The importance of ancient observations in the detection of the Yarkovsky effect

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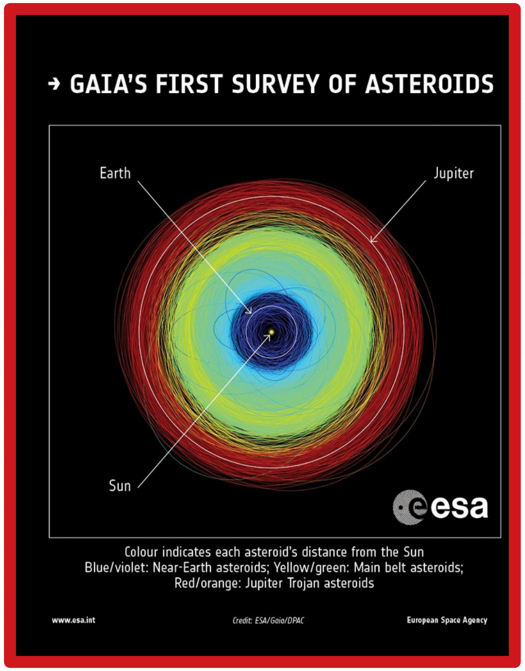
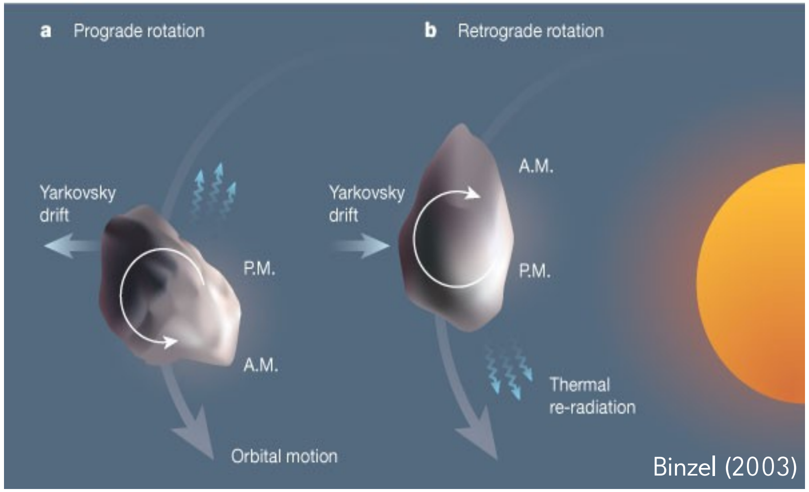


NAROO CIAS Workshop
Atelier CIAS 2019

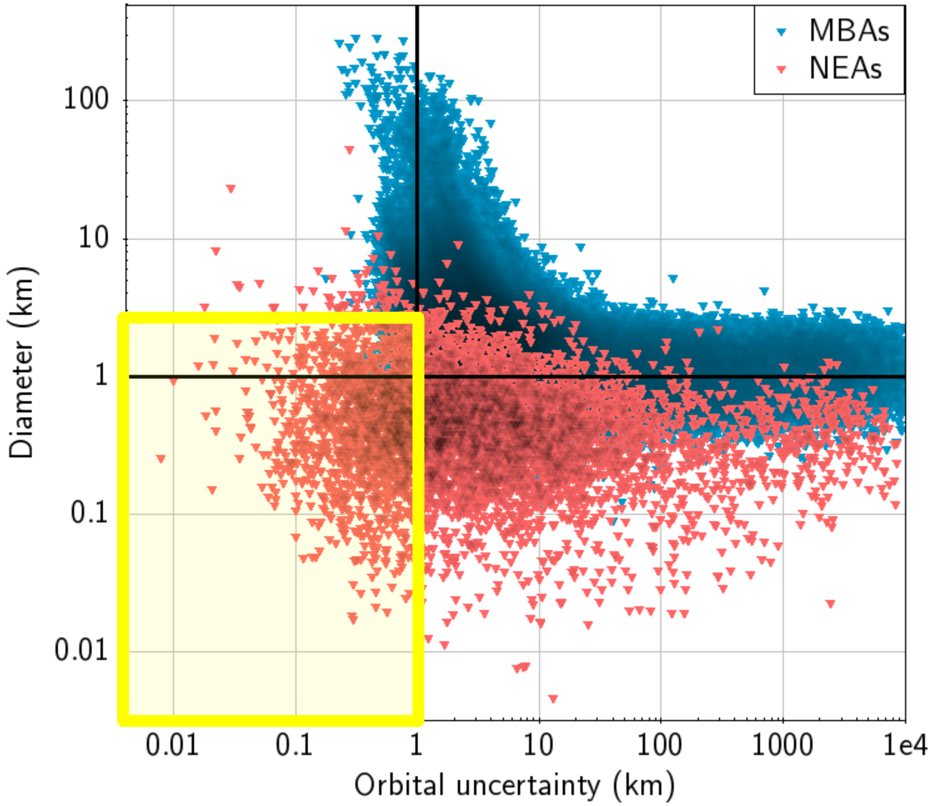
Observatoire de Paris, Meudon
2019, April 01-03

The Yarkovsky effect



- Anisotropic thermal emission
- **Secular evolution of the semi-major axis**
- Long period of time

- **Small objects**
- **Very accurate orbits**

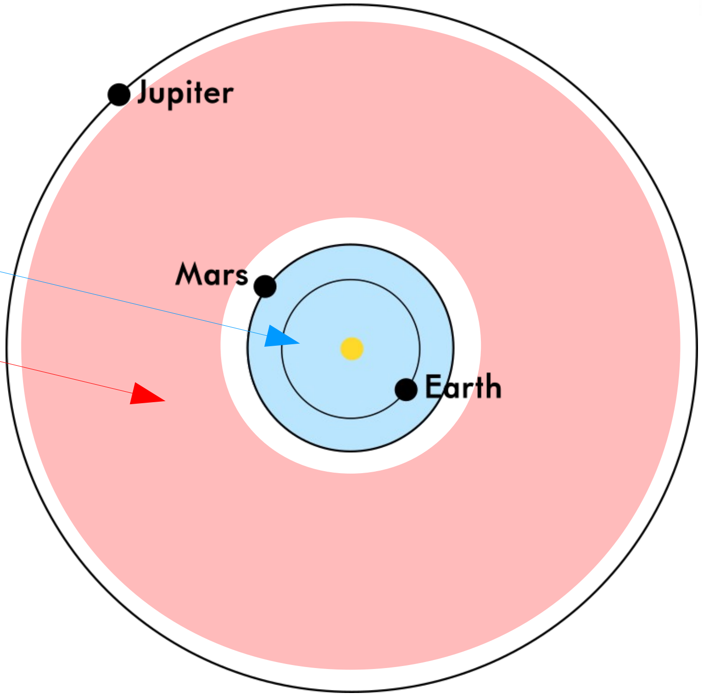


Applications

- NEOs and meteorite transport
- Physical properties (densities and spin)
- Family dispersion and age

2. The Yarkovsky effect

- **Main goal:** having the largest possible sample of detections
  - **Earth crossers:** impact probabilities
  - **Main Belt:** astronomical clock
- **Challenge: detections**
  - Depend on **physical properties**:
    - *Thermal inertia, diameter, spin, …*
    - *Not measured on small bodies*
  - **New approach: astrometry**
    (Farnocchia et al. 2013)



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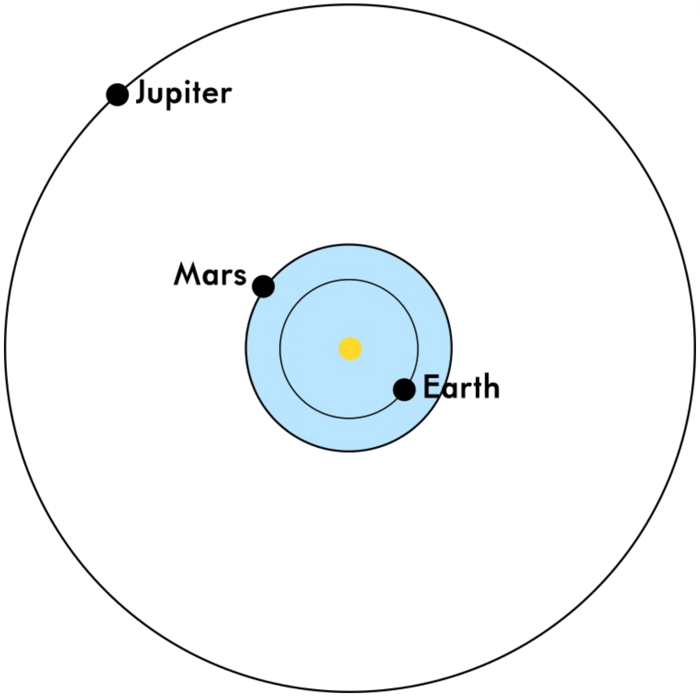

- **87 detections for Earth crossers**
  (Del Vigna et al. 2018)
  - Impact probabilities + **density** for Bennu
    - **Validated in-situ by OSIRIS-REx**
      *(Chesley et al. 2014, **Spoto** et al. 2014)*

2. The Yarkovsky effect – dreams come true

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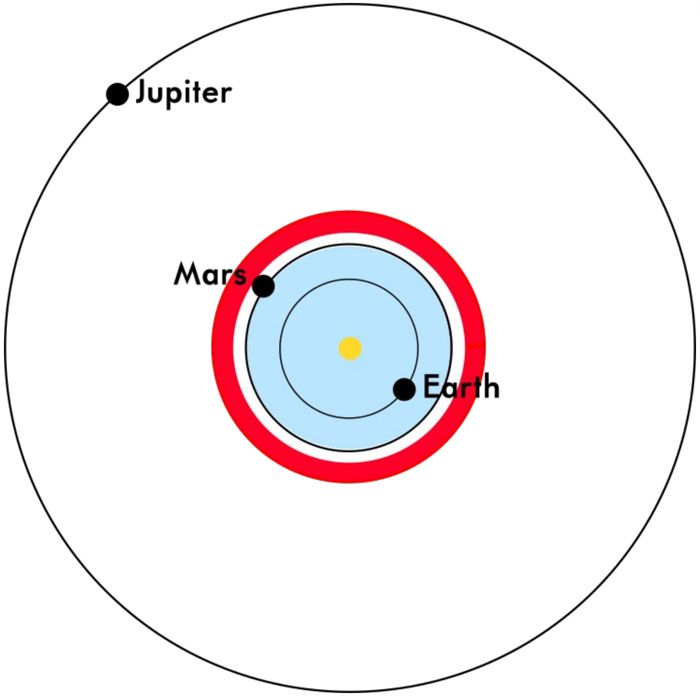

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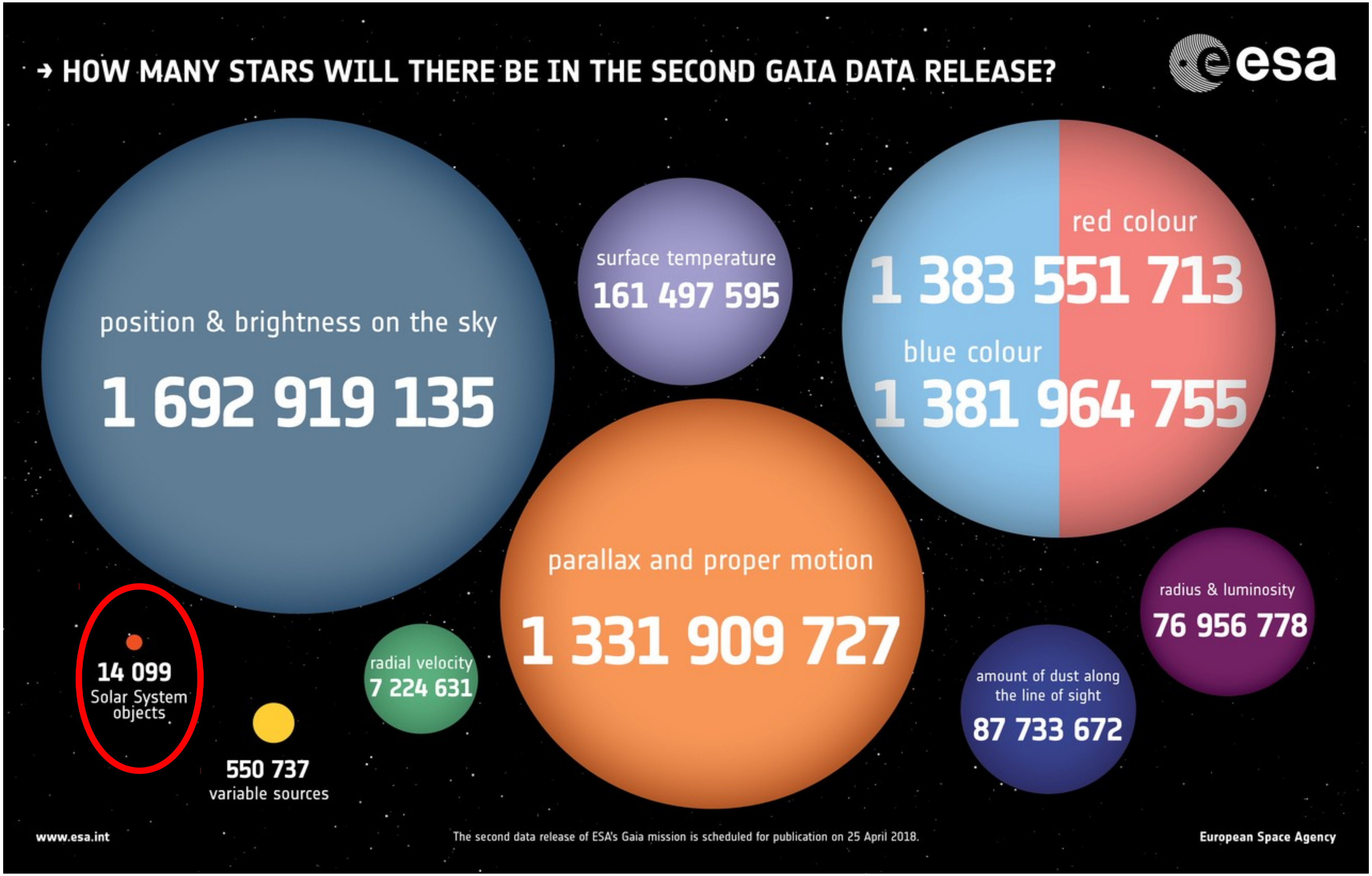
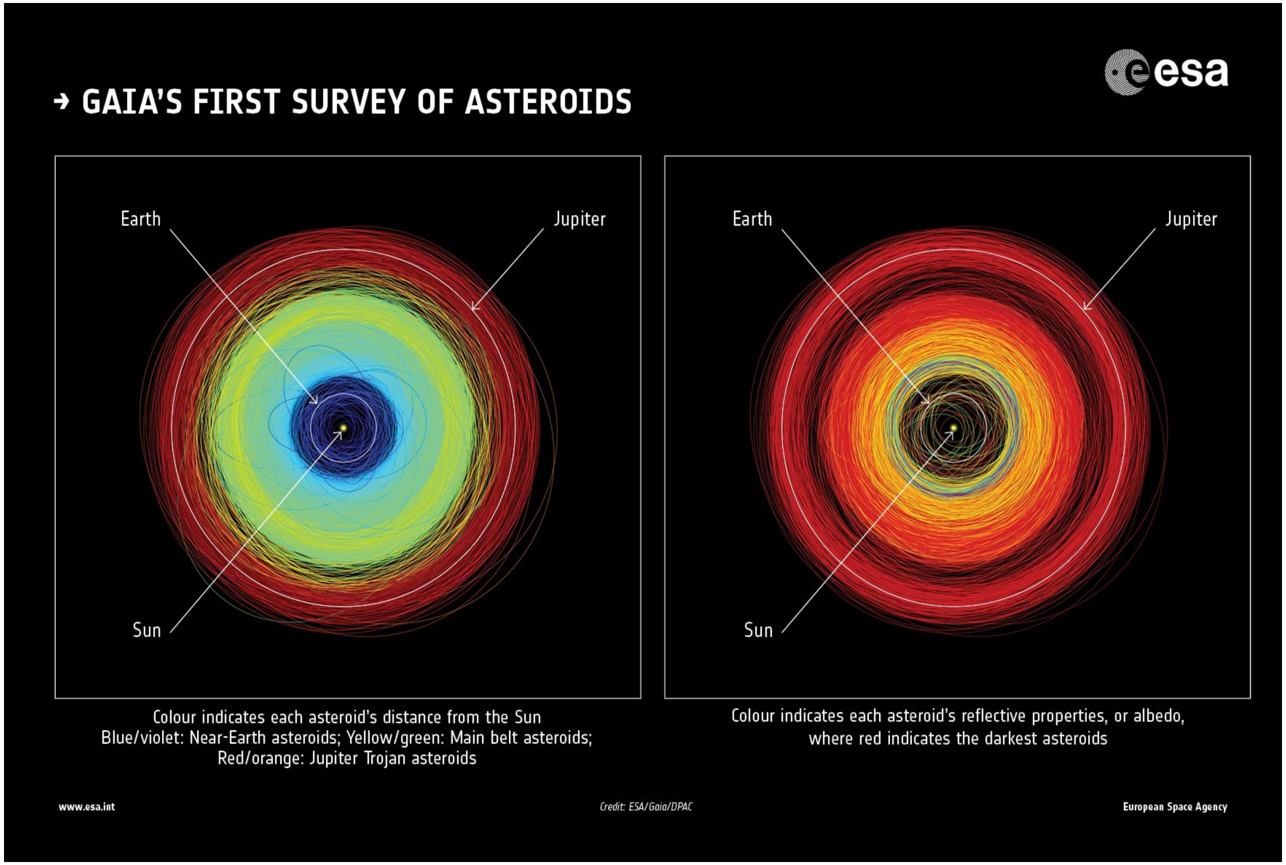
- **22 new detections + densities:**
  *(**Spoto** et al. 2019, submitted)*
  - 20 Earth crossers
  - **Towards the main belt**

Gaia Data Release 2

2018, April 25th



Gaia DR2 – Solar System Objects



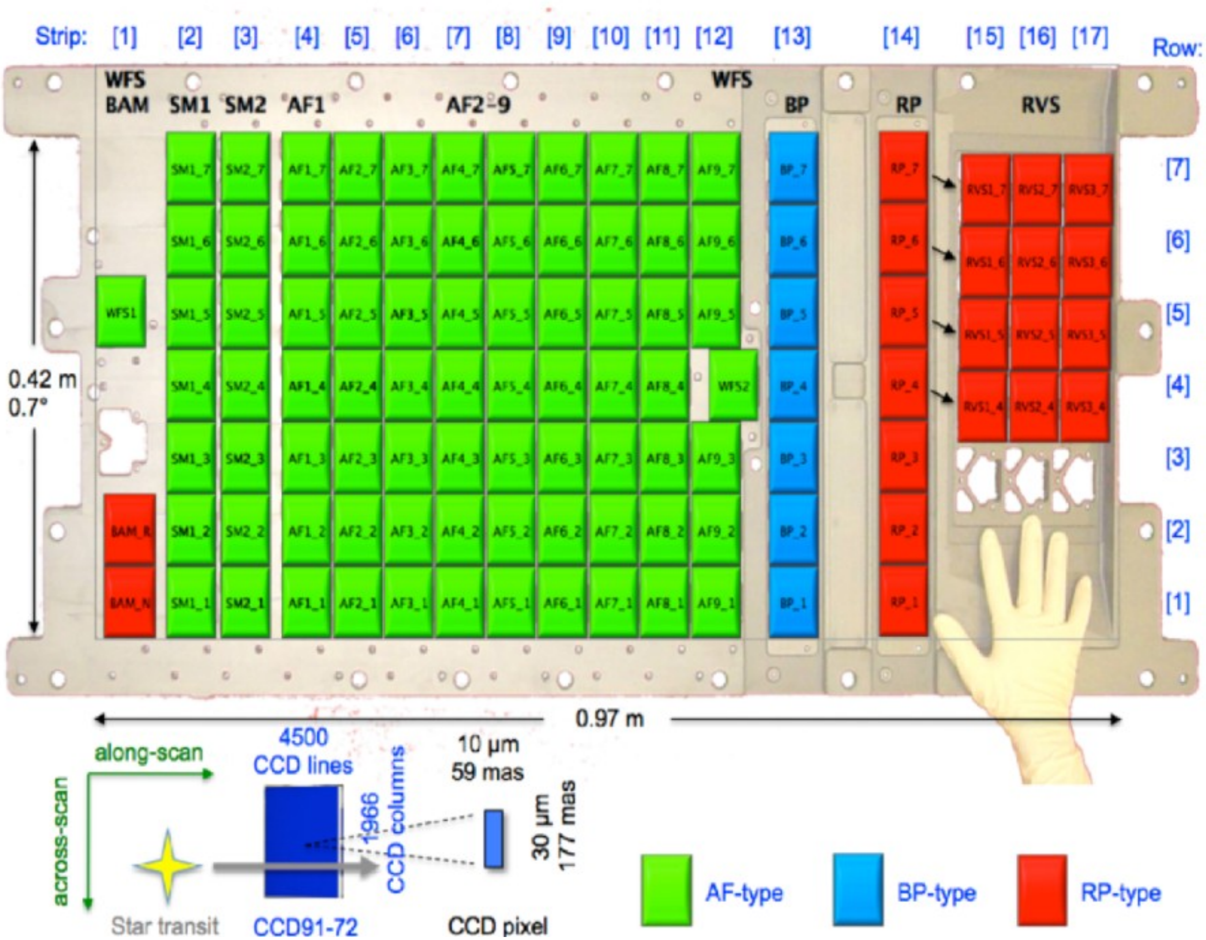
14 099 Asteroids

- 81 NEAs
- 2 TNOs
- 14 016 MBAs (including Trojans)

Our sample

- 70 asteroids
  (13 MBAs, 1 MC, 56 NEAs)
- D < 10 km
- Orbital uncertainty < 500 m

Gaia observations



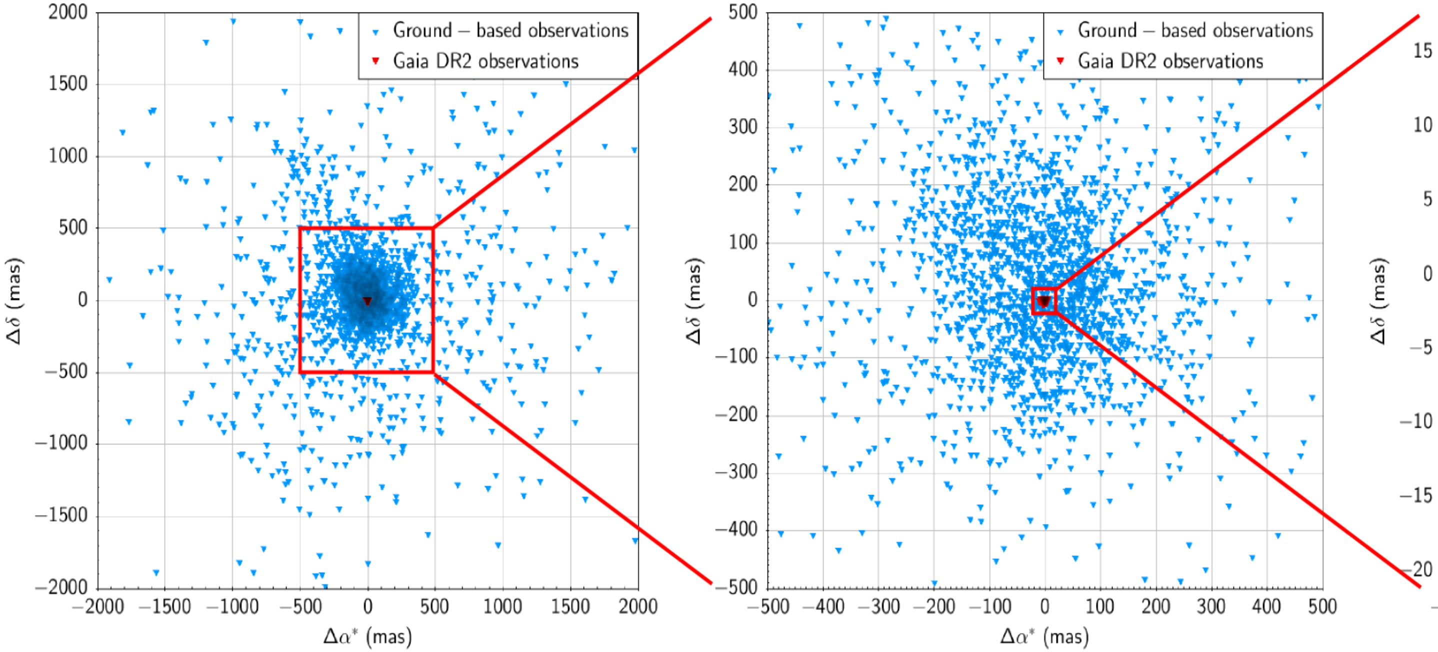
Gaia focal plane

- SM: source detection
- **AF: astrometric field (CCDs)**
- BP/RP: photometry
- RVS: spectroscopy

Transits

- **9 observations**
- **50 second**

Asteroid observation accuracy



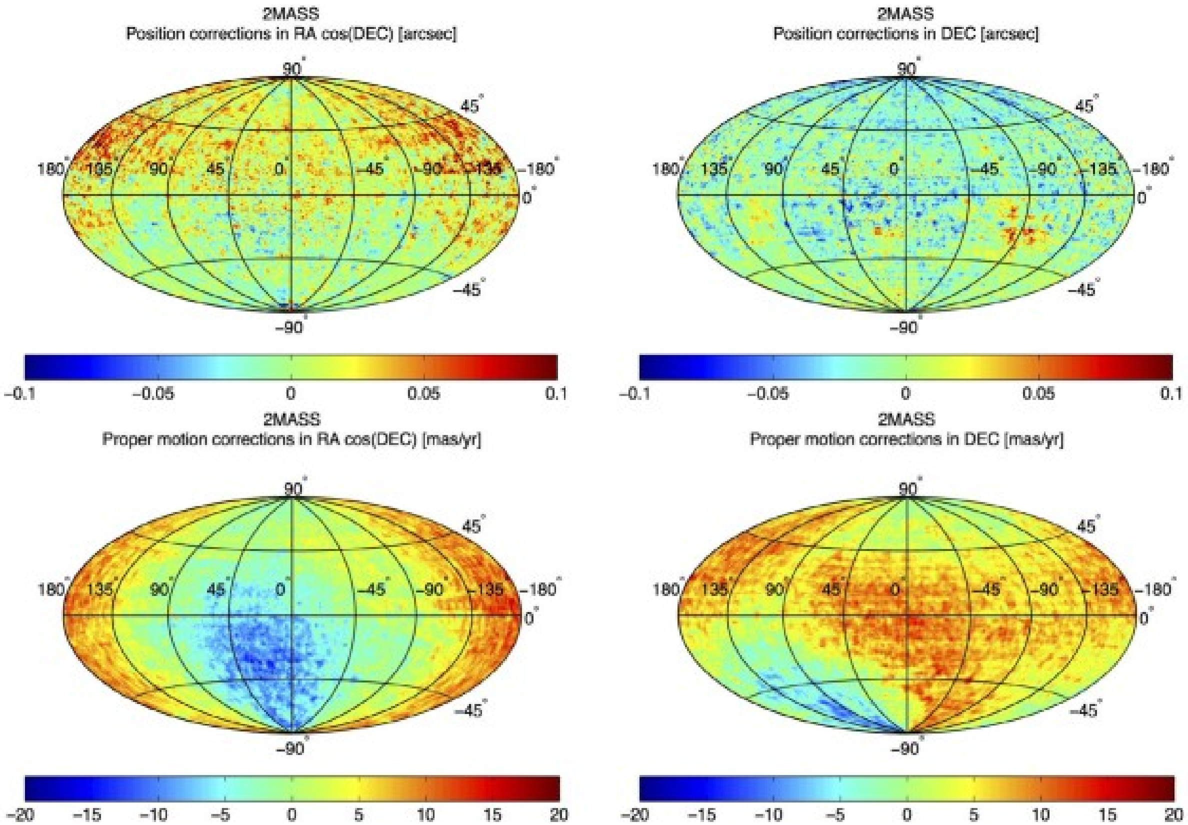
[Gaia DR2](Gaia Collaboration, Spoto et al. 2018)

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

MPC

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

Debiasing

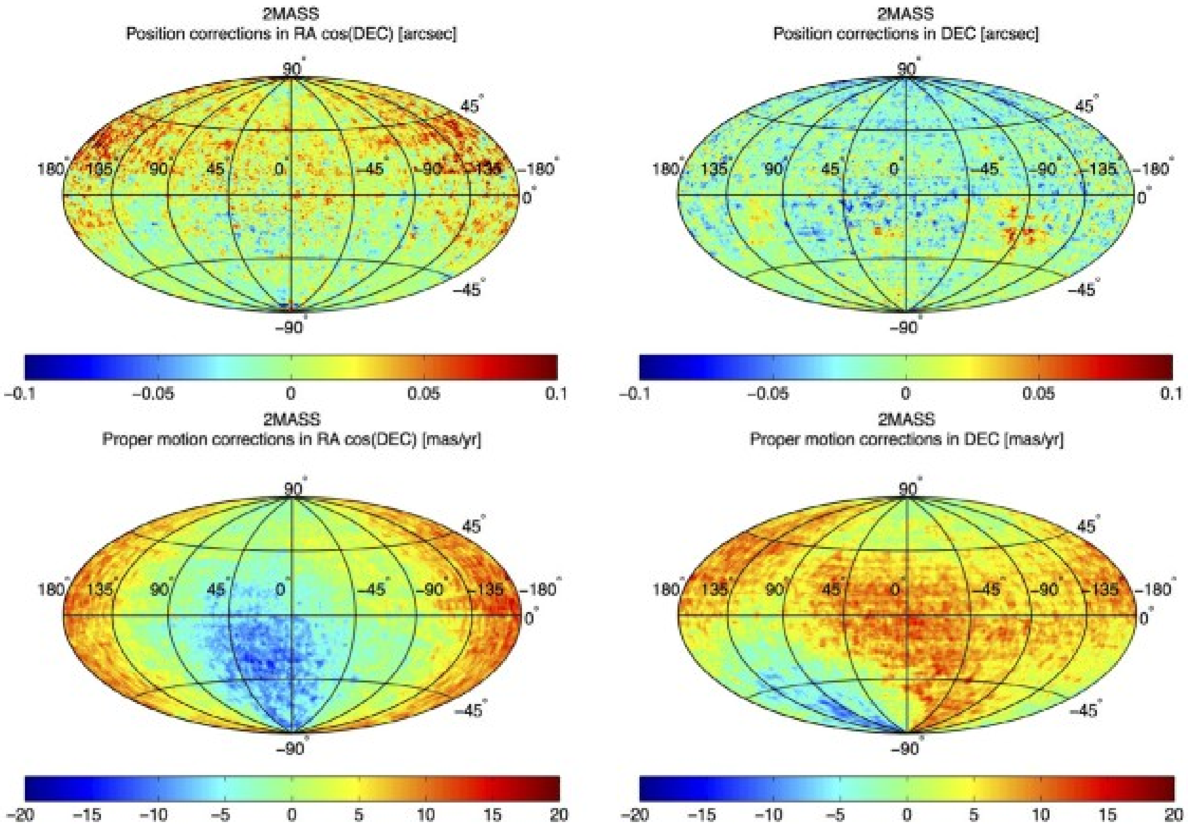


(Farnocchia et al. 2015)

Observations

- ~ **200 millions** of observations
- ~ **180 millions** of observations of **numbered objects**
- ~ **20 millions** of observations of **unnumbered objects**

Debiasing



(Farnocchia et al. 2015)

Observations

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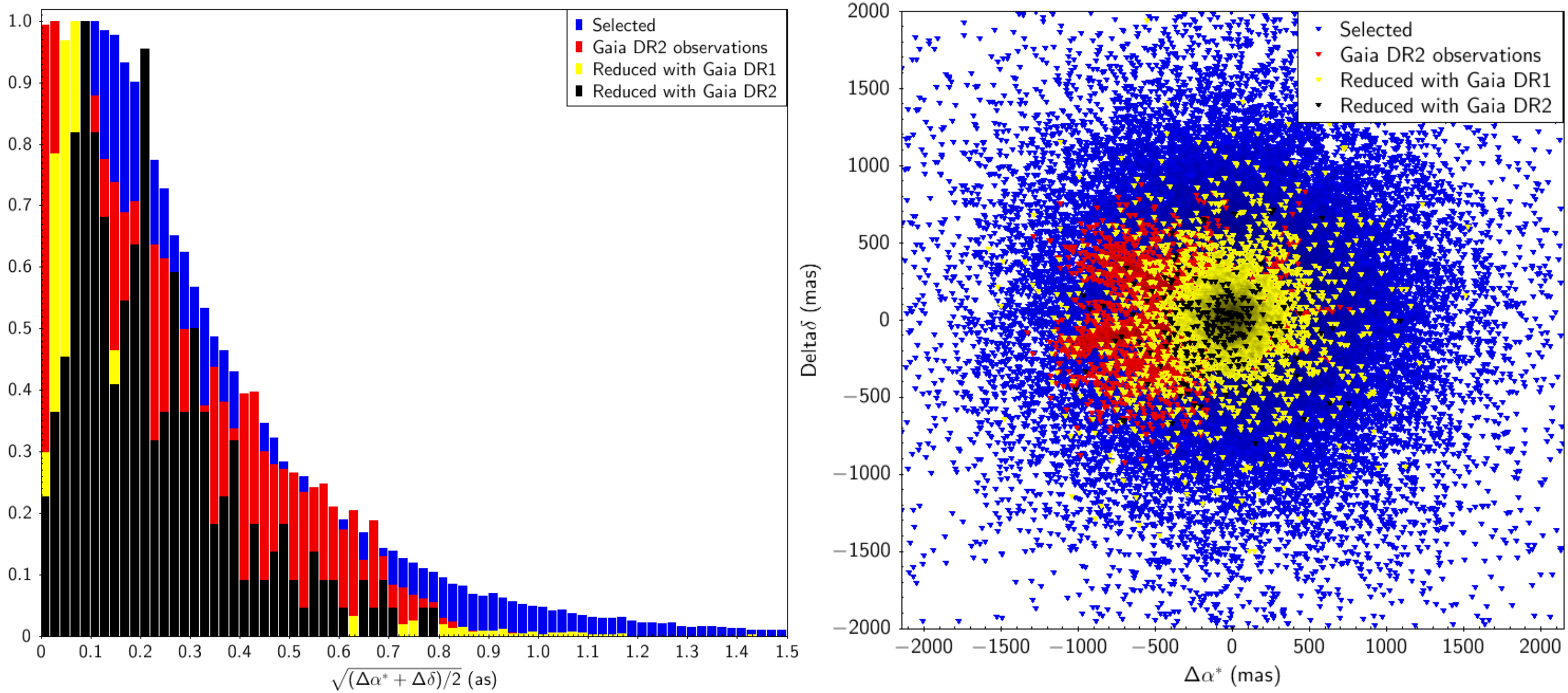
Catalogs

- 49 catalogs

Work in progress! (See P. Tanga)

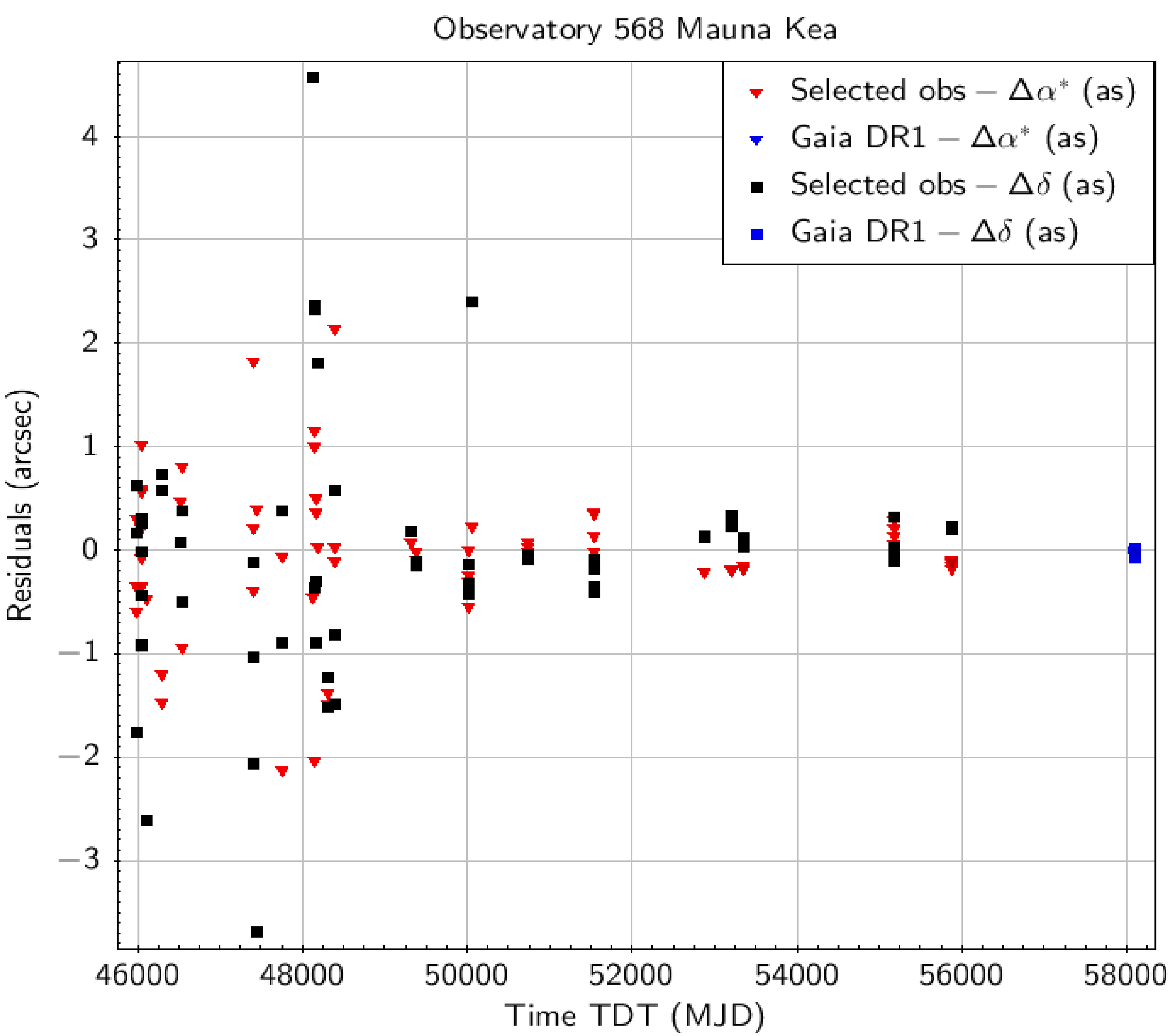
Weighting scheme



Catalogs

- ~ **17 millions** of observations reduced with **Gaia DR1**
- ~ **5 millions** of observations reduced with **Gaia DR2**

Weighting scheme



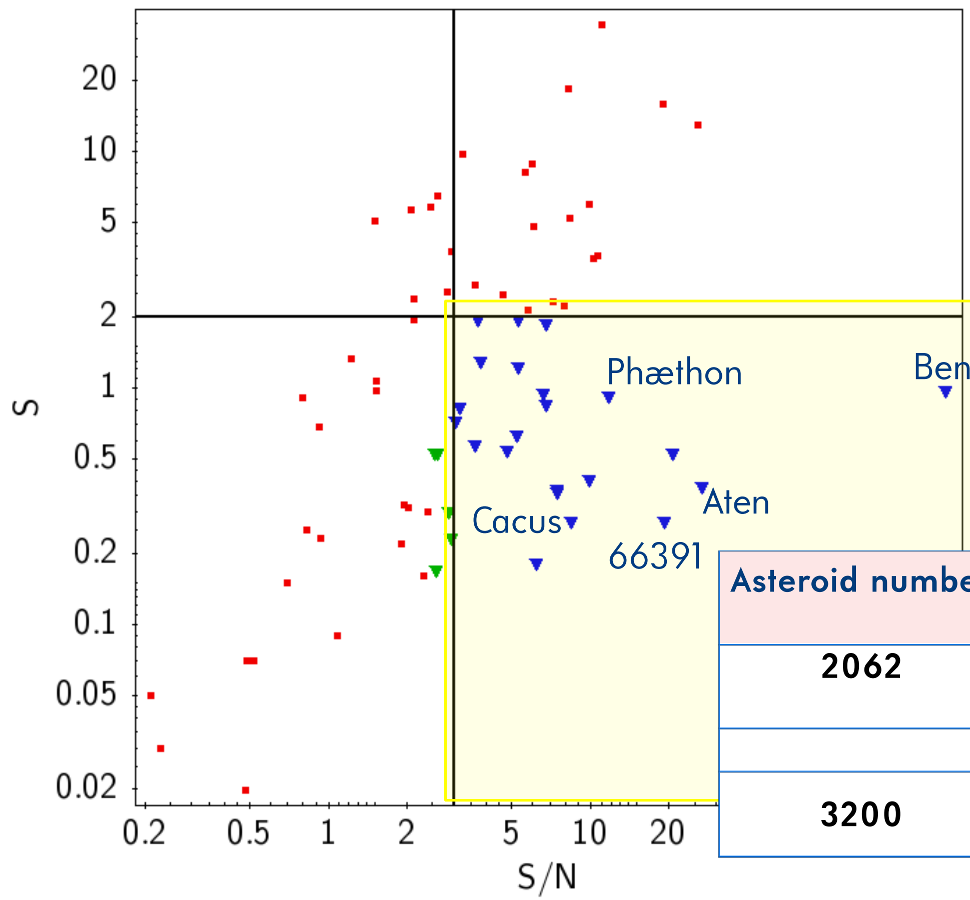
Weighting scheme

- **RMS of the post-fit residuals**
(the performance of each observatory)
- **For each catalog**
- **For each year**

Results – detections

20 new detections

- **15 new + 3 already known** (2062) Aten, (1685) Toro and (2100) Ra-Shalom
- S/N > 3
- S (expected Yarkovsky value) < 2



Asteroid number	A_2 10^{-15} au/d^2	S/N	da/dt 10^{-4} au/Myr	
2062	-10.85 +/- 0.41 -13.18 +/- 1.53	**26.74** 8.64	-4.84 +/- 0.18 -5.98 +/- 0.68	This work Del Vigna et al. 2018
3200	-4.11 +/- 0.35	**11.73**	-7.45 +/- 0.63 -6.90 +/- 1.90	This work Hanuš et al. 2018

Results - densities

From Yarkovsky detections to densities:

$$\frac{da}{dt} = \left.\frac{da}{dt}\right|_{\text{diurnal}} + \left.\frac{da}{dt}\right|_{\text{seasonal}}$$

$$= \frac{(1-A)\pi D^2 S_\odot}{9mc\Delta^2}\left[W_n \sin^2\gamma - 2W_\omega \cos\gamma\right]$$

with

$$A = p_V \cdot q \approx p_V(0.29 + 0.684G),$$

$$W_\nu \approx \frac{0.5\Theta_\nu}{1 + \Theta_\nu + 0.5\Theta_\nu^2},$$

$$\Theta_\nu = \frac{\Gamma\sqrt{\nu}}{\epsilon\sigma_B T_\star^3}, \text{ with } \nu \text{ in } \{n, \omega\}, \text{ and}$$

$$T_\star^4 = \frac{(1-A)S_\odot}{\eta\sigma_B\epsilon\Delta^2}$$

(Adapted from Farinella et al. 1998 and Vokrouhlický et al. 2015)

- **Taxonomic class, rotation period and diameter are known for all the asteroid**s
- When the **albedo is missing**, we assume the **average albedo** from its **taxonomic class**
- When the **thermal inertia is missing**, we assume **200 ± 40 J m^{-2} $s^{-1/2}$** K^{-1} (Delbo et al. 2007)
- When the **obliquity is missing**, we assume a **flat distribution between 90° and 180°**
- **Monte Carlo approach to estimate the mass of the asteroids**:
  - we evaluate 100 000 times the equation, taking randomly each parameter

TOP 5

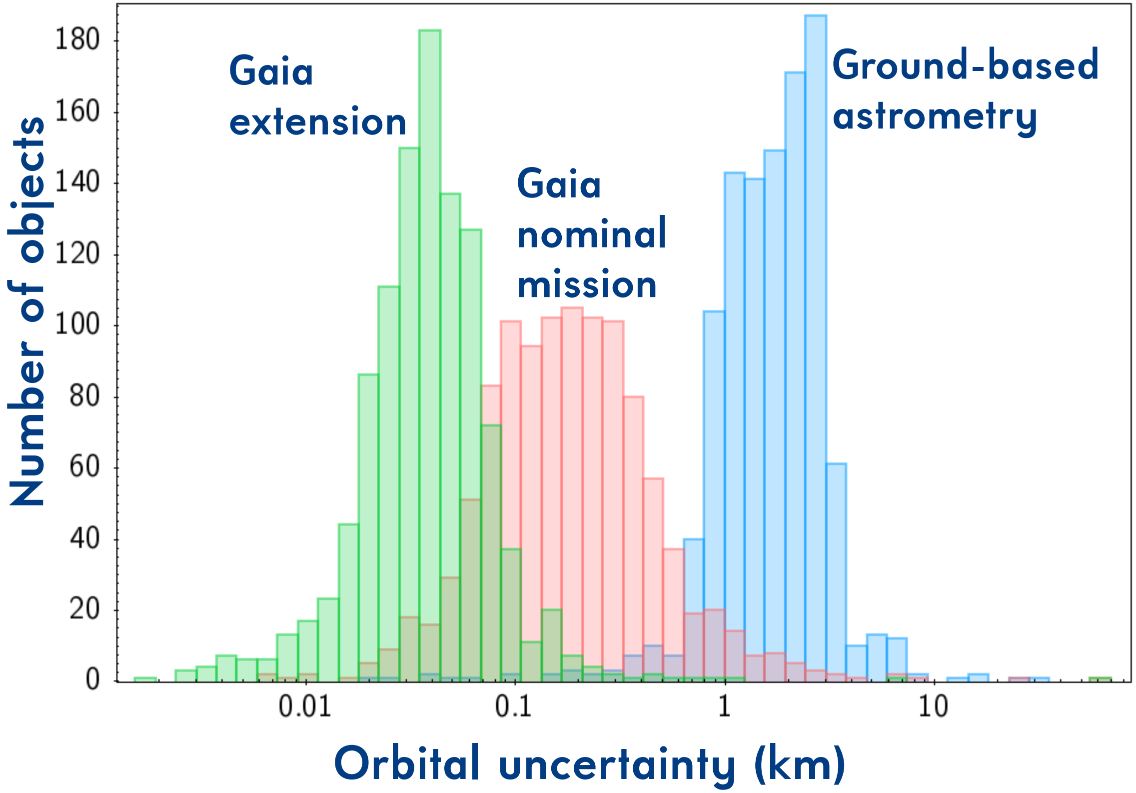
Asteroid number	A_2 10^{-15} au/d^2	S/N	da/dt 10^{-4} au/Myr	Density kg m^{-3}
2062	-10.85 +/- 0.41	**26.74**	-4.84 +/- 0.18	2076 +/- 436
5381	8.55 +/- 0.41	**20.64**	4.09 +/- 0.19	564 +/- 343
66391	-4.75 +/- 0.25	**19.17**	-4.78 +/- 0.25	3249 +/- 439
3200	-4.11 +/- 0.35	**11.73**	-7.45 +/- 0.63	1186 +/- 171
161989	-9.28 +/- 0.94	**9.92**	-3.90 +/- 0.54	2835 +/- 1020

- **18 Yarkovsky detections** and **density computation**
  - **15 new** + 3 already known (better estimation)

- **Main limitation**:
  - Small sample of objects from Gaia DR2
  - Little statistics

The best is yet to come…

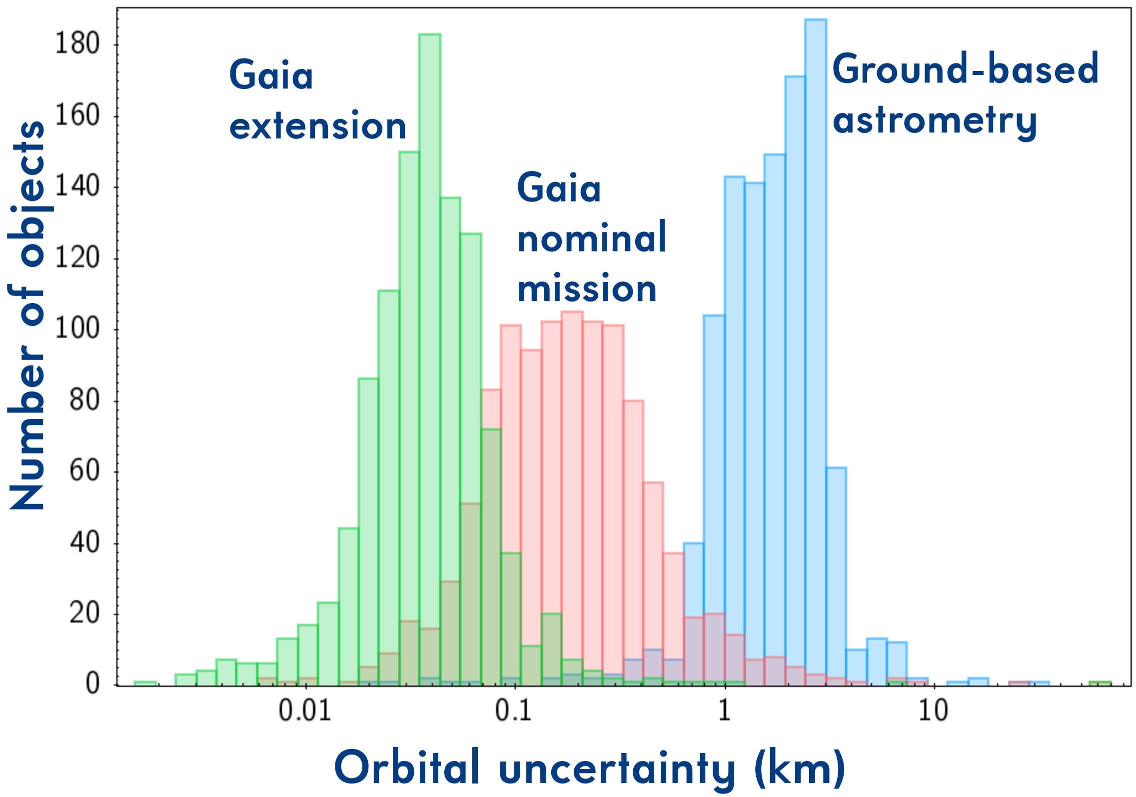
Thousands of ultra-accurate orbits



A revolution in orbit qualities:
Uncertainties in age computation

F. Spoto & F. Mignard
Gaia mission extension → **2025**

Thousands of ultra-accurate orbits



A revolution in orbit qualities:
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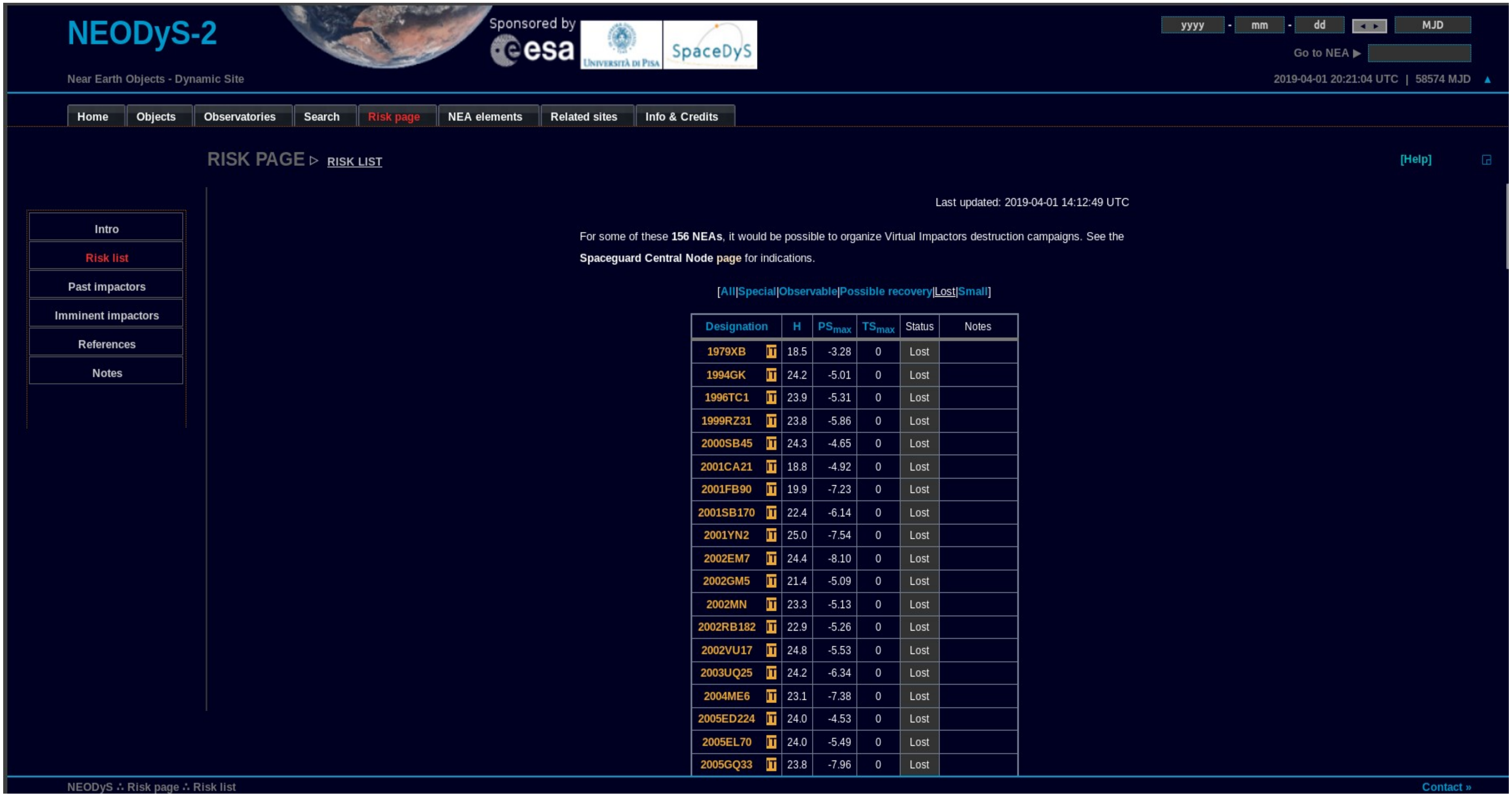
Lost objects



NEODyS-2

Near Earth Objects - Dynamic Site

Sponsored by esa Università di Pisa SpaceDyS

yyyy - mm - dd MJD

Go to NEA ▶

2019-04-01 20:21:04 UTC | 58574 MJD

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RISK PAGE ▷ RISK LIST

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Intro
Risk list
Past impactors
Imminent impactors
References
Notes

Last updated: 2019-04-01 14:12:49 UTC

For some of these **156 NEAs**, it would be possible to organize Virtual Impactors destruction campaigns. See the **Spaceguard Central Node page** for indications.

[All|Special|Observable|Possible recovery|Lost|Small]

Designation		H	PS_{max}	TS_{max}	Status	Notes
1979XB		18.5	-3.28	0	Lost	
1994GK		24.2	-5.01	0	Lost	
1996TC1		23.9	-5.31	0	Lost	
1999RZ31		23.8	-5.86	0	Lost	
2000SB45		24.3	-4.65	0	Lost	
2001CA21		18.8	-4.92	0	Lost	
2001FB90		19.9	-7.23	0	Lost	
2001SB170		22.4	-6.14	0	Lost	
2001YN2		25.0	-7.54	0	Lost	
2002EM7		24.4	-8.10	0	Lost	
2002GM5		21.4	-5.09	0	Lost	
2002MN		23.3	-5.13	0	Lost	
2002RB182		22.9	-5.26	0	Lost	
2002VU17		24.8	-5.53	0	Lost	
2003UQ25		24.2	-6.34	0	Lost	
2004ME6		23.1	-7.38	0	Lost	
2005ED224		24.0	-4.53	0	Lost	
2005EL70		24.0	-5.49	0	Lost	
2005GQ33		23.8	-7.96	0	Lost	

NEODyS ∴ Risk page ∴ Risk list

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