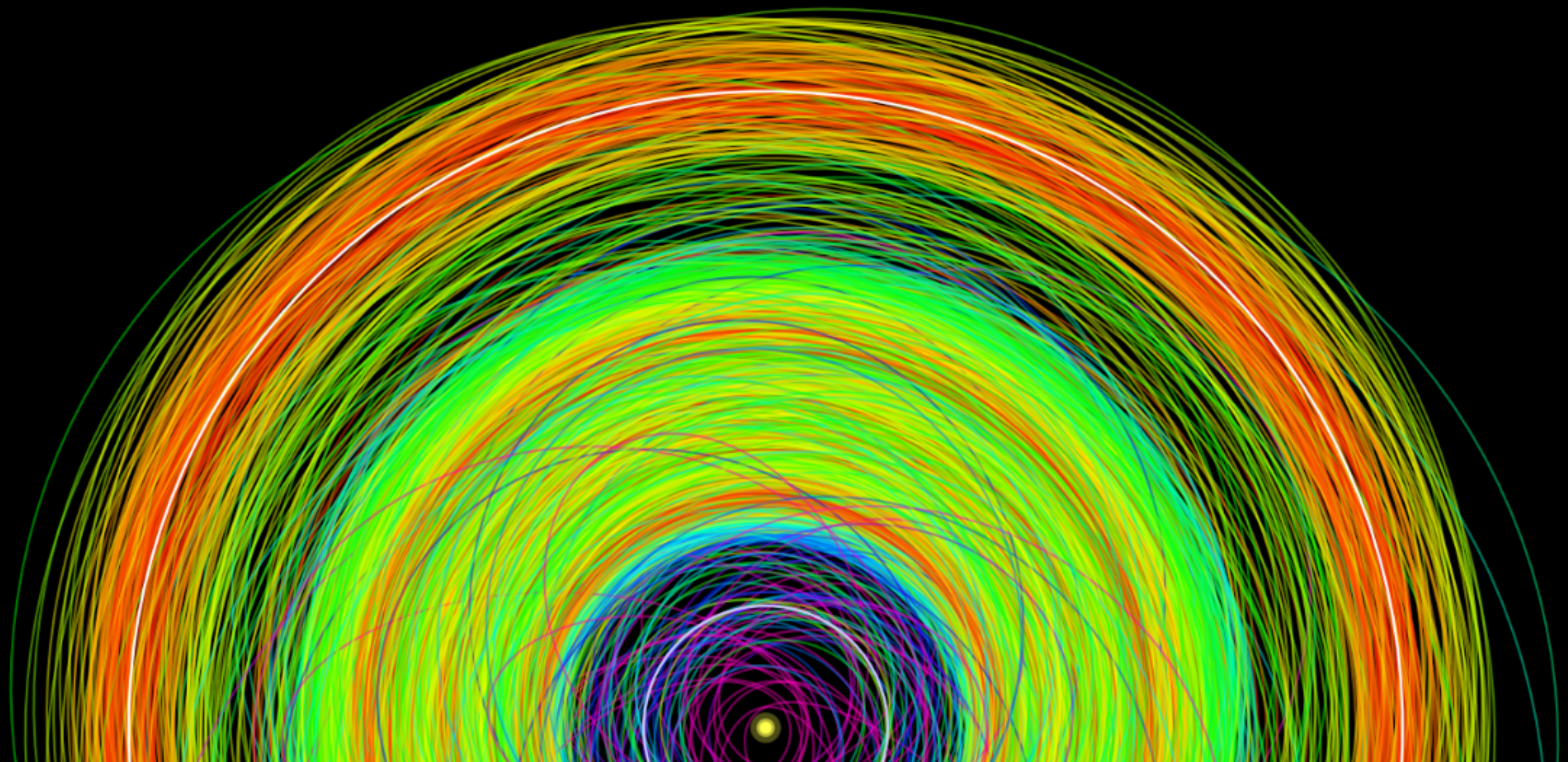


GAIA ASTEROID OBSERVATIONS

P. Tanga

Observatoire de la Côte d'Azur, Nice, France




Diffusion of asteroid alerts

Gaia Follow-Up Network for Solar System Objects

Goal

The GAIA Follow-Up Network for Solar System Objects (Gaia-FUN-SSO) has been set up in the framework of a task (DU458) of the Coordination Unit 4 (Object processing) of the DPAC Gaia consortium. Its goal is to coordinate ground-based observations on alert triggered by the data processing system during the mission for the confirmation of newly detected moving objects or for the improvement of orbits of some critical targets. Gaia will scan the sky following a pre-defined scanning law and such ground-based observations are required to avoid the loss of newly detected Solar System objects and to facilitate their subsequent identification by the probe.

These pages provide an access to the alerts, including the ephemeris to help finding the targets, for the registered members of the Gaia Follow-up network. The network currently (September 2015) consists in 56 observing sites, spread all over the world.



Workshops

Three Gaia-FUN-SSO workshops dedicated to the astrometric follow-up of the Solar System Objects have already been organized in 2010, 2012 and 2014 in Paris Observatory. Discussions have been held about this network and the tasks to be accomplished, the capabilities of the observing sites and the preliminary actions already performed.

- Proceedings of the 2010 workshop have been published and can be freely downloaded from the [workshop web site](#).
- Proceedings of the 2012 workshop have been published. These proceedings and the talks are accessible on the [workshop web site](#).
- Proceedings of the 2014 workshop have been published. These proceedings and the talks are accessible on the [workshop web site](#).

Registration

To get a full access to these pages and to share data, you must be registered as active participant of this observing network. For this registration, please use this [form](#). This network needs to have a large geographical coverage: if you are interested, do not hesitate to contact us!

© Please report bugs here in project "Gaia-FUN-SSO", or contact us at gaia-fun-ss@imcce.fr.

List of active alerts

Selected alerts: 3/12


ID ▲▼	Begin ▲▼	End ▲▼	V _{mag} ▲▼	RA ▲▼	Dec ▲▼	Area ▲▼	Name ▲▼	Report	Details
28741	2017-04-06	2017-04-15	19.94	141.533	-14.3815	0.41116	g1N00a		
28355	2017-04-04	2017-04-13	19.95	143.6757	-11.9679	0.72448	g1N002		
28125	2017-03-29	2017-04-15	20.13	142.9194	-22.5203	0.29496	g1M008		

<http://gaiafunssso.imcce.fr>

B. Carry (OCA), W. Thuillot
(IMCCE)

Register and contribute!

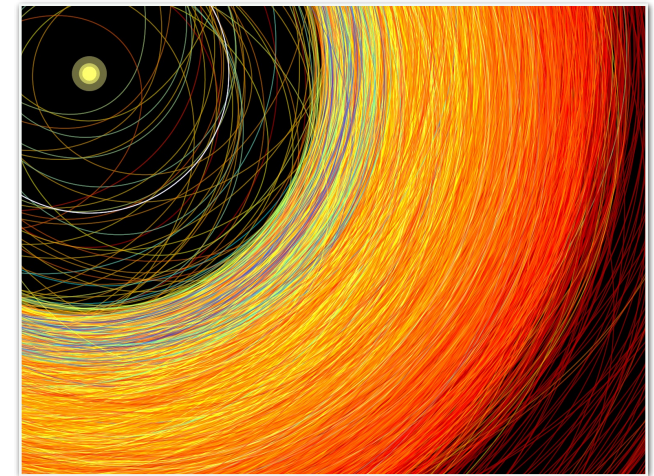
Sky view with Aladin -- Object expected magnitude $V = 18.4^{+0.6}_{-0.3}$



Footprints of areas to search for (in red) and the field of view (in blue, 15x15 arcmin²) of your device (OHP). You can change your device and its parameters in your [settings](#).

Gaia DR2 - Solar System

On the base of a pre-selected list of known objects
> 10 FOV transits over the 22 months of DR2
August 5, 2014 - May 23, 2016



Objects	14 099
Epoch	1 997 702 CCD positions
	287 904 transits (52% :
Typ. accuracy	<1 mas (along scan)

Asteroids DR2 data

gaia archive



- asteroid ID and BCRS positions (Ra, Dec) as seen by Gaia
- barycentric positions of Gaia
- TCB gaiacentric epochs for the positions
- uncertainties & correlation:
 - systematic component <— constant along a transit
 - random component <— uncorrelated over a transit
- brightness (1 per transit): G magnitude, flux and uncertainty



The result of a >15 years effort

In the frame of the Data Processing and Analysis Consortium (DPAC)

Main contributors to processing :

IMCCE, France:

INAF, Italy:

UTINAM, France:

OCA, France:

Spoto,

ORB, Belgium:

U. Helsinki, Finland:

J. Berthier, P. David, D. Hestroffer, W. Thuillot

A. Cellino, A. Dell'Oro

J.M. Petit

M. Delbo, L. Galluccio, F. Mignard, Ch. Ordenovic, F.

P. Tanga

Th. Pauwels

K. Muinonen, G. Fedorets

Validation :

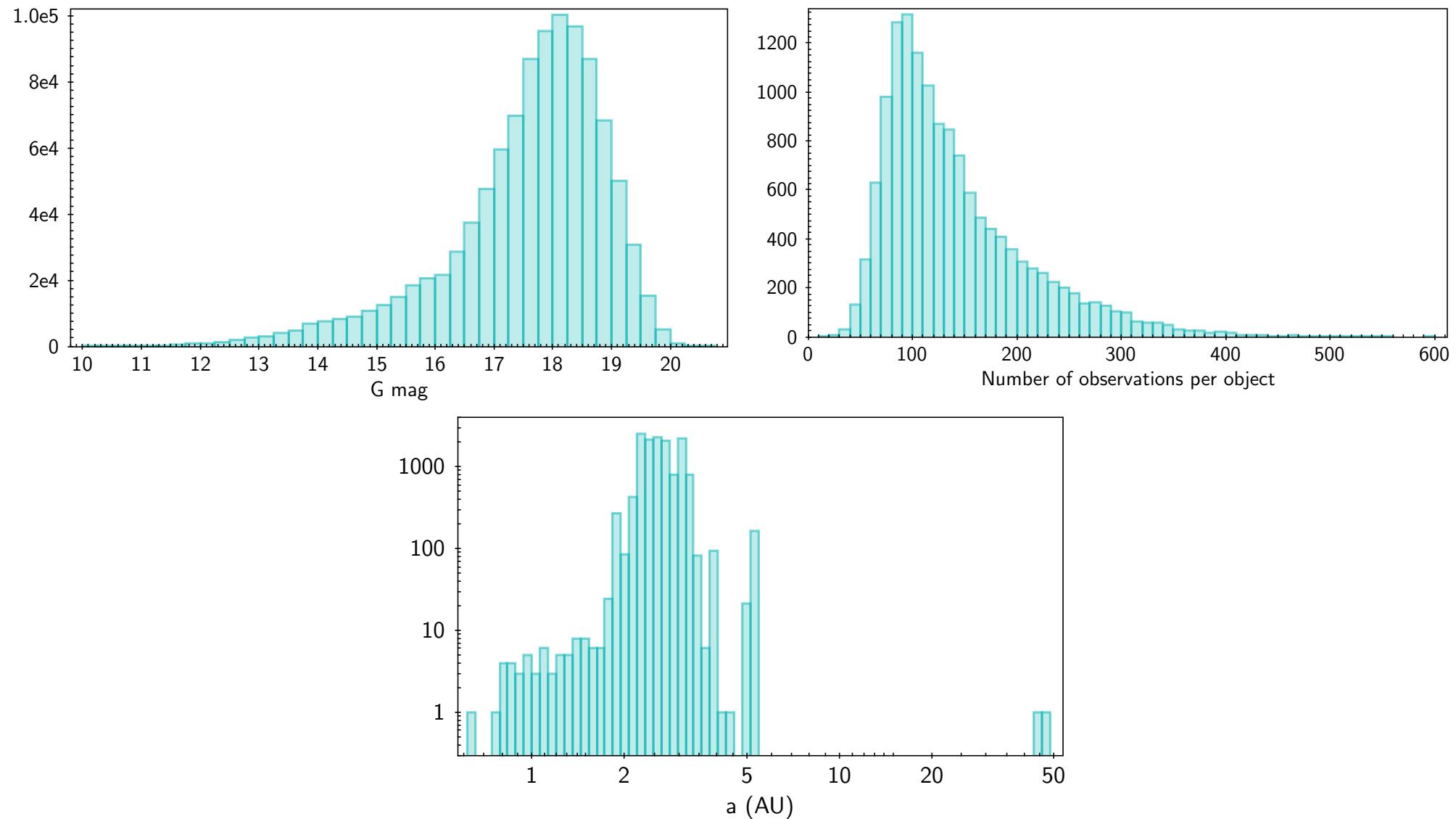
OCA, France:

F. Spoto, A. Cellino

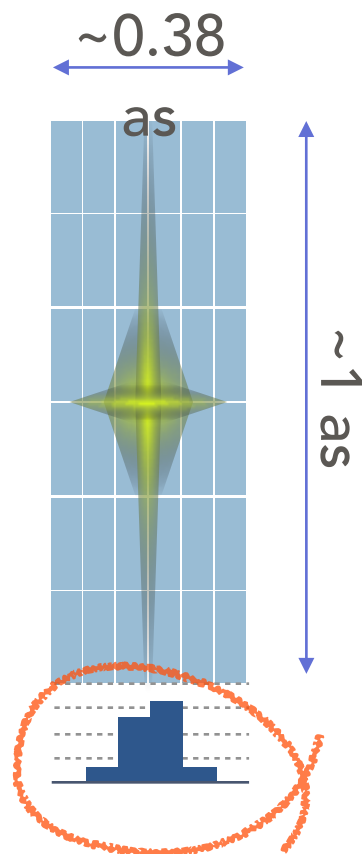
Now preparing DR3!



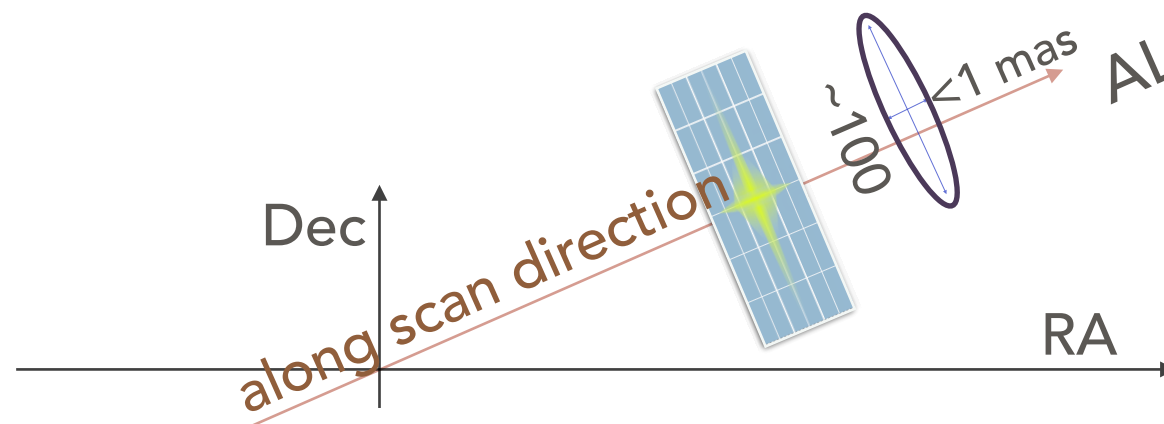
Gaia DR2 - Solar System statistics

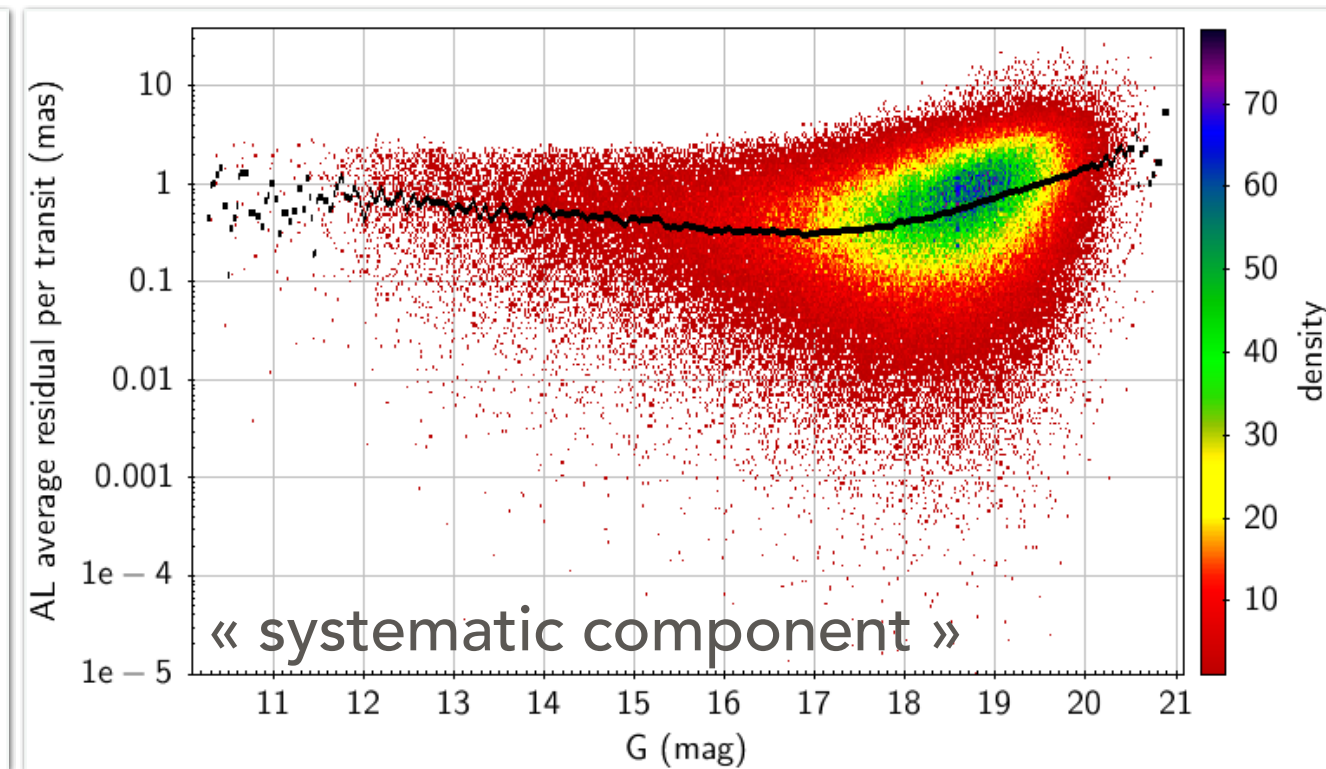
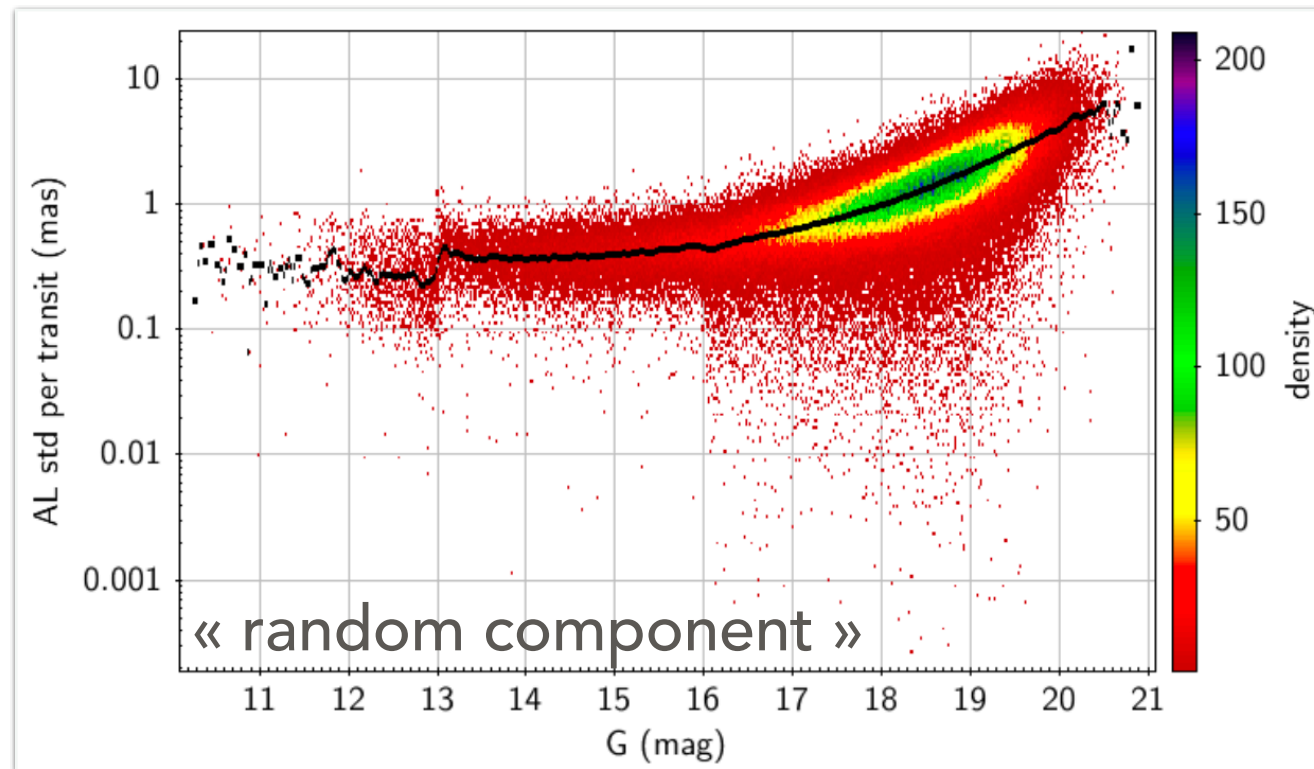


Gaia elementary observation: highly correlated errors



- Tools must be ready to handle accuracy ~ 100 X better
- Highly correlated (RA, Dec) positions.
 - Not (very) relevant for stars
 - Fundamental for asteroids!
- Random and systematic components given

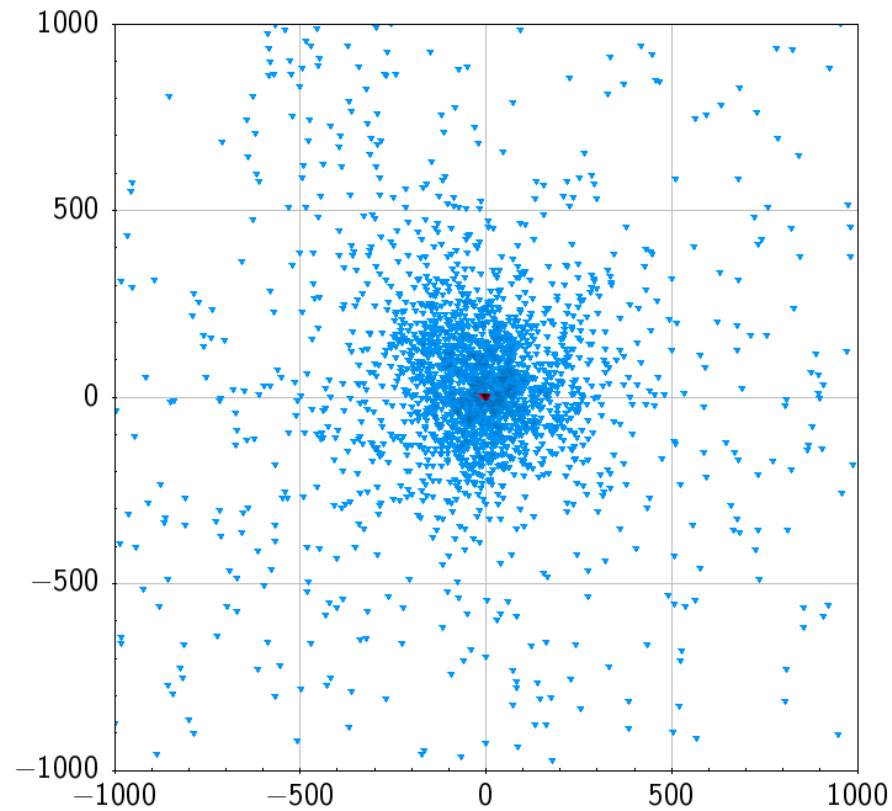




Residuals from the orbital fit of Gaia DR2 data only (AL direction)

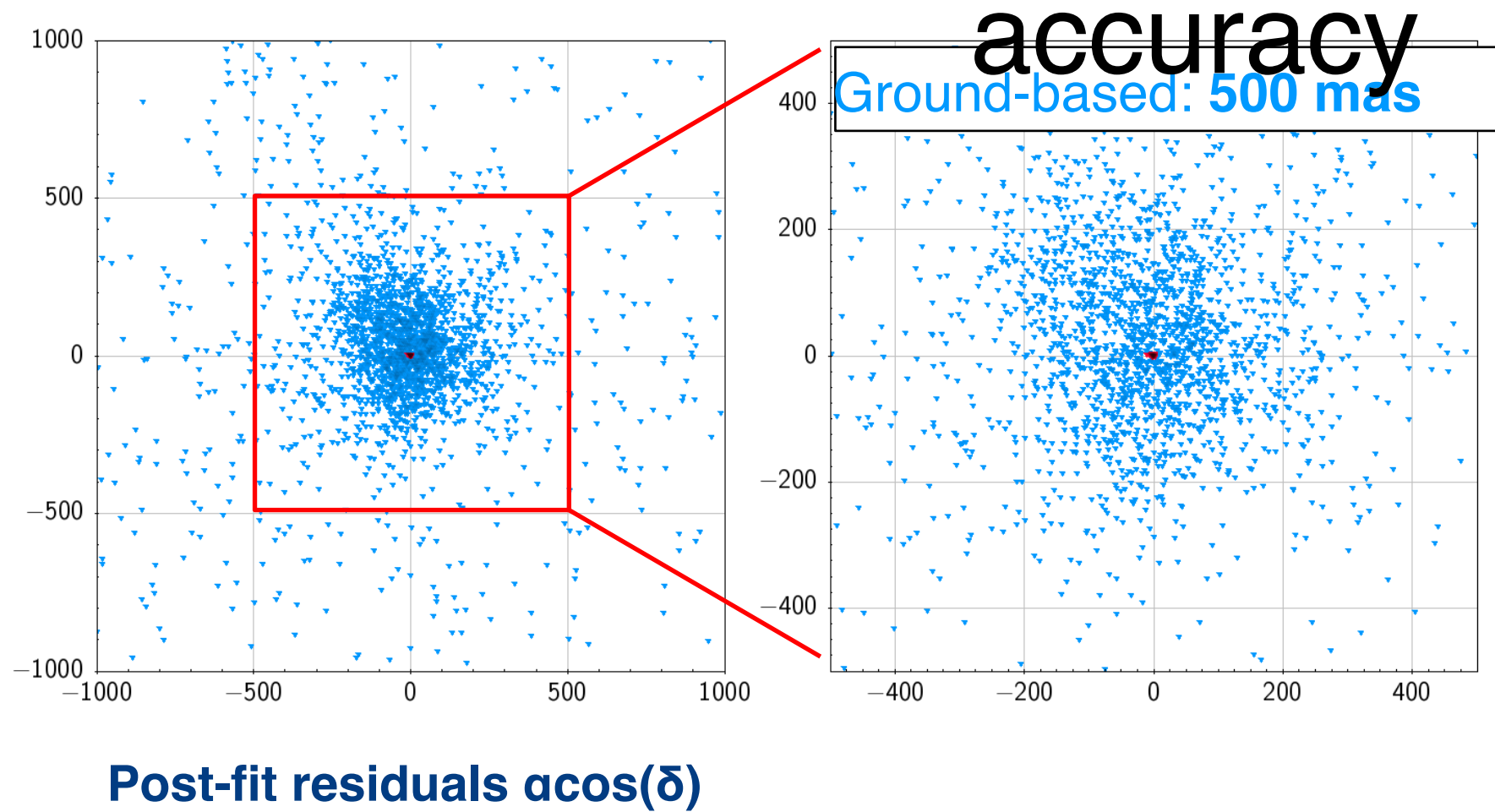
The Gaia collaboration: Spoto et al. 2018

Gaia DR2- asteroid observation accuracy

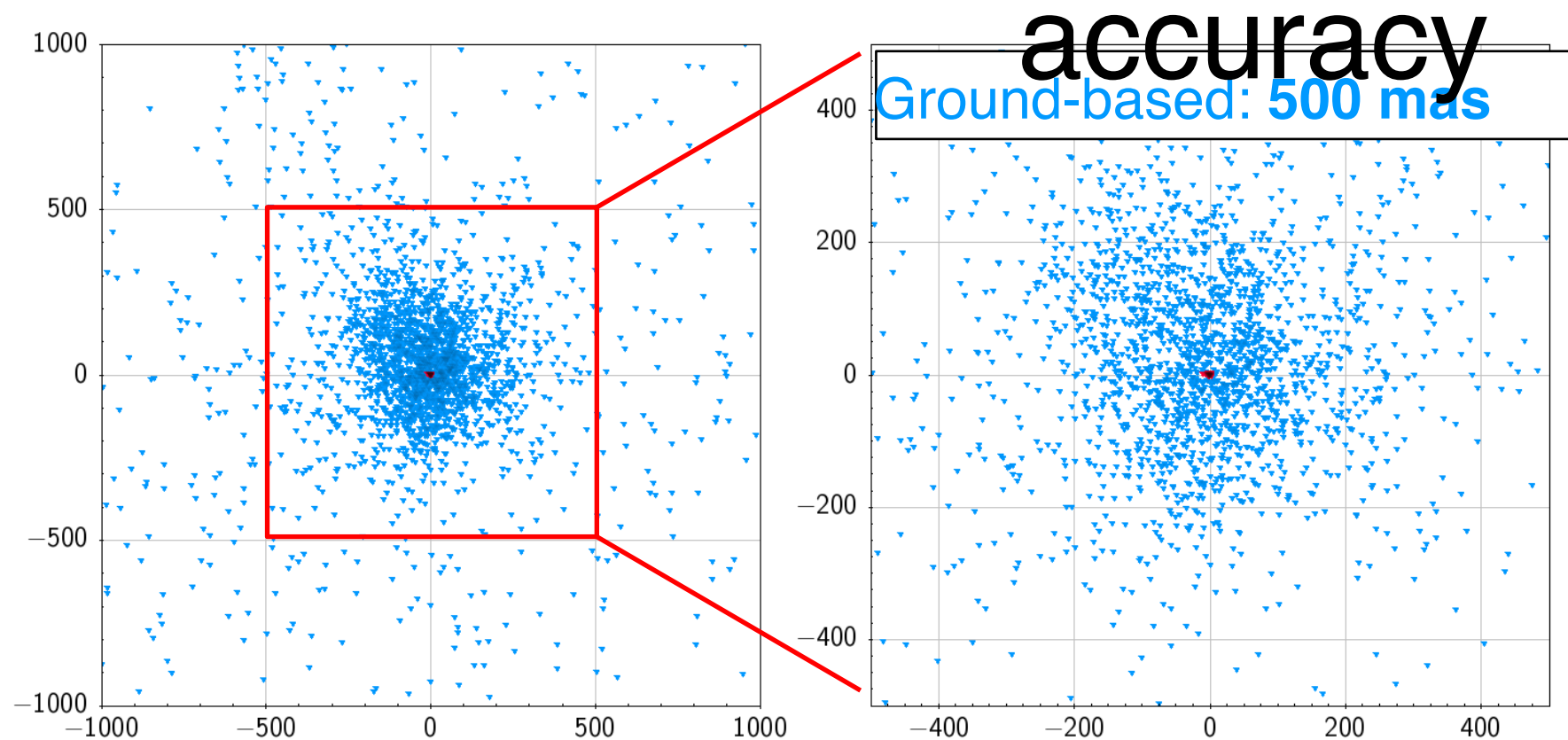


Post-fit residuals $\alpha \cos(\delta)$

Gaia DR2- asteroid observation



Gaia DR2- asteroid observation

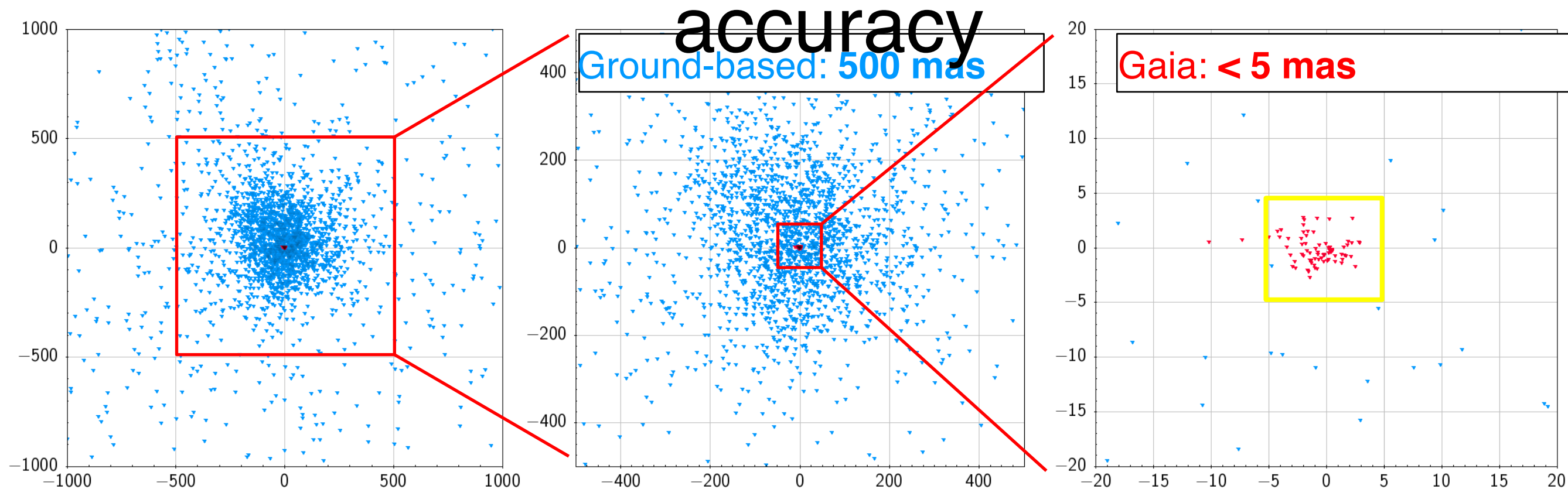


Post-fit residuals $\alpha \cos(\delta)$

Available ground-based astrometry

- **200 millions** of observations (mid Feb. 2019)
- Typical accuracy: between **400** and **500 mas**
- **2 000** accurate observations (mostly radar)

Gaia DR2- asteroid observation

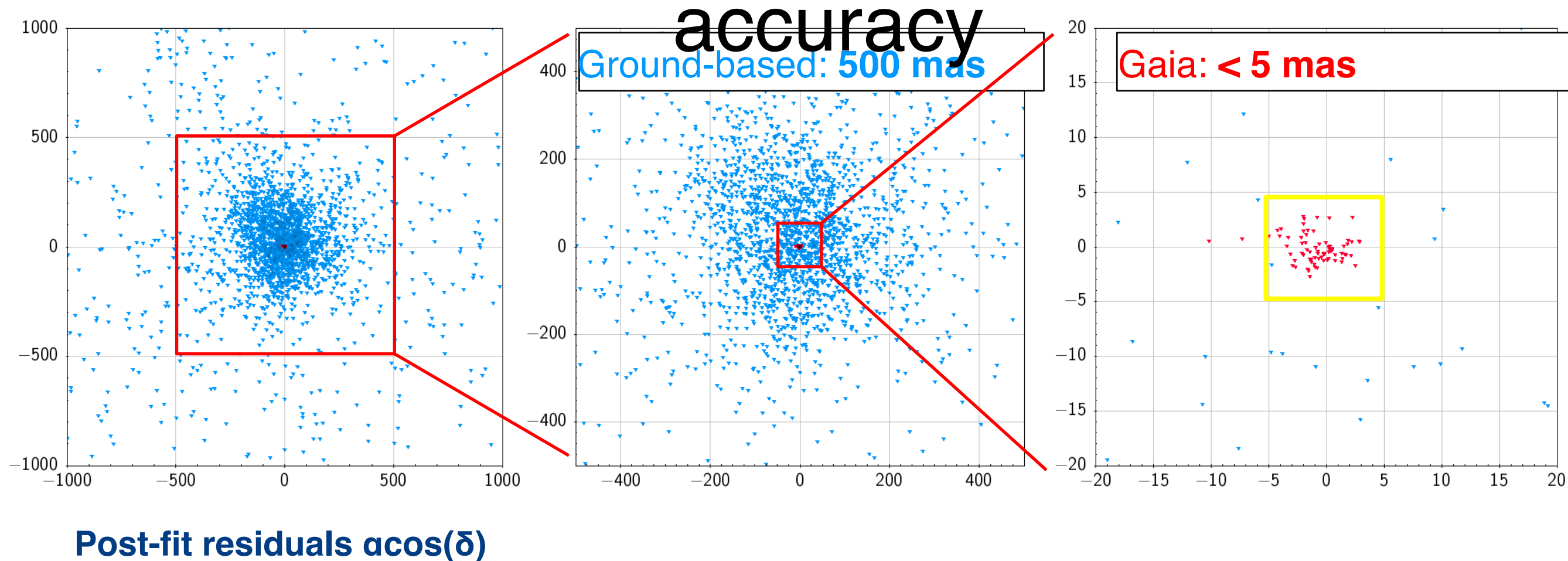


Post-fit residuals $\alpha \cos(\delta)$

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Gaia DR2- asteroid observation



Available ground-based astrometry

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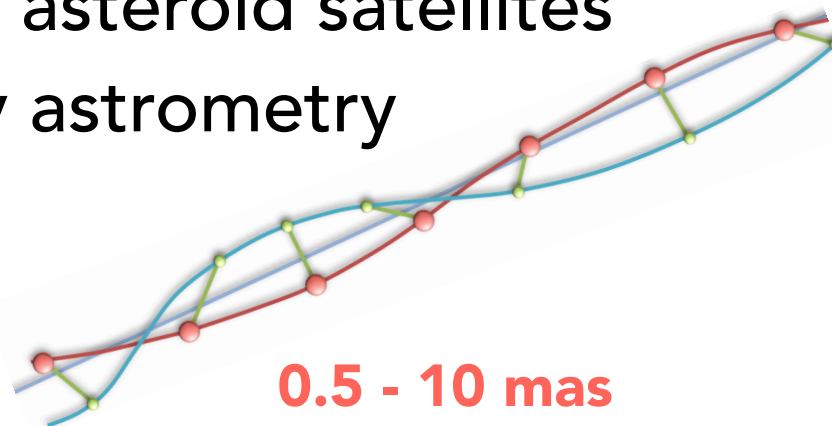
Gaia DR2 (Gaia Collaboration et al. 2018)

- **1 977 702** observations
- Accuracy between **2** and **5 mas** ($V \sim 20.5$)
- Accuracy at the **sub-mas** level (bright objects)

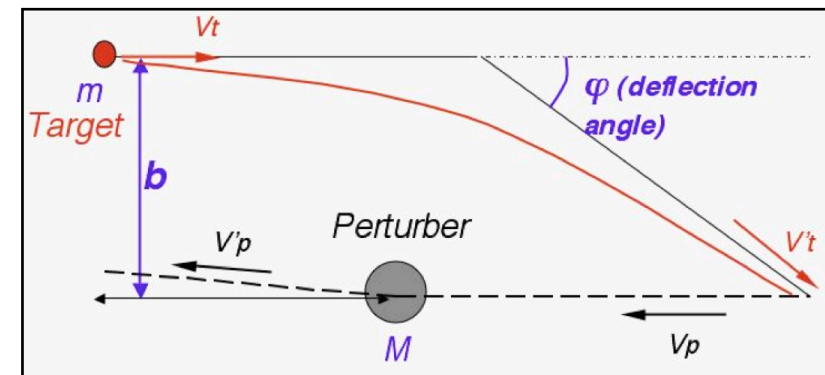
13

Some challenges for asteroid astrometry require long observational arcs

Discover asteroid satellites
by astrometry

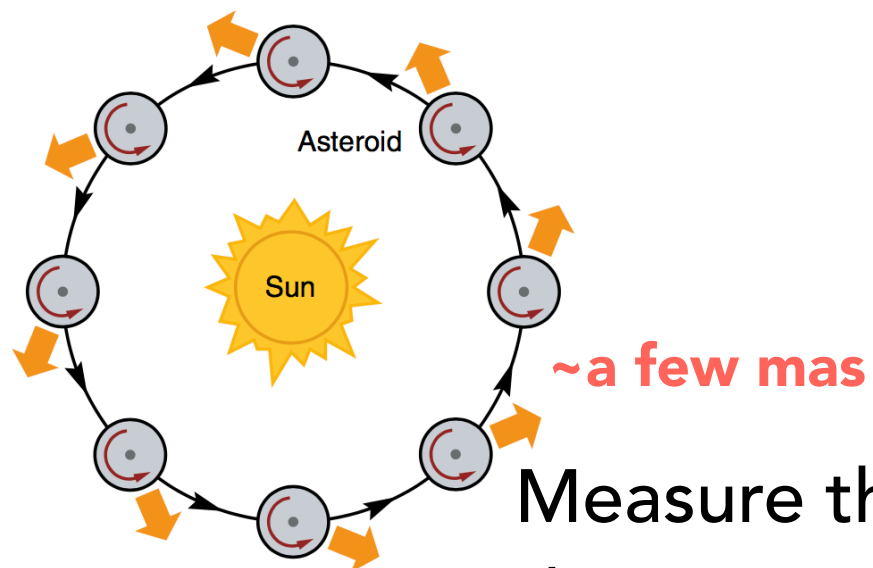
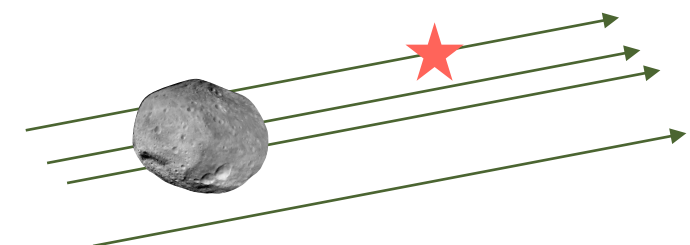


New / precise asteroid masses



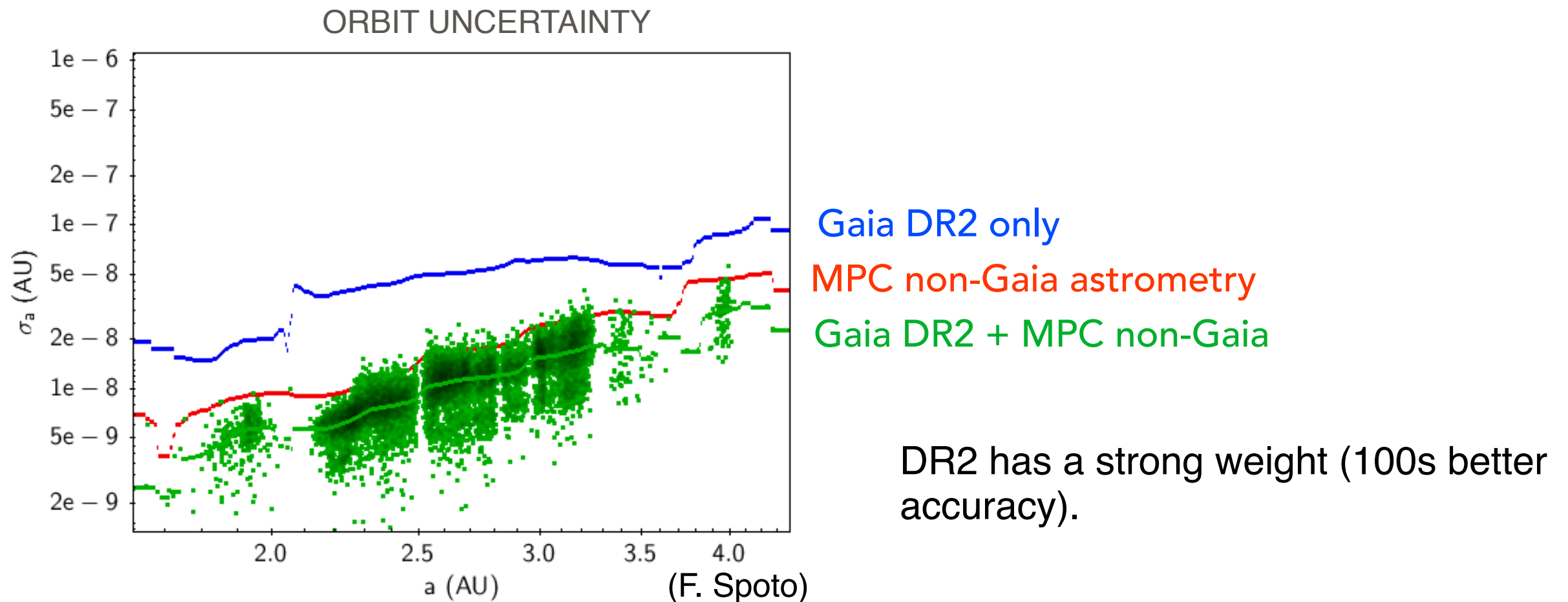
~ 10 mas

Improve predictions of stellar
occultations



Measure the orbital drift
due to *Yarkovsky force*

« Tentative » orbit improvement by DR2



- A factor ~ 2 (only) average improvement by using DR2 + all other data
- But: most other data are affected by systematic (zonal) errors of the pre-Gaia catalogs

Data sources

- Minor Planet Center
 - 200 million astrometric positions, for ~800k asteroids
 - starting in 1802
 - different techniques (visual, photography, meridian circles, CCD...)
 - data include the telescope used, filter, calibration catalogue (for a large fraction)
- Gaia DR2
 - ~2 million CCD-level, epoch positions for 14.099 asteroids
 - over 22 months
 - Gaia DR3 → ~100.000 asteroids
 - Gaia final → ~350.000 asteroids



Typical errors

- Minor Planet Center

	Fraction	Average residuals
CCD	94.1 %	380 mas
WISE, HST...	4.2 %	580 mas
pre-CCD	1.2 %	500-1000 mas
Hipparcos, occultations, radar	0.5 %	10-150 mas

Desmars et al. 2013

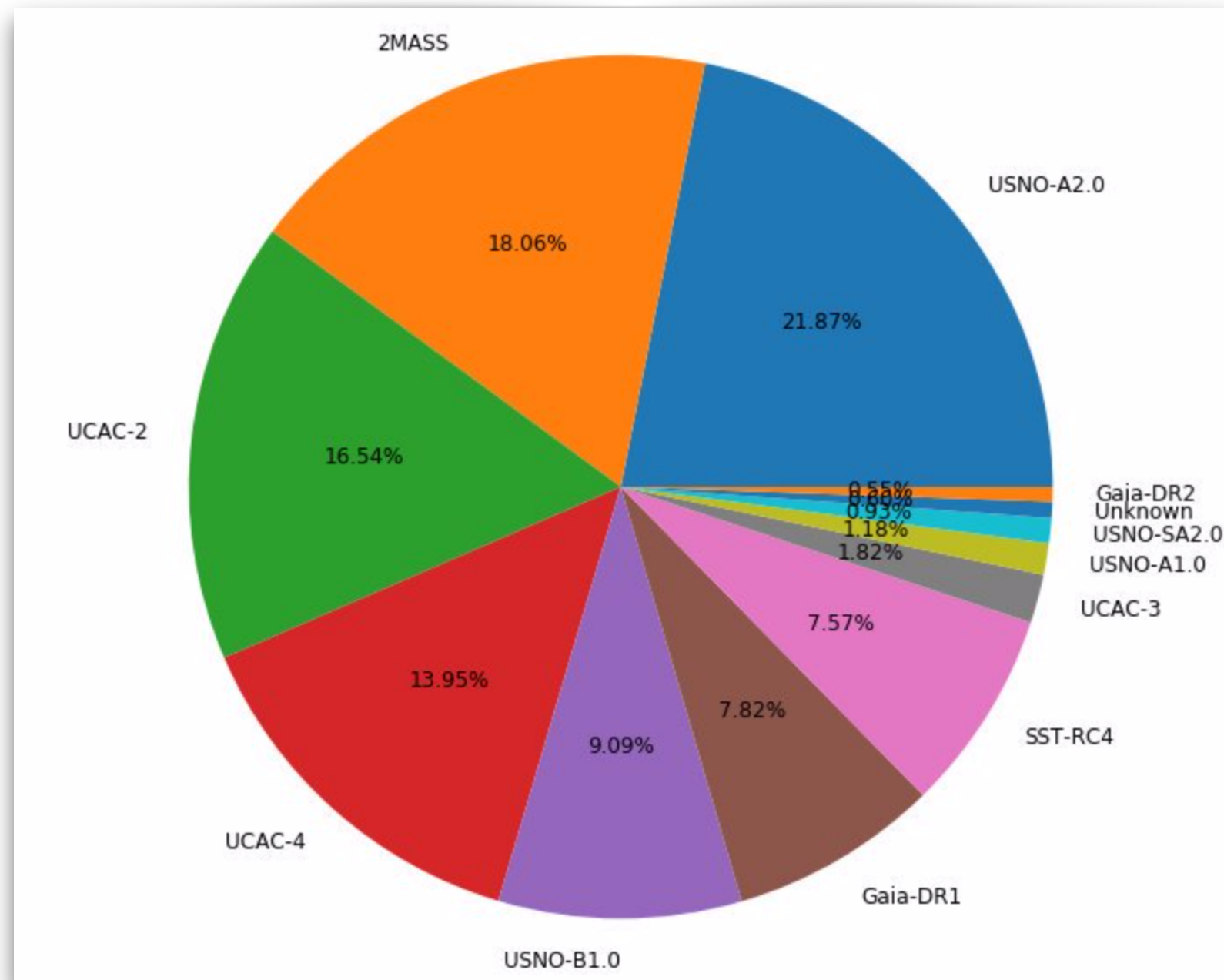
- Gaia DR2 (14.099 asteroid set)

Fraction	Residuals
52 %	< 1 mas
96 %	< 5 mas



Catalogue used in MPC data

- ~191 million positions, updated at Oct 2018



courtesy M. Kretlow

The problem

An appropriate use of Gaia + pre-Gaia astrometry (calibrated by “old” catalogs)
requires
the correction of systematic effects present in old catalogs

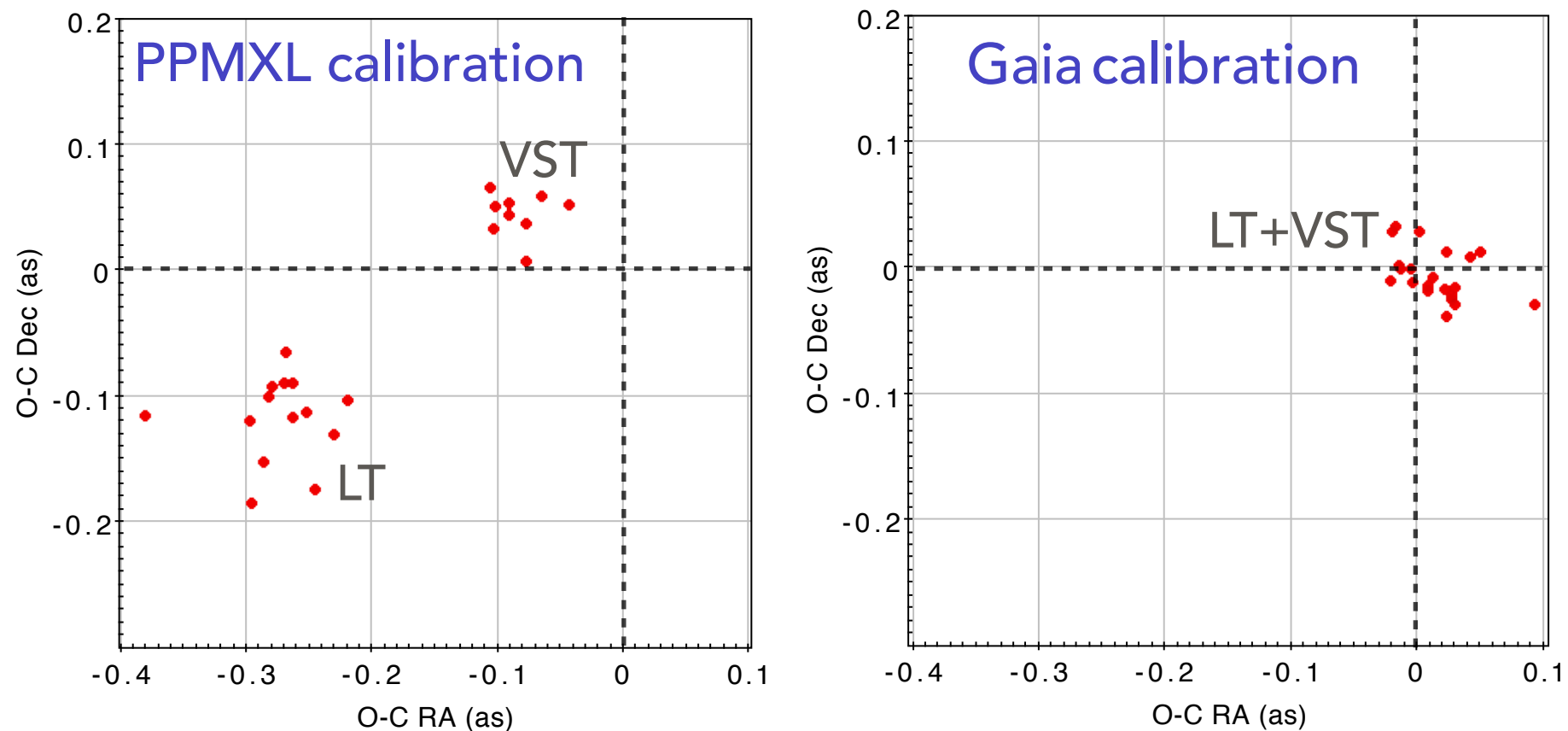
- Such effects can be:
 - different definitions of the reference system/frame
 - local (zonal) discrepancies, mostly due to:
 - ~plate size used for astrometric imaging
 - errors inherited in proper motions from pre-existing astrometry
- Going back to old raw data (plates, CCD images) and performing a new data reduction solves (nearly) all problems but it is not applicable to all the observations available (!)



Bias example: joint exploitation Gaia + pre-Gaia astrometry

Asteroid (1132) Hollandia

Liverpool Telescope + VST (8 hours apart) & MPC ground-based data (~1900 positions)



(credits: Gaia GBOT team)

Correction of catalogue errors: “de-biasing”

- The idea is to use the “best” available catalogue as a reference
- “Local” positions of stars in the old catalogs, at a given epoch t , can be compared to the same stars in the reference (here assumed at $t = J2000.0$):
 - the average difference in position $\Delta RA_{2000}, \Delta DEC_{2000}$ is computed
 - an additional contribution, the difference in proper motion $\Delta\mu_{RA}, \Delta\mu_{DEC}$, must be included (at t of each observation)

$$\Delta RA = \Delta RA_{2000} + \Delta\mu_{RA}(t - 2000.0)$$

$$\Delta DEC = \Delta DEC_{2000} + \Delta\mu_{DEC}(t - 2000.0)$$

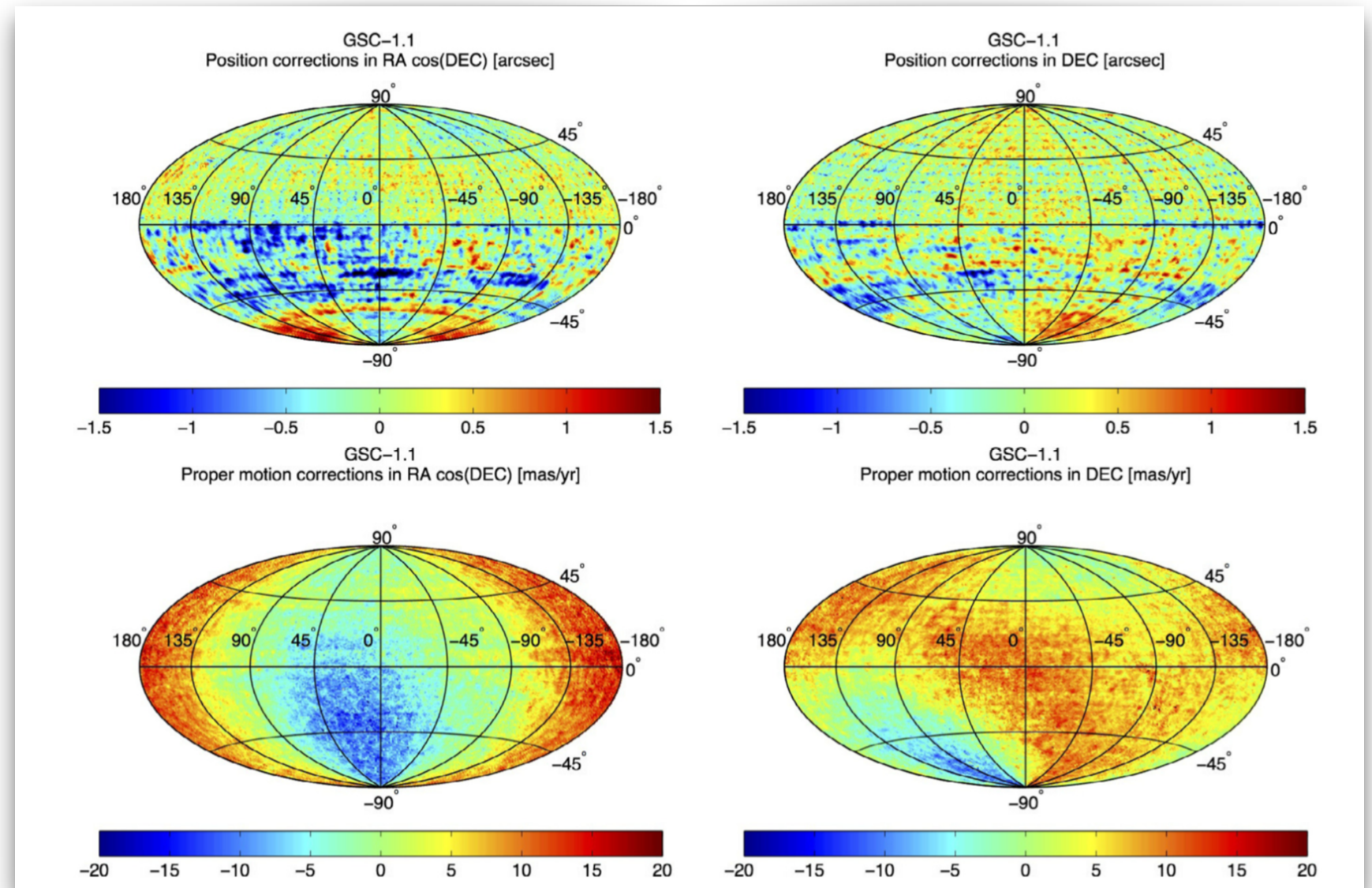


Standard approach: Farnocchia et al. 2015

Correction computed on healpix tassellation of the sky.

Reference: a subset of PPMXL, in common with 2MASS.

Example of resulting corrections for GSC-1.1



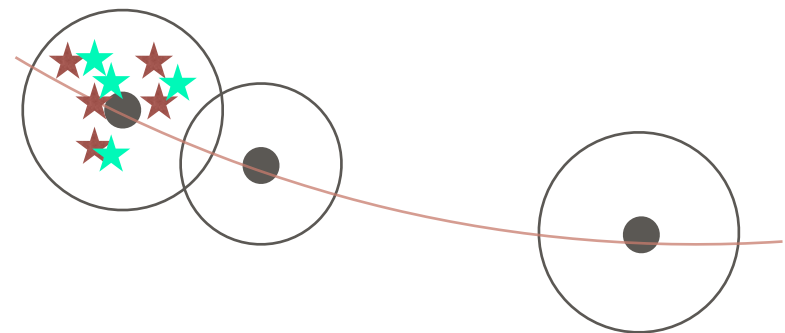
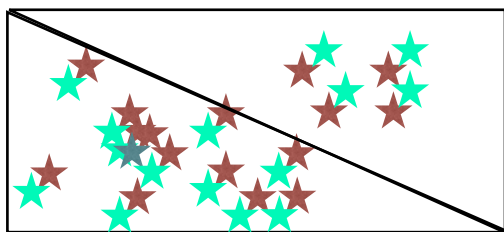
- Advantages:
 - Fast
 - Computed once, applicable to old/new data.
- Limitations:
 - Rigid (tassellation is fixed)
 - Discontinuities between adjacent zones.
 - No relation to the real observing conditions.

New approach (our own)

- No tassellation: differences are computed around each astrometric position of an asteroid (source: MPC).
- Advantages, flexibility
 - large discontinuities are avoided
 - domain size and limiting magnitude can be adapted for each observation
- Limitations
 - large amount of data to correct, need to query many catalogues several times
 - overhead of computation on overlapping regions



Quick look comparison



Method 1 (used up to now): corrections
of catalogs computed on a healpix
tassellation of the sky
(Farnocchia et al. 2015)

Method 2 (our own) :
corrections of single archive
observations referred to Gaia DR2

Robotic observations of asteroid occultations

- Extension to faint magnitudes and small asteroids

- Only method providing ~ accuracy

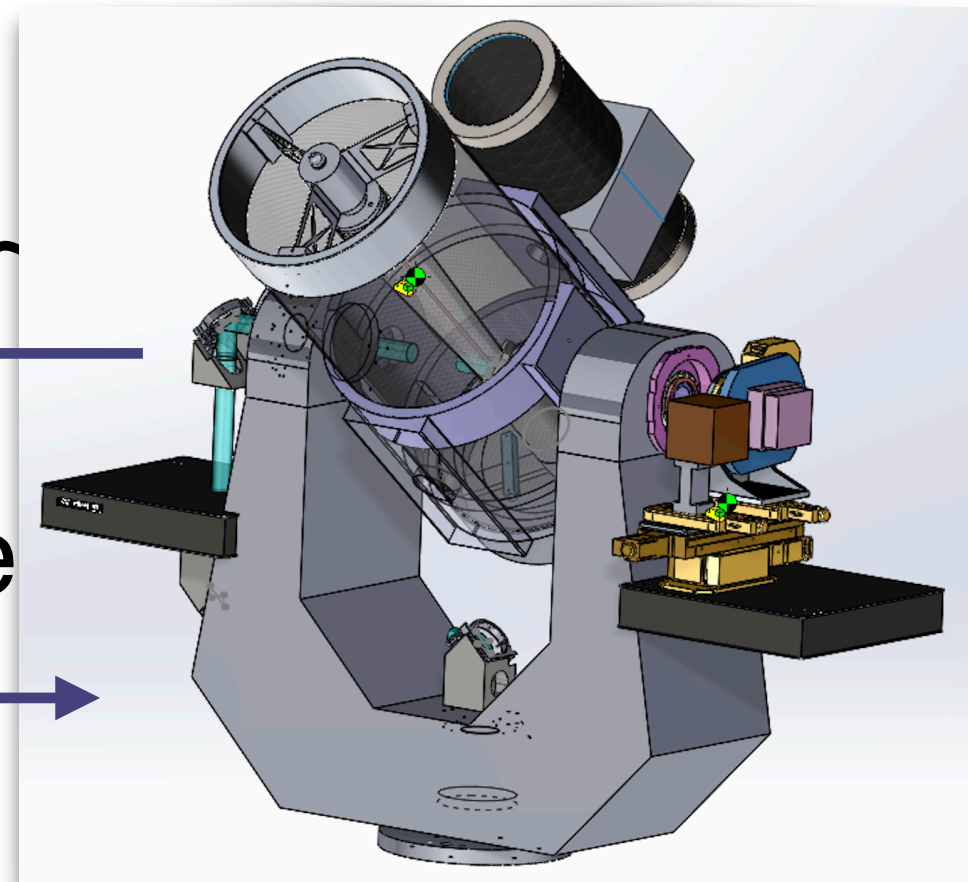
ASTROMETRIC
DATA

OBSERVATIO

- 50 cm robotic telescope France

EXPLOITATION:
YARKOVSKY
IMPROVED
DYNAMICAL

OCCULTATI
ON

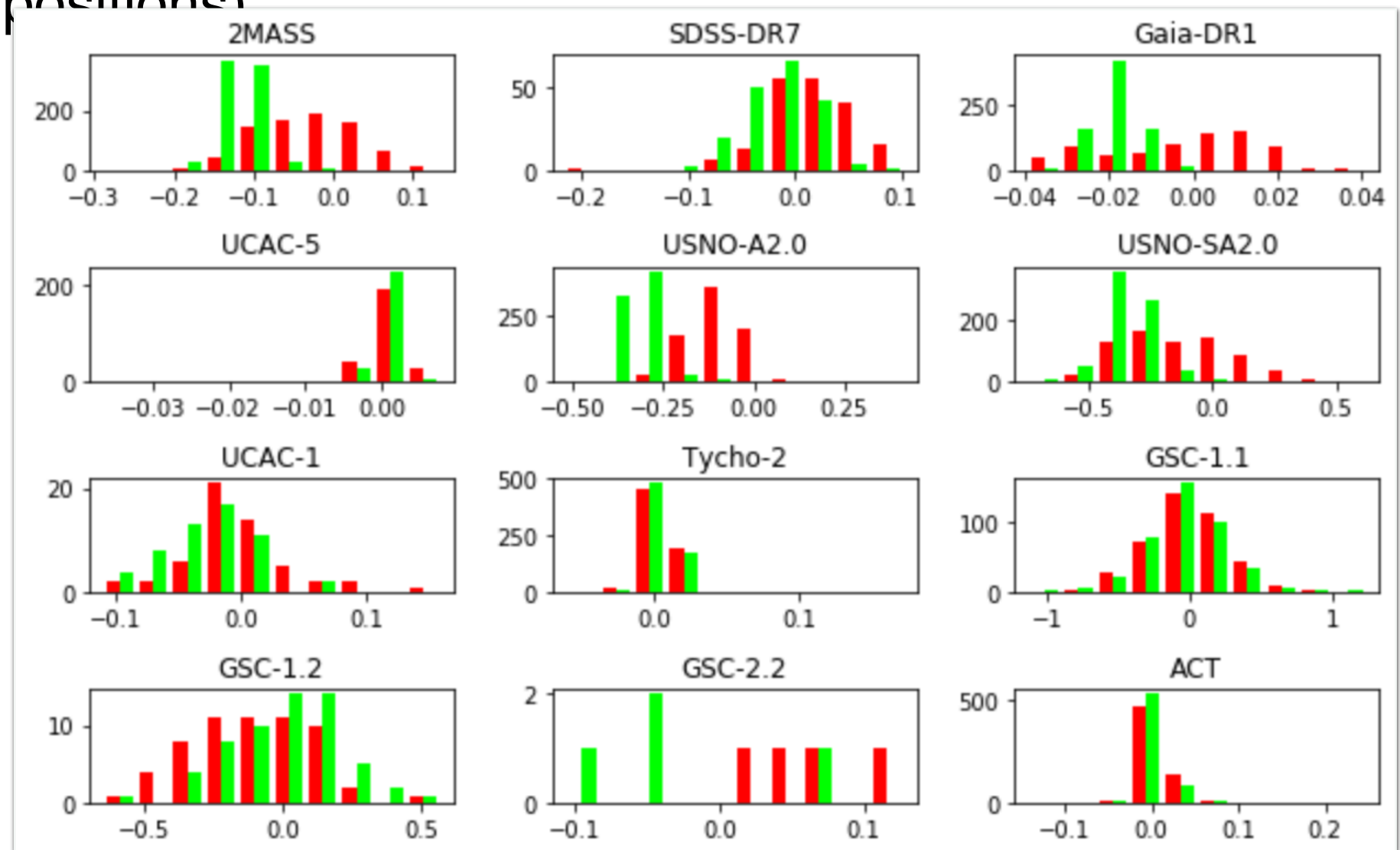


New approach: preliminary version

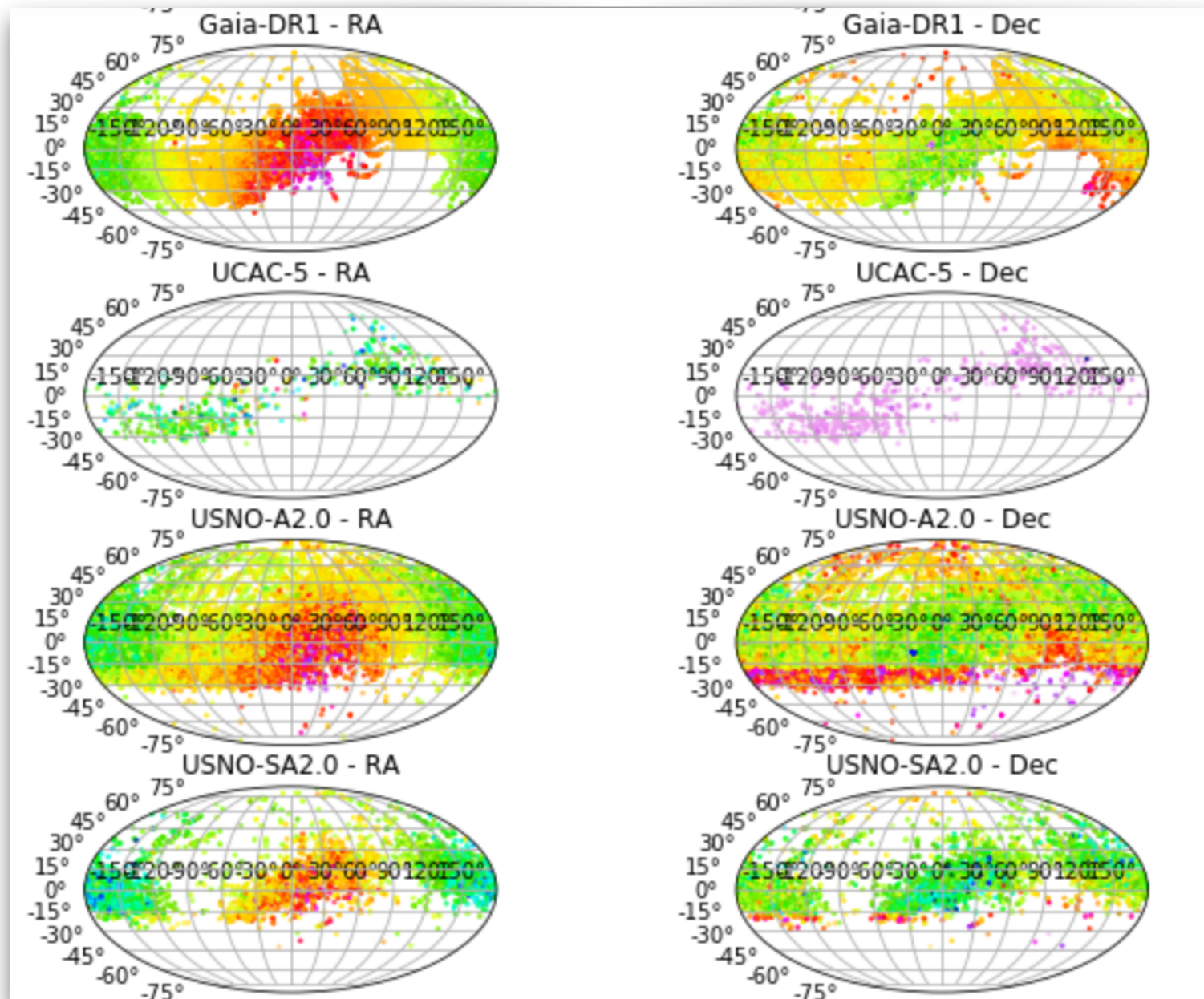
ACT
 USNO-A2.0
 USNO-SA2.0
 USNO-B1.0
 CMC-14
 UCAC-1
 UCAC-2
 UCAC-3
 UCAC-4
 UCAC-5
 GSC-ACT
 GSC-1.1
 GSC-1.1
 GSC-2.2
 Tycho-2
 2MASS
 PPMXL
 SDSS-DR7
 Gaia-DR1

Current magnitude limit $V < 15$

Bias distribution (arcsec): ~3000 asteroids (~1 million positions)

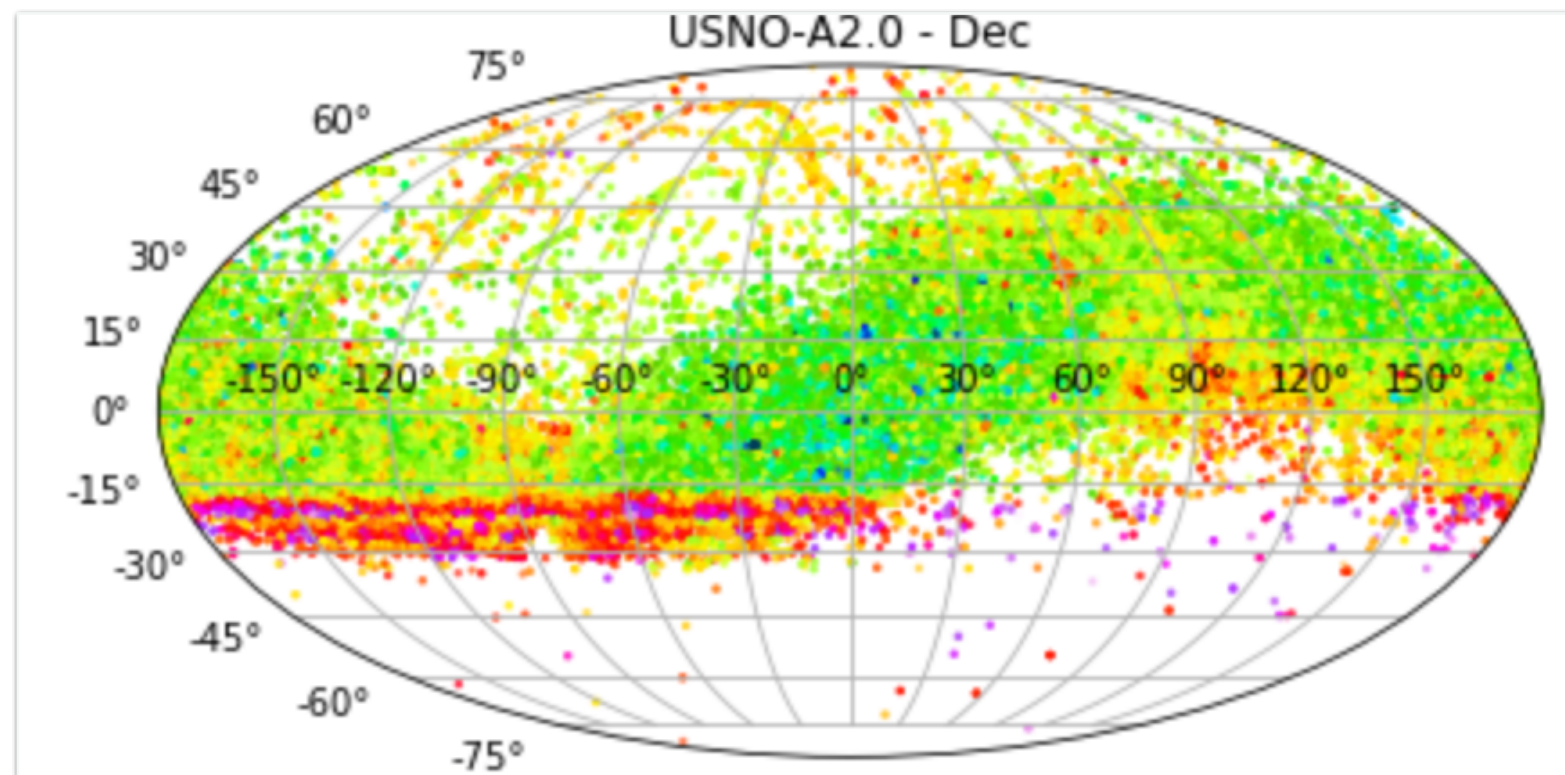


New approach: preliminary version



Sky distribution: example on 4 catalogues
position difference at J2000.0

A detailed look: declination bands



amplitude ~ 50 mas

New approach : current (and future) implementation

- Current (test) version:
 - Corrections on 20 catalogues
 - 30 arcmin field radius around each position
 - limiting magnitude $G < 15$
- New version for massive exploitation:
 - FOV tuned on ~ 40 telescopes/surveys
 - adapted limiting magnitude



Conclusions

- Correction of local systematics is required if old astrometric positions of Solar System objects are used.
- The new method works
 - The final validation of the correction can be done by an orbital fit
 - Comparison of residuals, prediction (or post-diction) of stellar occultations
- Limitations:
 - deterioration of proper motion accuracy strongly affects the result
 - when faint stars are involved
 - lack of information on the original astrometric calibration
- Debiasing methods cannot replace direct DR2 calibration
 - but are the best we can do for all other astrometric data

