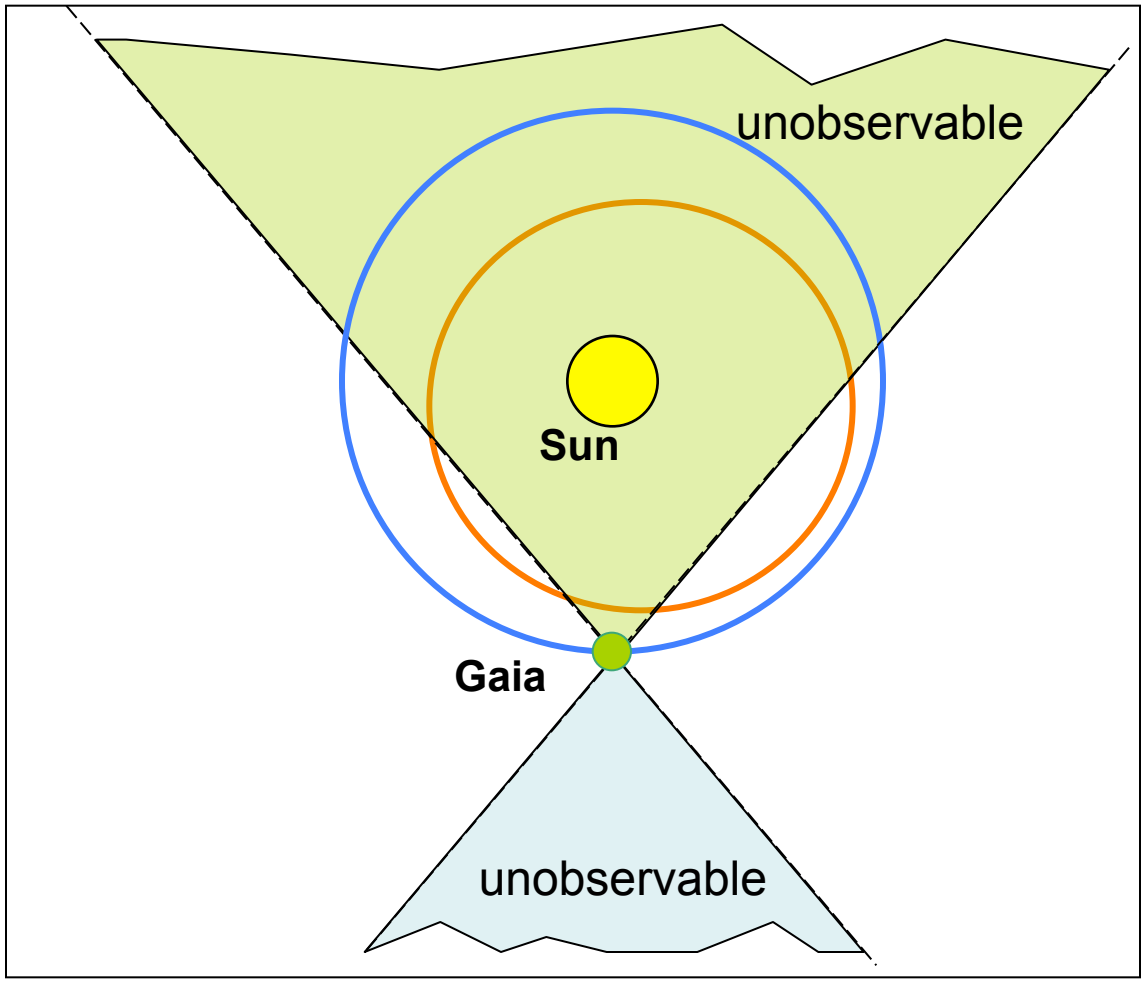
Date of MPCs	Grand total	Minor Planets Total	Num.	Unnum.	Total	Comets Num. P/	Other
2012 AUG. 31	94083945	93442293	84085285	9357008	641652	237148	404504
2012 AUG. 2	93649246	93012753	83541997	9470756	636493	235656	400837
2012 JULY 3	93461684	92830381	83353040	9477341	631303	234596	396707
2012 JUNE 4	93097846	92469742	82954315	9515427	628104	233316	394788

- Problems
  - Proper motion (accuracy degradation)
  - Ambiguous / failed identifications → « threading » of the observations
  - Short-arc orbit determination (2-3 transits).

Number of observations



Observable region on the ecliptic and discoveries



- Discovery space:
  - Low elongations (~45-60°)
  - Inner Earth Objects (~unknown)
  - Other NEOs
  - Small fraction of MBA

Solar System and Gaia – before DPAC

- before 2000 : preliminary studies
- 2001 – 2005 : Solar System Working Group
  - 8 meetings
  - coordinator: F. Mignard
  - main achievements:
    - simulation of Gaia data on SSO
    - preliminary assessment of performance and science outcome
    - identification of problematic technical issues
    - increased awareness of the community on the contribution of Gaia
- Smooth transition to CU4/SSO from 2006 (D. Pourbaix / P. Tanga)

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

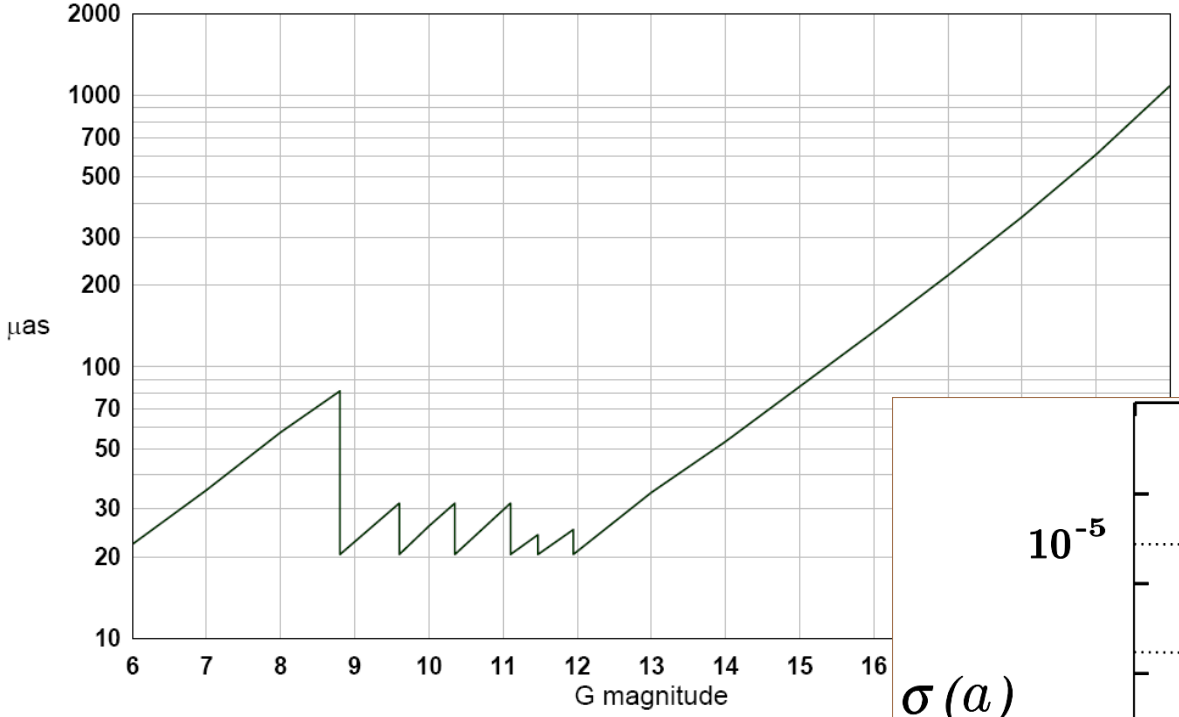
CCD signal

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

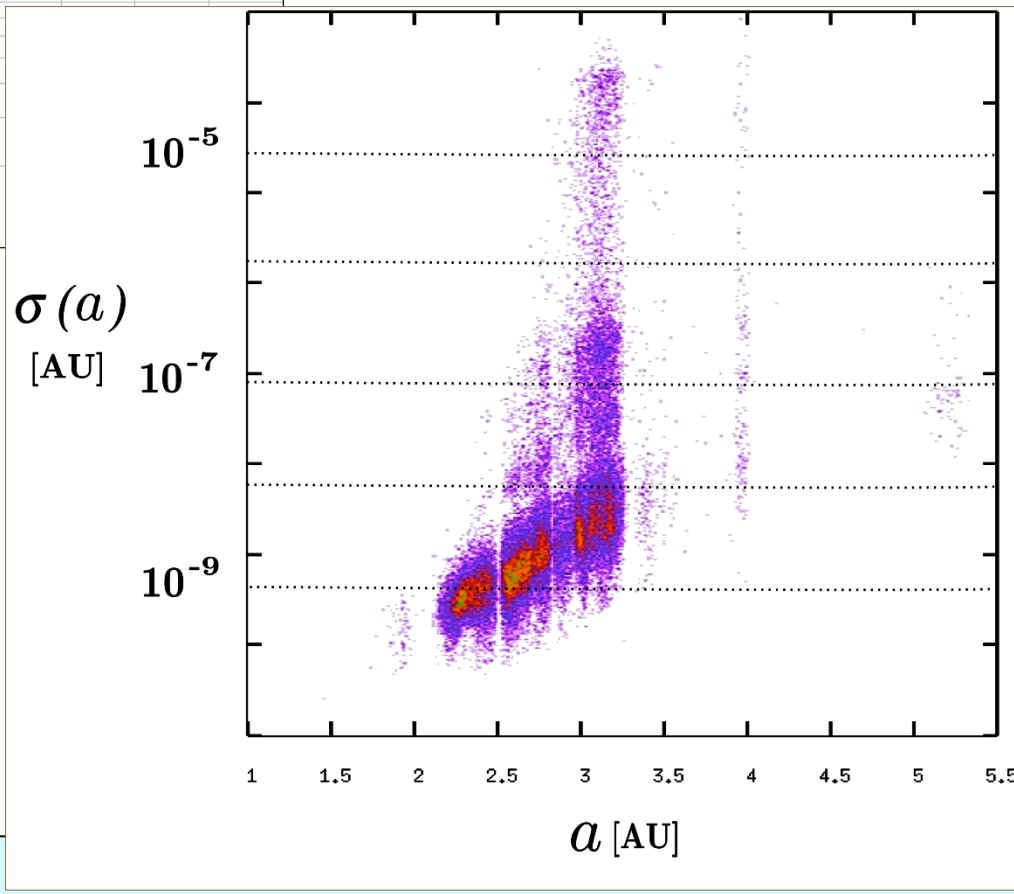
RP/BP spectrophot.

- Photometric data in several bands : albedo, taxonomic classification
- Light curves over 5 years : rotation, pole, shape.

Astrometry → orbit refinement



Single-scan astrometric accuracy



Simulated orbit determination:

> 10^2 better than current accuracy

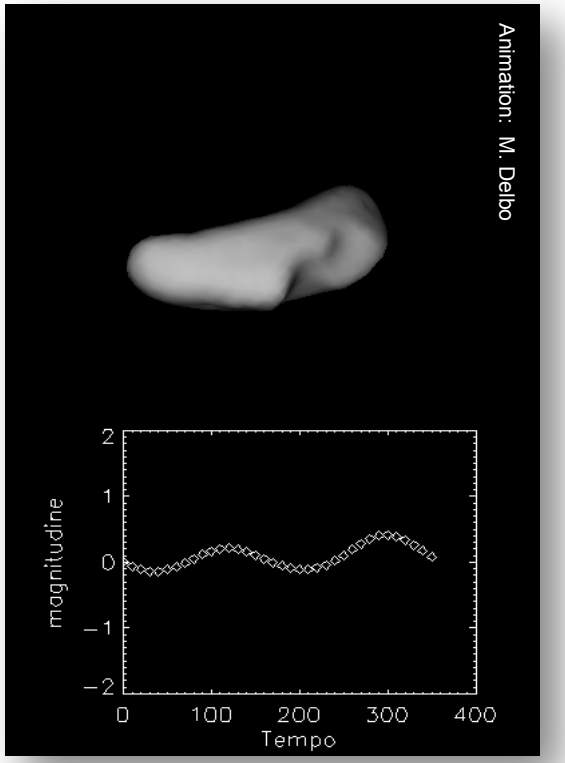
Mouret et al. 2007

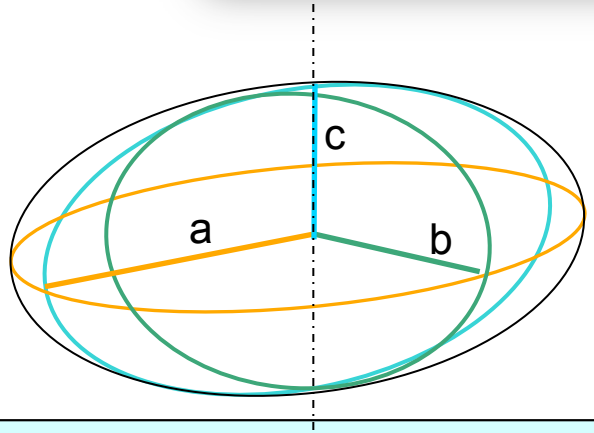
Photometry → Shapes

- Inverse problem:
  - find the rotation parameters from photometric data
  - strongly non linear
  - usually solved from "dense" light curves (~100s-1000 observations)

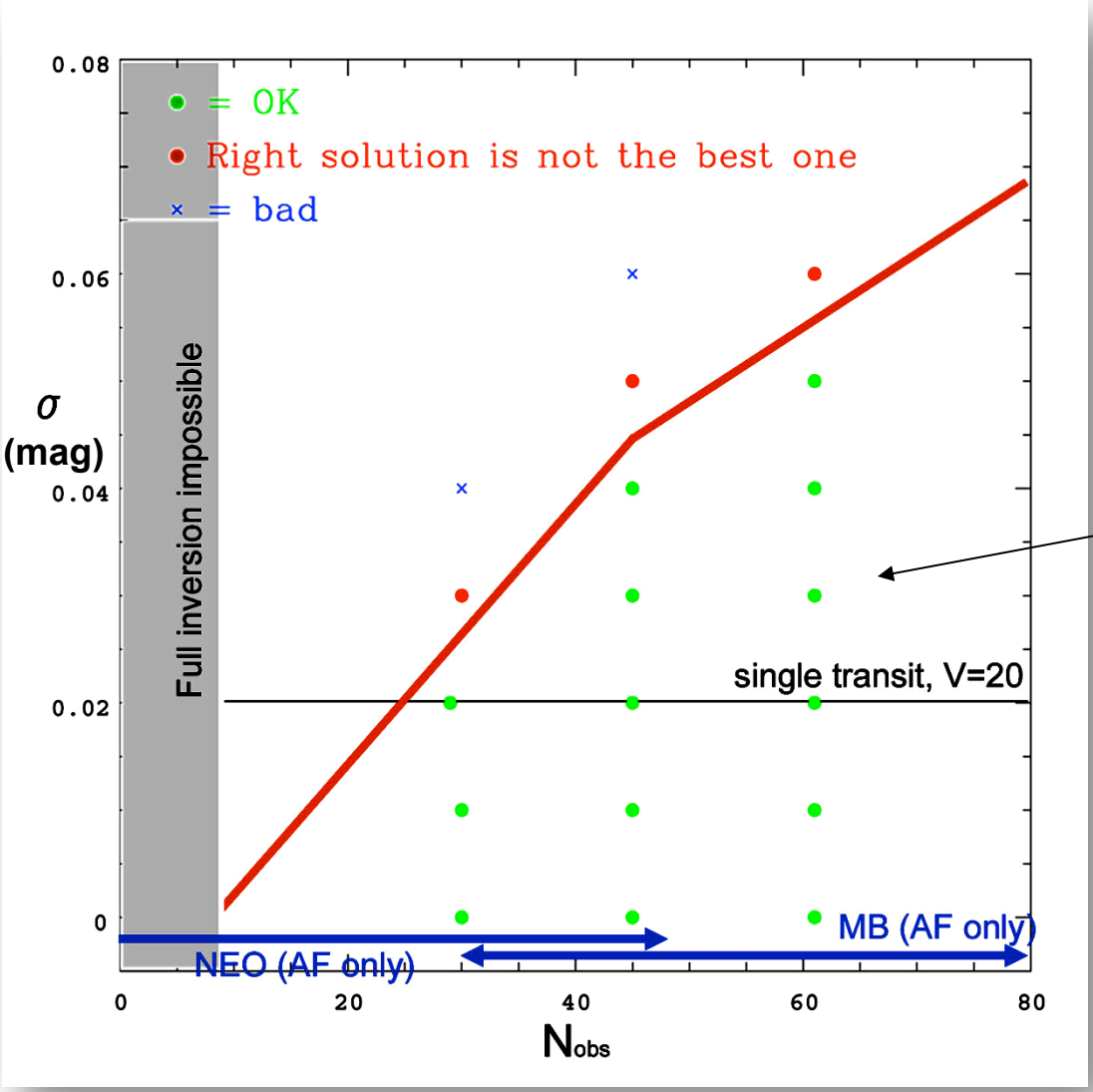
- Choice for Gaia:
  - Three-axial ellipsoids
  - Genetic algorithm for determining 7 parameters:
    - Semi-axis (a, b, c)
    - Pole coordinates (λ, β)
    - Rotation period (T)
    - Slope magnitude vs. phase angle (→ scattering)

- Deep testing and validation:
  - inversion of Hipparcos photometry
    - 22 objects (Cellino et al. 2009: A&A 506, 935)
  - extensive simulations.
  - still a challenge in terms of computing time





Photometric inversion limits



Green circles: successful inversion

A. Cellino, P. Tanga

RP/BP → Taxonomic classification

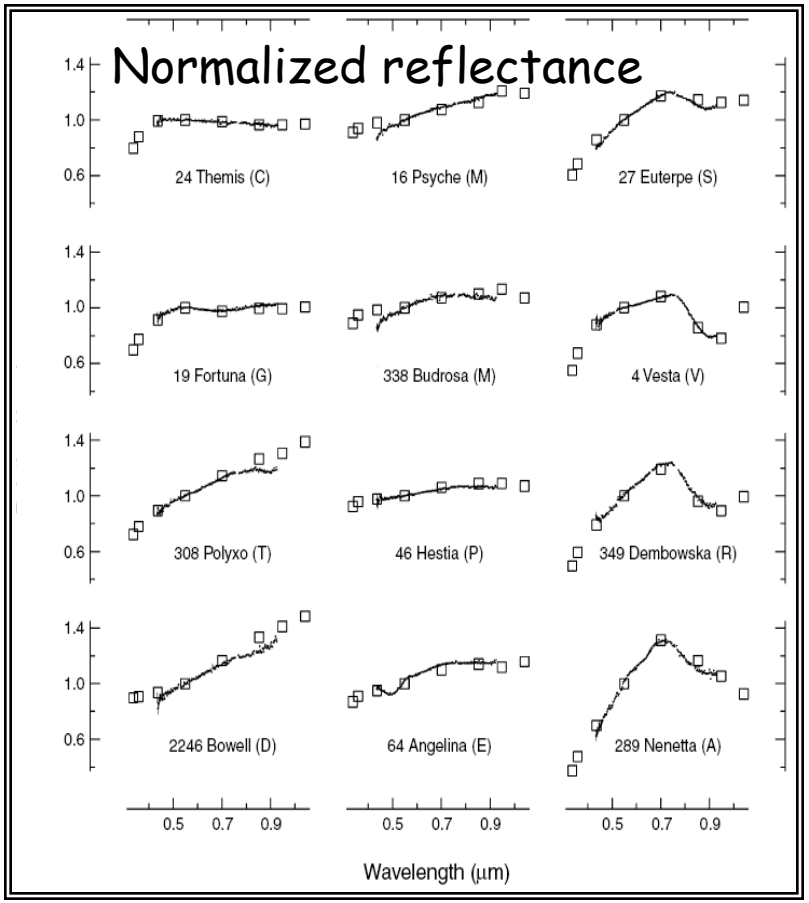
- Taxonomy classifies asteroids on the basis of visible *and* near-IR reflectance spectroscopy
  - Based on ~1000 objects today

- Gaia special features:
  - High solar elongation
  - Blue spectrum coverage
  - Several “bands”

  → *Gaia taxonomy*

- Unsupervised classifier
  - based on a Minimum Spanning Tree alg.
  - specific metric for cluster discrimination

  → *training on Earth-based observations.*

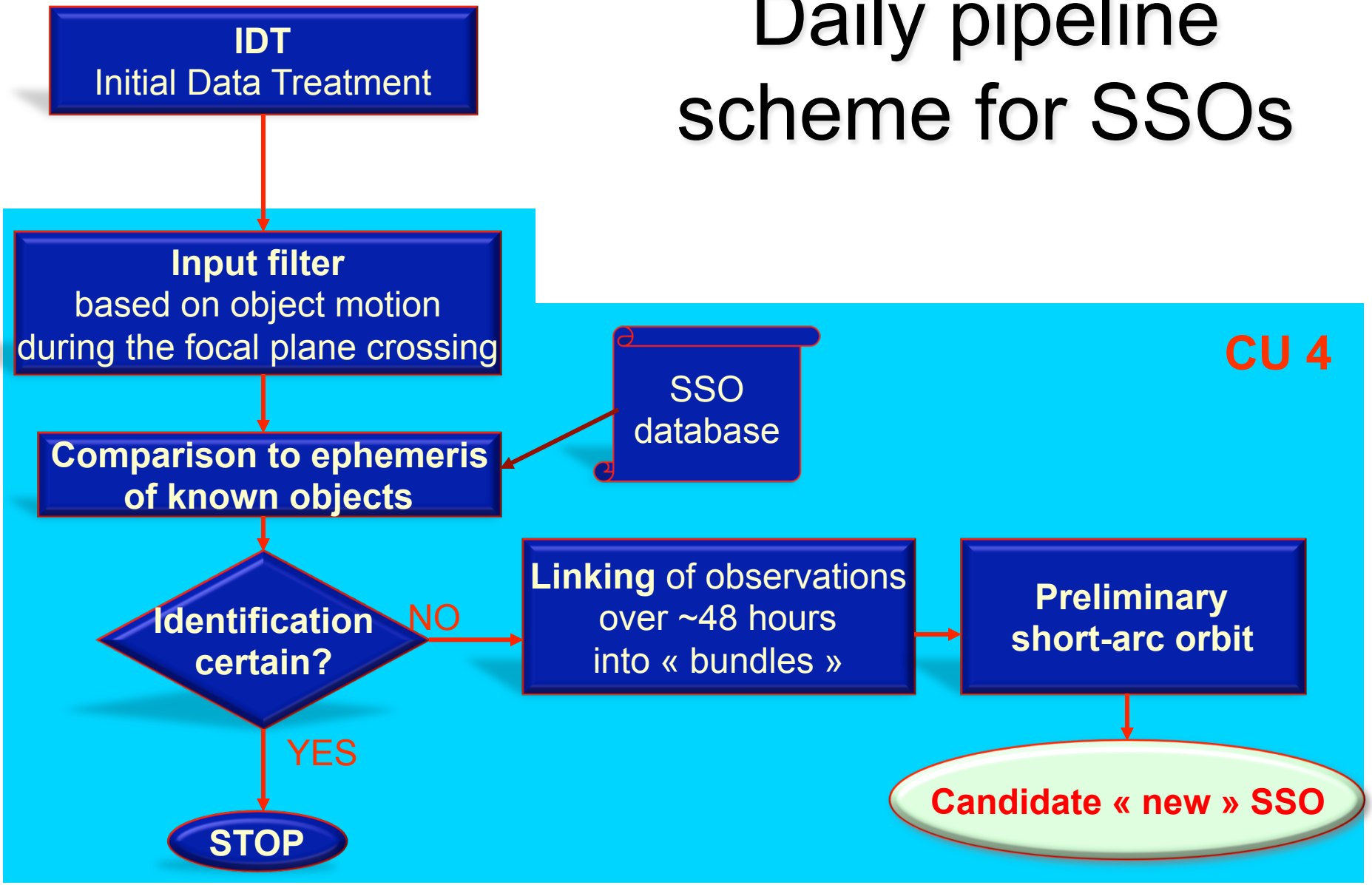


Two pipelines for reaching the science goals

- Daily processing
  - Maximize science return by processing « new » asteroids or ambiguous identifications
  - Data input from *Inital Data Treatment* (non-matched sources)

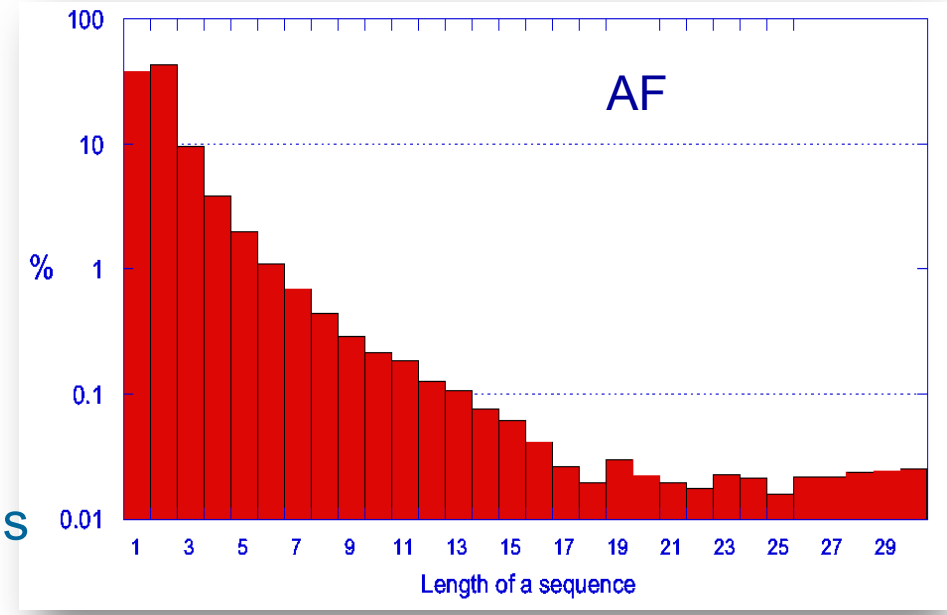
- Long –term processing
  - Processing of all sources
  - Devoted to obtain for SSOs the final output of the mission

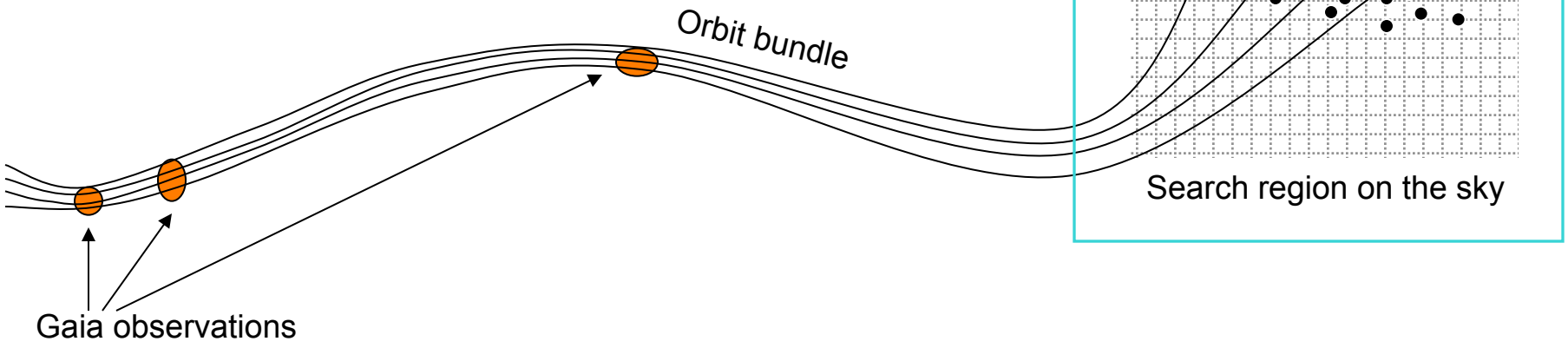
Daily pipeline scheme for SSOs



Core of the daily chain

- Short arc threading (bundling)
  - 2-3 consecutive detections are frequent
  - Algorithm based on velocity extrapolation
- Short arc orbit determination
  - It exploits single CCD observations
  - Statistical method : Markov-Chain Monte-Carlo, MCMC → bundle of possible orbits.



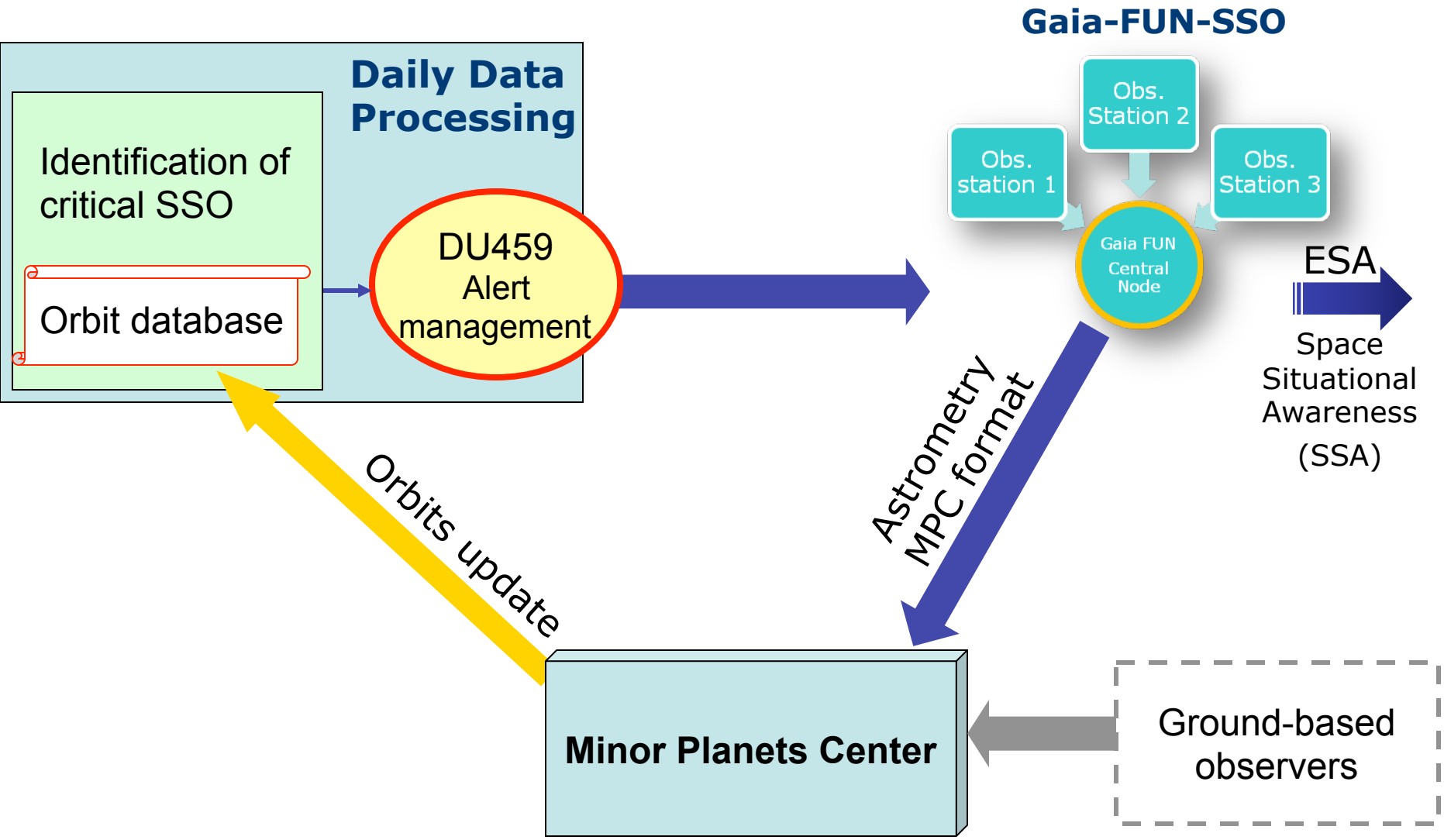


Managing asteroid alerts: goals

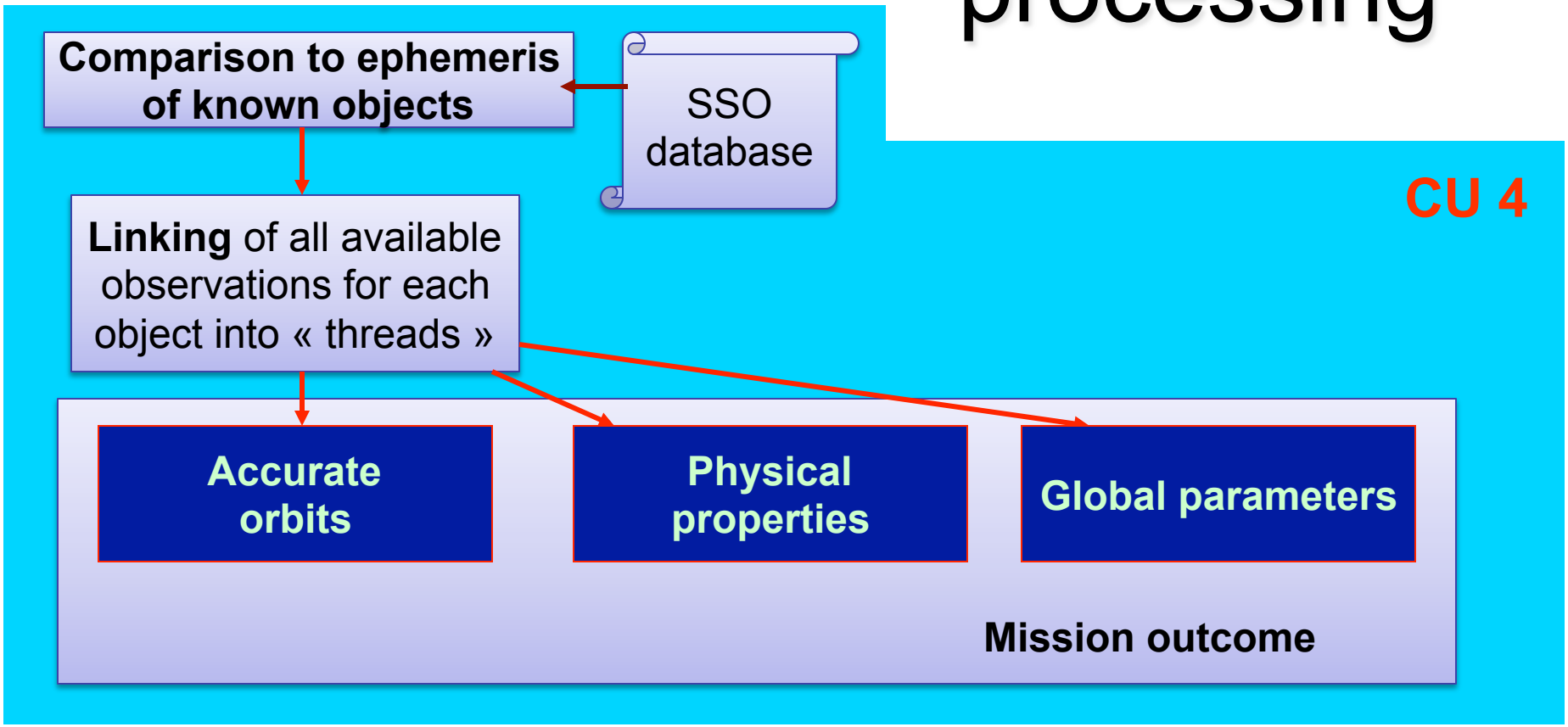
- Validation of the «new» objects
  - Ground based recovery can discriminate « false » and « true » SSO
  - Reliability verification of the daily processing chain
  - *(verification procedures are common to other large surveys such as Pan-STARRS)*
- Recovery of the highest possible number of
  - New objects, discovered by Gaia
  - Objects with « poor » orbits (→ ambiguous identification)
- Improve orbit accuracy
  - Interesting Earth-crossers can be severely under-observed

→ Maximization of the scientific impact of the mission.

Follow-up Network for SSO



Long-term processing



- End-of-mission task (+ intermediate runs)
- Iterations possible

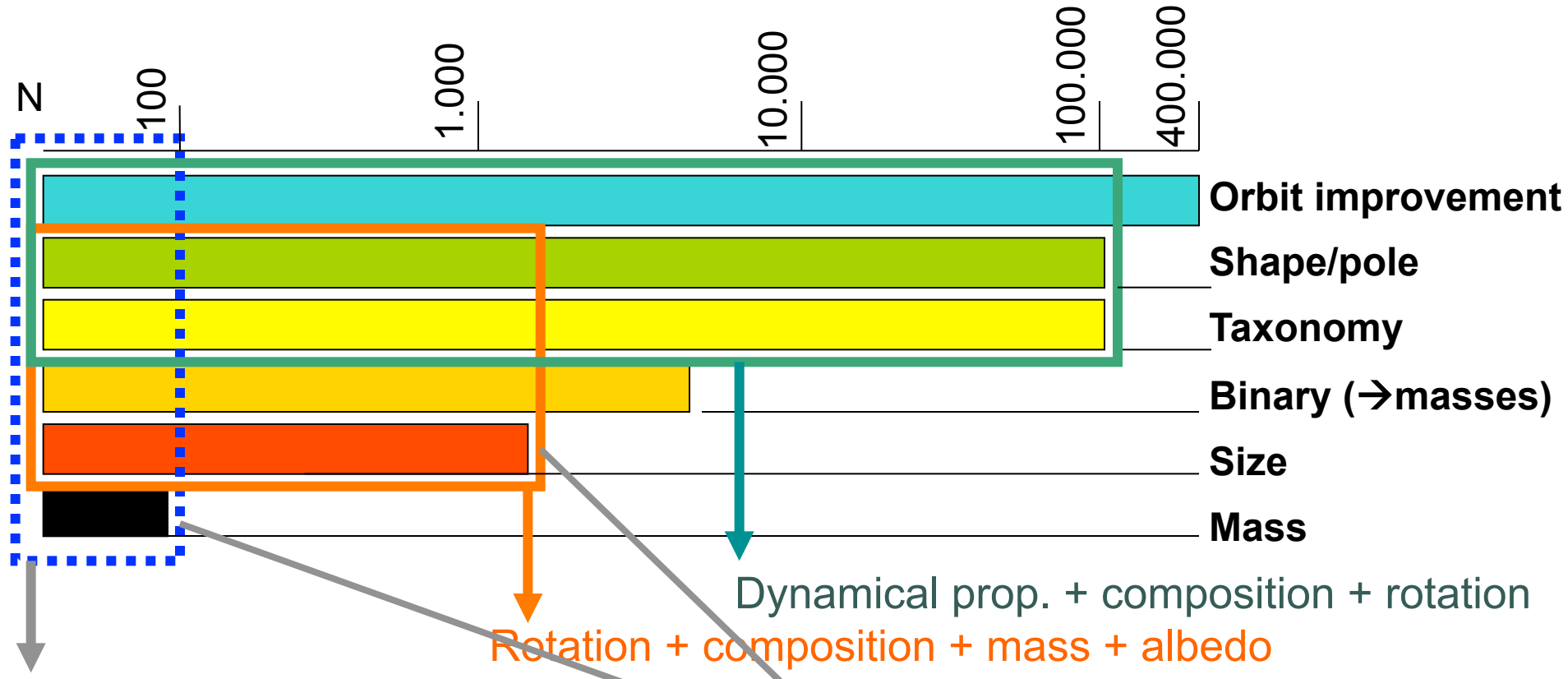
Expected output

	Number of objects
• Epoch position, brightness	~400.000
• Orbital elements	~300.000
• Mass of the largest perturbers	~70
• Bulk shape (ellipsoidal model)	~100.000
• Pole direction	~100.000
• Rotation period	~200.000
• Photometric parameters (H, phase law)	~200.000
• Size	<1000
• Albedo	<1000
• Density	~70
• Spectrophotometry	~200.000
• Taxonomy	~200.000
• Index of cometary activity	?
• Index of binariety	5% ?
• Orbits of binary asteroids	?

Implementation – current situation

Raw signal processing (centroiding, signal properties)	done
Astrometric reduction (conversion to sky coords.)	part. done, test
Object identification	done, test
Orbit database update (for identification)	done
Short-arc observation bundling	test
Long term-threading	*in progress*
Short arc orbits	test
Orbits of binary asteroids	*under evaluation*
Orbit refinement	*in progress*
Photometry inversion	done
Processing of RP-BP spectra	*in progress*
Taxonomy	done, test

Asteroids after Gaia: a new global picture



Ground – based support
Joint exploitation with other surveys such as the Wide-field Infrared Survey Explorer (WISE)

Validation

- Asteroid shape / rotation parameters
  - databases of shapes from dense lightcurve inversion
  - detailed shapes from space probe encounters
  - radar shapes
  - projected shapes from stellar occultations
- Size
  - WISE / Spitzer shapes (from thermal IR) ~100.000 sources
  - Available stellar occultations
- Spectral types
  - Bus and Binzel / De Meo taxonomy
- Orbital parameters
  - Best known orbits
  - Available stellar occultations (accuracy ~0.1s = ~2 km for MBAs).

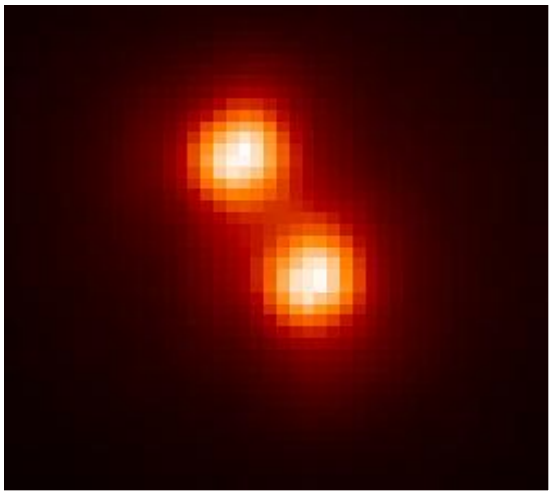
What will NOT be done in the DPAC frame?

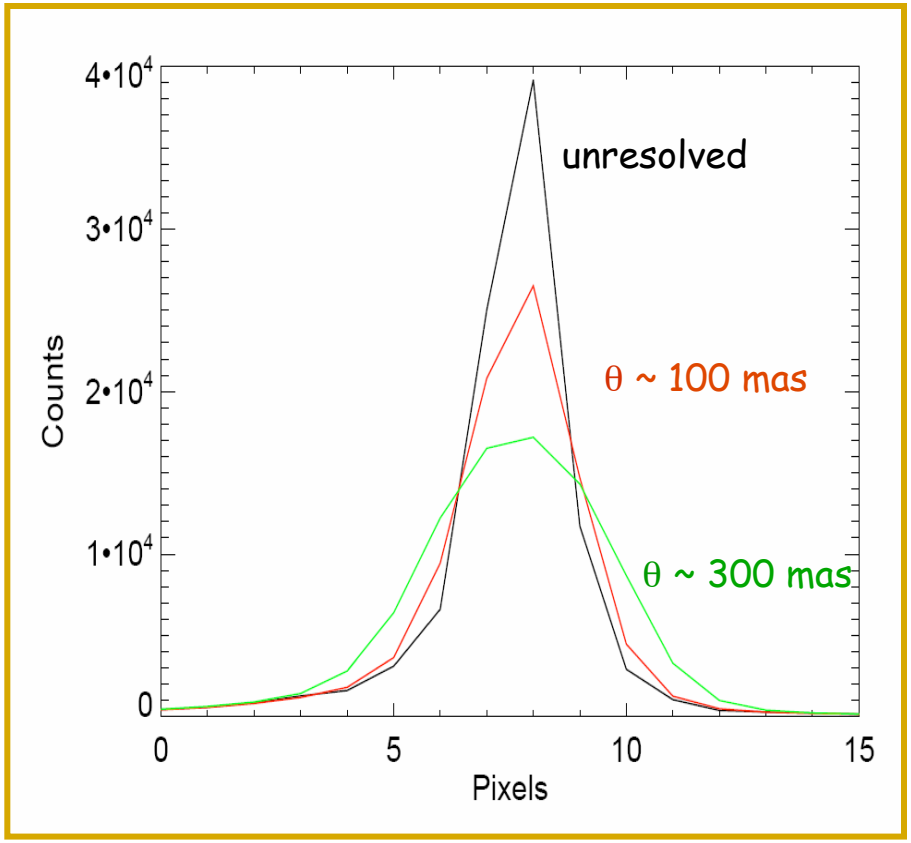
- From the astrometry:
  - Computation of proper elements of the asteroids
  - Complete analysis of residuals of orbital fitting
    - Signatures of satellites?
    - Irregular shapes?
- From photometry:
  - Shape search for objects failing the ellipsoidal fit
  - Binary solution from mutual eclipses
- From spectrophotometry
  - Epoch spectra / variations

Some specific science issues

Size of the asteroids

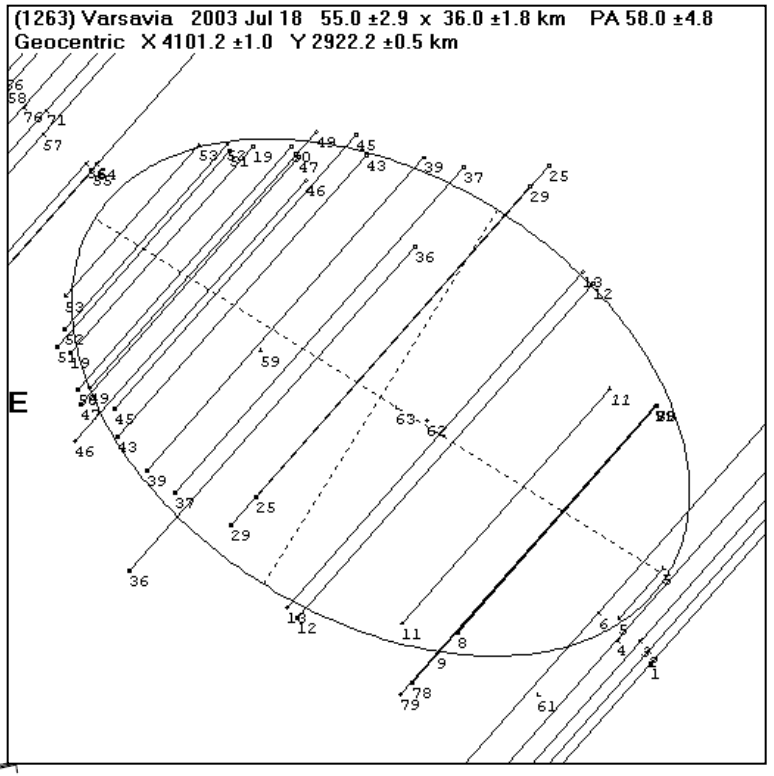
- Direct size determination for over 1000 asteroids
- Good quality sizes for D>40km
- Object's size at different epochs
  → overall shape
- Binarity

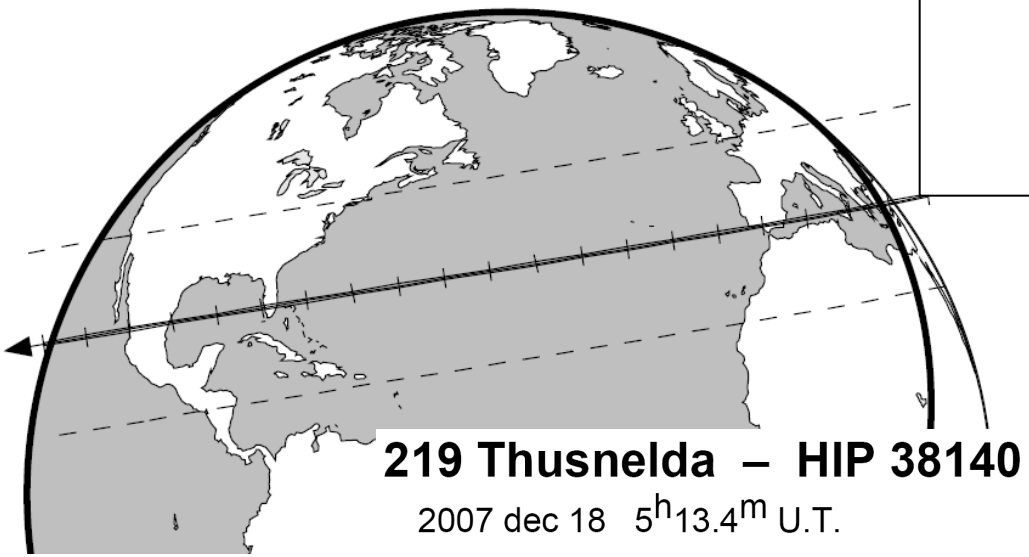




Signals for different diameters

A possible solution to the problem of sizes





219 Thusnelda – HIP 38140

2007 dec 18 $5^h13.4^m$ U.T.

Today: poor predictability for objects < 40 km

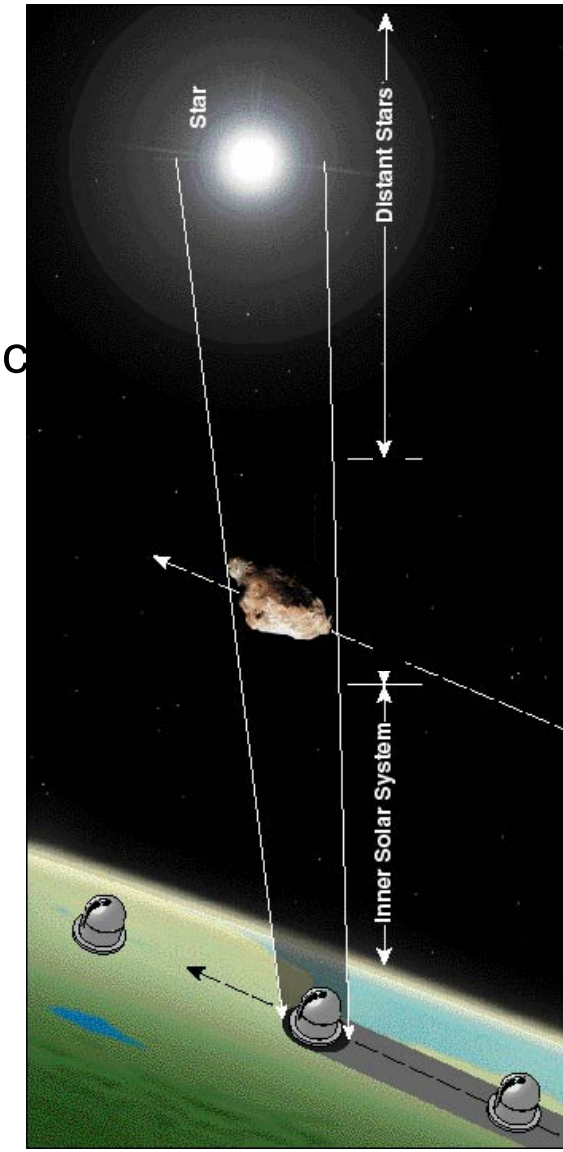
The occultation opportunity

Today

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

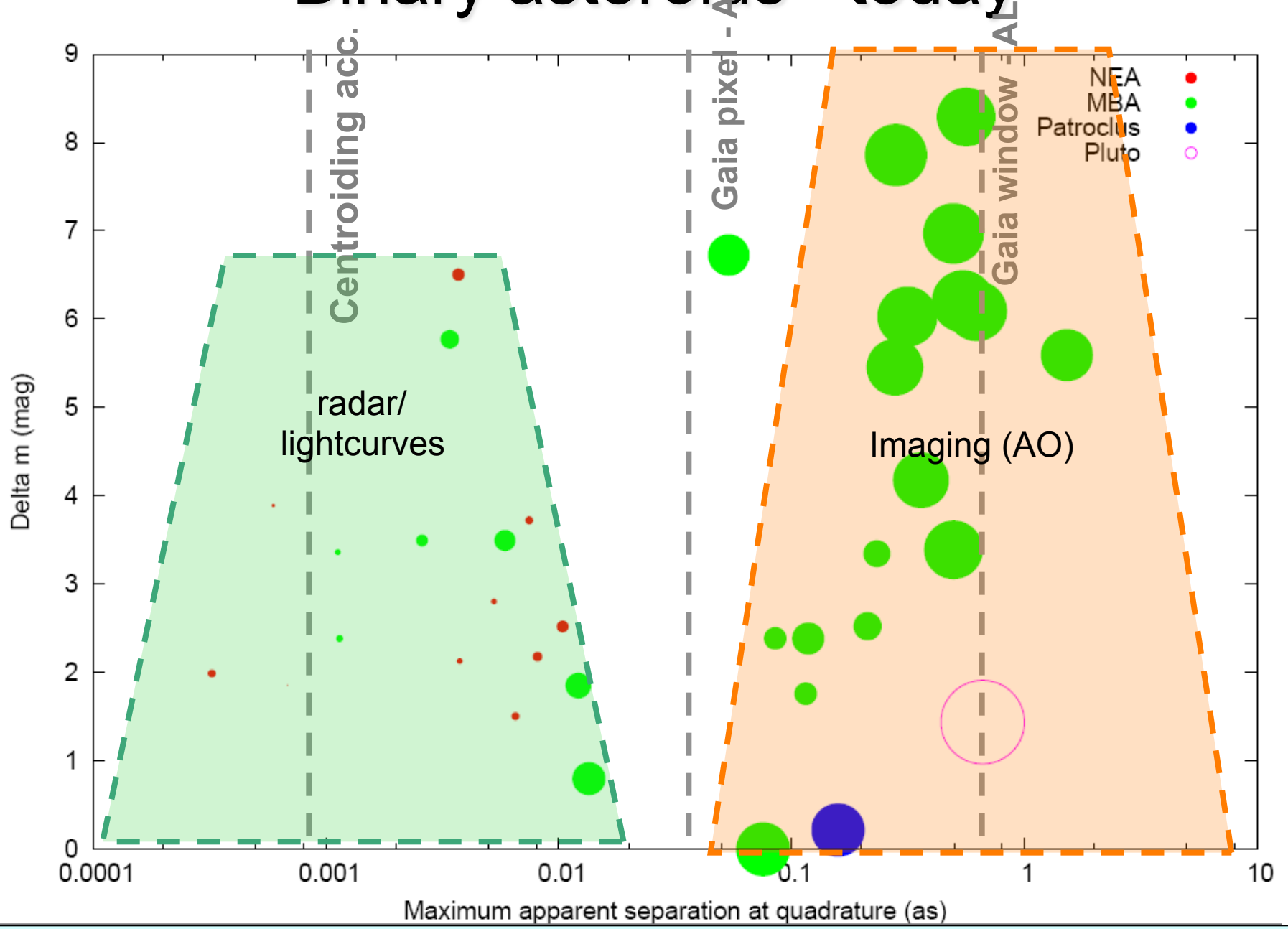
After Gaia (100 X orbit improvement):

- Uncertainty smaller than the asteroid at >20 km
- 1-m automated telescope(s):
  - Single site: 20-40 events/yr for an object of ~20 km
  - Network: completeness of diameters > 20 km in a few yr
- Projected shape known
- TNO will benefit of the stellar accuracy



Tanga, Delbo A&A 2007

Binary asteroids - today



Possible actions triggered by the Gaia output

- Further data exploitation
  - Computation of proper elements, new dynamical family classifications
  - Deeper analysis of anomalous sources (suspect binaries, comets…)
- Obtention of new data
  - TNO/asteroid occultations
  - Complementary observations:
    - Spectra
    - Photometry
    - Astrometry (candidates for mass / Yarkovsky determination)
- Exploitation by associating data of other surveys:
  - Pan-STARRS, LSST, Spitzer & WISE …

→ GREAT Network

GREAT - WGC4 Solar System

- Current list *http://great.ast.cam.ac.uk/Greatwiki*

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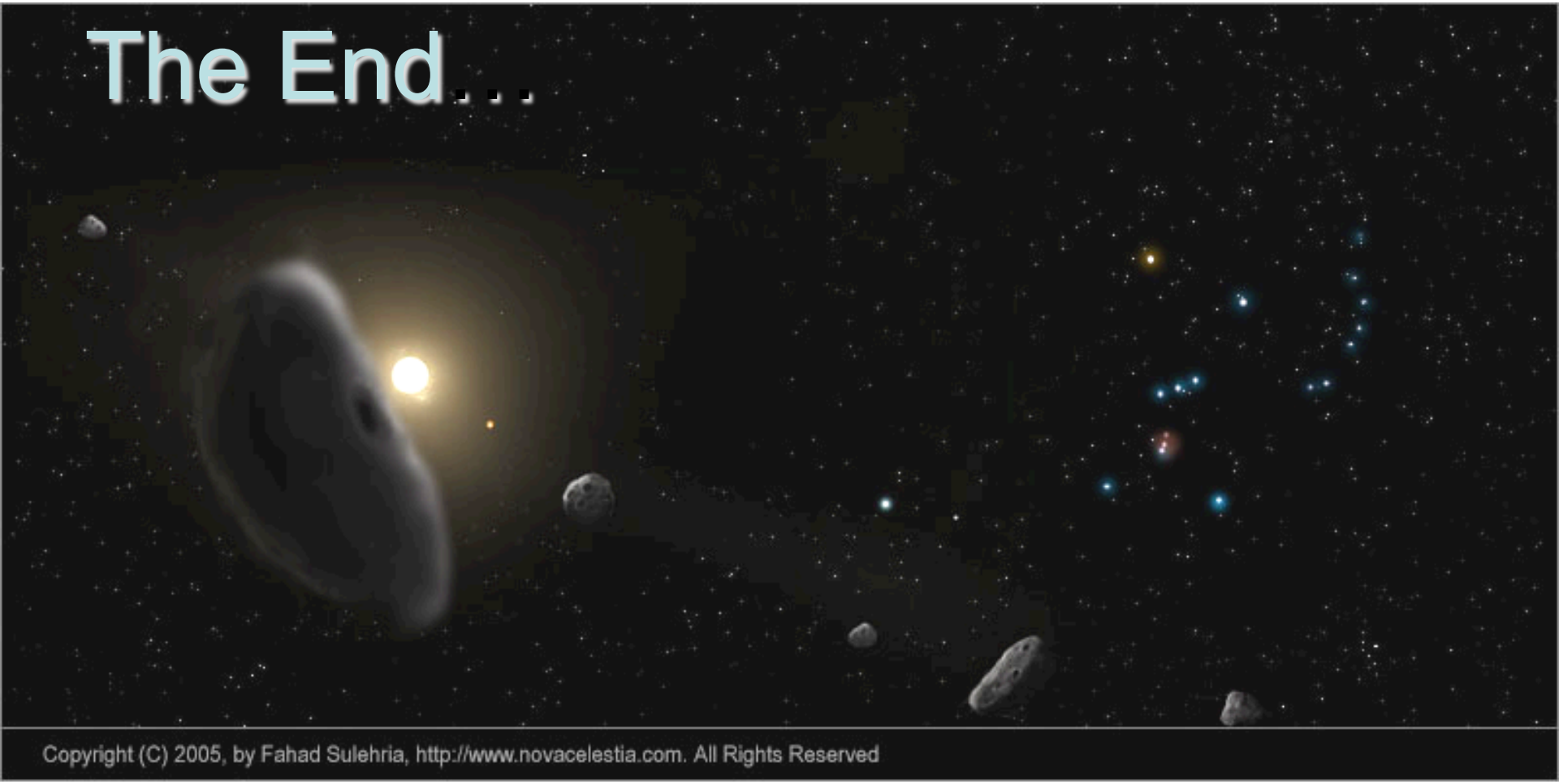
The End…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