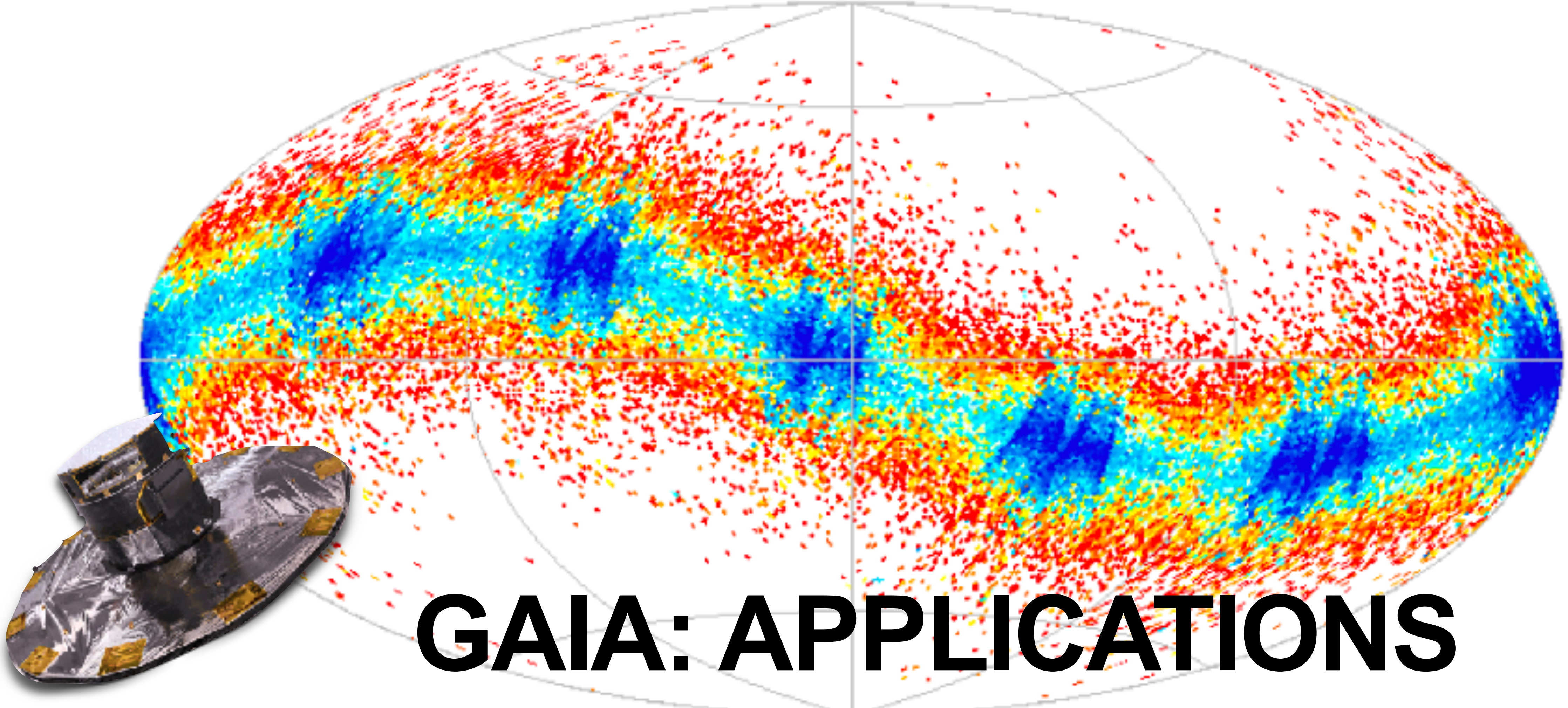

GAIA: APPLICATIONS TO PLANETOLOGY

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Bordeaux - Sf2A 2018

Gaia Data Release 2 (April 25, 2018)

Resources (DR2 access, documentation, journal articles, tutorials) :

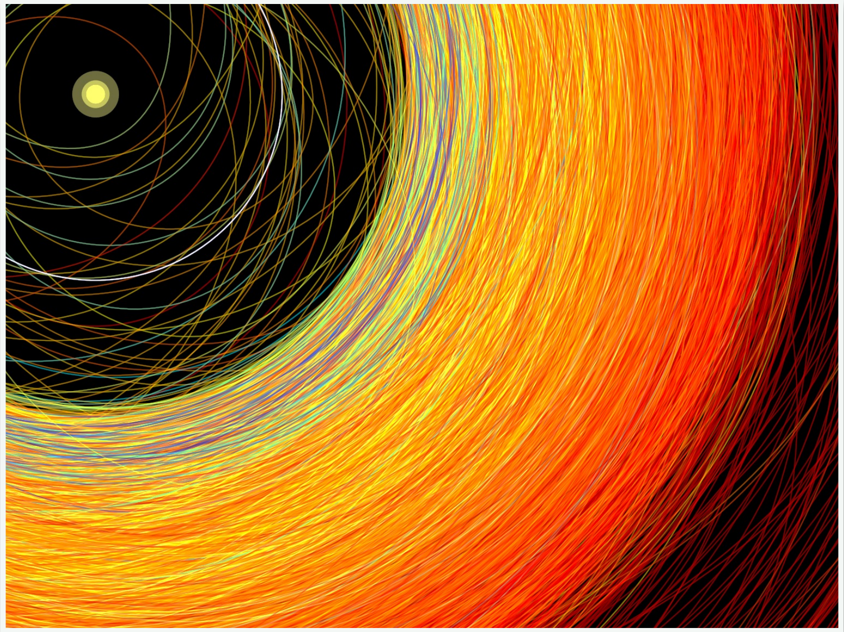
https://www.cosmos.esa.int/web/gaia

Total sources, limit at G~20.7	1 693 M
5-parameters astrometry	1 332 M
Photometry and colors	1 381 M
ICRF prototype sources	2 820
Gaia-CRF2 extra-galactic sources	556 869
Position accuracy	0.03 mas at G=15, 0.7 mas at G=20

Gaia DR2 - Solar System

On the base of a pre-selected list of *known* objects

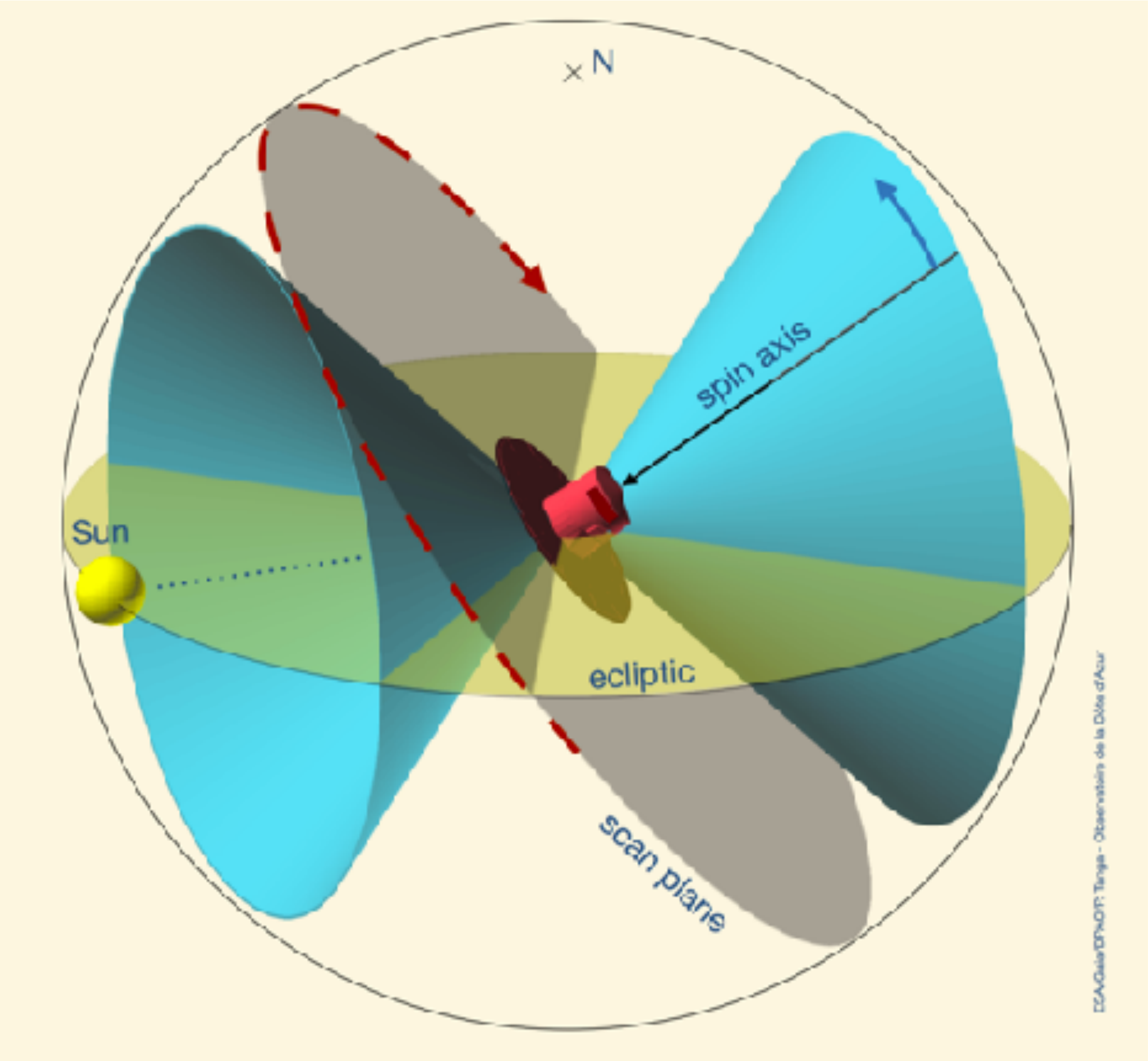
> 10 FOV transits over the 22 months of DR2
August 5, 2014 - May 23, 2016

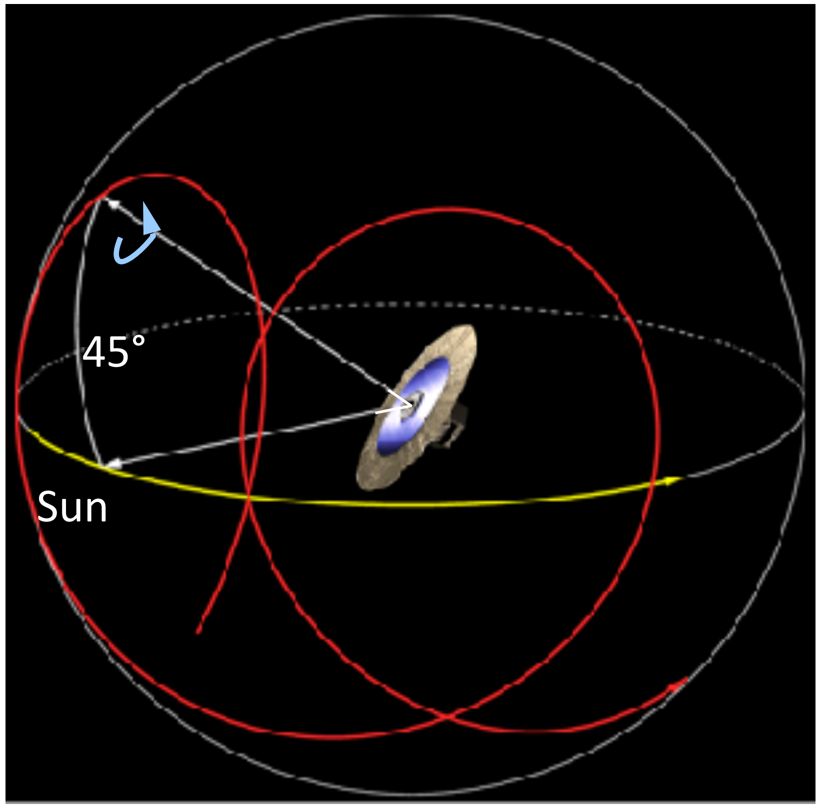


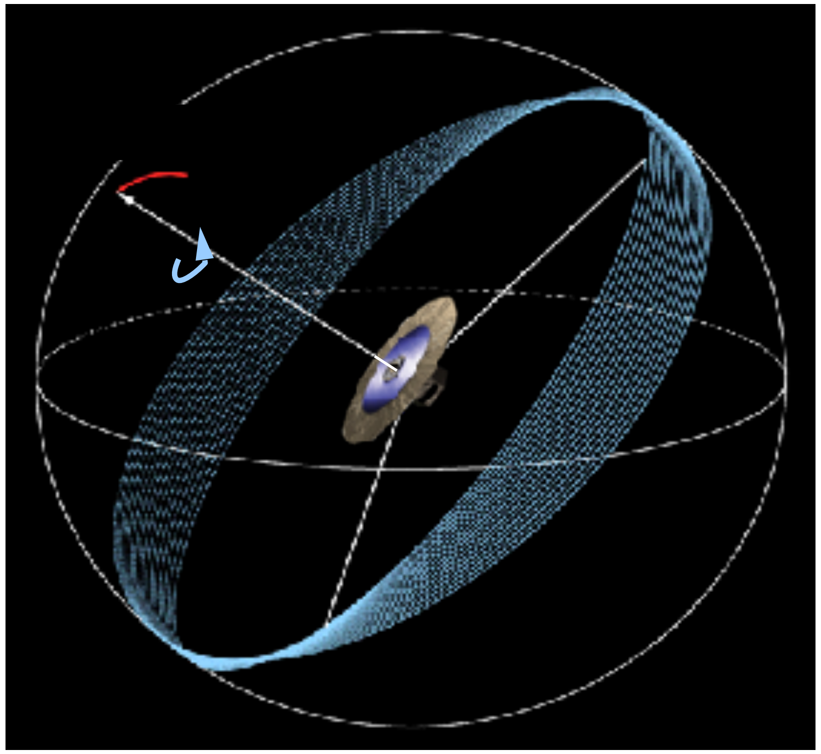
Objects	14 099	
Epoch astrometry	1 997 702	CCD positions
	287 904	transits (52% : photometry)
Typ. accuracy	<1 mas	(along scan)

Gaia is observing asteroids

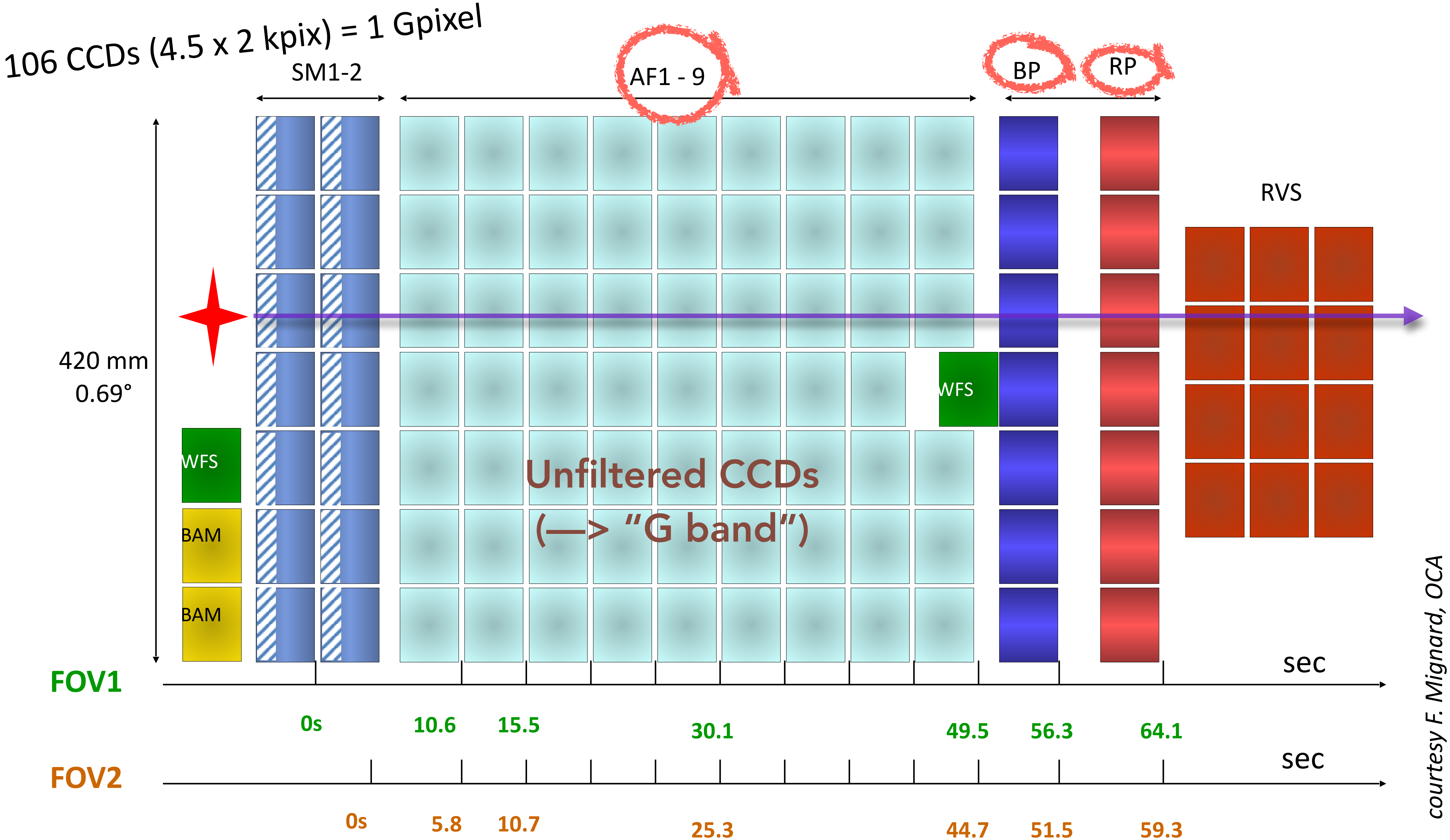
- Scanning the sky since July 2014 (operational phase)
- Solar elongations 45° to 135°
- Limiting magnitude V~20.5
- 100.000 asteroid observations (CCD level) / day





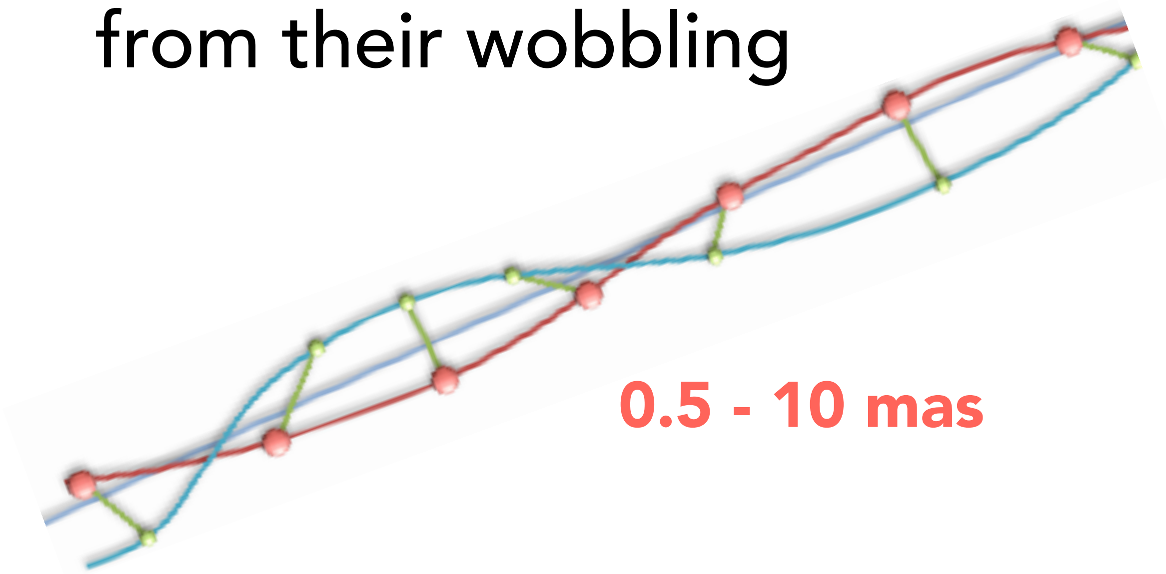


An observation = a transit = 10 positions + spectra



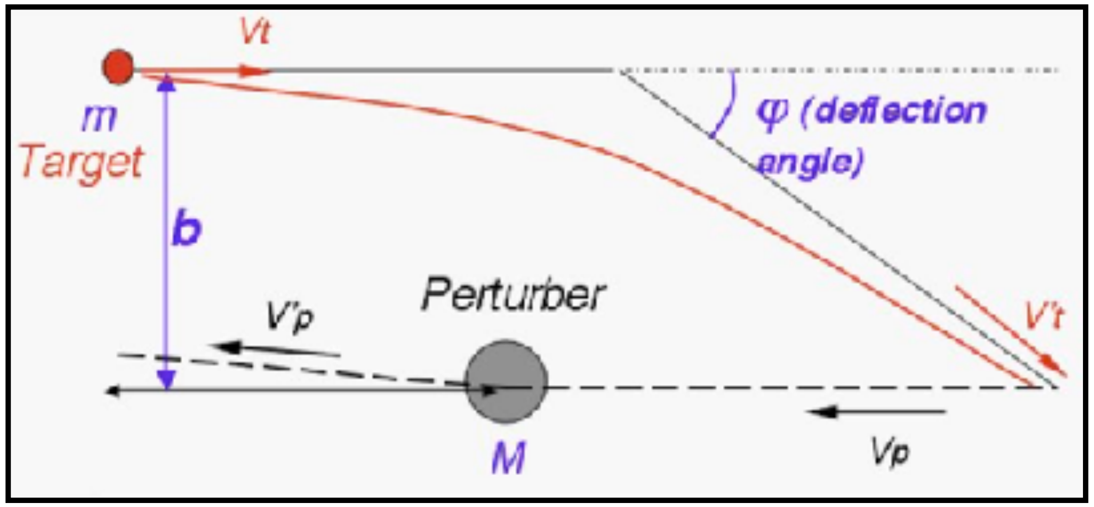
Some challenges for asteroid astrometry

Discover asteroid satellites from their wobbling

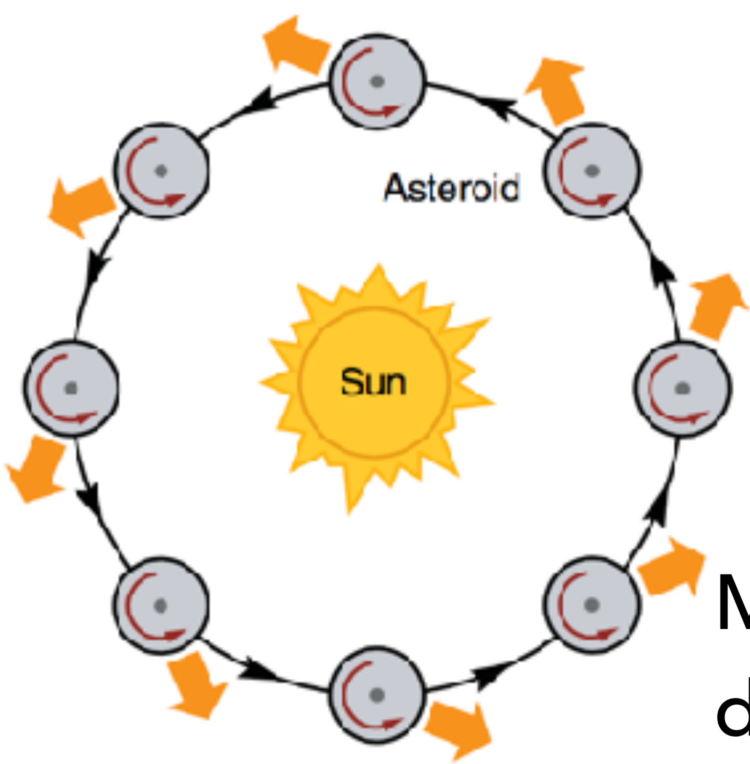


0.5 - 10 mas

New / precise asteroid masses



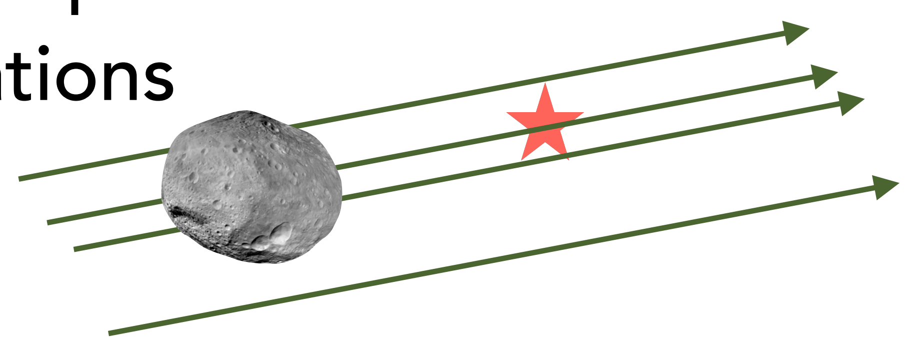
1000s encounters/year > 10 mas



~a few mas

Measure the orbital drift due to *Yarkovsky force*

Improve predictions of stellar occultations



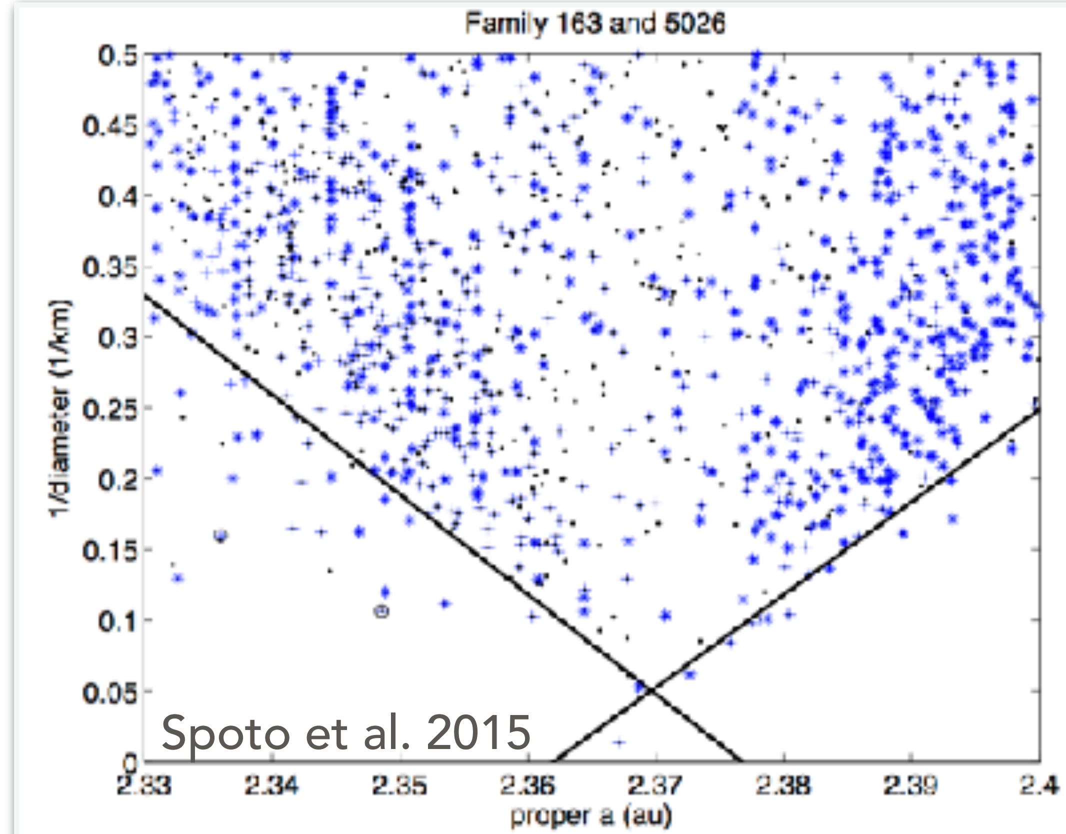
The situation, before Gaia

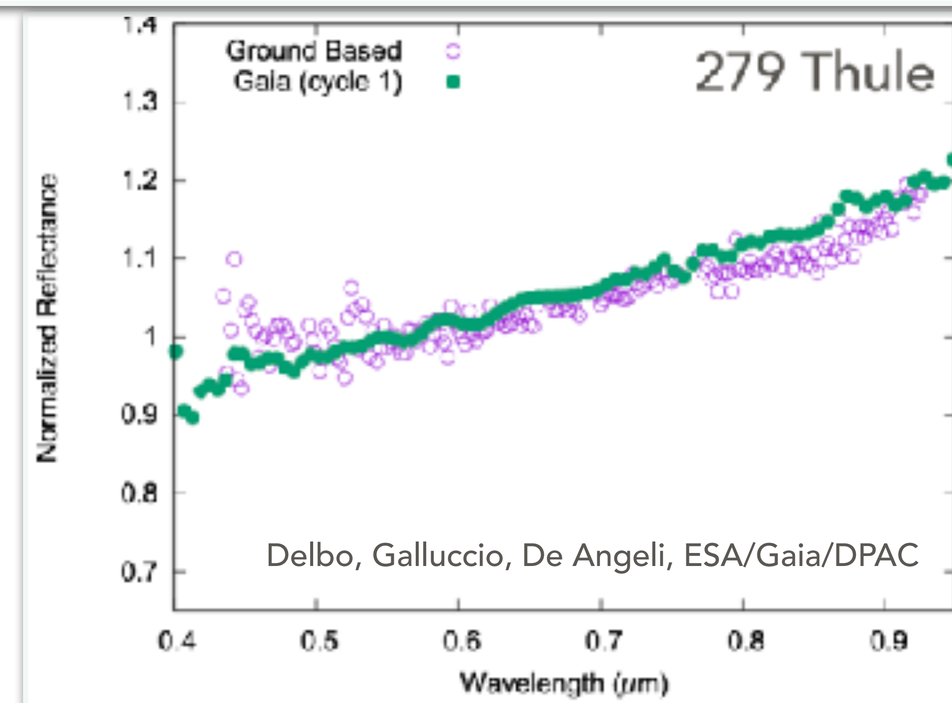
- **1.9 x 10^8** measurements in the archives of the Minor Planet Center
  - mostly CCD imaging
  - average accuracy: 0.4 as

- ~**2000** radar ranging measurements
  - equivalent accuracy : 10-50 mas

Yarkovsky effect: why we care

- Yarkovsky applications:
  - NEO and meteorite transport
  - physical properties (spin, density…)
  - family dispersion, ages
- connection to spectro- photometry by Gaia:
  - low-res spectra: taxonomy in the visible
  - *mmag* photometry: shape determinations
- Large sample by end of mission: ~ 350 000

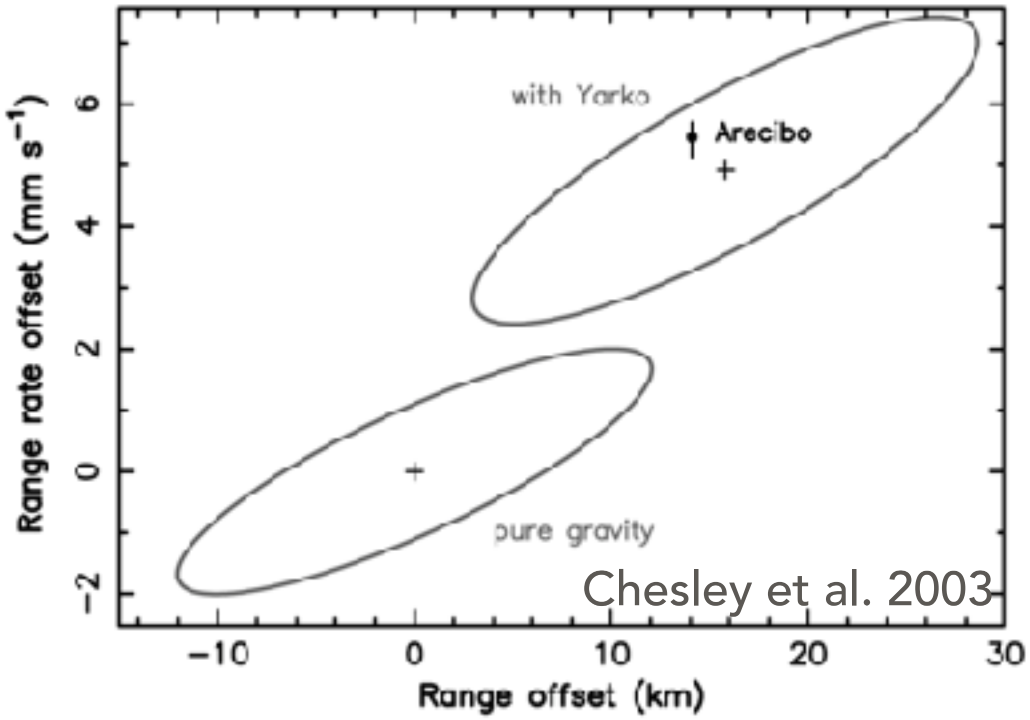




The problem of measuring Yarkovsky

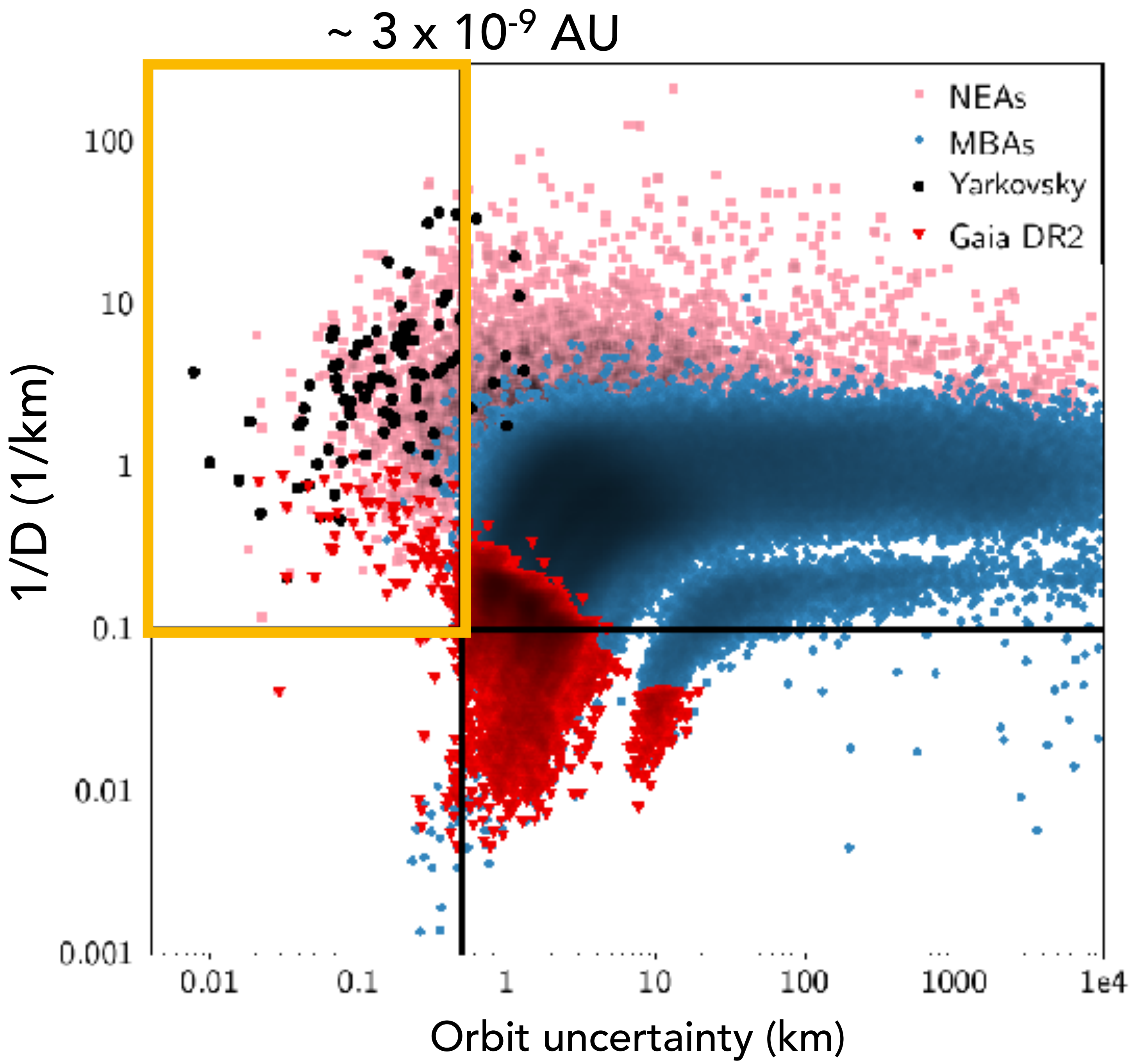
- Weak semi-major axis drift ~10^{-4} au/Myr (at 1 au)
  - decreasing with size (1/D) and distance ($1/r^2$)
- It requires:
  - accurate observations
  - …spanning a « large » interval of time
  - accurate weighting
- Results:
  - **36 NEOs** with *valid* detections (SNR>3)
  - **4 with SNR > 10** (Vokrouhlicky´ et al. 2015)
  - ….radar observations essential !!
- for a small fraction of asteroids, only, $\sigma_a < 10^{-9}$ au

6489 Golevka



Chesley et al. 2003

Yarkovsky and Gaia ?



Pre-Gaia orbit quality (MPC data)

In DR2:

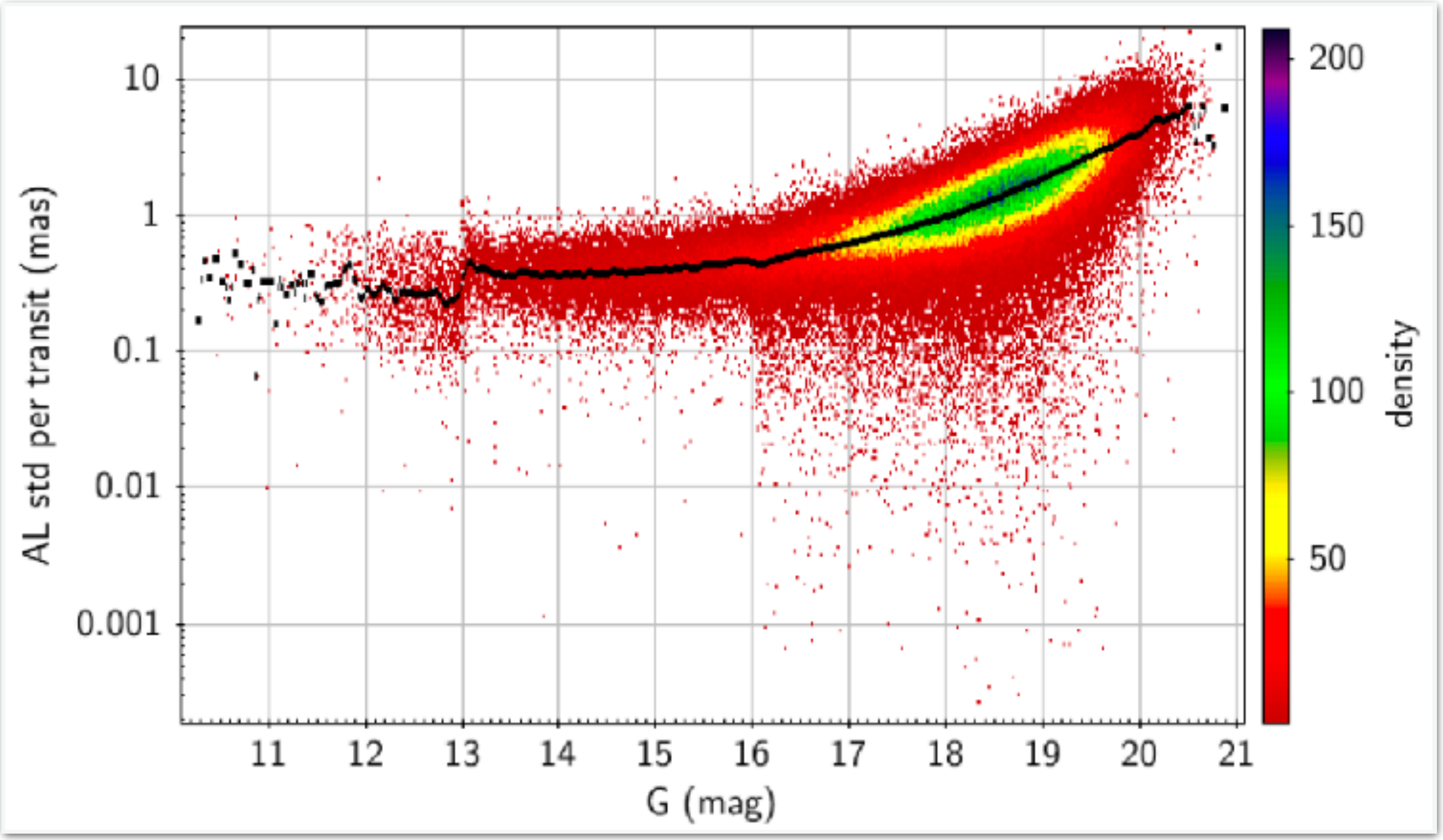
- 3 NEOs with measured Yarkovsky
- 5 NEOs with marginal detection
- about 20 good MB candidates

Gaia and the asteroids - the challenge

- Is the error model for epoch observations consistent with expectations?
  - How motion / size impacts precision & accuracy?
- Can « 1-dimensional » measurements provide the expected orbit accuracy?
- Is our dynamical Solar System model accurate enough?
- How to combine Gaia and « pre-Gaia » astrometry?

Results

Gaia DR2 - Solar System - single transit astrometric performance

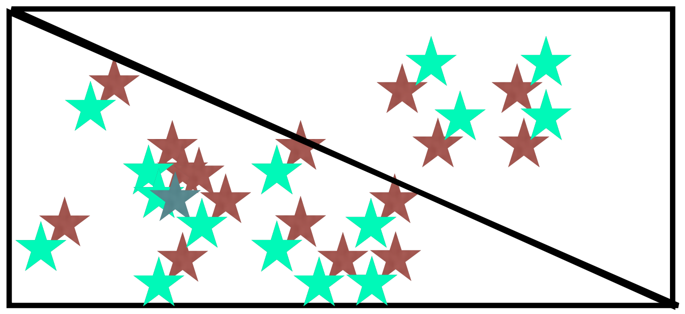


Residuals from the orbital fit of Gaia DR2 data only (along-scan direction)

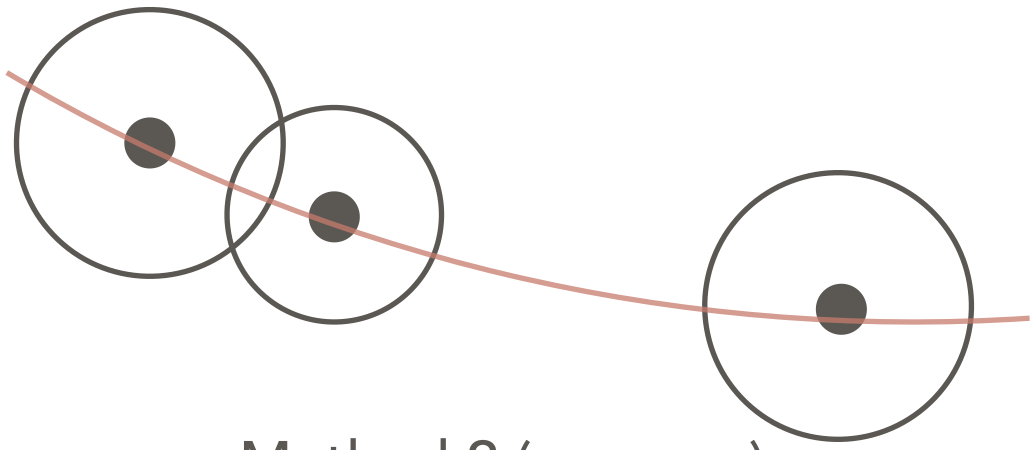
Spoto et al. 2018

Orbit improvement : DR2 + other observations

- 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
- **Debiasing required!**
  - exploit the catalog information provided by MPC with the asteroid data
  - compute local biases per catalog (positions and pm) and correct observations



Method 1 : Farnocchia et al. (2015)
all catalogs referred to PPMXL
corrections computed on a grid
(F2015 scheme)

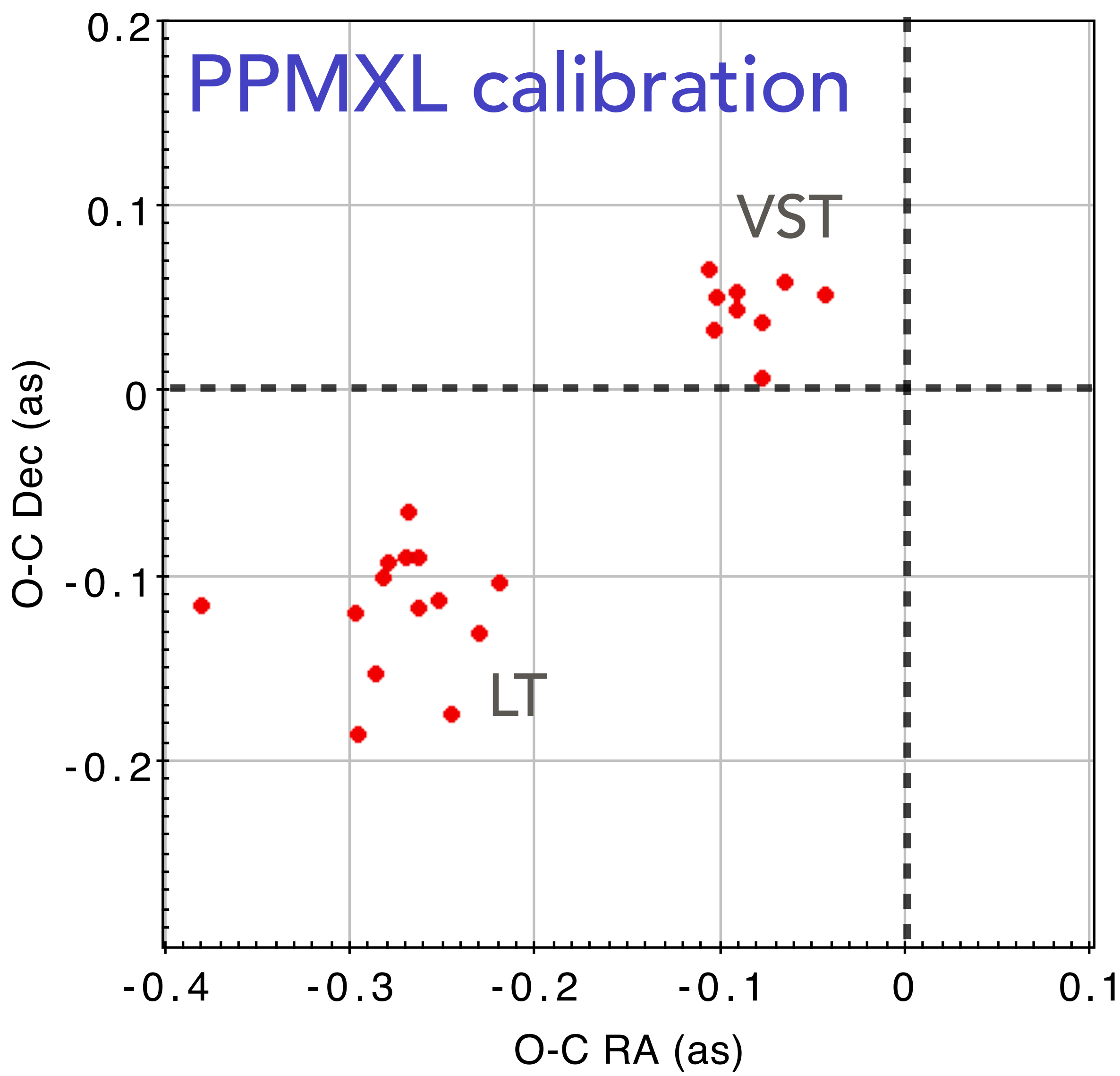


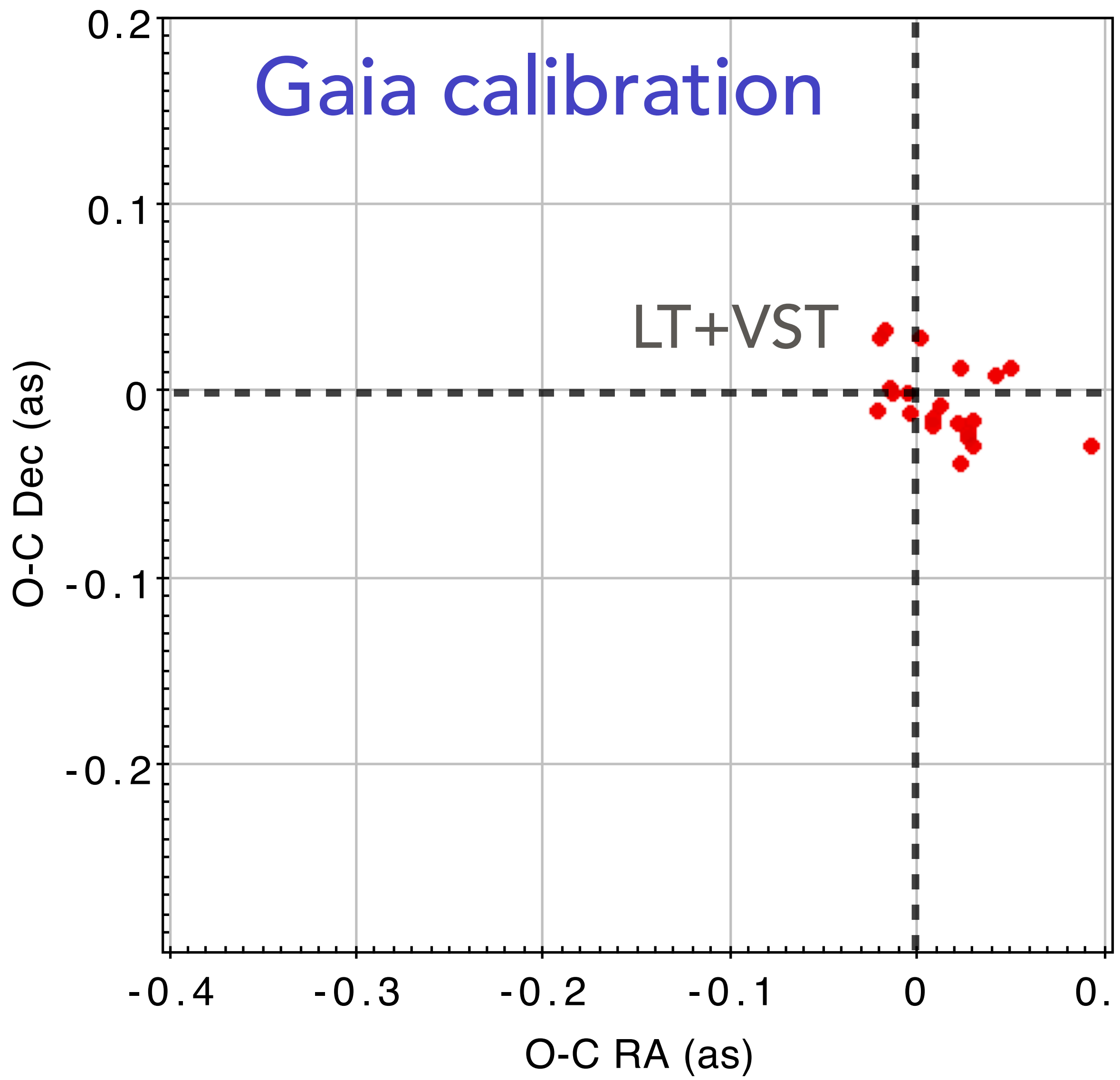
Method 2 (our own) :
areas centered on archive asteroid observations
Reference: Gaia DR2
(DR2 scheme)

De-biasing effect: example

Asteroid (1132) Hollandia

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

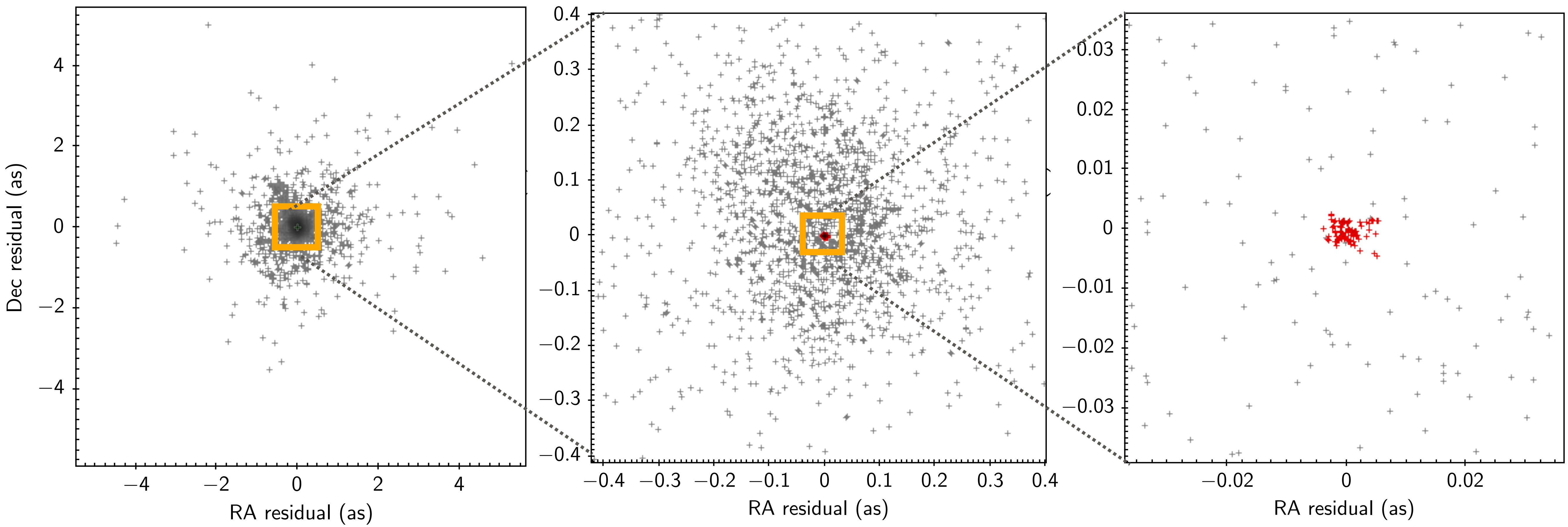




(credits: Gaia GBOT team)

Asteroid (386) Siegena - residuals from orbital fit

Combining archive data (2776 obs.) to GDR2



factor 100 X improvement!

First Yarkovsky measurement by Gaia: (2062) Aten

- ground-based observations from 1955 to 2017
- good pre-Gaia orbital fit with Yarkovsky measurement

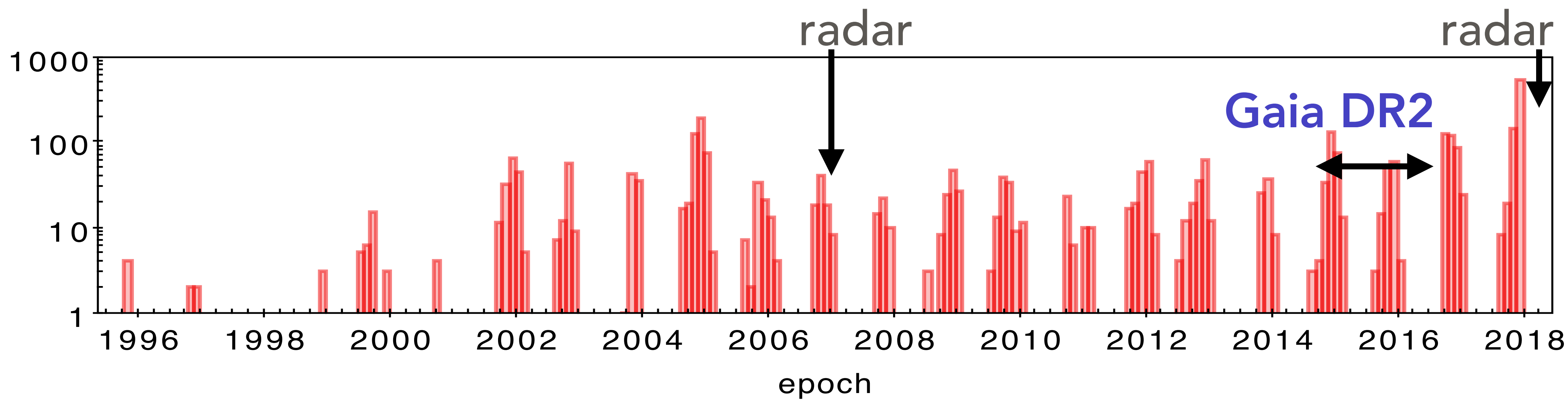
	SNR_{A2}	da/dt $10^{-4} au/Myr$
69 Gaia + 959 optical + 7 radar	14.63	-4.90 ± 0.34
959 optical + 7 radar	8.64	-5.98 ± 0.68

Spoto et al. 2018

- The combination of Gaia + other data significantly changes the value and improves SNR
- A coherent debasing is fundamental: only the *DR2 scheme* correctly combines Gaia + other observations (—> no rejection of DR2 astrometry)
- Note: $\sigma_a = 1\ 10^{-10}$ au !!!

Another important case: (3200) Phaethon

- B-type, associated to the Geminid meteor stream
- Close encounter in Dec. 2017 (radar + many optical data)



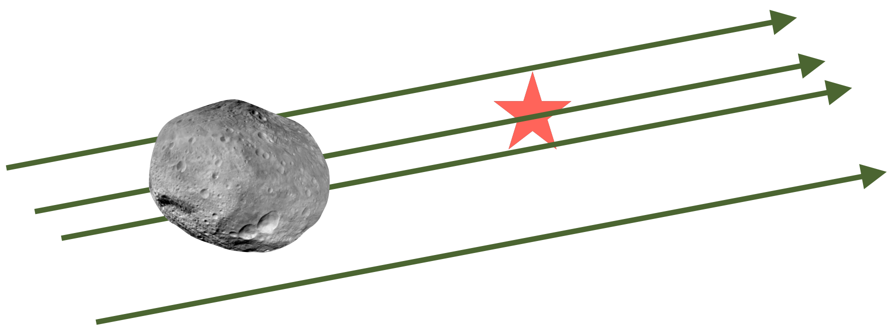
- Without Gaia : SNR ~ 3.4 (JPL)
- By using Gaia DR2 observations:

da/dt = - Embargoed! Publication to come ;-) yr) - SNR ~ 16

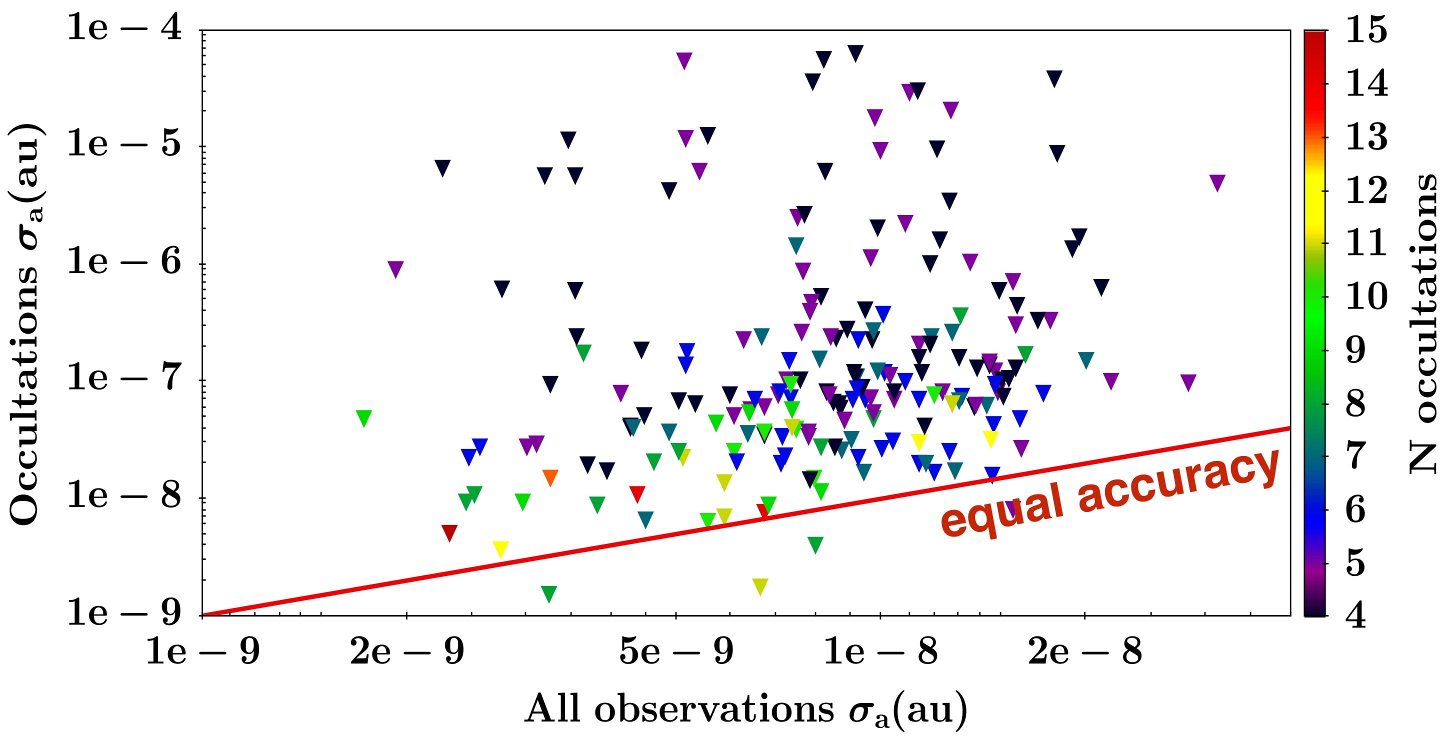
- A large amount of low-quality observations in 2017 « pollutes » the result

The *occultation astrometry* with Gaia

- DR2 successfully exploited
  - Triton (Octobre 3, 2017)
  - 2014 MU69 (V=27.5, 50 km KBO, ~1.4 mas)!!



- Occultations: very accurate asteroid position at the level of the star astrometry
- …Beyond the duration of Gaia!



Conclusions

- Gaia DR2 asteroid data: the first sample, already useful to test subtle dynamical effects
    - Yarkovsky determination
    - general orbit improvement
    - application to stellar occultations
- Combination with other observations: it starts to work…
    - but weighting of the data is critical
    - accurate debiasing is required
    - a new method successfully implemented and tested
- Yarkovsky detection *in the Main Belt* is getting closer…