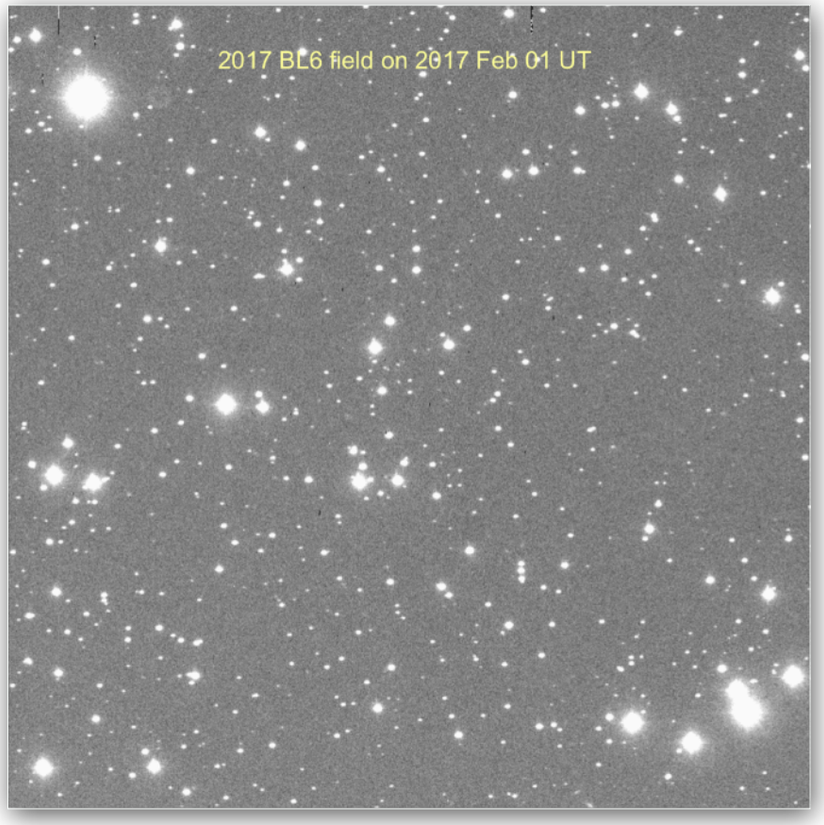
CORRECTING ARCHIVE ASTEROID ASTROMETRY BY GAIA DR2

P. Tanga

Observatoire de la Côte d'Azur, Nice, France

Astrometry reduced by Gaia DR2 (D. Tholen)

	PPMXL	Gaia DR2
Exposure time (sec)	30	30
Zero point (mag)	25.04 ± 0.27	25.48 ± 0.08
N stars in field	436	669
N stars rejected	93	91
N stars in solution	343	578
RMS (arcsec)	0.171	0.040
Reduced chi	4.527	0.829
Right ascension	06:16:06.4073	06:16:06.4063
Declination	+00:17:05.961	+00:17:05.903



University of Hawaii 2.24 m telescope

Astrometry (mostly) calibrated with pre-Gaia catalogues

- Minor Planet Center (200 million astrometric positions, for ~800k asteroids)

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

Desmars et al. 2013

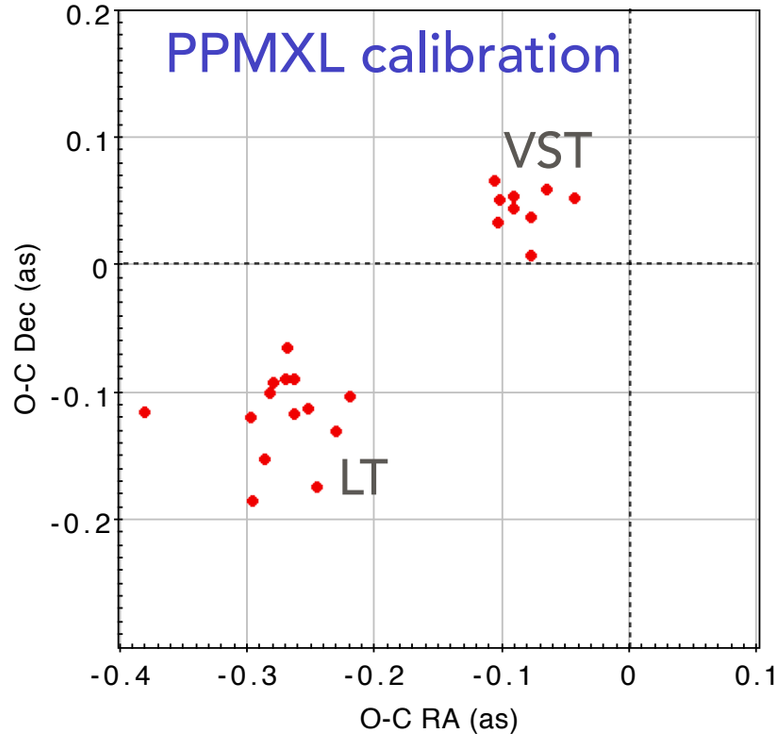
- Comparison to Gaia DR2 (14.099 asteroids)

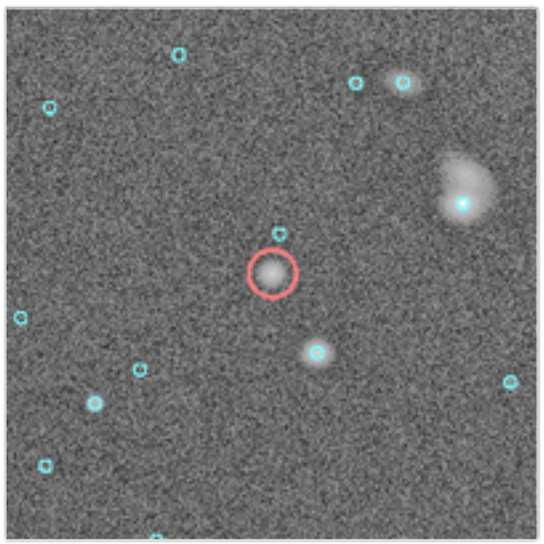
Fraction	Residuals
52 %	< 1 mas
96 %	< 5 mas

Bias effect: astrometry reduced with Gaia DR2 vs. PPMXL

Asteroid (1132) Hollandia

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





(credits: Gaia GBOT team)

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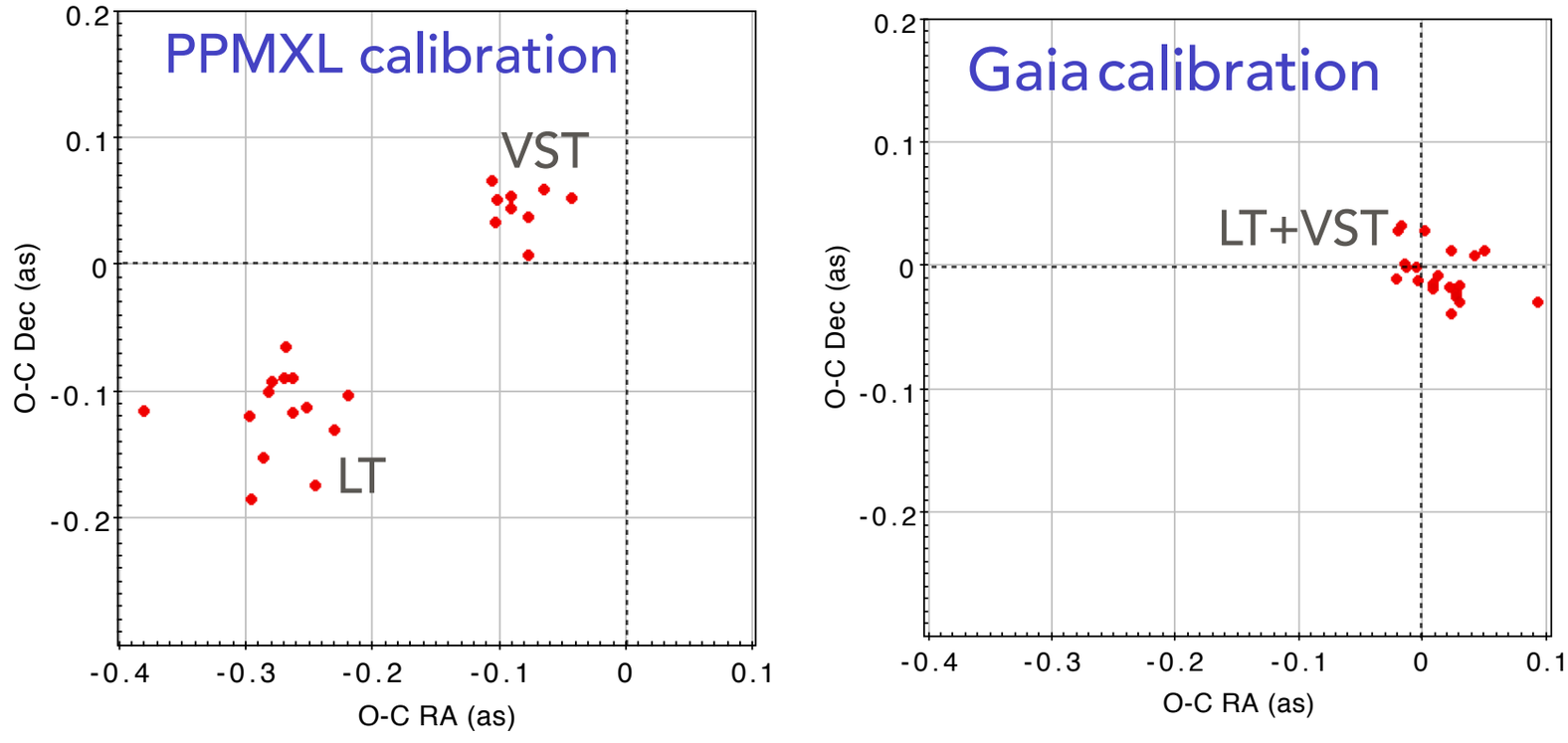
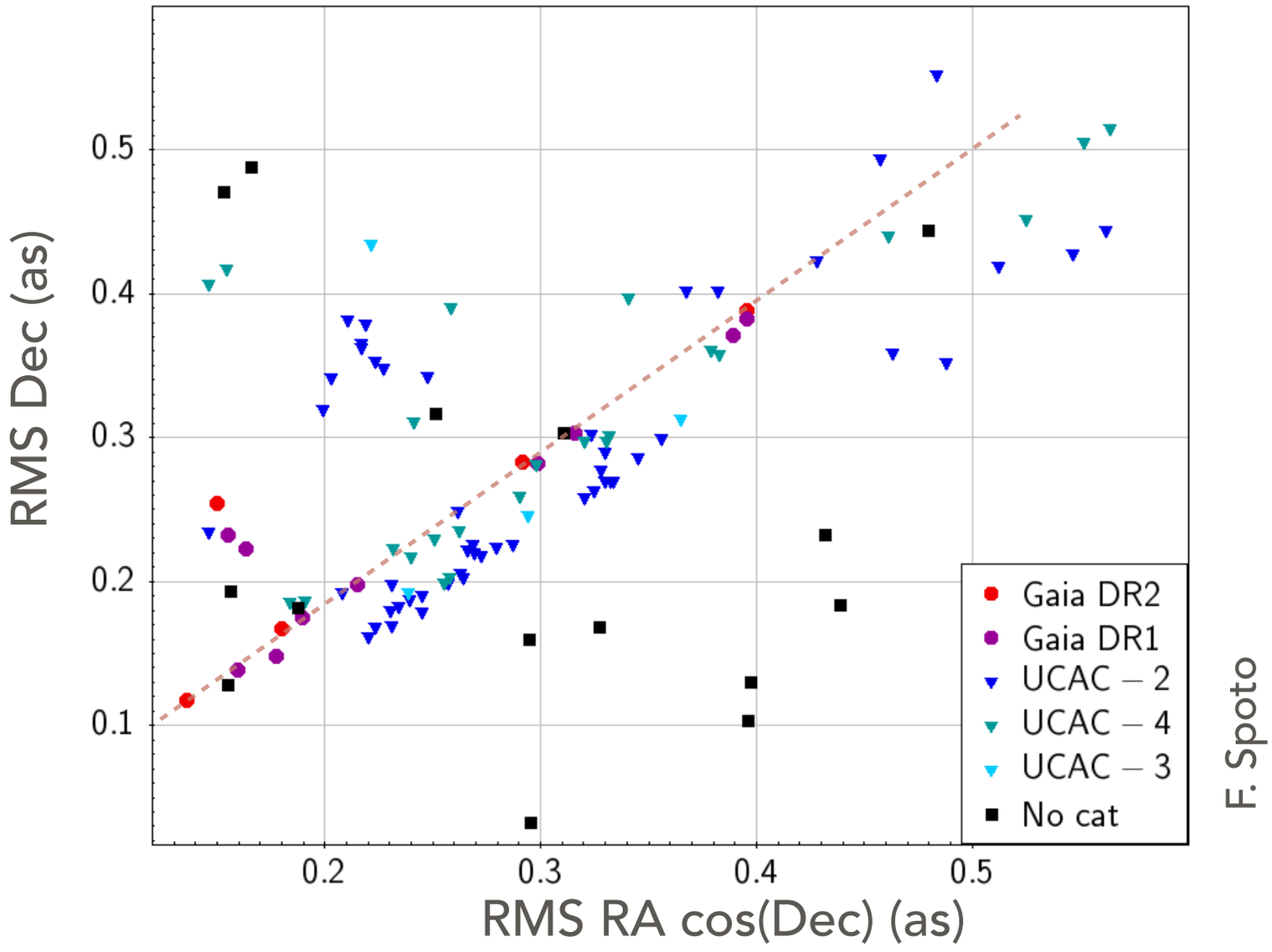


(credits: Gaia GBOT team)

Bias effect: orbit post-fit residuals



How to solve the problem of systematic errors?

- **Two options:**

  – Re-reduce old observations from raw data (ex. NAROO project)
    - Best performance in theory
    - Not always possible (data not available)
    - On large sample of asteroids it is an enormous task

  – Compute locally the expected systematic errors in old catalogue and apply a correction to the existing astrometry (debiasing)

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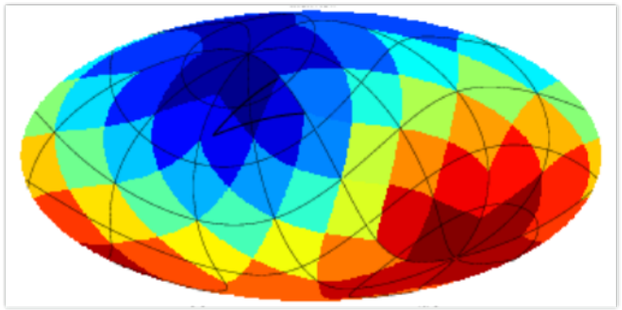
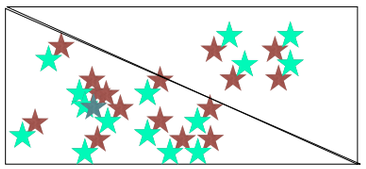
Correction of catalogue errors: “de-biasing”

- The idea is to use the “best” available catalogue as a reference
- “Local” positions of stars in the old catalogs, at epoch t, can be compared to the same stars in the reference (here assumed at t = J2000.0):
  - On average, on a given sky area:

$$\Delta\mathrm{RA} = \Delta\mathrm{RA}_{2000} + \Delta\mu_{\mathrm{RA}}(t - 2000.0)$$
$$\Delta\mathrm{DEC} = \Delta\mathrm{DEC}_{2000} + \Delta\mu_{\mathrm{DEC}}(t - 2000.0)$$

A new approach to debiasing





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

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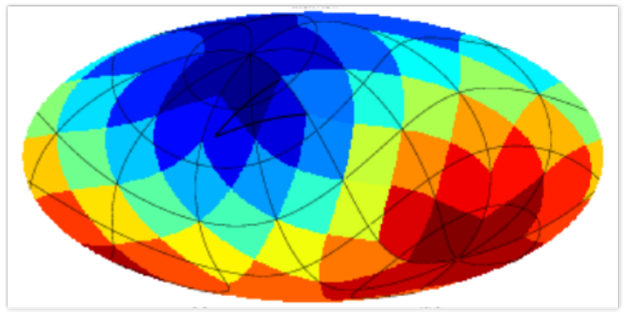

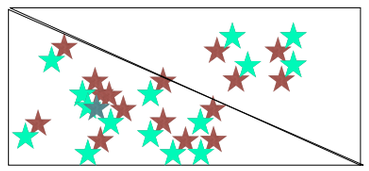

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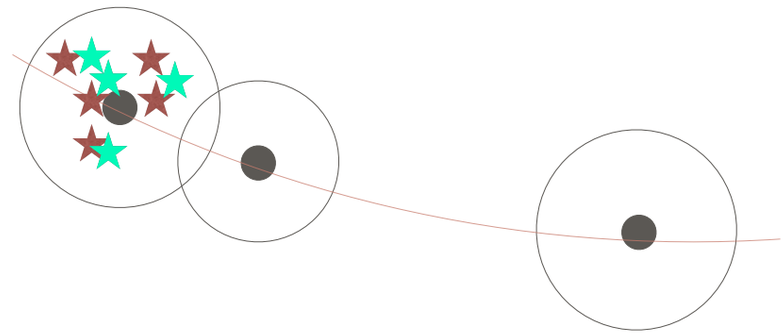

Method 2 (our own) :
corrections of single archive positions (MPC) referred to Gaia DR2

No discontinuities !

Can be tuned by:
Single-survey/telescope FOV size
Magnitude depth

The challenge: which stars were used for the calibration?

- **Catalogue**
  - Information at by Minor Planet Center (for a fraction)
- **The parameters that can reasonably be guessed, for each observatory or survey**
  - FOV size: from survey documentation, articles
  - Faintest stars used
- **Impossible to know in general**
  - Position of the asteroid in the FOV, FOV orientation, specific selection of reference stars…

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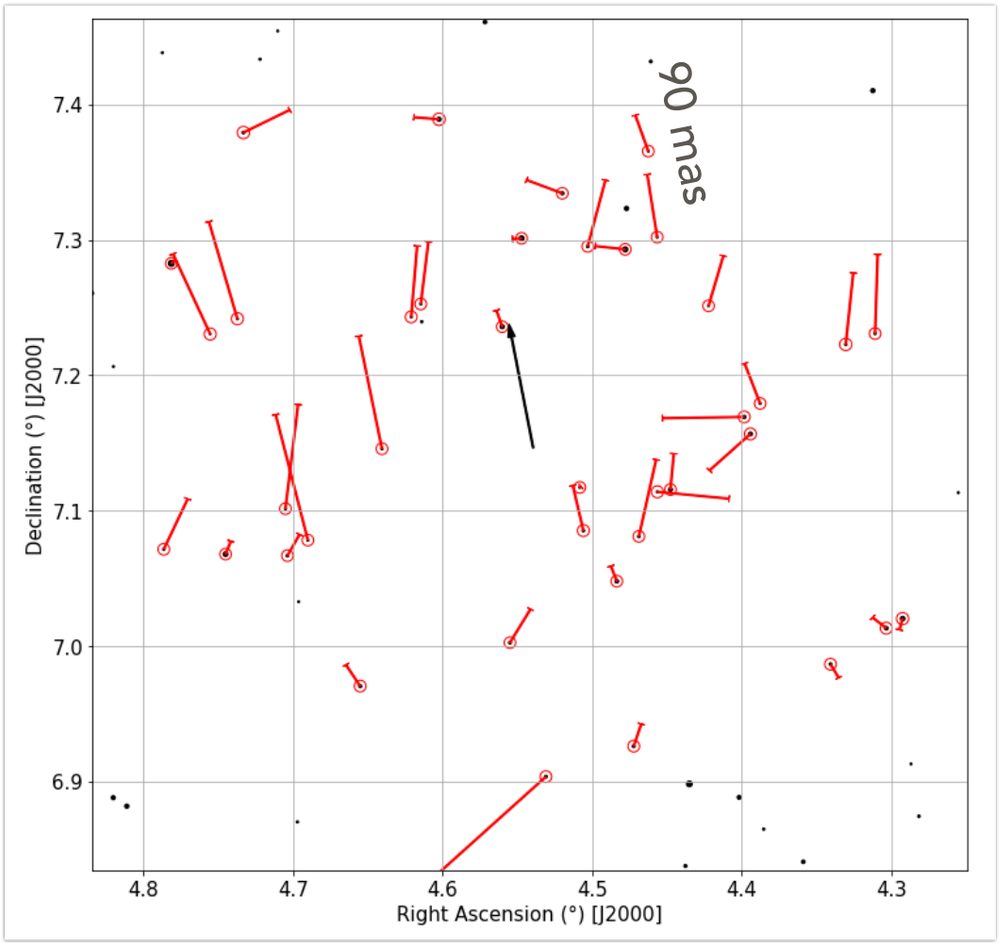
→ **Our parameters for each observation:**
Original catalogue
FOV size
Limiting magnitude

Example on a specific field

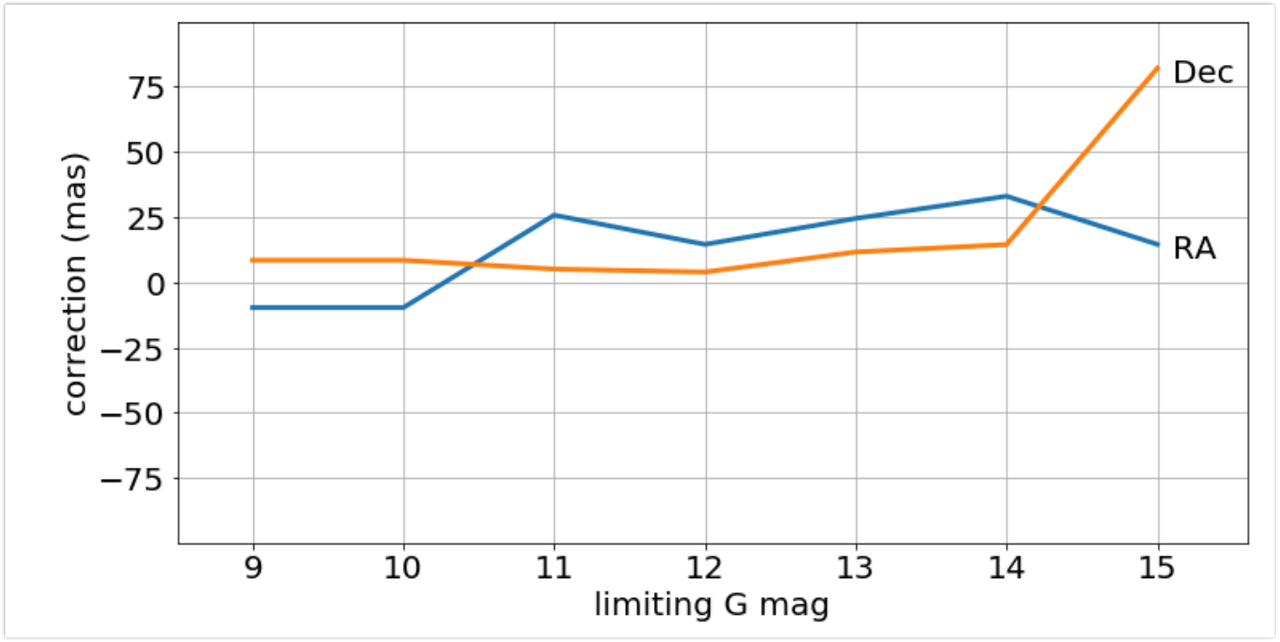
Procedure:

- ADQL query of the catalogues (Gaia and original one) in the FOV
- Star match, filtering
- Propagation of positions at the epoch of the observation

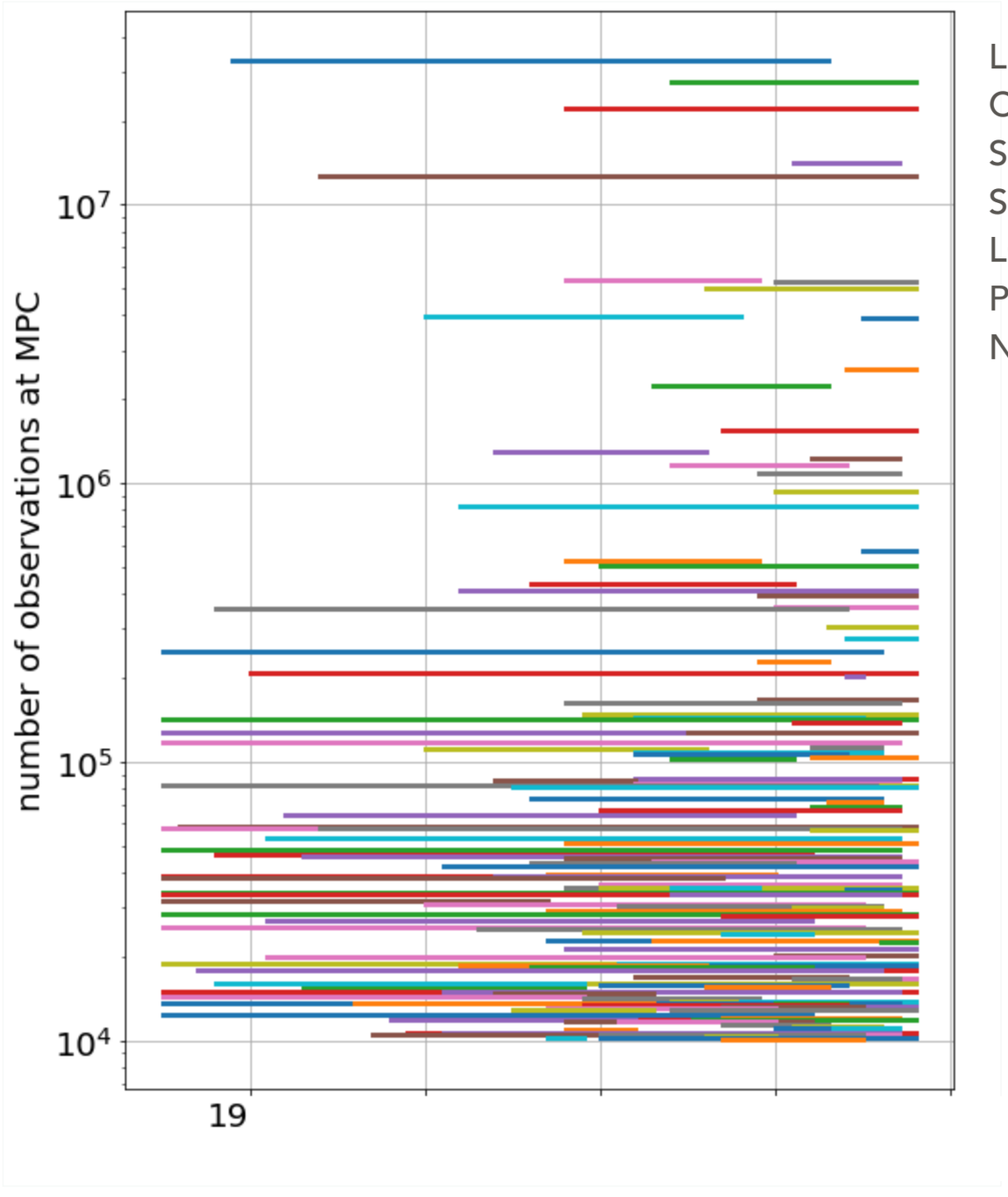
Original catalogue: UCAC4
corrections x 1000



Dependence of average correction from limiting magnitude



Challenges: number of observatories/telescope configurations



LINEAR
CSS (x 2)
SPACE SURVEILLANCE TEL.
SPACEWATCH
LONEOSS. WISE
PURPLE MOUNTAIN
NEAT. ATLAS-HKO

→ The TOP 10 : 80% of observations at MPC

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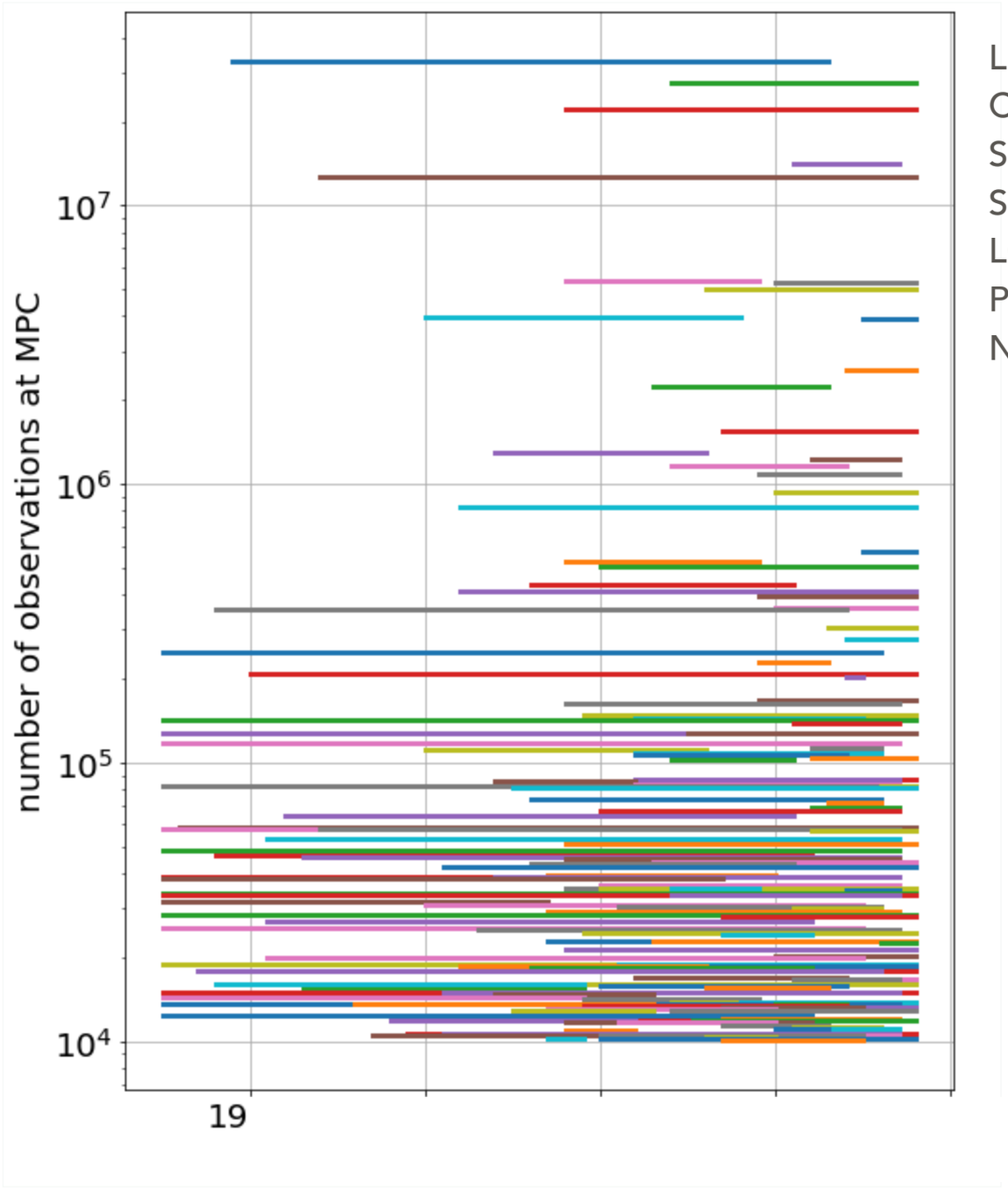

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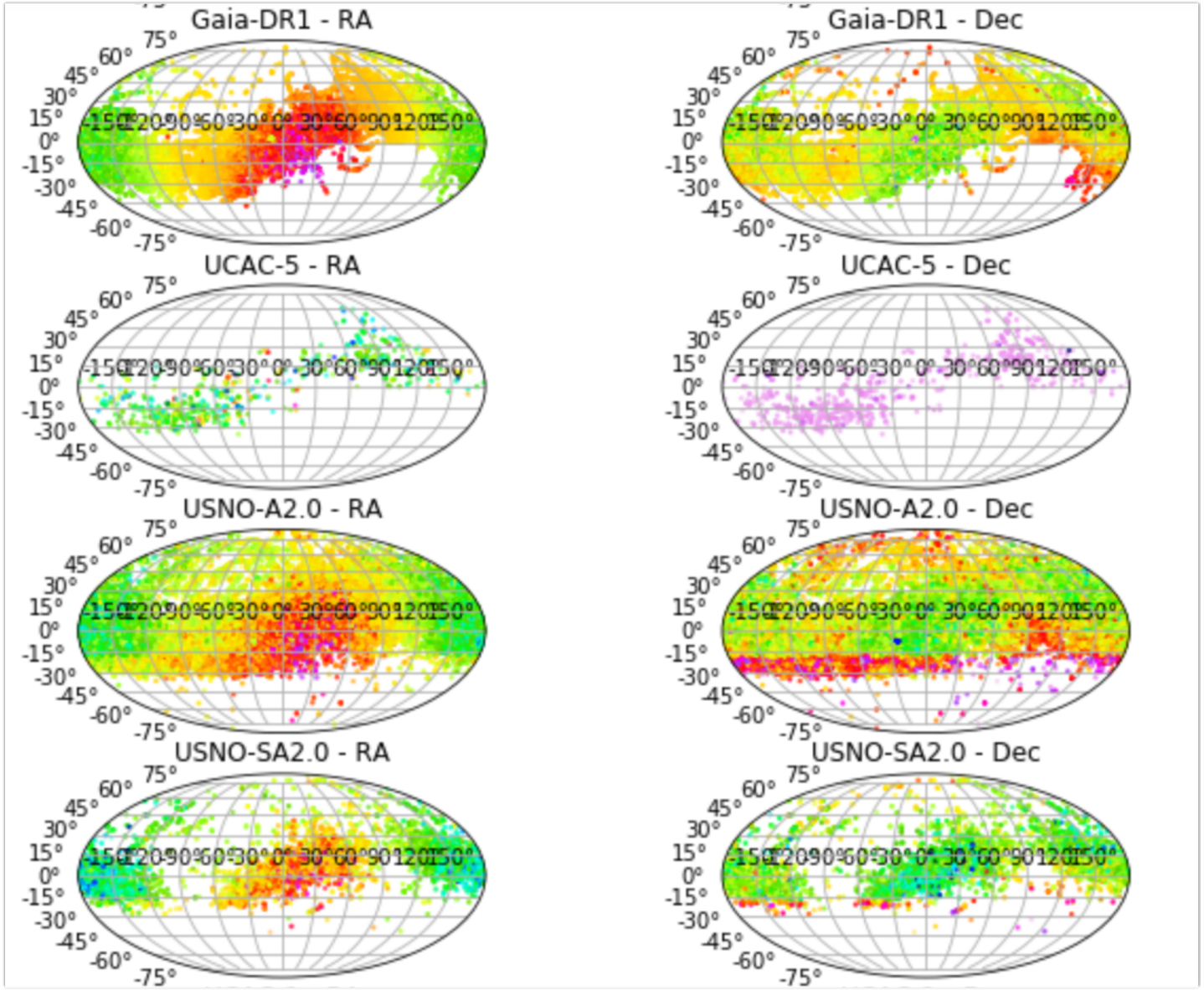
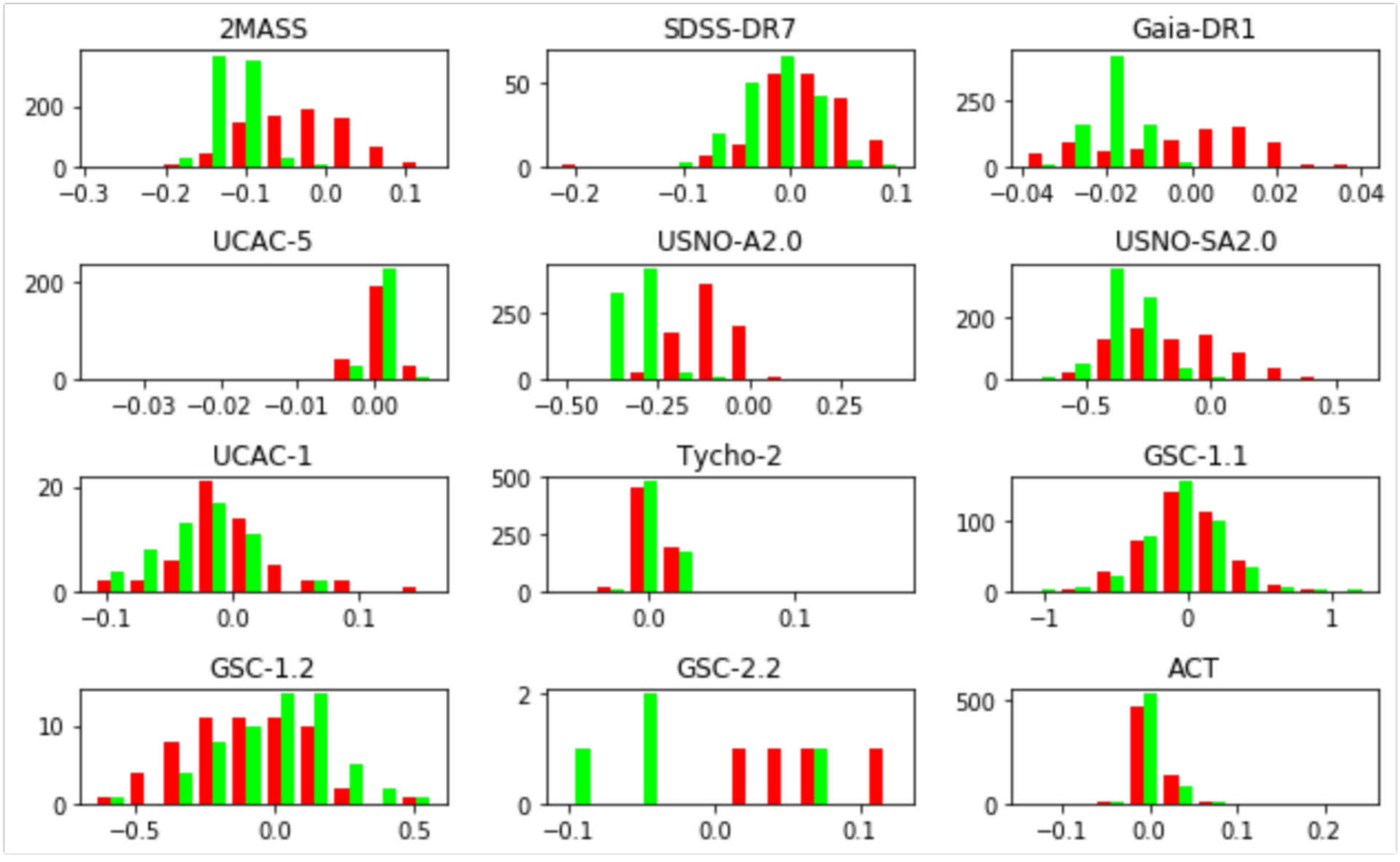
FIFA
INTERNATIONAL FEDERATION FOR ASTEROIDS

Sky distribution of differences

Example on 4 catalogues, observations of 3000 asteroids



Distribution of differences in RA, Dec at J2000



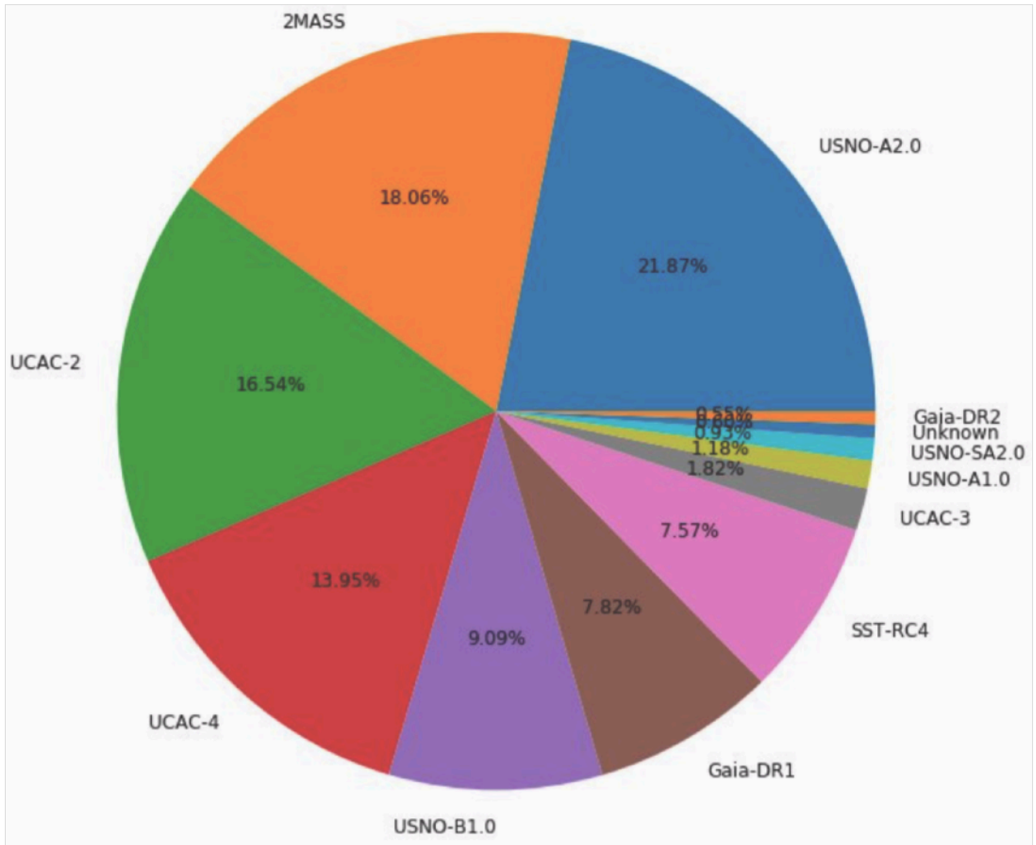
Conclusions

- **New debasing now operational**
  - But time for computation / remote catalogue query is critical!

- **First encouraging results from orbits fits**

- **The limits**
  - The exact choices for the observation (telescope configuration, FOV center…) and the data reduction (choice of stars…) cannot be reproduced.
  - … but often our procedure is the only possible (and the best we can do!)

Challenges : several catalogues



- Information about the catalogue used is provided by MPC (for a consistent fraction of data)

Gaia DR2 - Solar System - single transit astrometric performance

A&A 616, A13 (2018)
https://doi.org/10.1051/0004-6361/201832900

Gaia Data Release 2

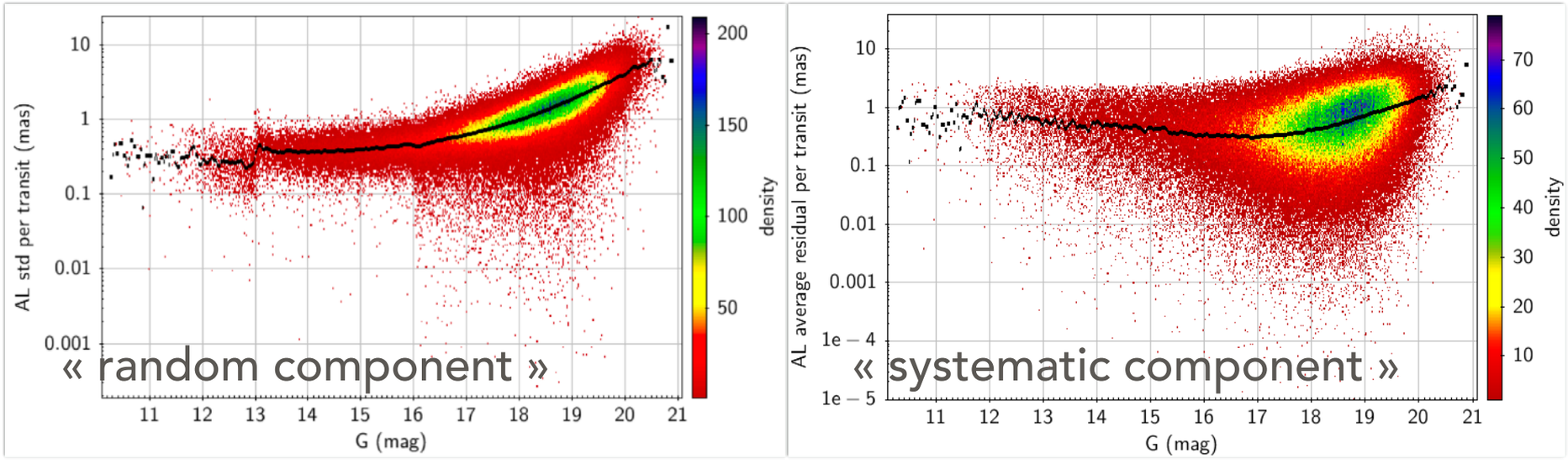
Gaia Data Release 2

Observations of solar system objects

Astronomy & Astrophysics

Special issue

Gaia Collaboration, F. Spoto[1,2,⋆], P. Tanga[1], F. Mignard[1], J. Berthier[2], B. Carry[1,2], A. Cellino[3], A. Dell'Oro[4], D. Hestroffer[2], K. Muinonen[5,6], T. Pauwels[7], J.-M. Petit[8], P. David[2], F. De Angeli[9], M. Delbo[1], B. Frézouls[10], L. Galluccio[1], M. Granvik[5,11], J. Guiraud[10], J. Hernández[12], C. Ordénovic[1], J. Portell[13], E. Poujoulet[14],

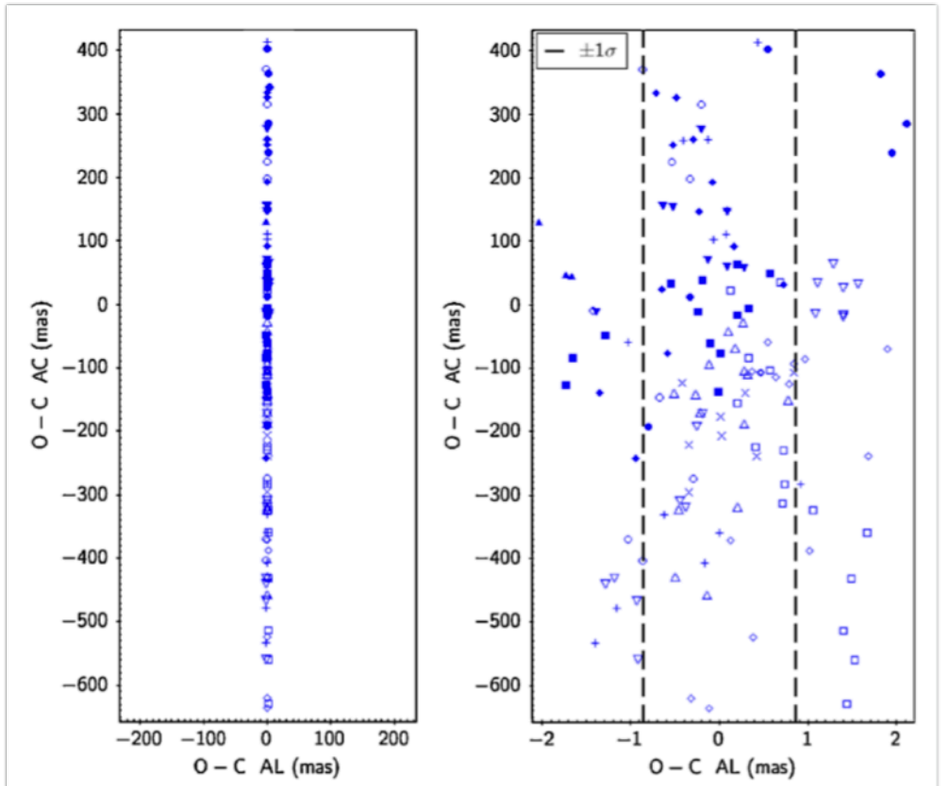


Residuals from the orbital fit of Gaia DR2 data only (AL direction)

The Gaia collaboration: Spoto et al. 2018

Residuals on a single asteroid

367 Amicitia



Astrometry reduced by Gaia DR2 (D. Tholen)

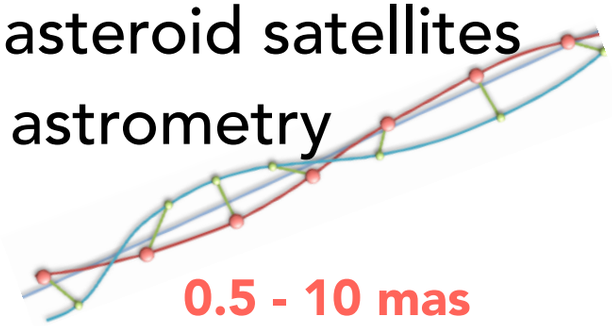
Global statistics to Sept 11, 2019

	Number of Gaia-based NEO Obs.	Astrometric Solution (arcsec)	Object Centroiding (arcsec)	RSS (arcsec)
UH 2.24-m	4850	0.007	0.057	0.058
CFHT	638	0.012	0.042	0.049
Subaru	86	0.014	0.043	0.048

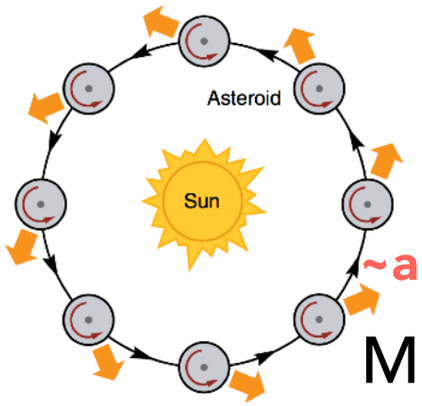
No problem! No systematic errors, same reference as Gaia DR2. Catalogue errors are negligible.

Some challenges for asteroid astrometry

Discover asteroid satellites by astrometry

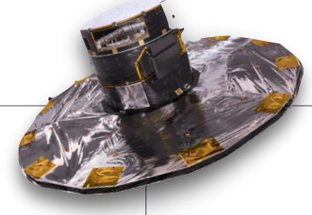


0.5 - 10 mas

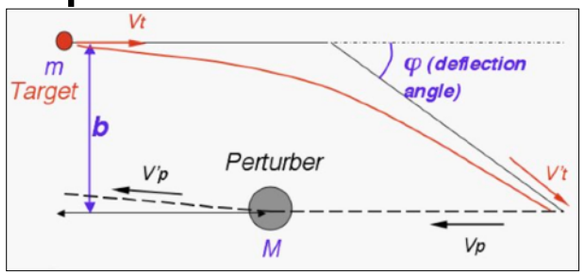


~a few mas

Measure the orbital drift due to *Yarkovsky force*



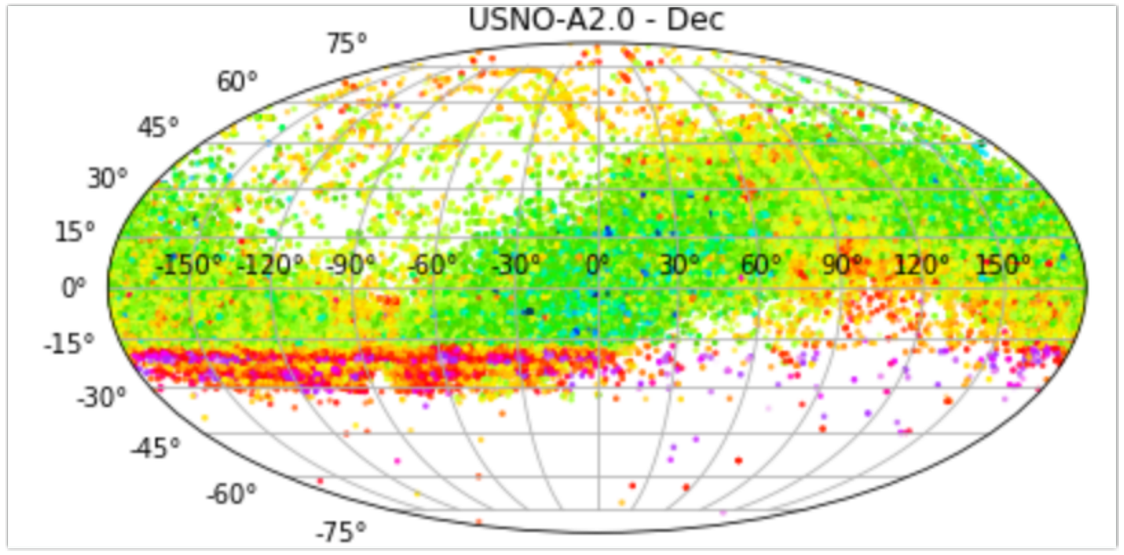
New / precise asteroid masses



~ 10 mas

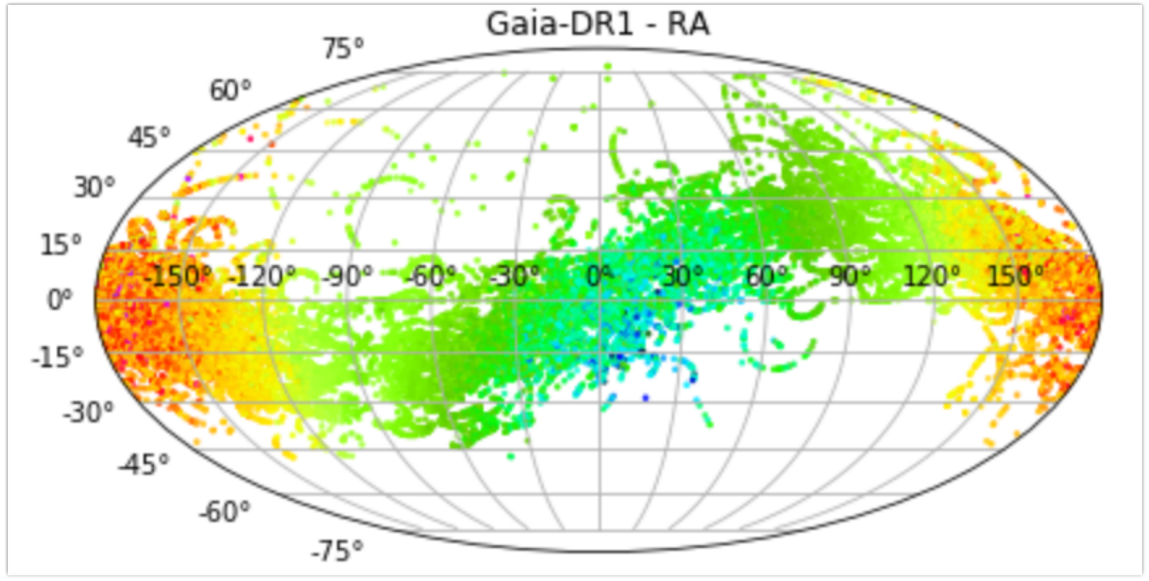
Improve predictions of star occultations

A detailed look: declination bands



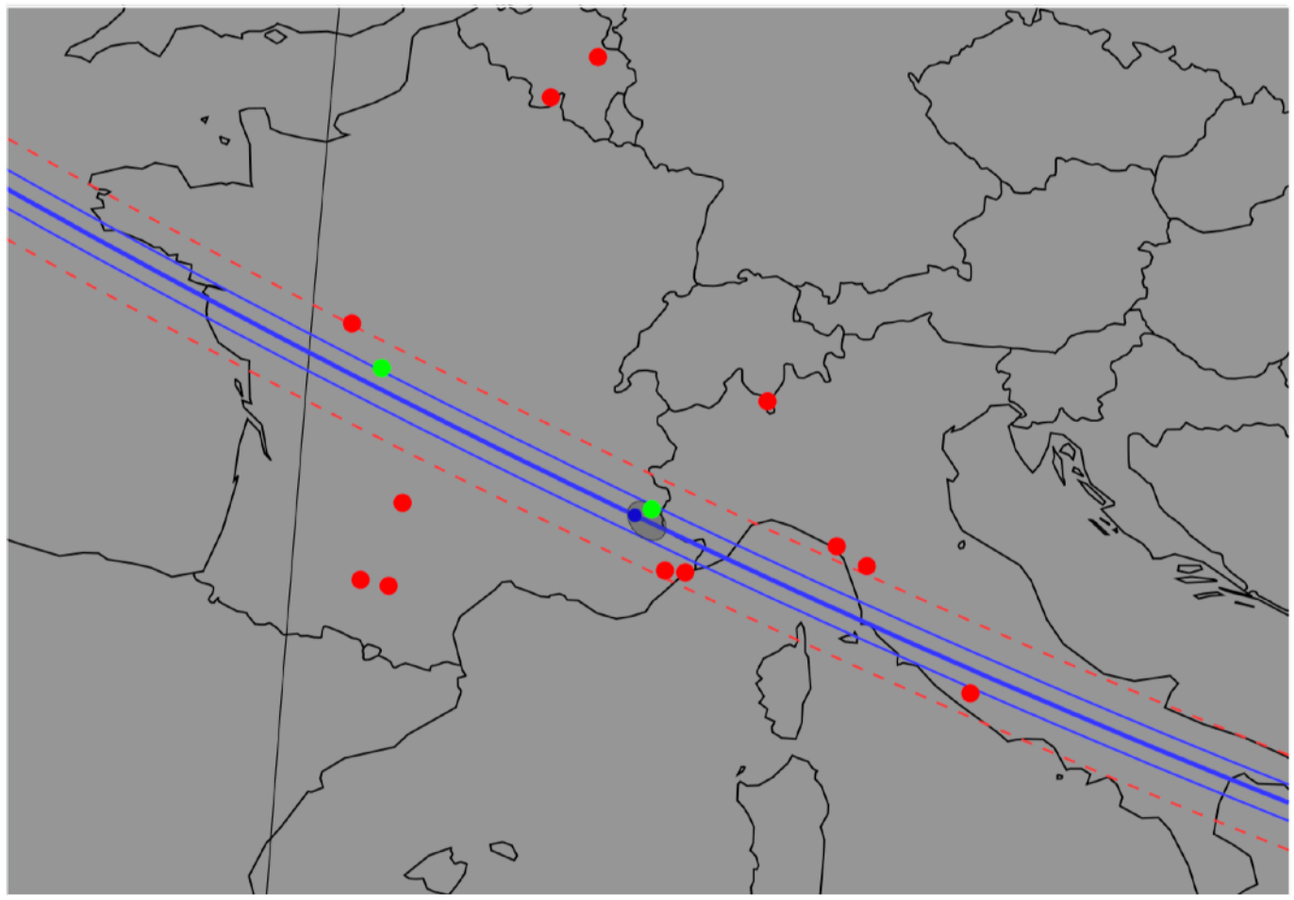
Probably linked to older surveys used to computed proper motions and different telescopes S/N hemisphere

A detailed look: large scale patterns



Due to global rotation pattern in the proper motion of bright stars (favoured here) and to different reference system.
(amplitude +/- 30 mas)

Example: the Trojan (5638) Deikoon



Prediction
Asteroid orbit: MPC ta data
+ DR2 astrometry
Star: DR2

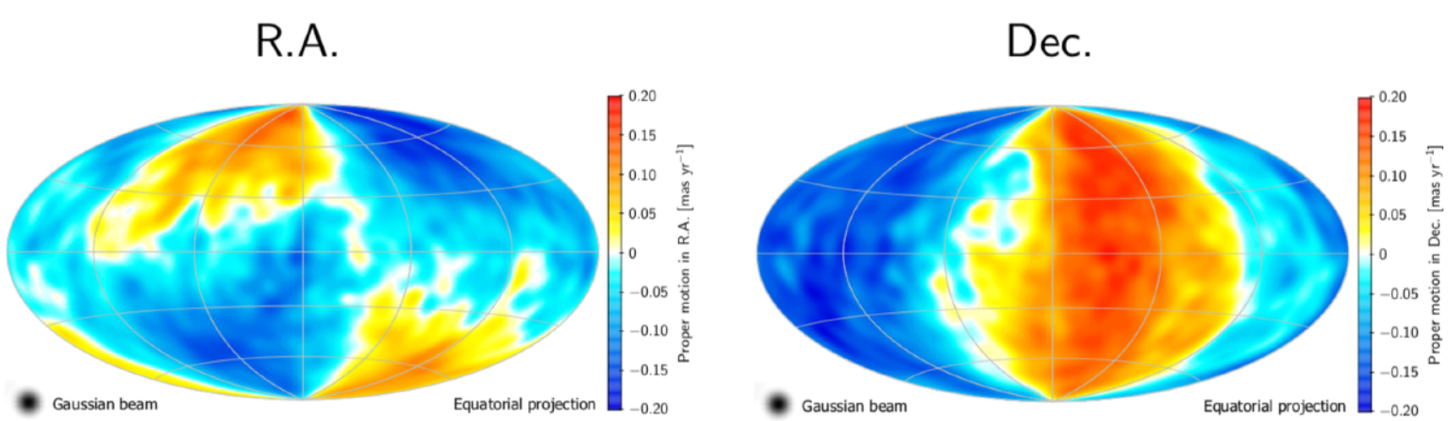
Final O-C : ~2.4 mas

Debiasing applied to MPC, DR2 used for reference

Courtesy J. Desmars (LESIA, Obs. de Paris)

Main correction: proper motion

Large-scale systematics for bright stars ($G \lesssim 12$)



Smoothed $\Delta\mu_{\alpha*}$, $\Delta\mu_\delta$ calculated for the HIPPARCOS subset of *Gaia* DR2

$$\left.\begin{aligned}\Delta\mu_{\alpha*} &= \mu_{\alpha*}^{\mathrm{DR2}} - (\alpha^{\mathrm{DR2}} - \alpha^{\mathrm{HIP}})\cos\delta/(24.25\ \mathrm{yr}) \\ \Delta\mu_\delta &= \mu_\delta^{\mathrm{DR2}} - (\delta^{\mathrm{DR2}} - \delta^{\mathrm{HIP}})/(24.25\ \mathrm{yr})\end{aligned}\right\} \quad (9)$$

Very clear signature of global rotation $\simeq 0.15$ mas yr^{-1} (cf. L18, Fig. 4)

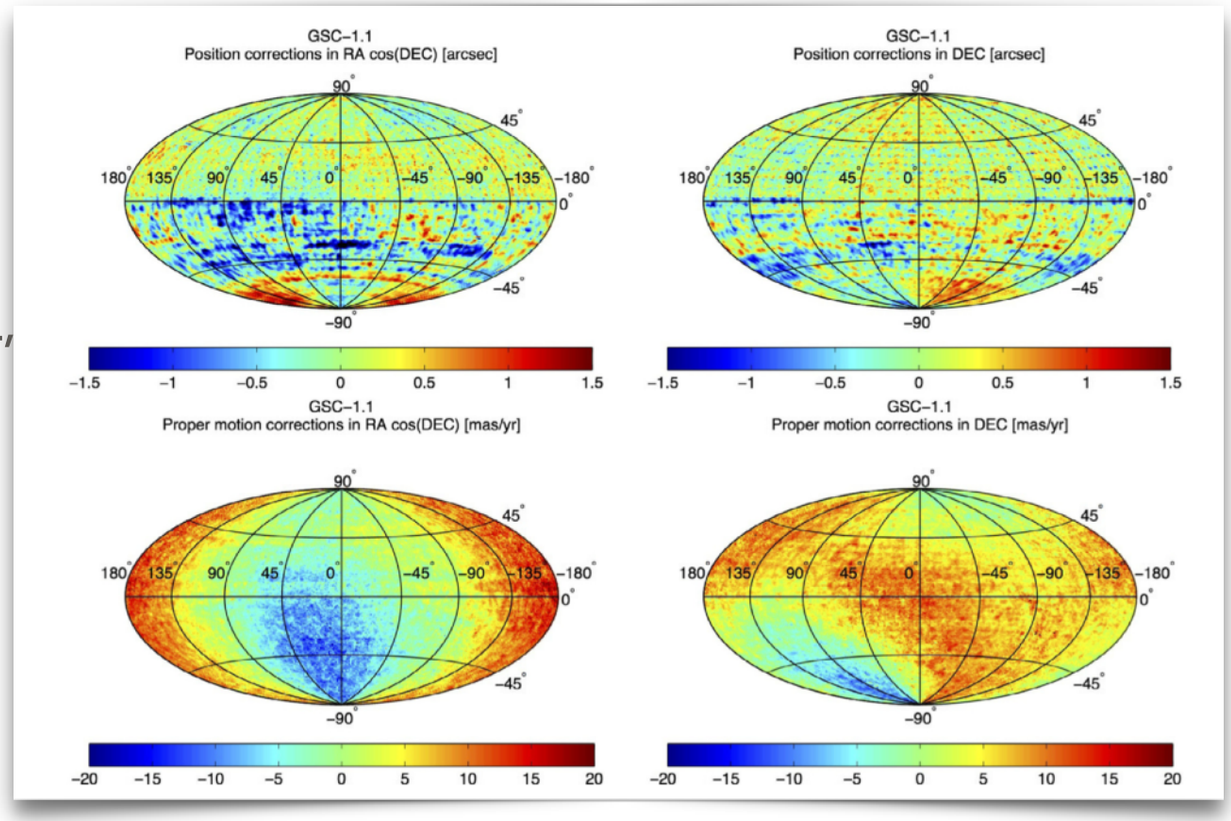
From Lindegren et al. 2018 https://www.cosmos.esa.int/documents/29201/1770596/Lindegren_GaiaDR2_Astrometry_extended.pdf

see also “Known issues” page of Gaia DR2

Standard approach: Farnocchia et al. 2015

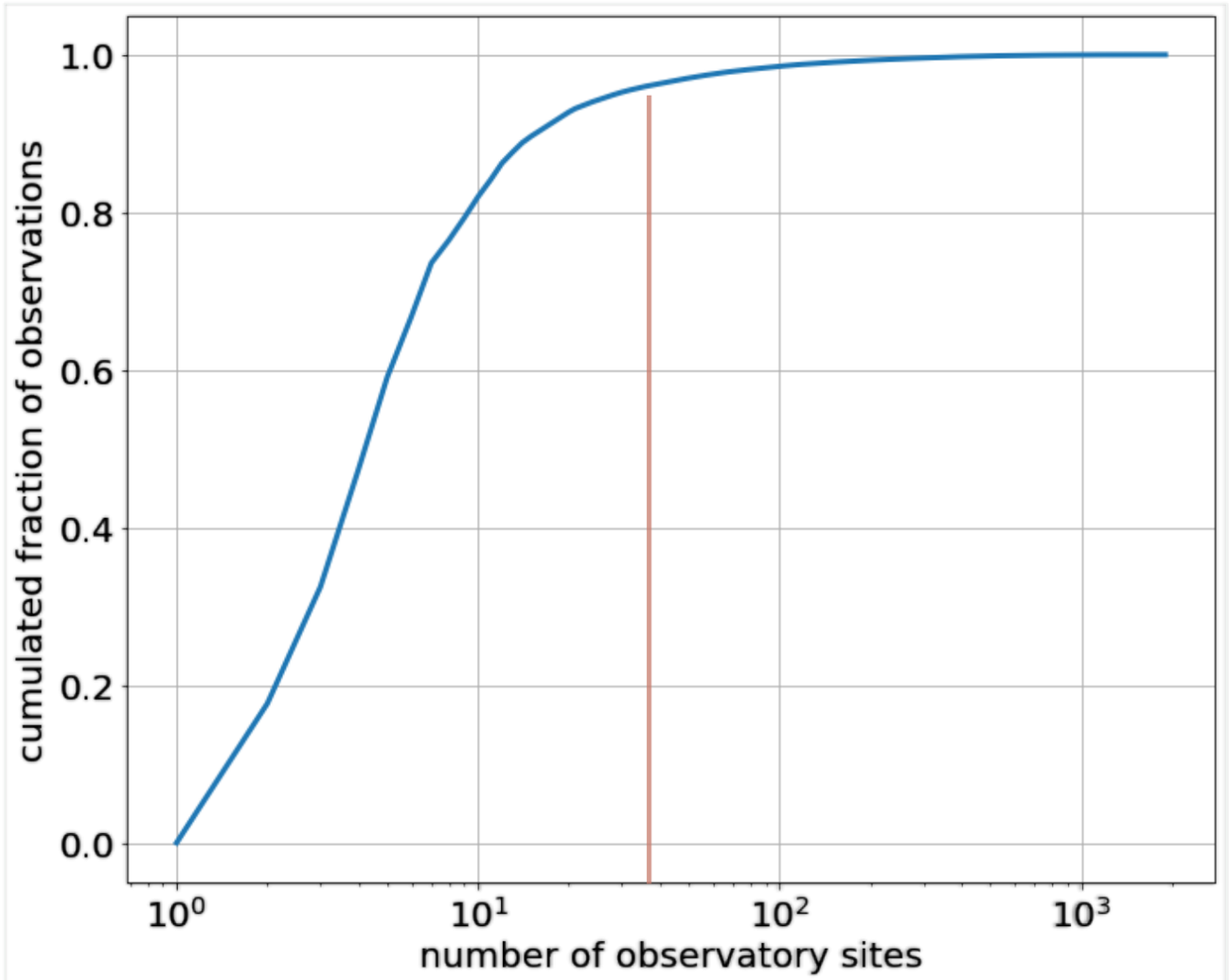
Correction computed on healpix tassellation of the sky.

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



Example of resulting corrections on 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.


1.0
0.8
0.6
0.4
0.2
0.0
cumulated fraction of observations
10^0
10^1
10^2
10^3
number of observatory sites