Gaia DR3

Results & Prospects for Asteroids (SSOs)

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acknow. CU4-SSO

DH — 18 juin 2022

gaia

cnes Gaia DPAC GRAM cnrs MW Gaia

l'Observatoire de Paris | PSL

Gaia DR3

CU4

in memoriam ***Dimitri Pourbaix***

Gaia Data Release 3 will be published on 13 June 2022

the G-day

days hh:mm:ss

In addition to astrometry and broad-band photometry from Gaia EDR3 revealing spectra - classifications - non single stars - asteroids - galaxies - variability - astrophysical parameters - extinction - interstellar medium - radial velocities - lightcurves - more

Gaia DR3

see https://www.cosmos.esa.int/web/gaia/data-release-3

GAIA DR3 CONTENTS

Information on Gaia Data Release 3 contents, completeness and limitations. Last update on 28 March!

GAIA DR3 PAPERS

The titles of the expected papers describing the data processing and verifying the science performance of Gaia Data Release 3 are published. Links to the papers will be added after the release.

GAIA DR3 DOCUMENTATION

The data release documentation for Gaia Data Release 3, describing the processing of the data from raw to Gaia DR3 will appear both on webpages and through a downloadable PDF-file.

GAIA DR3 DATA RELEASE EVENTS

Overview of the Gaia DR3 release events can be found here. Events are planned in many countries in many different languages.

GAIA DR3 DATA MODEL

The Gaia DR3 data model explains in further details the tables and columns providing the Gaia data. A draft version is available now.

GAIA DR3 KNOWN ISSUES

Find here the issues found with Gaia DR3 data after the release / data release documentation was published.

GAIA DR3 AUXILIARY DATA

Passbands, extinction law, ... with additions on the release day for the G_{RVS} passband, exoplanet list, solar analogue spectrum from SSOs and more.

GAIA DR3 PREVIEWS

Explore some previews of Gaia Data Release 3.

PYTHON ACCESS

Gaia data can be accessed using Python. Learn more about the astroquery package for Gaia here.

TUTORIALS AND HELP

Help is available to guide you through the process of getting the data you need. Extensive information on writing ADQL Queries is provided as well to bring the code to your data.

GAIA DATA CREDITS

When using Gaia DR3 data, please acknowledge the work of the people involved and provide credits and necessary citations. Each release comes with its own credit lines and DOI.

GAIA DR3 SOFTWARE TOOLS

The **GaiaXPy 1.0.0 tool** has been releaed now. More software code accompanying certain data products will be published on the release day.

PUBLIC OUTREACH MATERIAL

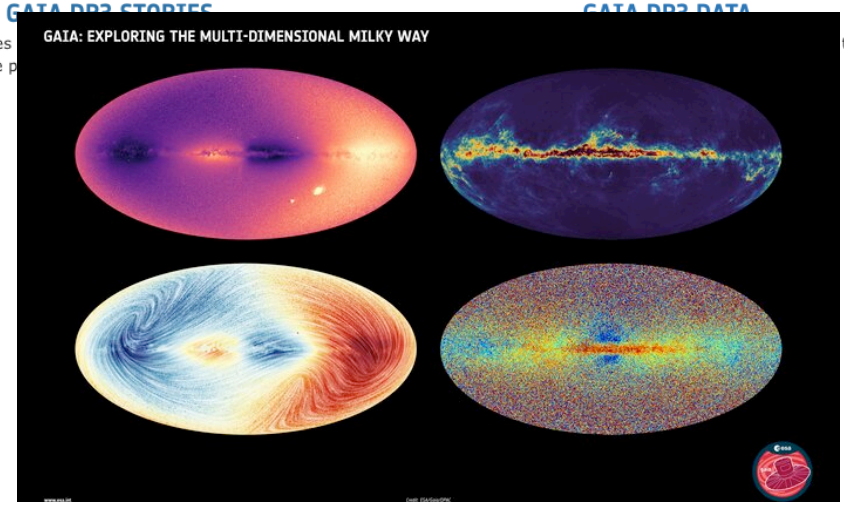
An overview of news and stories on the Gaia Mission and Gaia science are given here. The press release by ESA on Gaia DR3 will be shared at the release day.

GAIA DR3 STORIES

A selection of stories
3 and the science p

GAIA DR3 DATA

the Gaia



QUESTIONS

Read our FAQ or contact the Gaia Helpdesk.

Before DR3… (a story)

- Hipparcos 1989–1993
  - some 48 asteroids + satellites and planets
- Gaia DR1 & Gaia eDR3
  - no SSO directly, but stellar catalogues
- Gaia DR2
  - stellar catalogue, with proper motions
  - some 14,000 asteroids (show-case as DR1 stars)

now in Gaia DR3

- catalogue and auxiliary data for asteroids
- ≈158,000 asteroids pre-selected à priori if #.transits ≥ 8
  + add Pluto+Charon, satellites (dedicated treatment)

SSOs

	New in Gaia Data Release 3	Gaia DR2	Gaia DR1
Galaxy candidates - surface brightness profiles	914,837	-	-
Solar system objects	158,152	14,099	-
Solar system objects - epoch astrometry (CCD transits)	23,336,467	-	-
Solar system objects - orbits	154,787	-	-
Solar system objects - average BP/RP reflectance spectra	60,518	-	-
Solar system objects - planetary satellites	31	-	-
All-sky total galactic extinction maps at different spatial resolutions	HEALPix levels 6, 7, 8, and 9	-	-
Gaia Andromeda Photometric Survey (GAPS) with lightcurves for all objects	1,257,319	-	-

+SSO in DR2 - epoch photometry (transits) and epoch astrometry (CCD)

now in Gaia DR3

- cf. DR3 chapter for SSO
- Mostly epoch data (FOV transit -or- CDD level)
- Objects:
  - asteroids *mostly* -
    NEOs, MBAs, Trojans, TNOs, … + dwarf planets
    known & unmatched
  - planetary satellites
  - no comets (*yet*) & no planets (*never*)
- Time interval: [mid 2014 + 1000 days / 34 months]
  - i.e. ≈ 1.Period for MBA @2AU

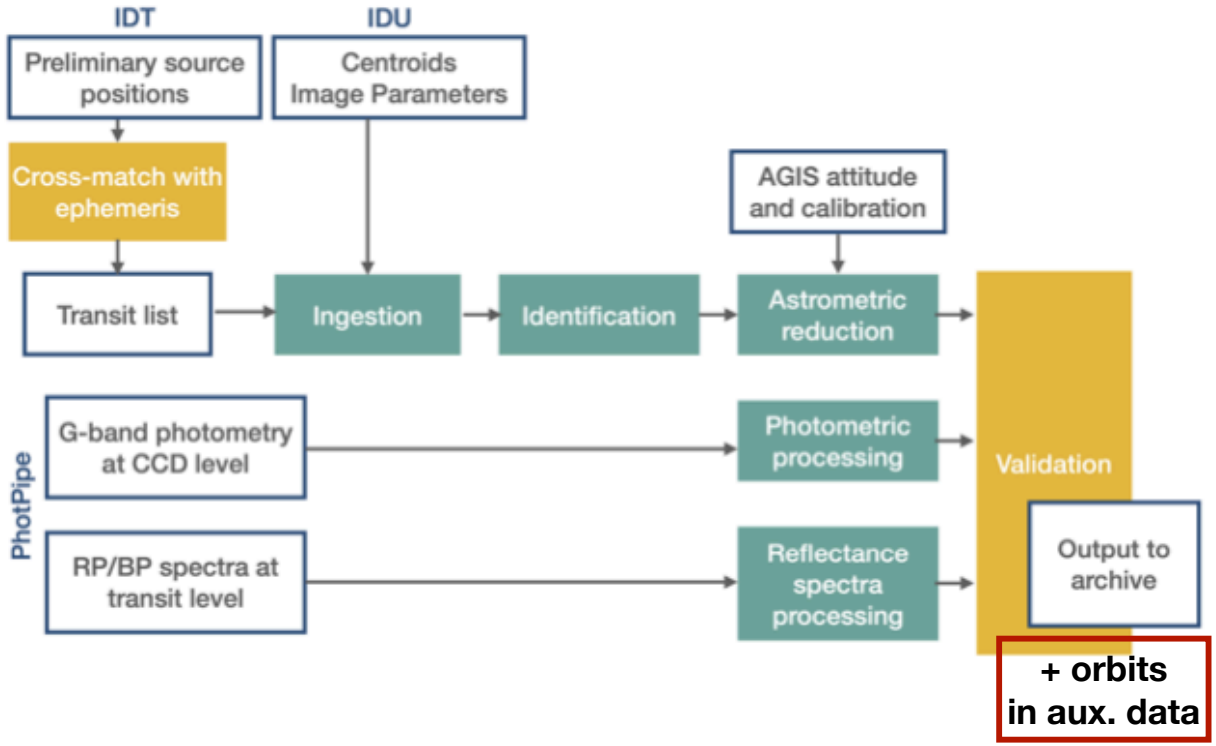
Object type	number of objects
Atira	1
Aten	43
Apollo	230
Amor	173
Mars Crossers	1550
Inner Main Belt	3305
Main Belt	144 975
Outer Main Belt	4940
Jupiter Trojans	1550
Centaurs	8
TNOs	24
Others	2
Total asteroids	156 801
Unmatched moving objects	1 320
Planetary satellites	31
Total	158 152

Gaia DR3

- General performances (asteroids only)

  NB: no photometry no spectra for natural satellites & unmatched objects

- **Astrometry** (CCD)
- Photometry (transit)
- Spectro-photometry (transit)



Gaia DR3

- **Photometry** –> sparse light curves, phase curves
- tests on Lutetia+Steins
- => see paper by Galluccio et al. & Tanga et al.
- **Spectrophotometry** –> spectra in the blue
- #60518 asteroids (MBAs, Hildas, Trojans)
- => see paper by Delbo et al.

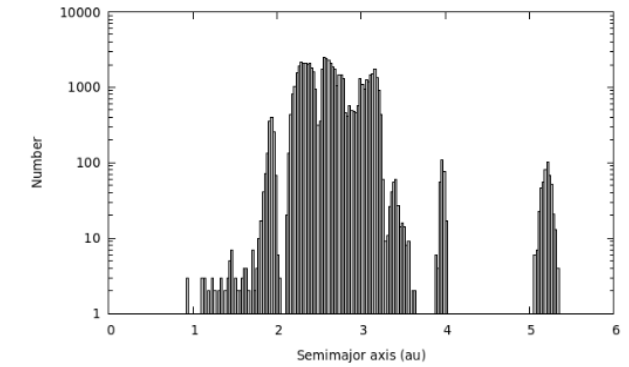


Figure 1.12: Orbital distribution of SSOs with BP-RP reflectance spectra in Gaia DR3.

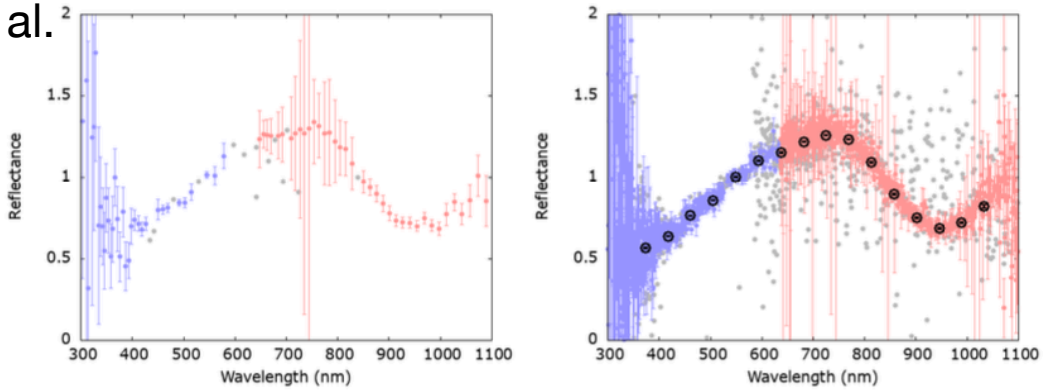


Figure 1.15: In the left, the epoch spectrum of an asteroid is plotted with its errors (BP in blue, RP in red). One can see that, for this case, the quality of the spectrum in the faint ends is poor. Large error bars are also present in the extremes of the spectrum and at the overlapping range between BP and RP. In the right, all epoch reflectance spectra of the same asteroid are plotted. The black dots correspond to the final mean reflectance spectrum computed, whereas the grey points identify the removed values.

Gaia DR3

- **Planetary satellites** = #31 (/44 possible)
- some with few data: from 1 to ≈60
- add: Pluton+Charon

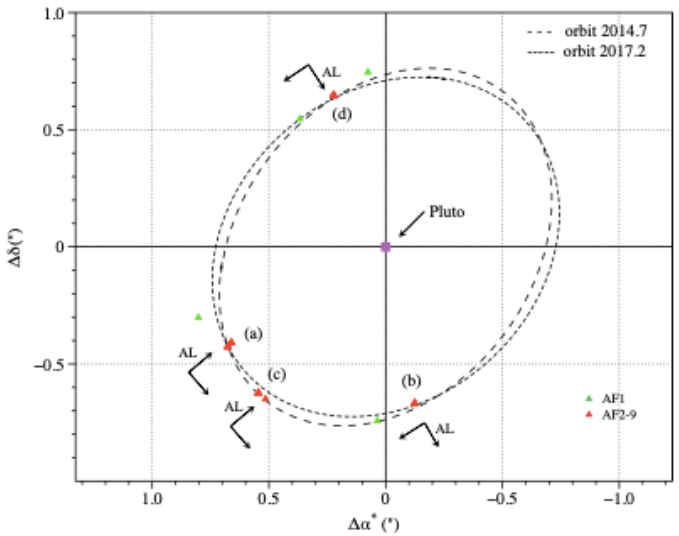


Table 1.2: Natural satellites: number of matched transits in the input list.

	Mars				
1	Phobos	9	4	Dione	56
2	Deimos	20	5	Rhea	45
	Jupiter		6	Titan	8
1	Io	23	7	Hyperion	64
2	Europa	32	8	Iapetus	54
3	Ganymede	6	9	Phoebe	62
4	Callisto	17	12	Helene	50
6	Himalia	27	13	Telesto	22
7	Elara	35	14	Calypso	18
8	Pasiphae	50	26	Albiorix	1
9	Sinope	23	29	Siarnaq	20
10	Lysithea	27		**Uranus**	
11	Carme	35	1	Ariel	29
12	Ananke	26	2	Umbriel	28
13	Leda	21	3	Titania	28
15	Adrastea	4	4	Oberon	28
16	Metis	7	5	Miranda	2
17	Callirrhoe	1	15	Puck	3
18	Themisto	13	17	Sycorax	17
	Saturn			**Neptune**	
1	Mimas	1	1	Triton	21
2	Enceladus	8	2	Nereid	23
3	Tethys	33	8	Proteus	1

Gaia DR3

- **Unmatched objects**
  - detection of unmatched moving sources
  - linking tracklets over successive PFOV-FFOV
  - potentially new object (or poor *a priori* ephemeris)
- pipeline started in 2017 (6months data)
- 1320 (/1531) chained transits
  - 60% with only two transits
  - 4% with more than 6 successive transits
- BUT at the time of auxiliary MPC knowledge (2017, not 2022)
  - identification available in auxiliary Gaia catalogue

Table 1.3: Distribution of the number of transits matched to the *new* asteroids.

Nbundles	NTransits
901	2
346	3
134	4
58	5
32	6
60	> 6

SSO DR3 – overview

- **Astrometric precision**
  - random (CCD) + systematic (transits)
  - depends on magnitude
  - 0.2–10 *mas*
    i.e. sub-mas 10 ≤ G ≤ 18
  - better than DR2, best for med-bright/faint
  - independent in (AL, AC) not in (RA, Dec)

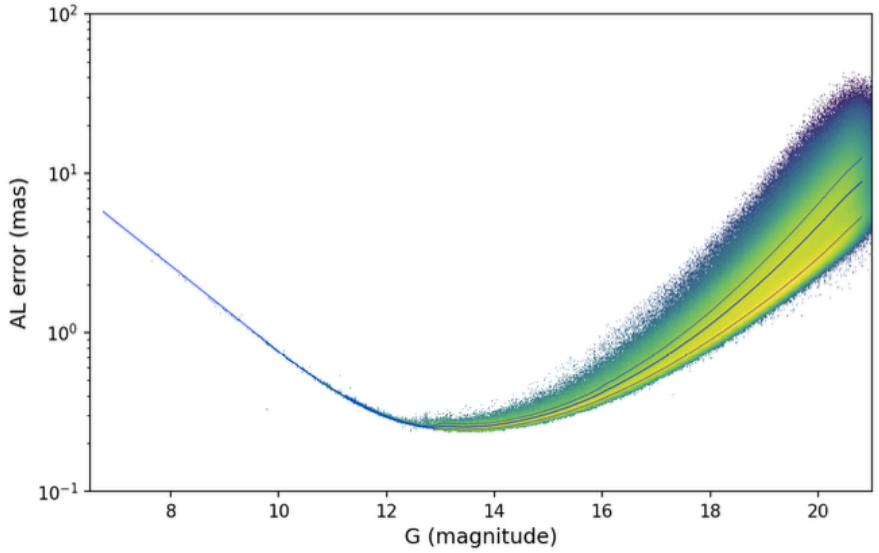


Fig. 6: Error model in the AL direction for the SSO astrometry in *Gaia* DR3, as a function of the G magnitude. The total error is represented, as given by the squared sum of the random and the systematic component. The colour represents the data density (yellow/light: higher density). The thick line and the two thin lines on each side are the quantiles corresponding to the mean and the 1-sigma level.

SSO DR3 – overview

- **Astrometric precision**
  - dedicated centring for SSOs
  - rms for transit level residuals
  - comparison DR2 wrt DR3

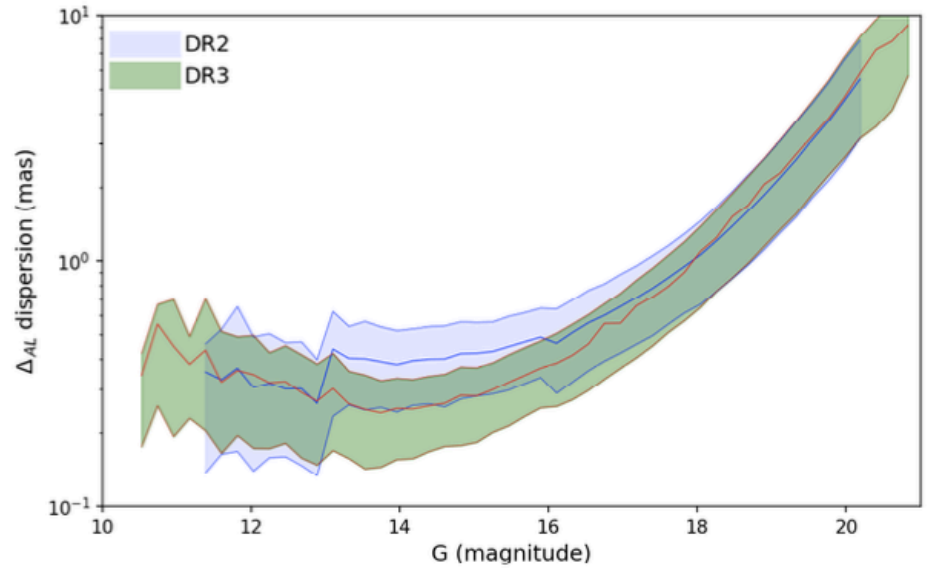


Fig. 13: The average and 1-sigma quantiles for the AL dispersion of the post-fit residuals, for all transits in common between DR2 and DR3. In comparison to Fig. 12, the single data points are not represented. The background curve (light blue) represents the distribution computed for *Gaia* DR2.

SSO DR3 – overview

- **Astrometry**
  - publication in classical (RA, Dec) +UTC
    no relativistic light-deflection applied (vs. DR2)
  - very high precision+accuracy in AL (vs. AC)
  - => highly correlated (RA, Dec)
    or non-diagonal weighting matrix
  - => analysis mostly in AL

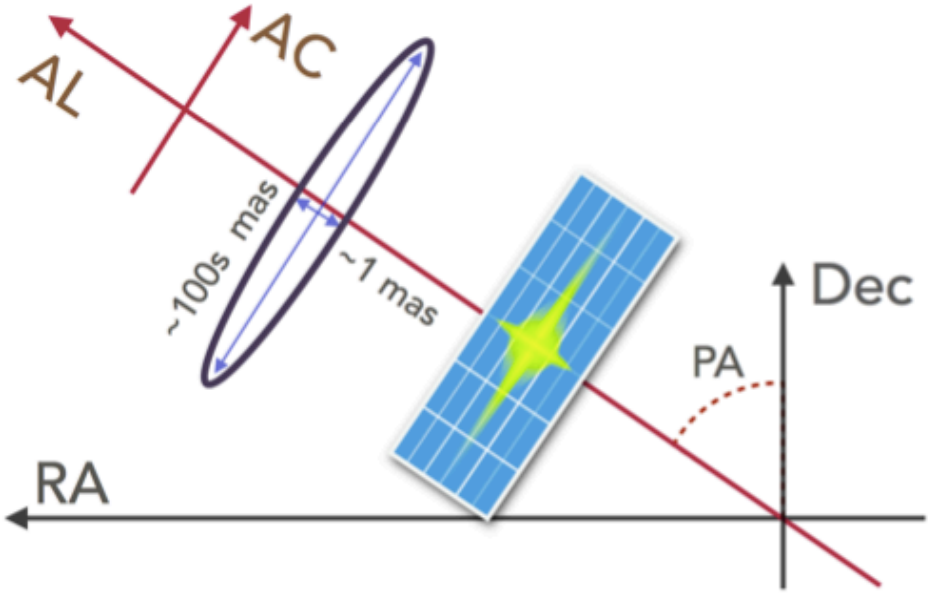


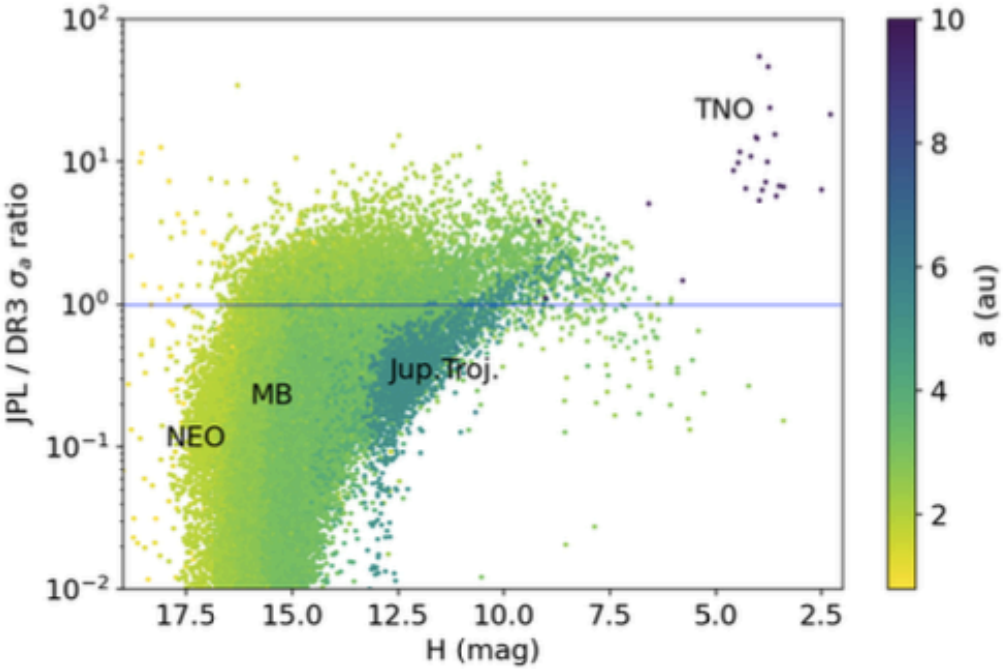
Figure 1.2: The uncertainty on the astrometric position corresponds to an ellipse extremely stretched in the AC direction. When such a position is expressed in another reference frame, such as the equatorial reference frame of Right Ascension and Declination, a high correlation appears for the uncertainties of the two coordinates. Figure taken from Gaia Collaboration et al. (2018).

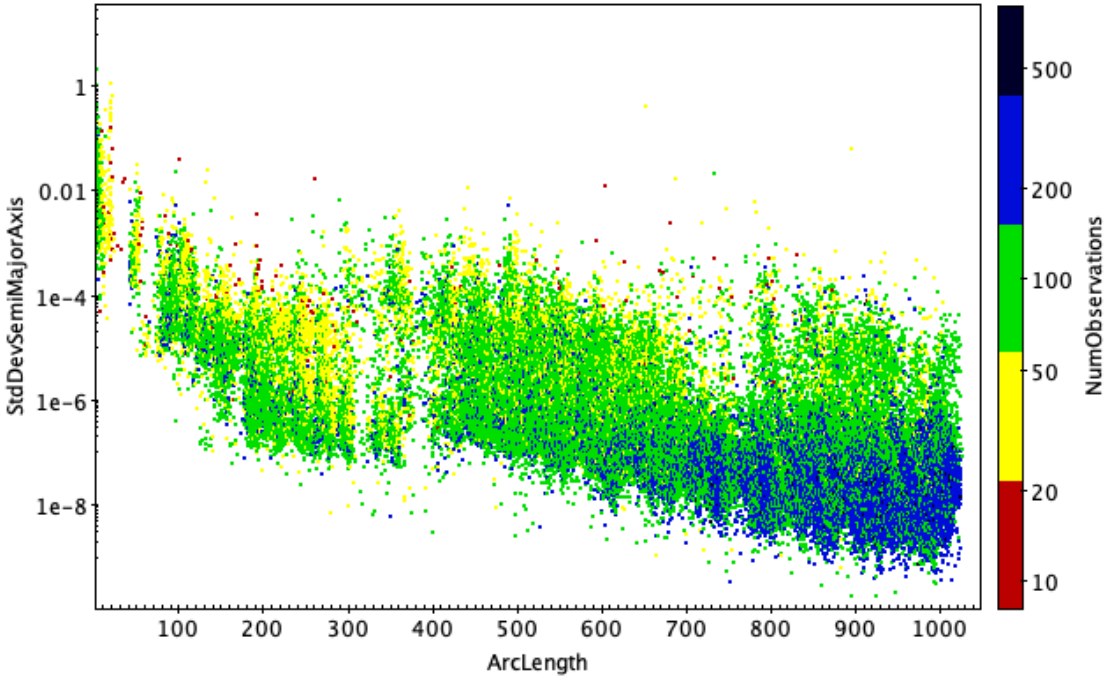
SSO DR3 – results

- **Some results from Gaia DR3 —** see PVP paper Tanga et al.
  - Orbits computations
  - Binary asteroid
  - Yarkovsky effect
  - Photocentre offset

SSO DR3 – results

- **Orbit improvements (σ_a)** ≈155k orbits
  - Gaia data *only* here (CNES cluster)
  - comparison to JPL ***with all*** g-b obs.





SSO DR3 – results

- **Binary asteroids**
  - (resolved Pluto+Charon)
  - MBA (4337) Arecibo discovered in 2021 from occultations
  - separation ≈ 30mas
  - 38 Gaia transits
  - LC inversion: spin-rate+pole+shape

SSO DR3 – results

- **Binary asteroids**
  - (4337) Arecibo
  - wobble on 13 successive transits over 2.3 days
  - fit for *orbital pole* and *semi-major axis*

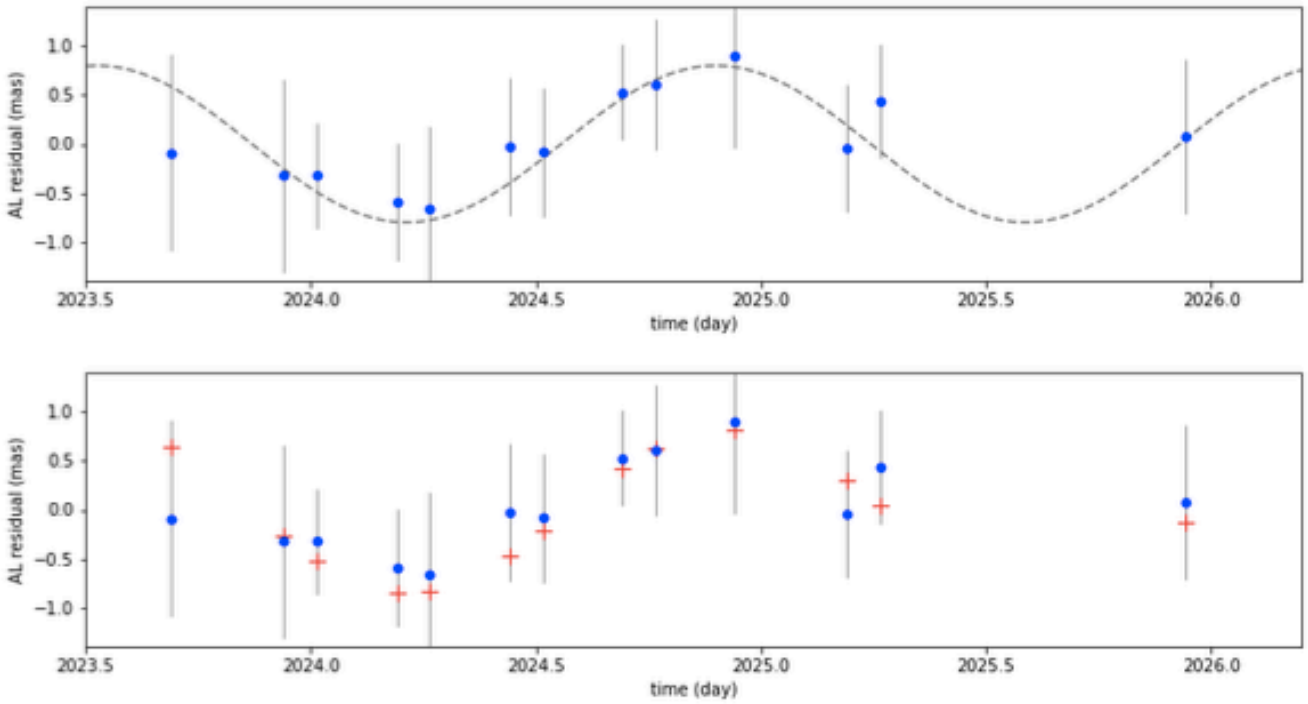


Fig. 15: The residuals to the orbital fit of (4337) Arecibo (blue dots). They are obtained from the average of single ob residuals over each transit. The error bars are given by their standard deviation. In the top panel, the grey dashed line is no fit, but a simple overplotting of a sinusoid of the period derived by photometry, adjusted in amplitude (0.8 mas) and ph data. In the bottom panel, the same data are shown with the residuals predicted by the optimised binary model described i (red crosses).

SSO DR3 – results

- **Binary asteroids**
  - (4337) Arecibo
  - wobble on 13 successive transits over 2.3 days
  - fit for *orbital pole* and *semi-major axis*
  - good residuals and agreement with occultations

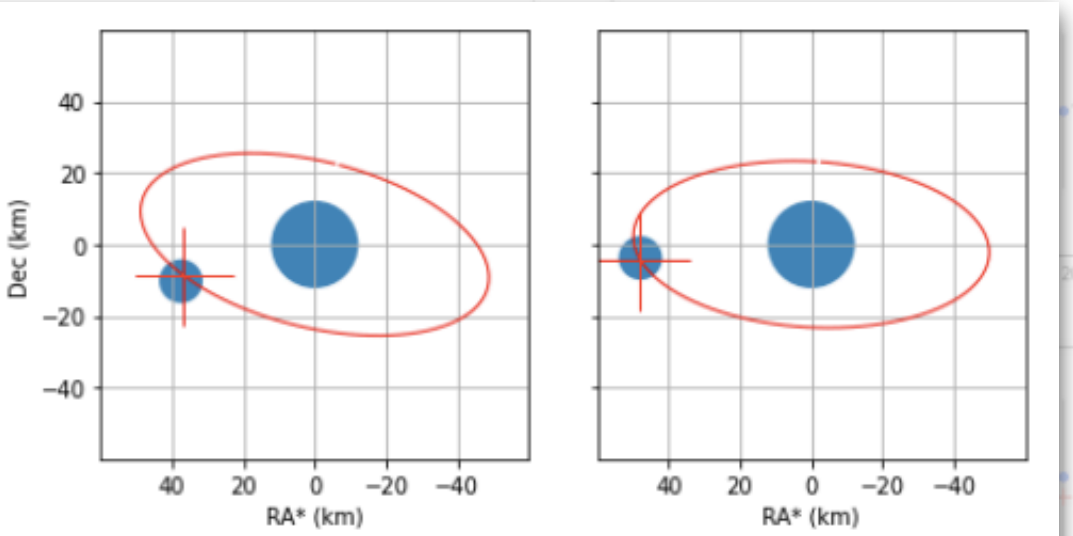


Fig. 14: The size and relative position of the primary and secondary components of (4337) Arecibo, as derived from the occultation (in blue) of 2021 May 19 (left), and 2021 June 9 (right), on the plane of the sky, in the equatorial reference. The red crosses and the orbit are derived from the model described in the text.

SSO DR3 – results

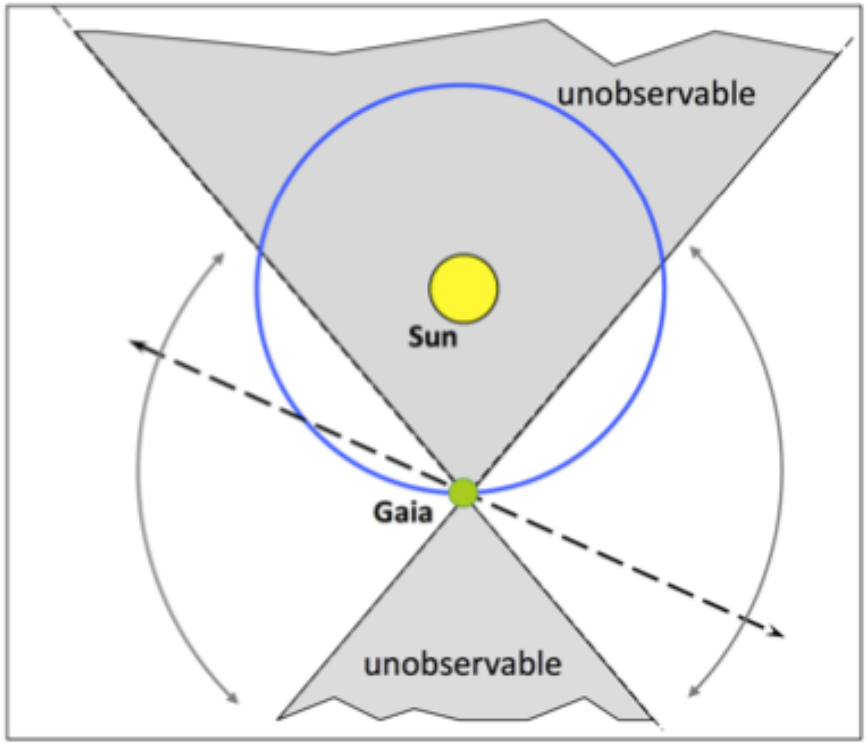
- **Yarkovsky effect**
  - long term (secular) variation of semi-major axis
    => combine g-b + Gaia
- example (3200) Phaeton
  - NEO object small ≤ 5km, with good orbit
  - with *known* Yarko (A_2 = –5.56E-15 ±0.7 AU/d^2)
    thanks to radar observations
  - ≈6400 g-b obs. (-*no* radar but) + 356 Gaia obs.
    (A_2 = –6.1E-15 ±0.75 AU/d^2)
- exple (1620) Geographos
  - marginal detection thanks to Gaia data

Gaia astrometry as good as radar measurement for NEOs

cf. Bancelin et al. 2013
Desmars et al. 2013

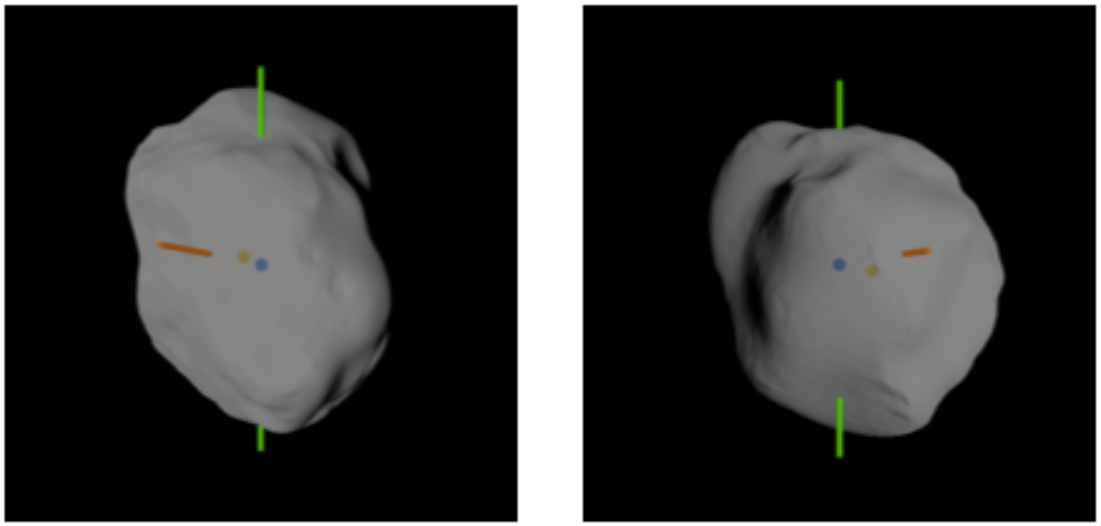
SSO DR3 – overview

- A particular scanning law
  - low solar elongations (45°)
  - moderate solar phase angle (up to 30°)



SSO DR3 – results

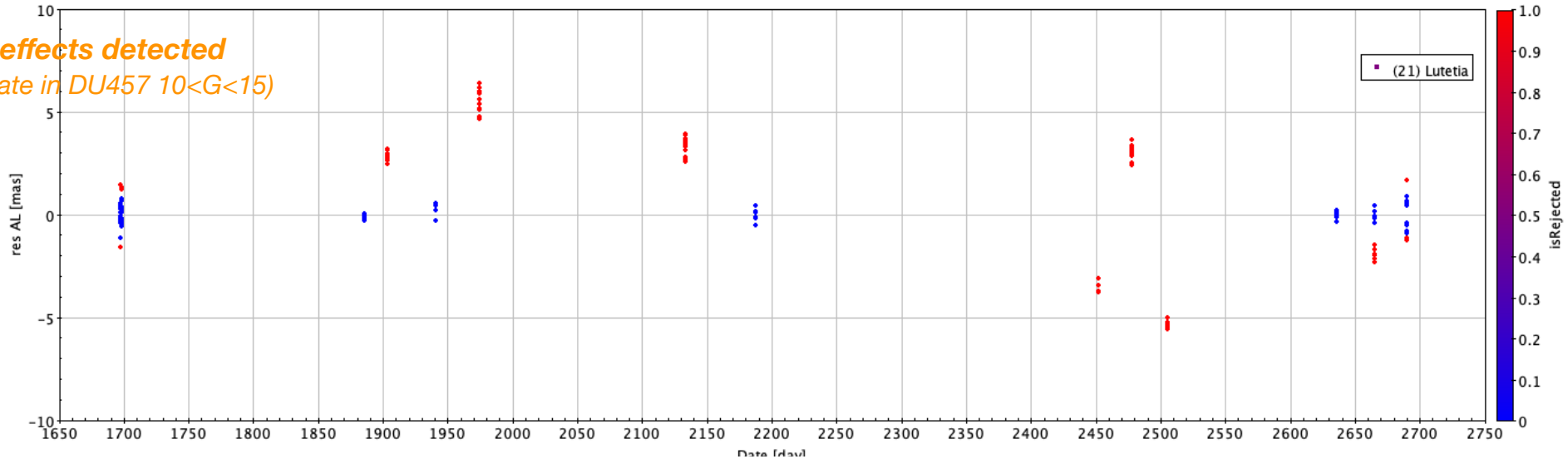
- **Photocentre offset**
- exple (21) Lutetia
  - ≈100km large object (121×101×75km)
  - 29 Gaia transits
  - models form photometry, LC inversion



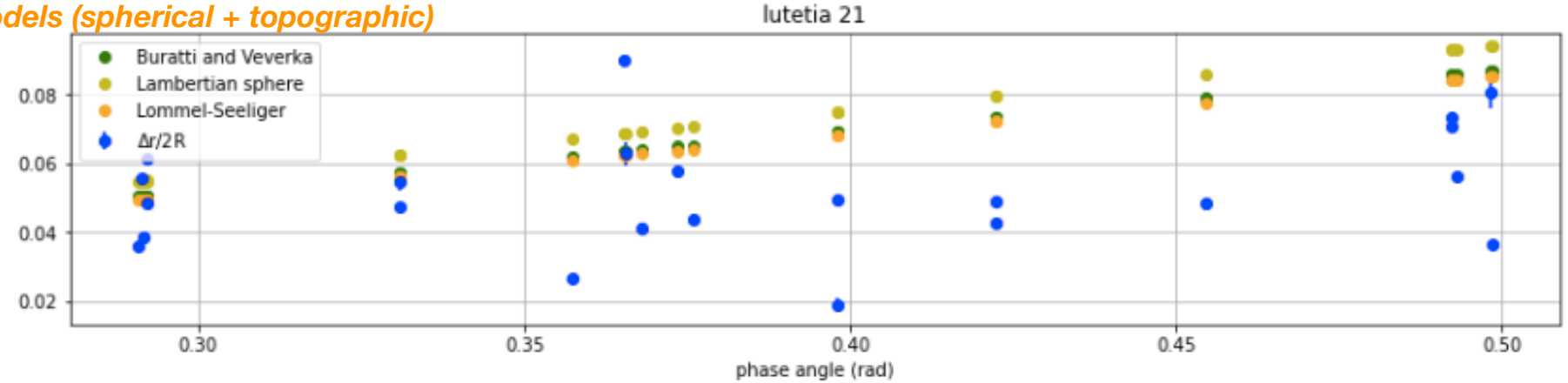
two images and photo centre displacement fo Lutetia
phase angle 24.2 and 20.9°
photocentre offset 5.96 and 10.91 km
i.e. 3.3 and 5.4 mas

SSO DR3 – results

systematic effects detected
(strong rejection rate in DU457 10<G<15)

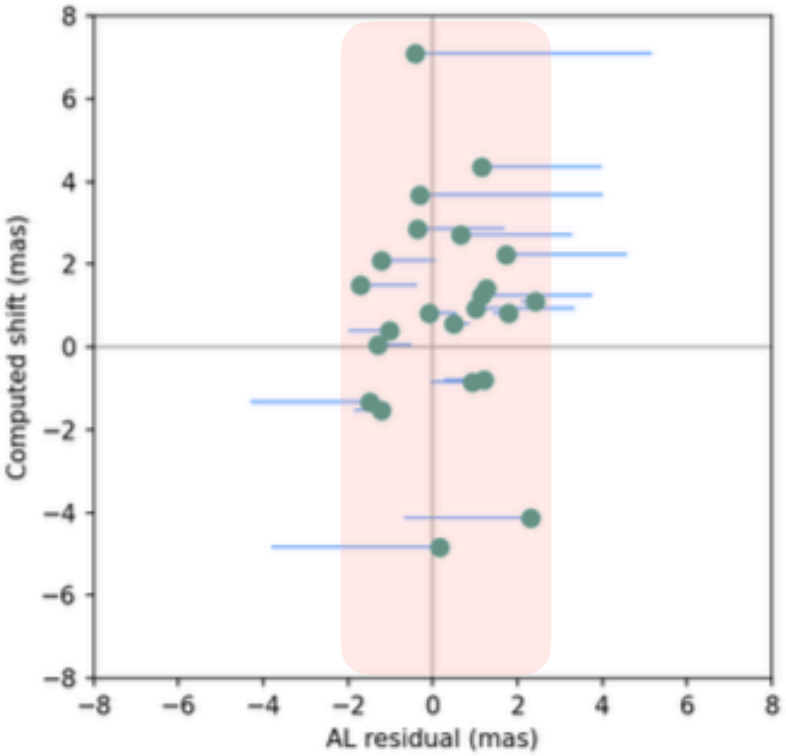


phot. offset *models (spherical + topographic)*

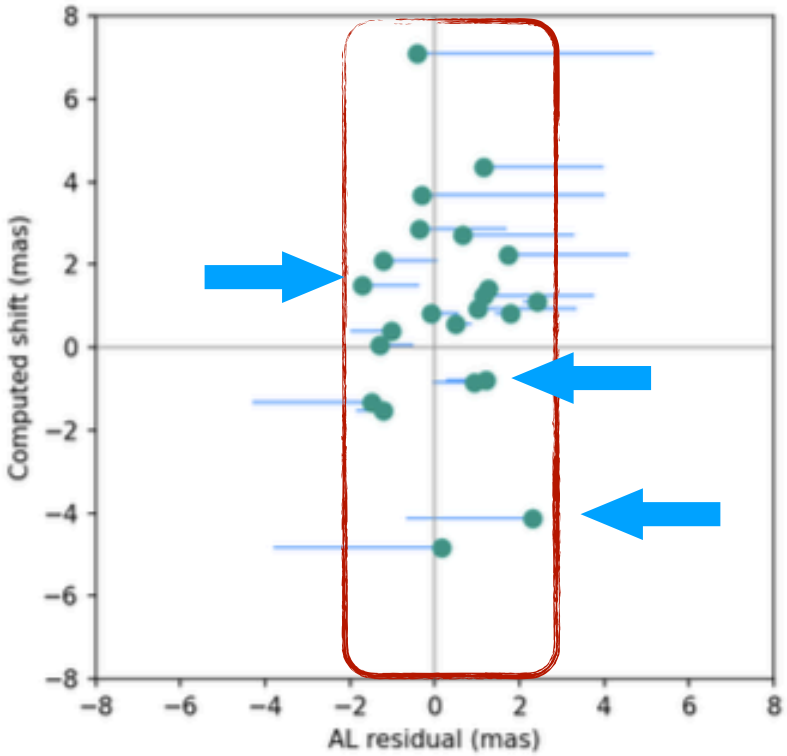


SSO DR3 – results

not corrected



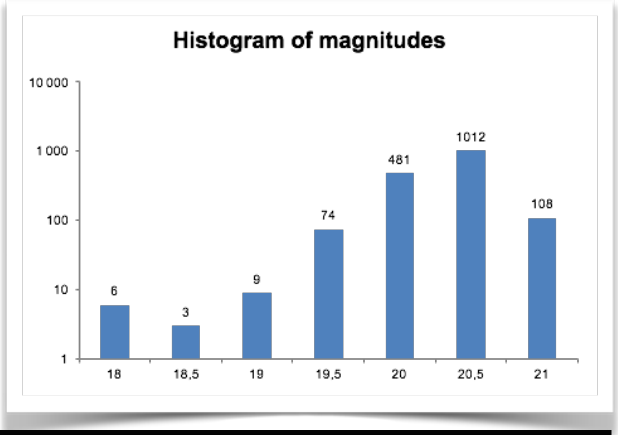
corrected



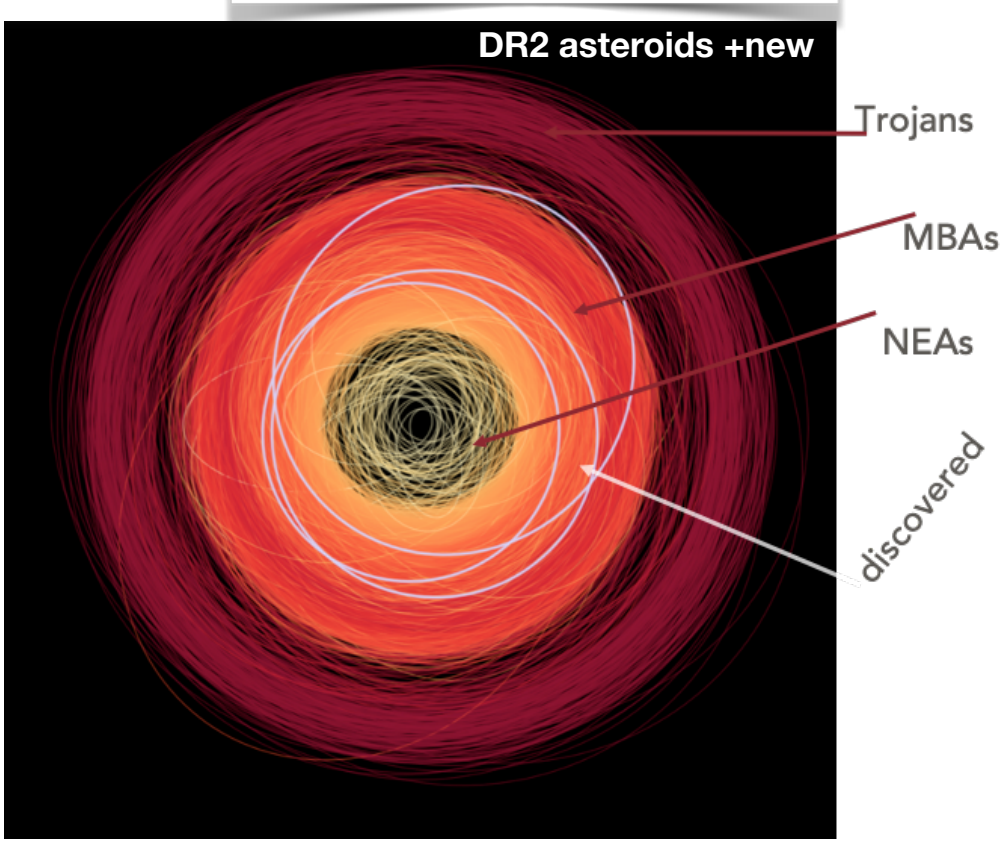
The lines represent the displacement of each data point with respect to the left panel.

General improvement, more centered residuals - albeit not perfectly (cf. →)
-> margin for improvement ; application to many smaller asteroids (DR4)

Gaia-FUN-SSO



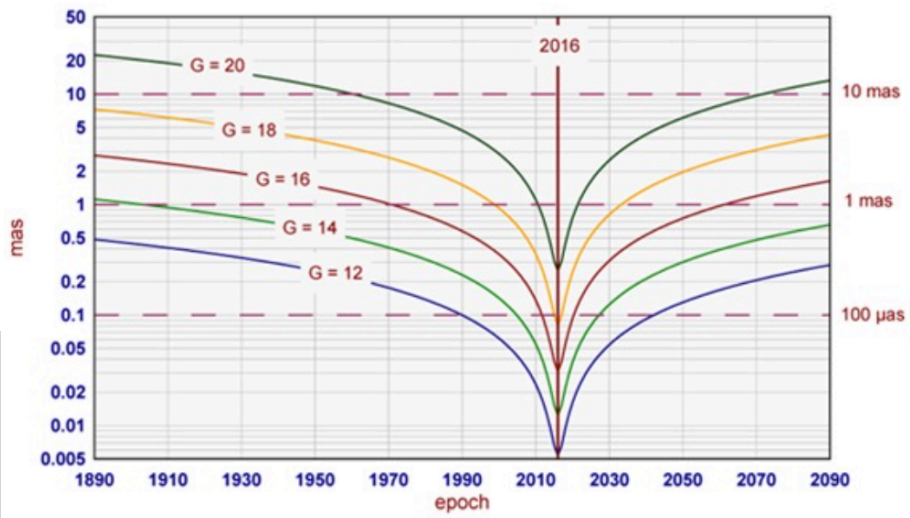
- also daily processing for detection of 'unknown' moving sources
- ground-based campaign Gaia-FUN-SSO gaia-fun-sso@imcce.fr
- discovery of asteroids
  - MBAs, mag>20, high inclination >15°

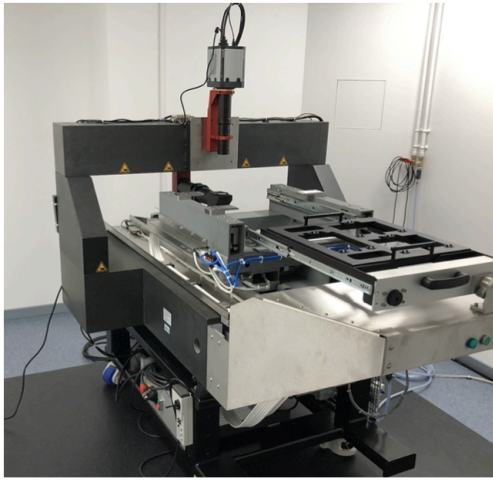


Astrometry of Asteroids

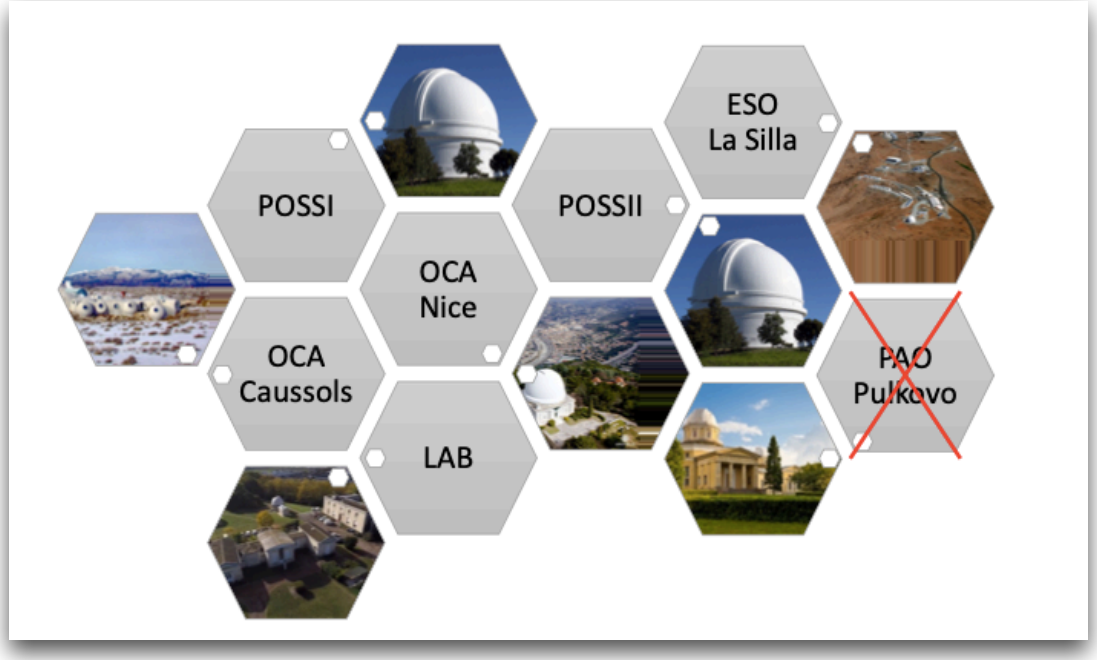
- New technique from stellar occultations (cf. Desmars et al.)
- Astrometry of asteroids is based on positioning relative to reference star, reference astrometric catalogue (…, GSC, USNO-A2, PPMXL, Tycho, UCAC, …)
  - Gaia DR2: reduction of CCDs and plates - calibration exple GBOT, OSSOS, …
- Corrections to MPC cata
  - Eggl et al. 2020 Icarus 339 *Star catalog position and proper motion corrections in asteroid astrometry*
  - Ivantsov et al. (in prep., IAUGA 2015) *On the degradation of asteroid astrometry due to background objects*
- Re-reduction of ancient observations (when available and not recent)
  - CCDs
  - photographic plates

NAROO

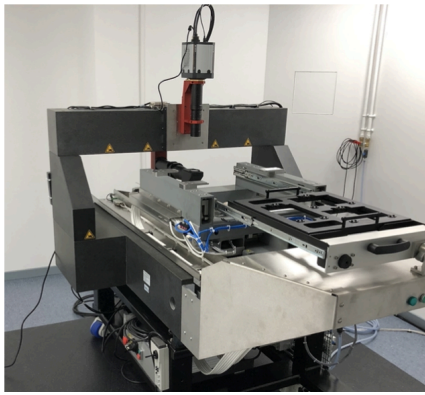




- The NAROO service @obspm
- Re-reduction of ancient observations
  - thanks to excellent proper motions
  - -> photographic plates
  - NAROO-AST
    pre-discovery of NEOs
    search in selected archives



NAROO

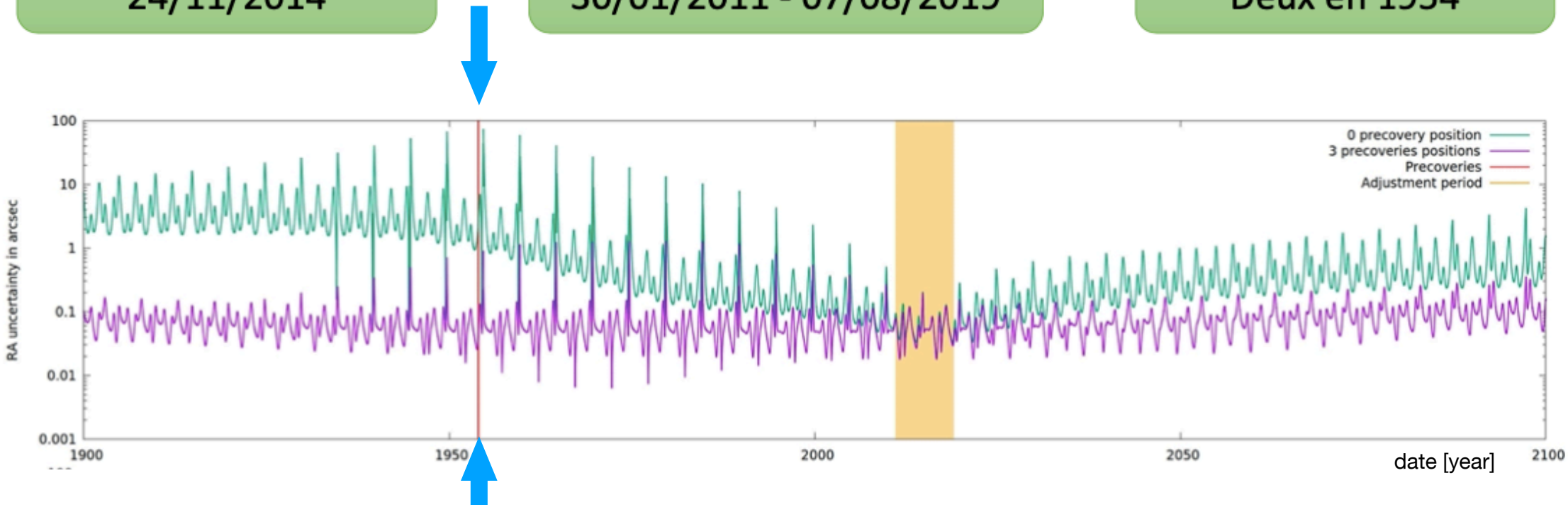


Orbit improvement for 2014 WV363 pre-recovery 60 years ago

Découverte
24/11/2014

Période d'observation
30/01/2011 - 07/08/2019

Pré-découverte(s)
Deux en 1954



Gaia DRs – next generations

- **What to expect in DR4 and later DR5**
  - a DR3+ (DR3 on longer time span)
  - comets with asteroids and satellites, more objects ≈350.000 asteroids
  - more calibration and corrections
  - more auxiliary data (e.g. masses)
  - longer time frame ≈10years (2014 – *2025*)

Prospects

- **Science**
  - from stellar catalogue (cont.)
  - from Gaia source directly
  - from Gaia **+** ground-based data
    - masses/density, tests of Gravitation, PHA and IP, occultations, Yarkovsky, comets, satellites, etc.
  - synergy Gaia + LSST
  - …