

# Global Dynamics & Ephemerides

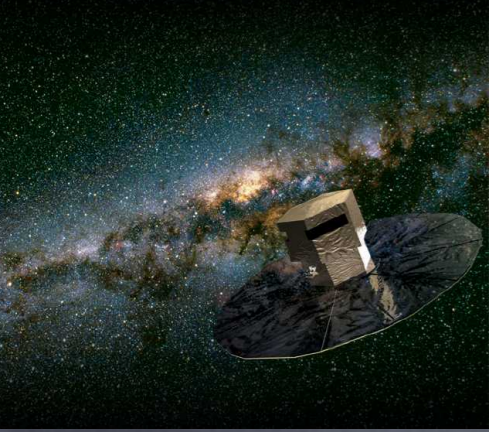
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IMCCE / Paris observatory

# Hipparcos



- Hipparcos precursor of Gaia
- 1989—1993:1997 ; 3 years
  - ▶ Hipparcos (120,000 stars) & Tycho (2million)
  - ▶ Input catalogue and SSO ephemerides
- SSO: 48 asteroids, 5 satellites (J & S), 2 planets
  - ▶ astrometry ( $\sigma \approx 10\text{mas}$ ) and photometry ( $\sigma \approx 0.05\text{mag}$ )
  - ▶ cf. Perryman's book (2009, chap10)
- Gaia is much more than a Hipparcos-2 (or  $2^{13}$ )

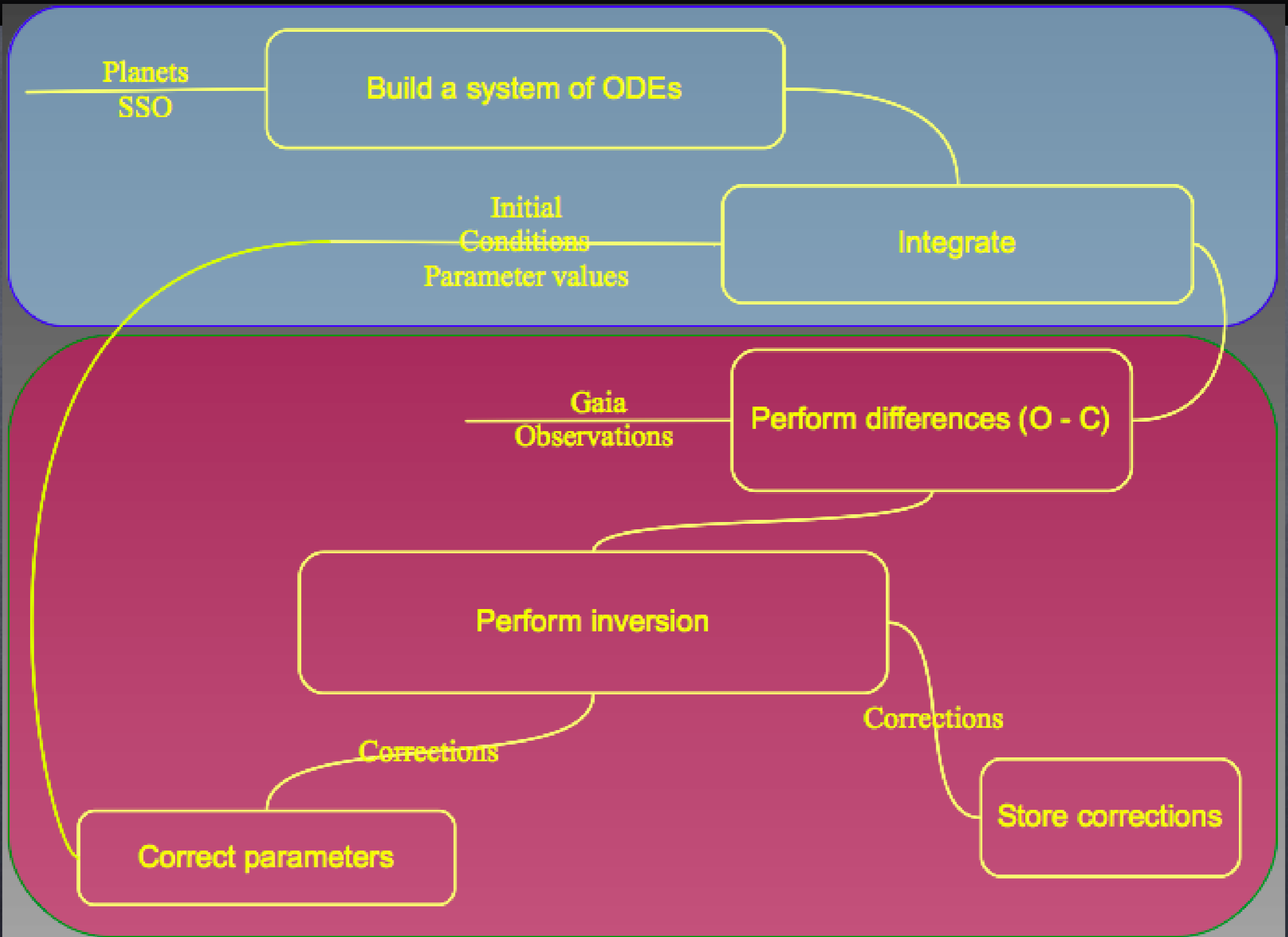


# Global Dynamics

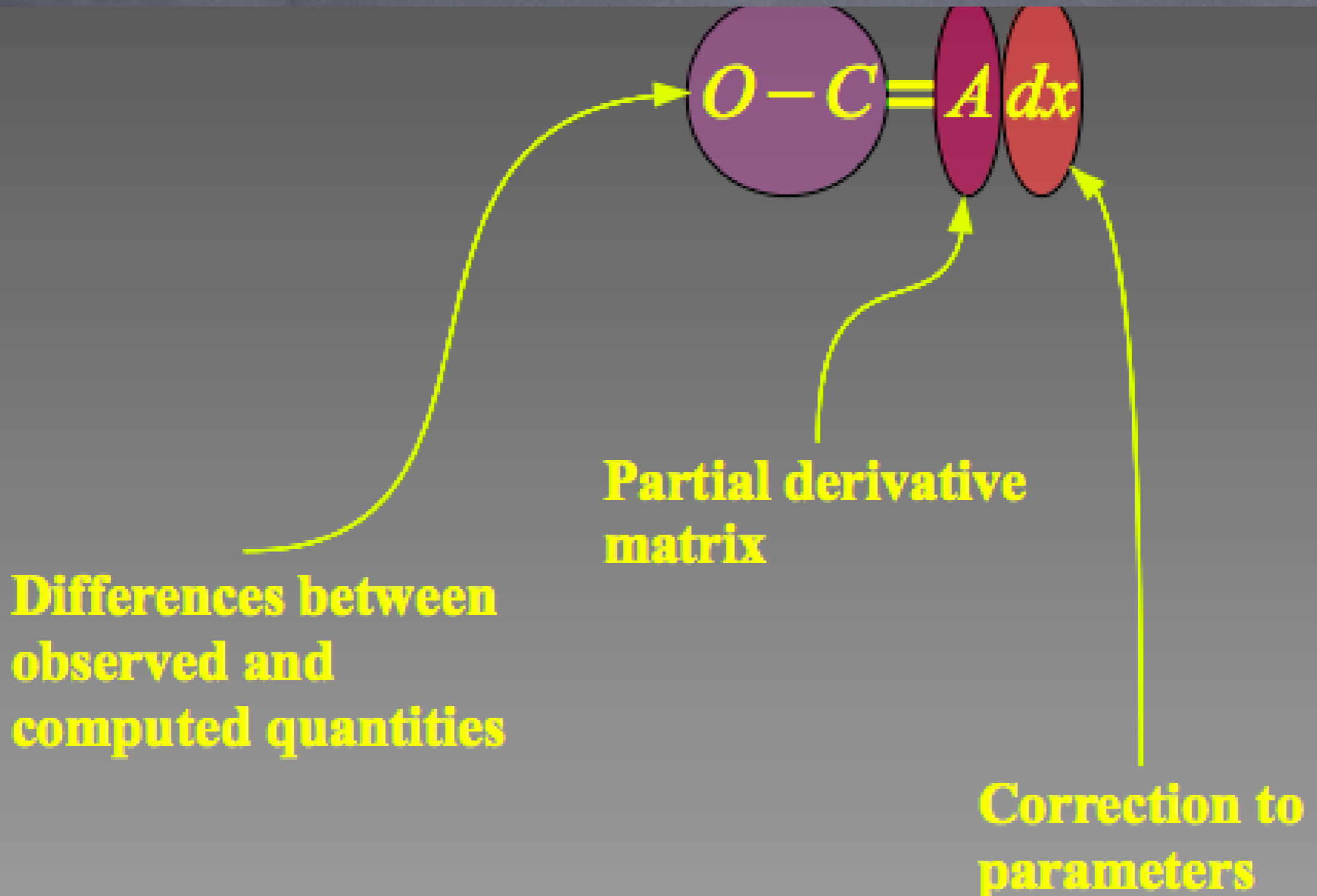
- Long Term LT processing (not ST, alert, ...)
  - ▶ Starts later during mission, run every  $\approx 6$  month
- Takes input from :
  - ▶ Gaia observations astrometry only
  - ▶ Initial condition Auxiliary DB (astorb.dat)
    - Loop closed via MPC for knew objects
    - **Gaia-FUN-SSO useful indirectly but rapidly**
- Inversion problem
  - ▶ Partial derivatives from variational equations

# WP Pipeline

Global dynamics

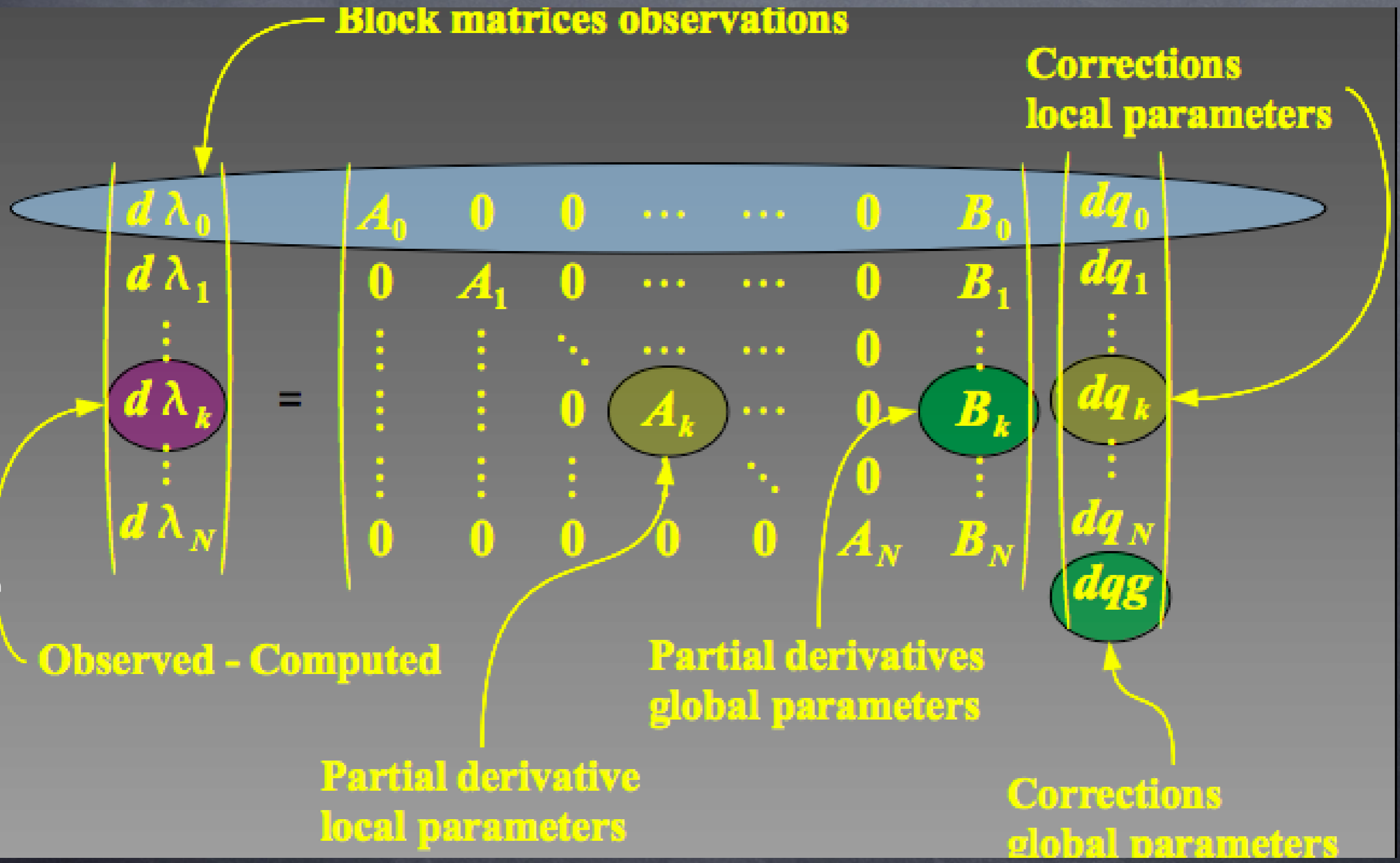


# Linear Least Squares - LLS



# LLS - Global solution

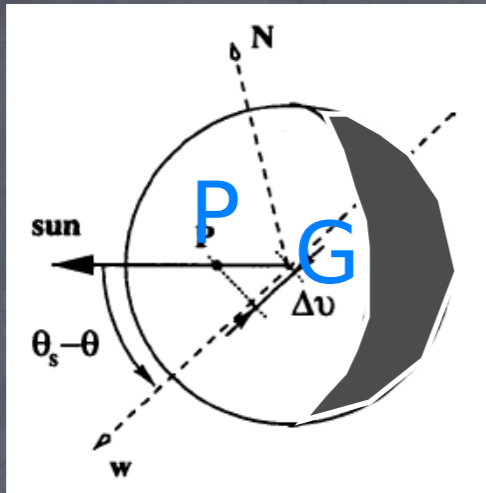
Global dynamics



# Orbit Adjustment

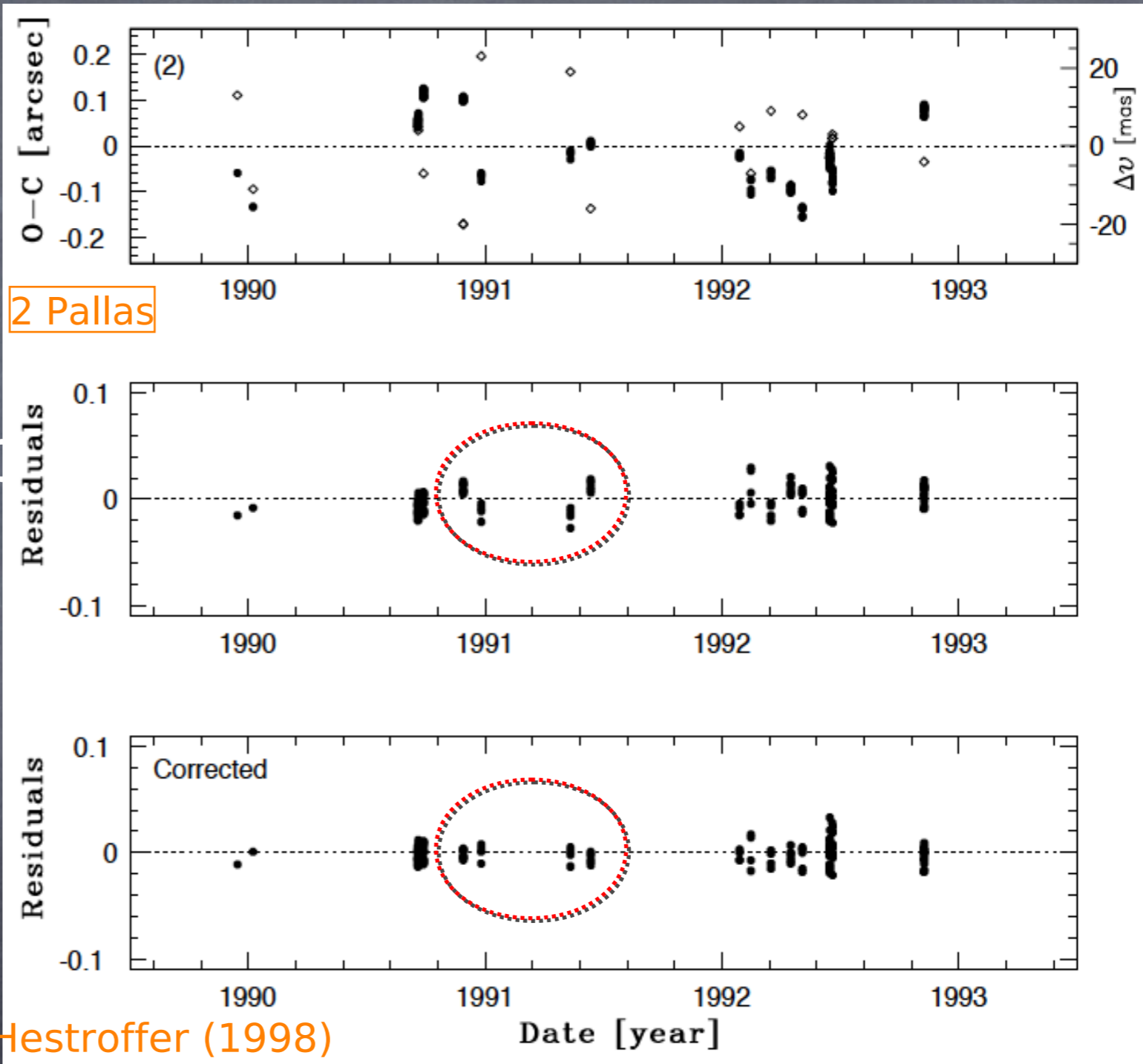
- Process all Gaia data available, and *only* Gaia (DPAC)
  - ▶ Object per object
  - ▶ Global solution
- Parameters determination
  - ▶ Dynamical parameters
  - ▶ Physical – (*not here, as input*)

# Photocentre offset



Global dynamics

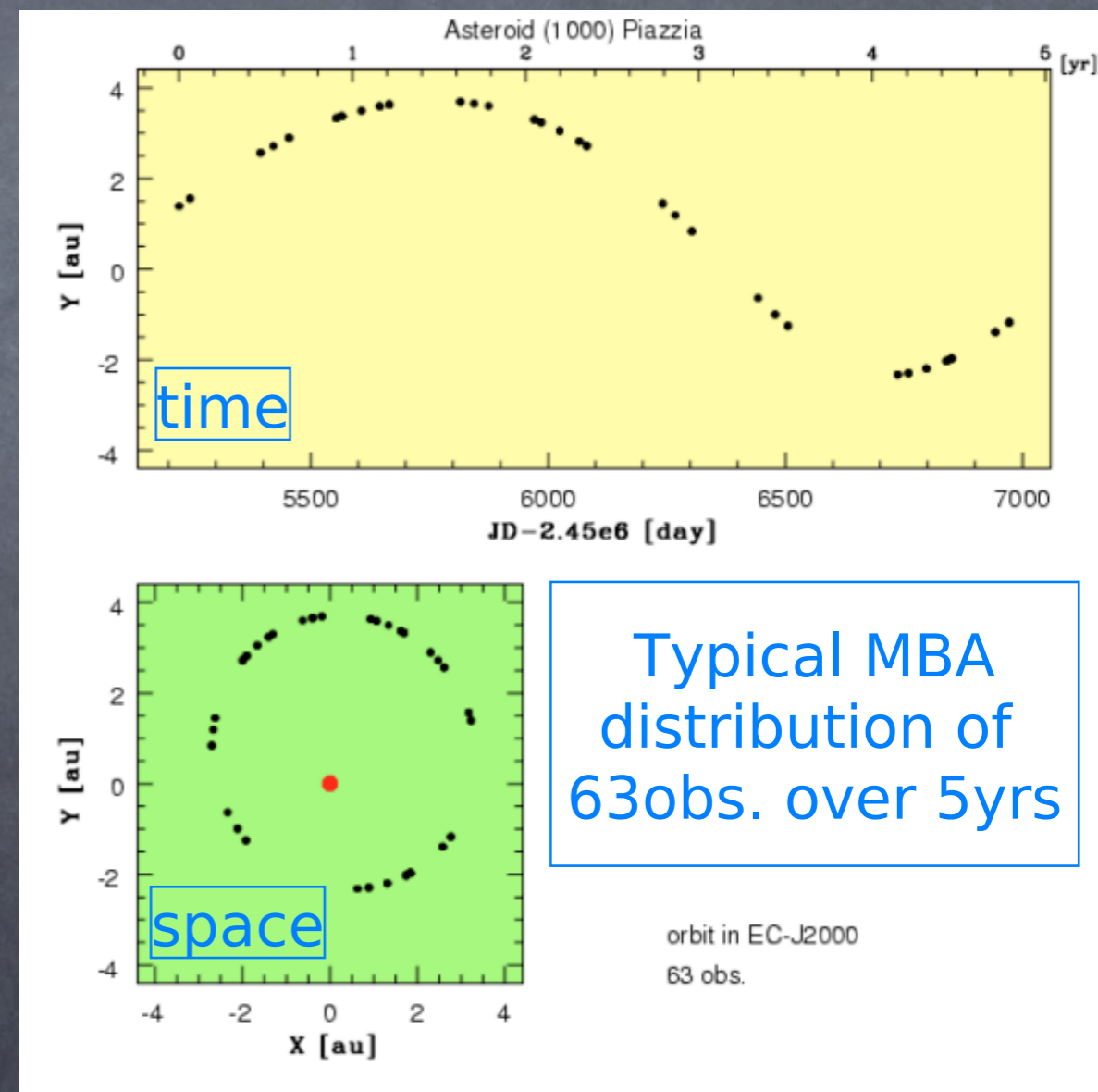
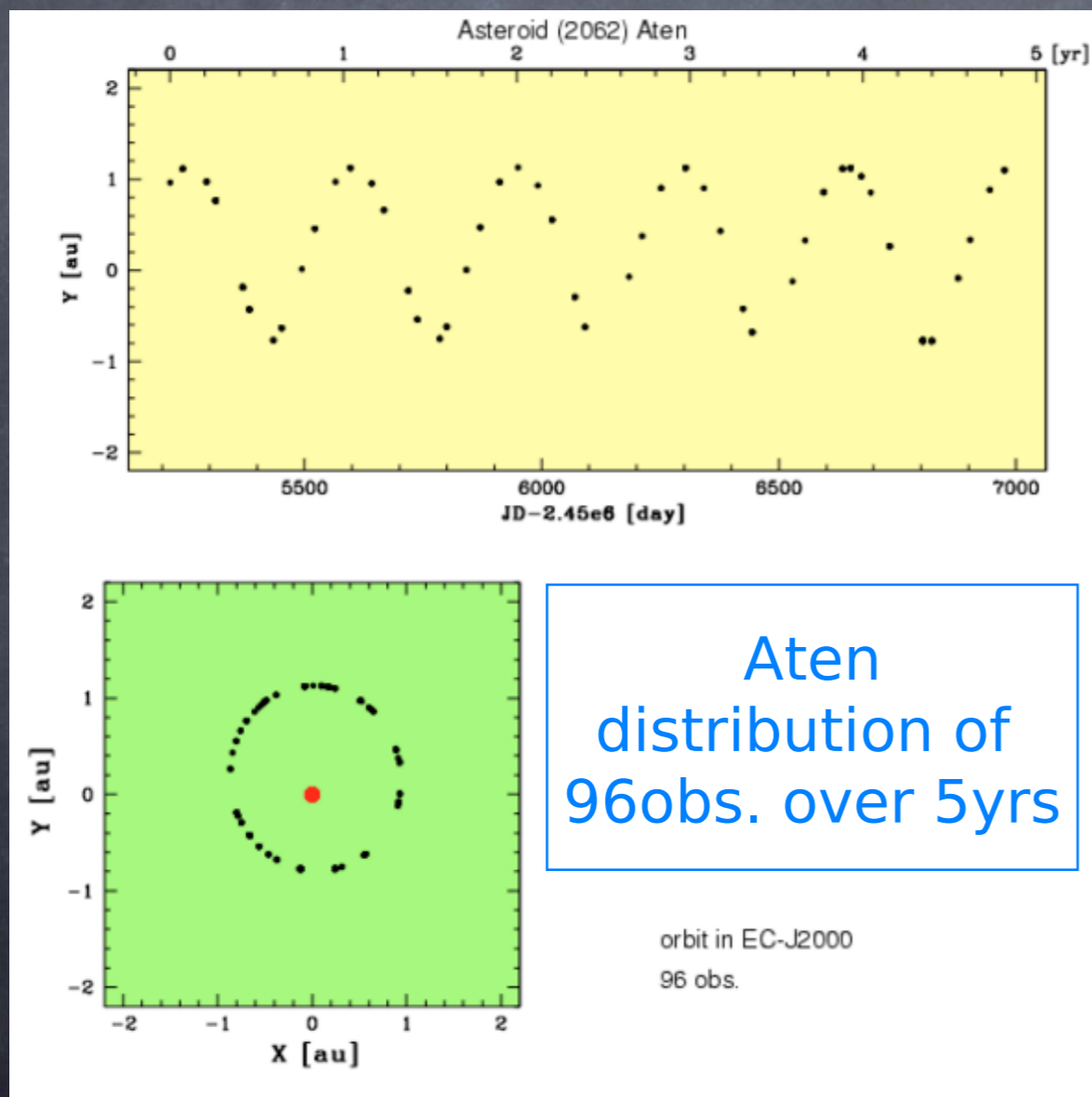
- Hipparcos example
- phase angle  $\approx 20-30^\circ$
- need size/shape information





# Observations distribution

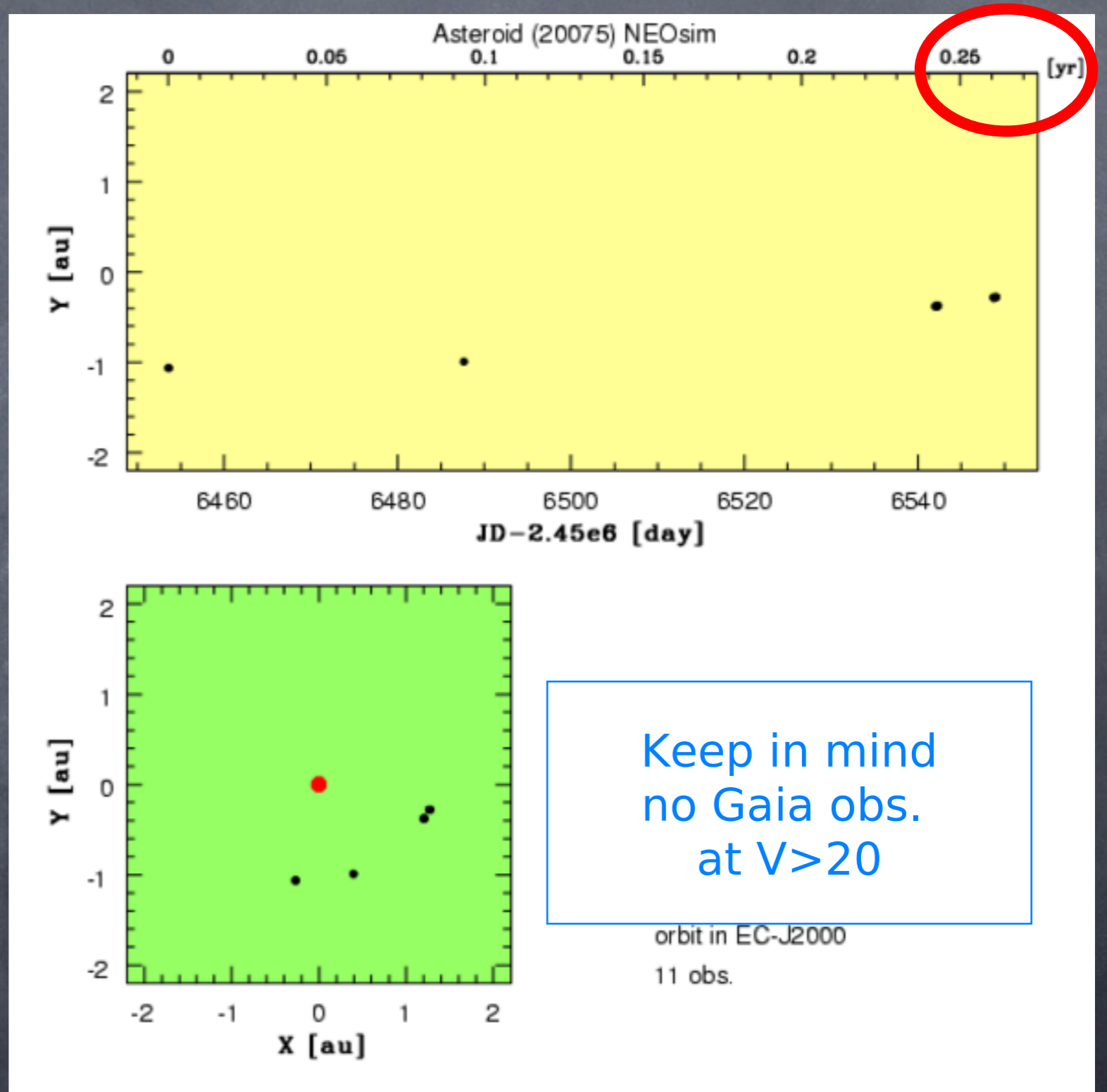
- ≈60 obs per object — Distribution Time & Space



Observations

# Observations distribution

- Bad situations



Observations

# Astrometry

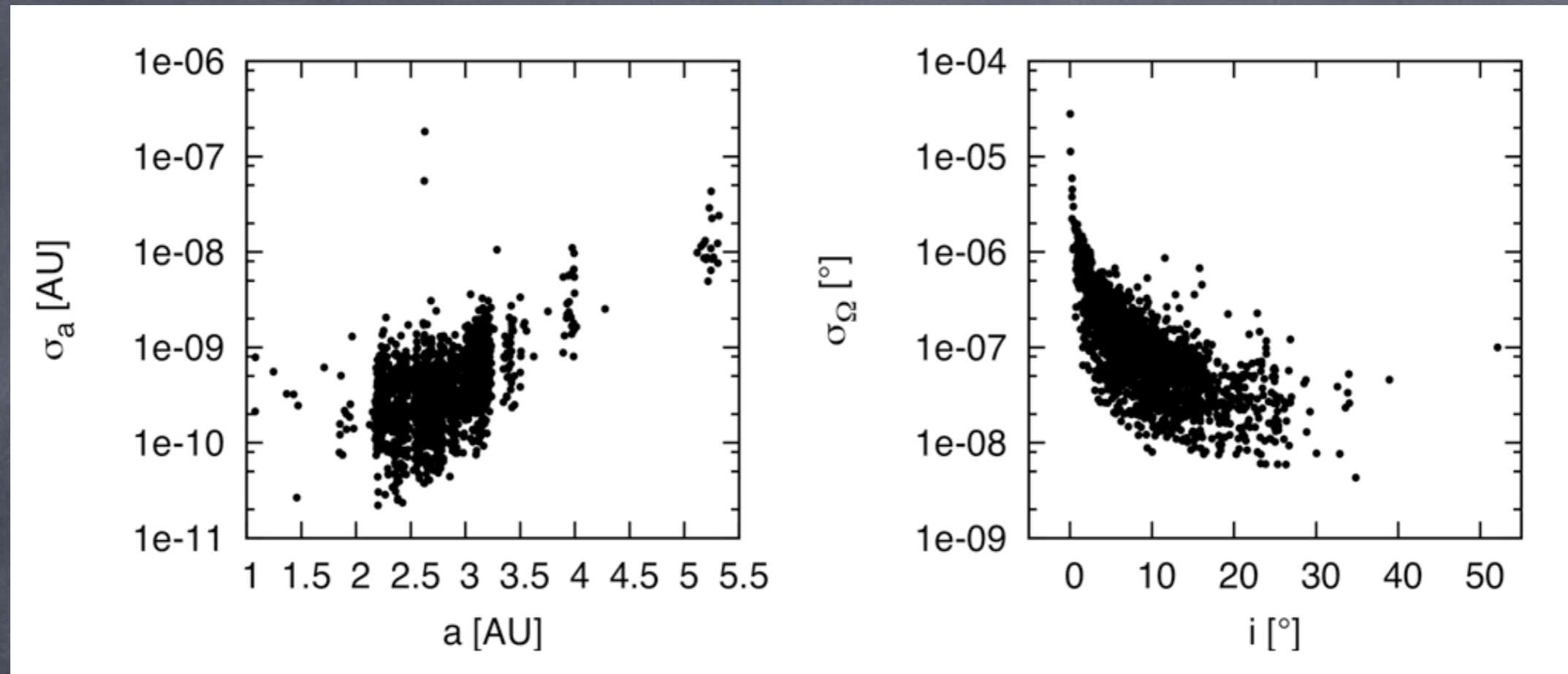
- sub-mas precision
  - ▶  $\sigma_{AL}(\lambda)$  0.3 - 5mas
- in our simulations  $1\text{CCD} = I_{\text{transit}}$

# Orbit Improvement

## • Orbit adjustment

- ▶ Local parameters (individual)
- ▶ Initial conditions ( $x, dx/dt, t_0$ )
- ▶ Not complete set for each object

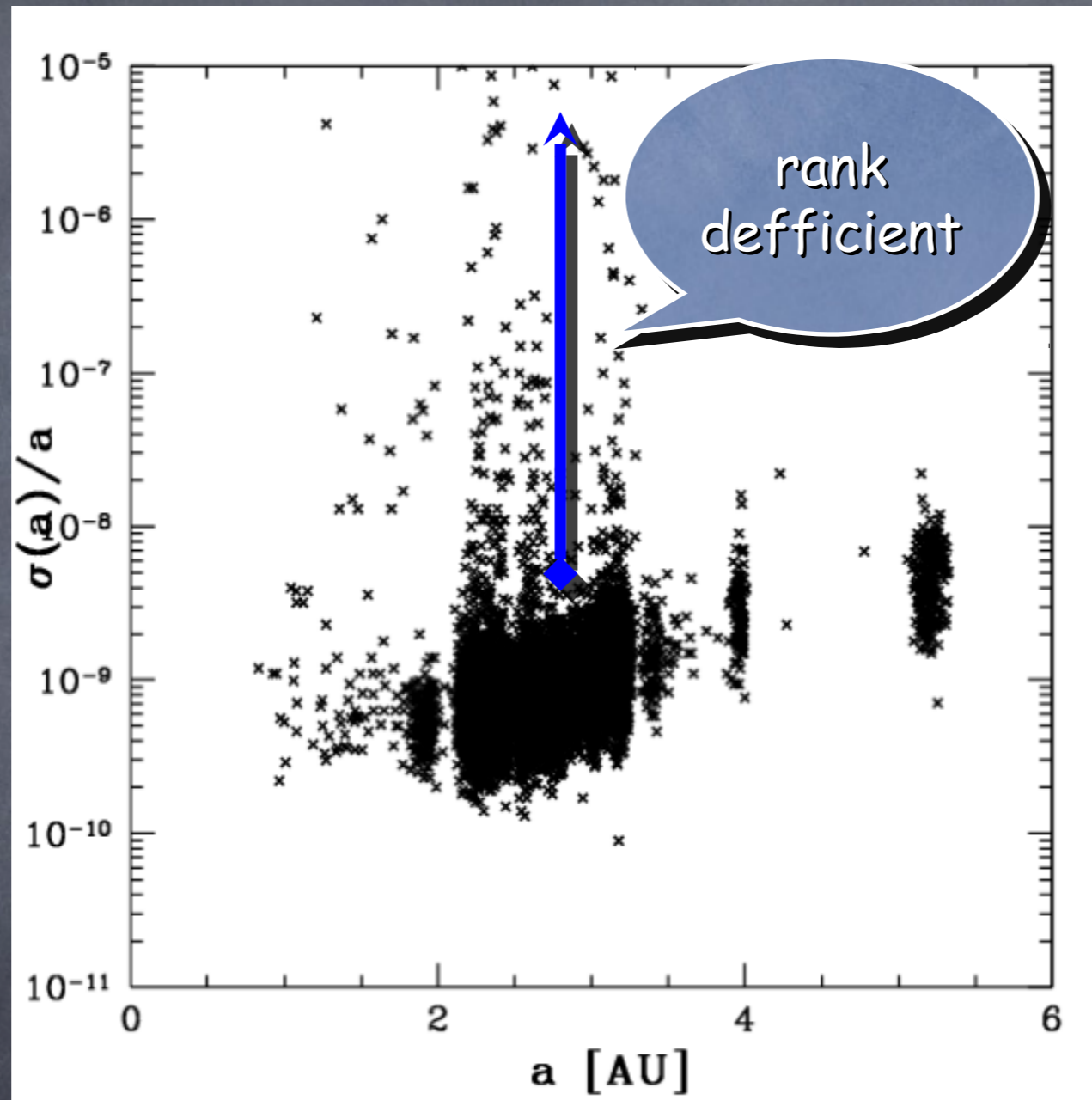
# Orbit improvement



Outcome

- improvement  $\approx 50x$  with 5 years of Gaia-only data
- no long-period effects (planetary satellites)

# Orbit improvement



Outcome

cases of rank deficiency - no full osculating elements

# Parameters estimation

- Non gravitational forces
  - ▶ Comets  $A_1, A_2, A_3$  (classical)  
how many JFC ? , LPC ( $\approx 5$ ) ? TBD
  - ▶ NEOs  $A_4 \approx$  simplified Yarkovsky  
handful from 60 candidates  
(Mouret & Mignard 2011 MNRAS)
  - ▶ *Later - Possible combination with ground-based*

# NEOs

- Global

Number of observations $n$	asteroids
$0 \leq n < 10$	720
$10 \leq n < 20$	326
$20 \leq n < 30$	131
$30 \leq n < 40$	71
$40 \leq n < 50$	48
$50 \leq n < 60$	44
$60 \leq n < 80$	32
$80 \leq n < 100$	7
$100 \leq n < 132$	7

- Local

- Yarkovsky effect derivation of one parameter

Number of NEAs		
$\zeta$	Diameter $d$	Thermal inertia $\Gamma$
Total	1386	1386
$\sigma(\zeta)/\zeta < 10\%$	1	0
$\sigma(\zeta)/\zeta < 20\%$	4	1
$\sigma(\zeta)/\zeta < 30\%$	8	2
$\sigma(\zeta)/\zeta < 40\%$	11	2
$\sigma(\zeta)/\zeta < 50\%$	14	2



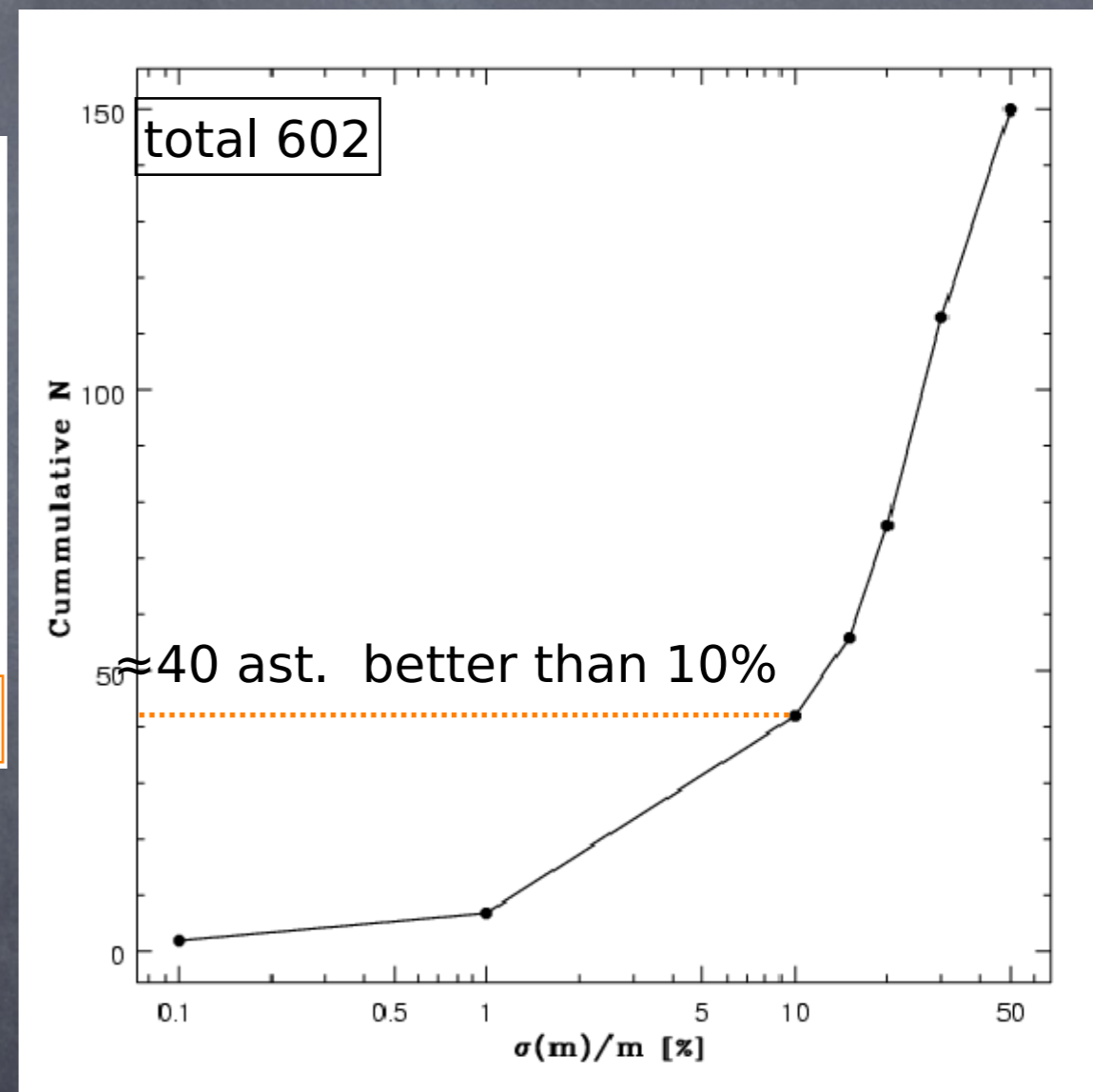
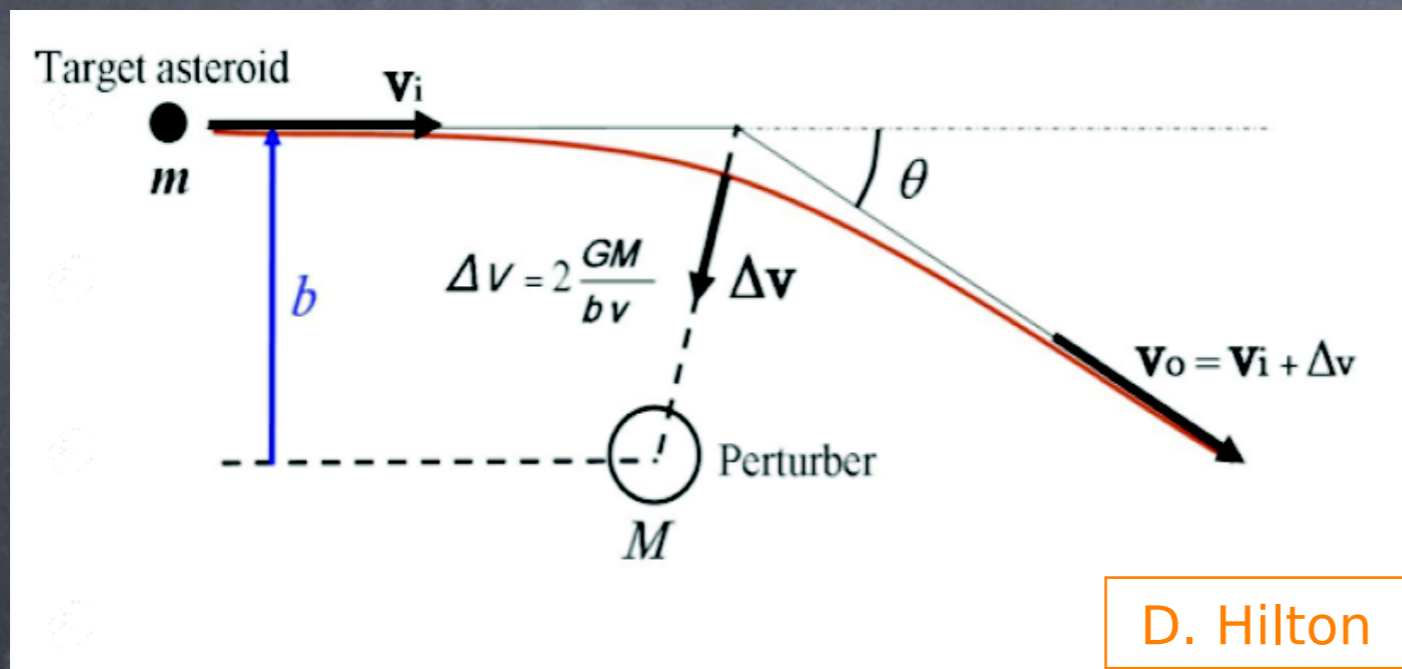
# Parameters estimation

## • Masses

- ▶ Binaries (to be fully implemented in pipeline)
- ▶ Absolute astrometry => full characterisation (q ratio)
- ▶ *Later – Possible combination with ground-based*
- ▶ Close encounter masses  $\approx 100$  ( $\sigma \leq 50\%$ ) ; 40 ( $\sigma \leq 10\%$ ) (Mouret et al. 2007 P&SS)
  - ▶ *Compare to binaries, space probes, planetary ephemerides (INPOP-EMP-DE)*

# Mass

- from asteroid binaries & from close encounters



Outcome

# Fundamental Physics

- Local tests of GR
  - ▶ PPN mainly from NEOs (Hestroffer et al. 2011) and Solar J2
  - ▶ *Later - Possible combination with ground-based (radar)*
- Reference Frames
  - ▶ dGM/dt all objects together
  - ▶ Link ICRF(optical Gaia) to dynamical (Ecliptic)
  - ▶ non-rotating frames
  - ▶ *Later - Possible combination with ground-based (Hipparcos)*

# NEOs

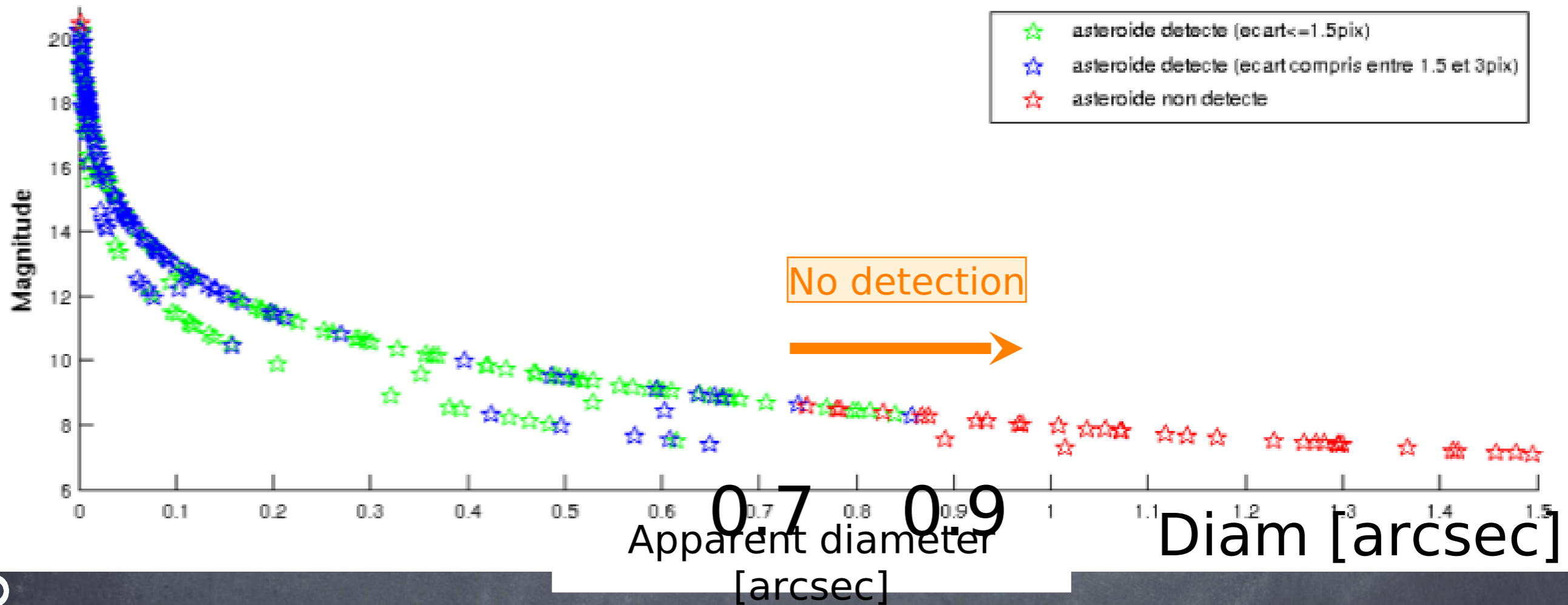
- $\approx 1500$  NEOs, important for GR test
- Decoupling non-grav. effects and GR
- Fast moving objects (100mas/s) not seen through all FOV, only a couple of CCDs
- Object not identified will not enter the orbit improvement pipeline
- Orbit determination from short term pipeline

Outcome

# NEOs

- Detection and threat
- Low elongation objects – IEO
  - ▶ IEO particular class of objects
- Parallax effect
  - ▶ Cons - increase uncertainty region
  - ▶ Pros – good orbit from few points  $\approx$  radar
  - ▶ Cf. D. Bancelin talk & B. Carry talk

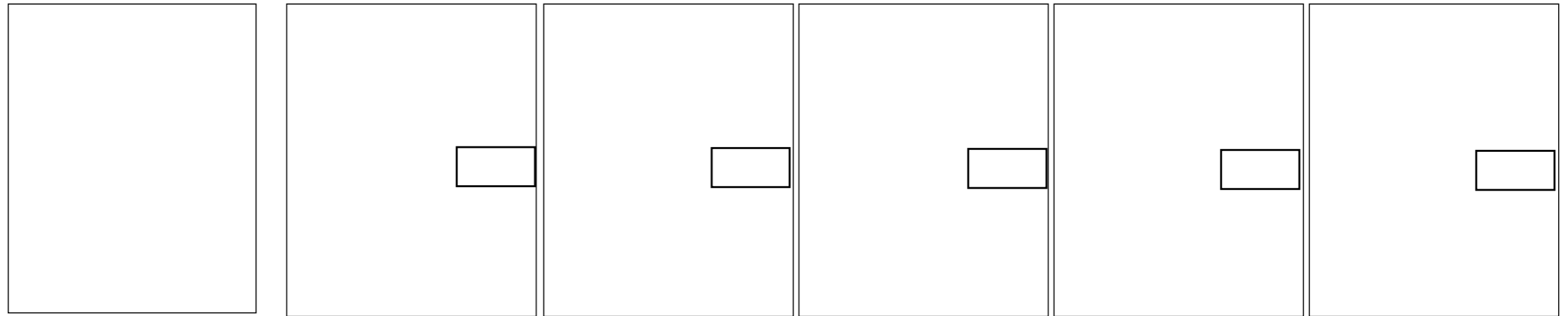
# Detection limit



Observations

- ▶ magnitude  $V \leq 20$
- ▶ diameter  $< 0''7 - 0''9$

# Limitations

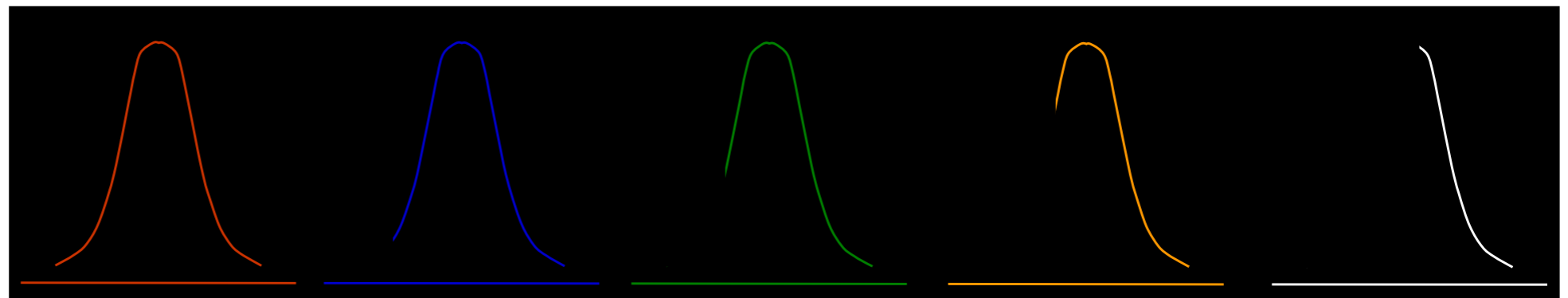


SM

AF1

AF2

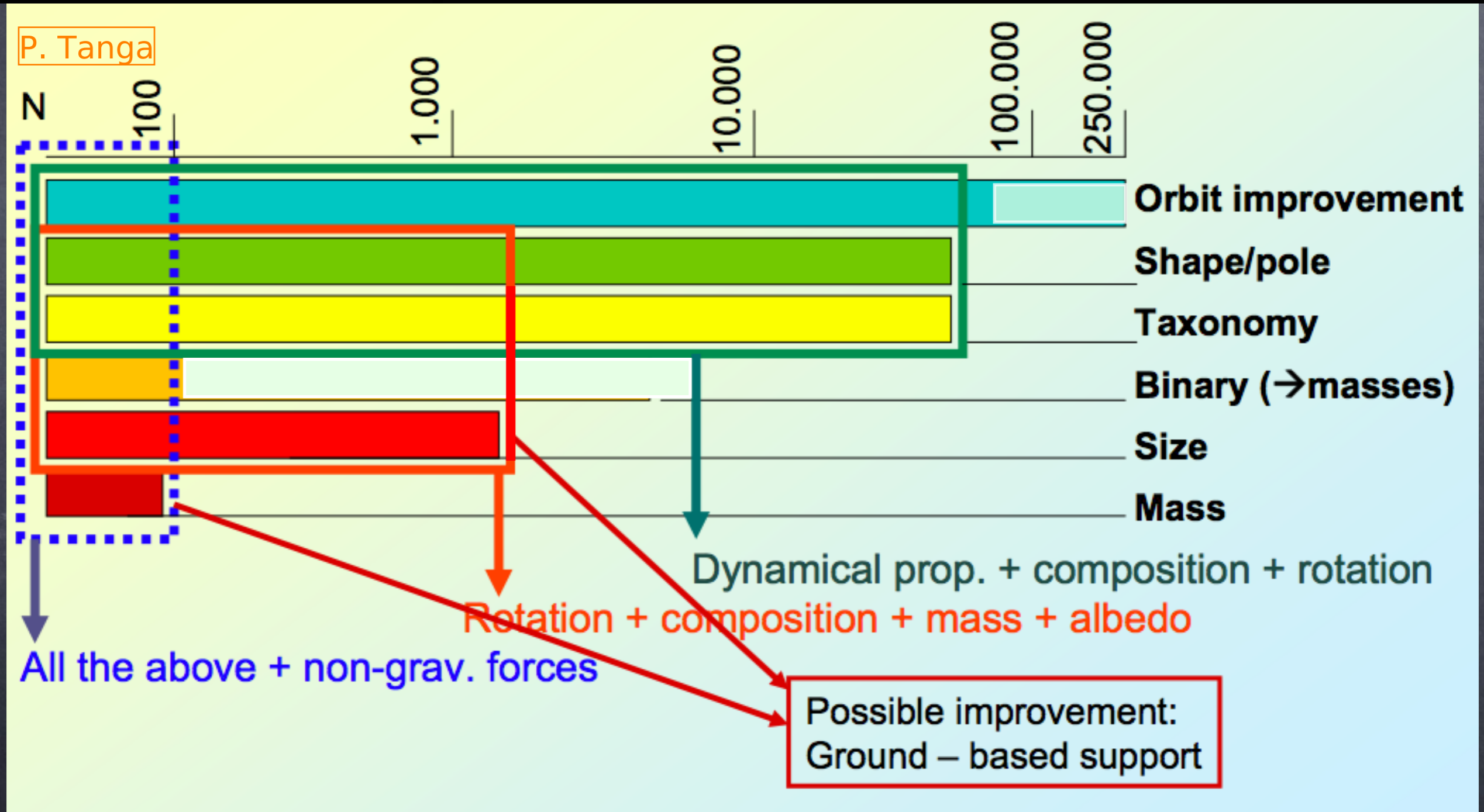
Signal recorded



- ▶ AC and AL fast motion
- ▶ smearing
- ▶ get out of window

# NOT only now, as alert FUN but experience on Gaia

Science outcome



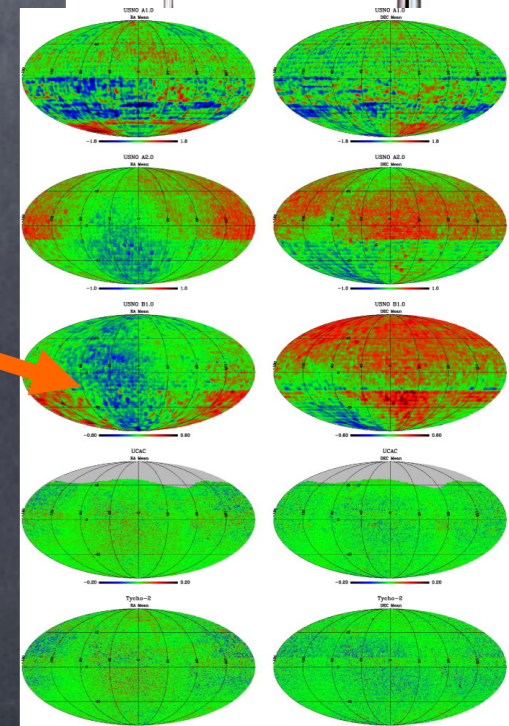


# Complementary

- Ground-based observations to complete time distribution and window
- Radar observations, ranging
- Observations for physical characterisation
  - ▶ size shape for density or phase effect
  - ▶ testing binarity
  - ▶ physical parameters for dynamical modeling (Yarkovsky)

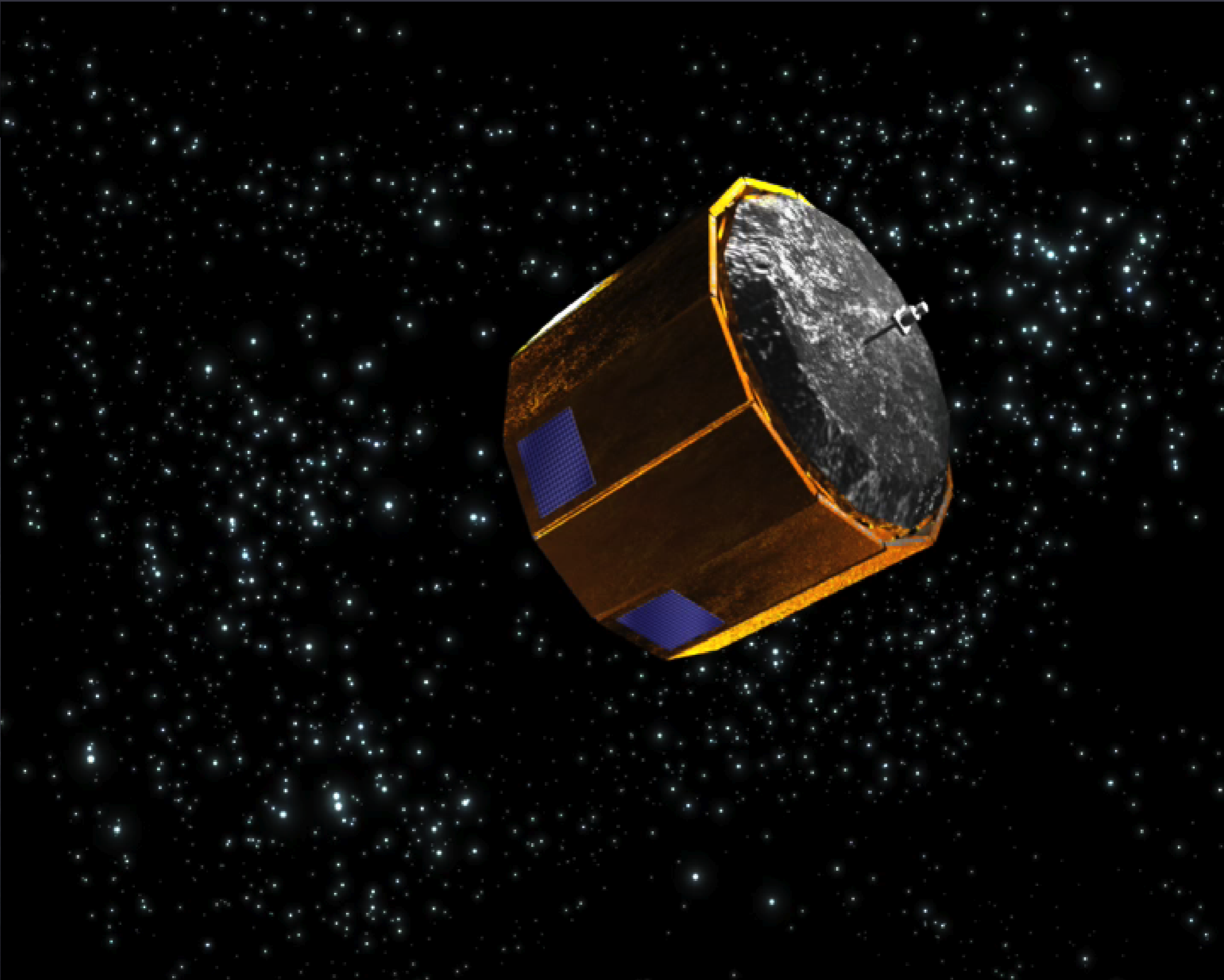
# Releases

- Global parameters at end of mission no intermediate
- Stellar catalogue is very important too
- Reduction with Gaia catalogue
  - ▶ Stochastic errors
  - ▶ Systematic errors (Chesley et al. 2010 Icarus 210)
- Mission extension (13 years?) and use of old data



Observations

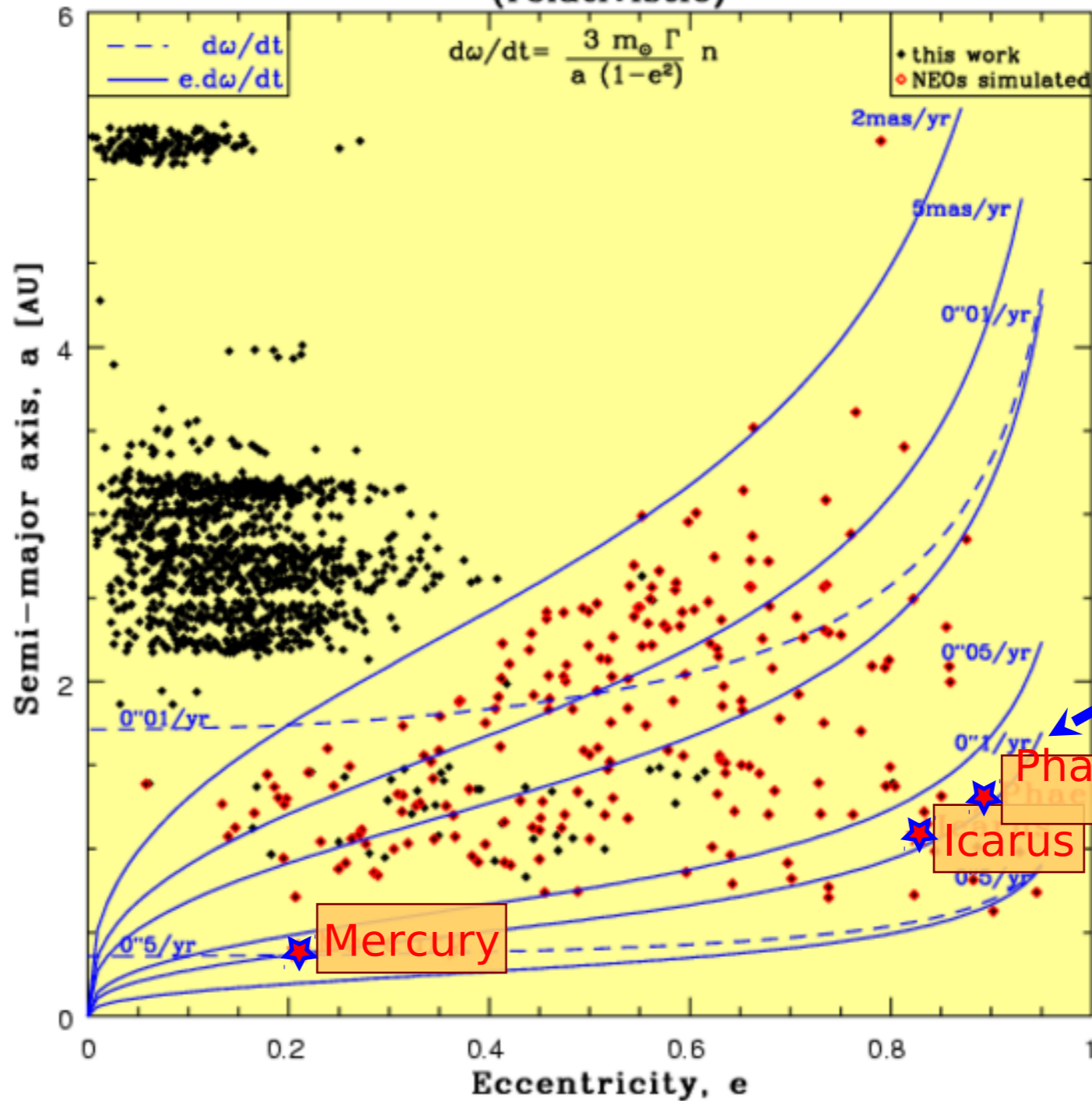
End (%)





Science outcome

Perihelion precession (relativistic)



as sensitive as Mercury

- large number of test particles throughout the Solar System
- **NEOs**: separate PPN  $\beta$   $(a \cdot (1-e^2))^{-1}$  and solar  $J_2$   $(a \cdot (1-e^2))^{-2}$
- all bodies:  $dG/dt$ ,  $\kappa$ ,  $\Omega$  and  $d\Omega/dt$

# Questions Daniel & Pedro

## • François – study two cases

- ▶ Mission extension of 1 year what improvement for the different case study ?
  - Right not only  $\sqrt{N}$  for e.g. mass determination
- ▶ Possibility to go to  $V \leq 20.5-21$ 
  - Simulations for NEOs could be done David B.
  - Precision gets lower too (Alberto) Right but still about 10-50mas which is acceptable

## • Alberto what about improvement with mission extension

- ▶ Yes right ,never dreamed of that!
- ▶ Basically  $\sqrt{N}$  but also degradation of signal with time to take into account

# Questions David B.

- Perrezi: Need all data after mission for improvement
  - No with only one point improvement is high (similar radar)
  - But ok precision from alert not 5mas...
- Field of view rather large (pas saisi question?)
  - Yes 45°, so Schmidt telescope not enough
- Distribution on sky N days later after discovery?
  - Yes will not be less than 2 days
- Alberto: Is geographos representative ?
  - Not only this other asteroids used see other graph with Toutais Apophis Phaeton etc.

# A faire

- Simulations NEOs avec population debiaisée, idem comètes
- Simulations rdv  $V < 21$ 
  - Test RG avec NEO David + Daniel + Pedro
  - Taux de detection objets nvx et alertes David et al.
- Simulations extension mission
  - Param globaux
  - Masses asteroides liste rencontres -> Tolya
- Simulations orbite Gaia-FUN avec precision en alerte (50mas?) David+Benoit+Jerome