Contribution of Gaia to asteroid dynamics

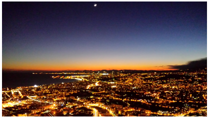
Federica Spoto

~~Frederica Spoto~~

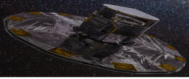
~~Frédérica Spoto~~

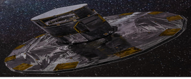
Seminaires Lagrange

7 March 2017, Nice



CNES Post-Doc





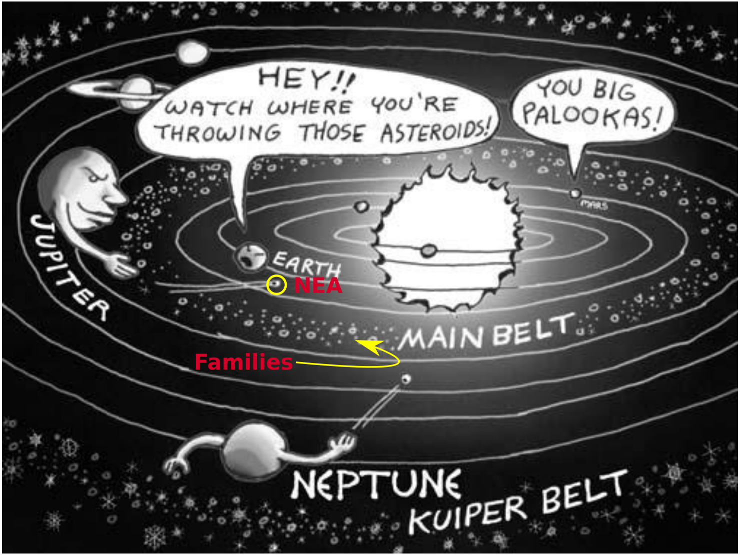
The Gaia mission

- Launched in December 2013.
- Currently surveying the sky from the Sun-Earth L2 Lagrangian Point.
- Provides astrometry of stars and **asteroids at the sub-milliarcsec accuracy**.

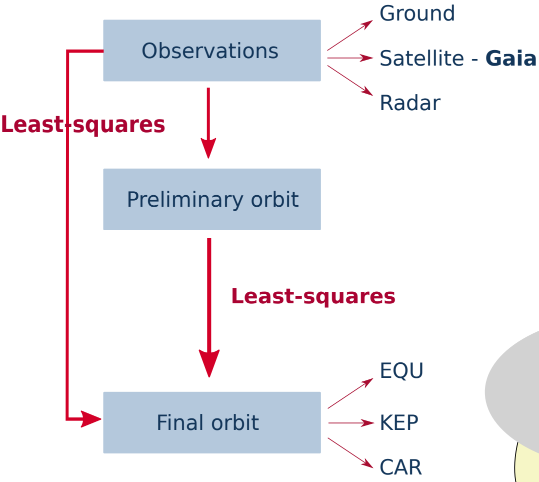
The first Gaia Data Release (GDR1)

- 14th September 2016
- 1.1 billion stars with **no proper motions** (G and position only)
- 2 million stars with **positions and proper motions**

Why asteroids?



How do we study asteroids?



Observations

- Ground
- Satellite - **Gaia**
- Radar

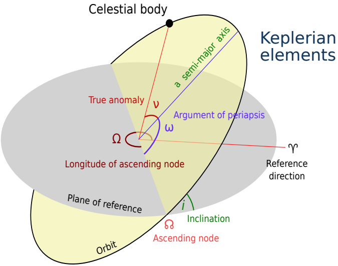
Least-squares

Preliminary orbit

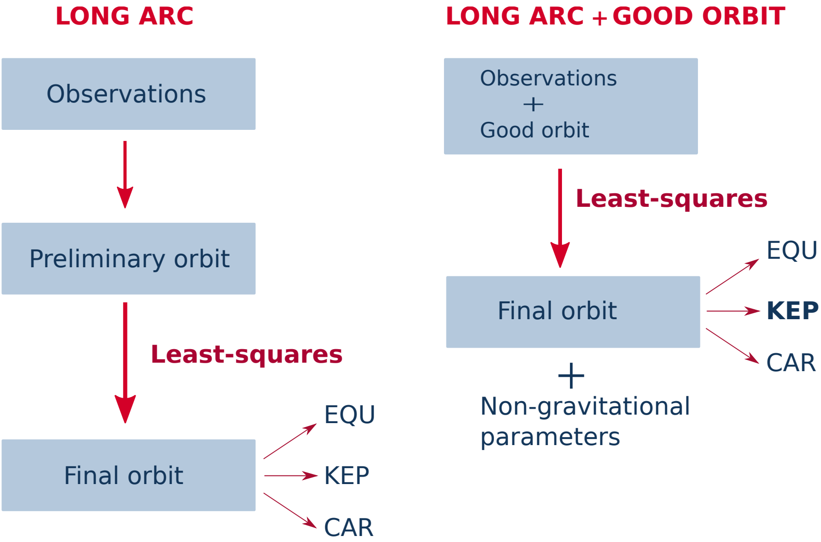
Least-squares

Final orbit

- EQU
- KEP
- CAR



Orbit determination



LONG ARC

Observations

Preliminary orbit

Least-squares

Final orbit

EQU

KEP

CAR

LONG ARC + GOOD ORBIT

Observations
+
Good orbit

Least-squares

Final orbit

EQU

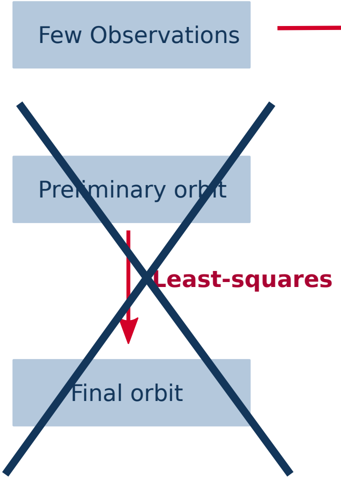
KEP

CAR

+
Non-gravitational parameters

Orbit determination

SHORT ARC

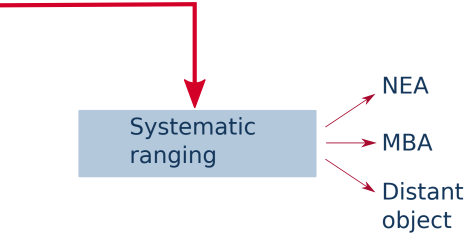


Few Observations

Preliminary orbit

Least-squares

Final orbit

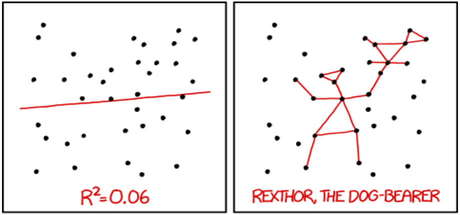


Systematic ranging

NEA

MBA

Distant object



I DON'T TRUST LINEAR REGRESSIONS WHEN IT'S HARDER TO GUESS THE DIRECTION OF THE CORRELATION FROM THE SCATTER PLOT THAN TO FIND NEW CONSTELLATIONS ON IT.

Gaia and asteroids

LONG ARC

Observations

Final orbit

SHORT ARC

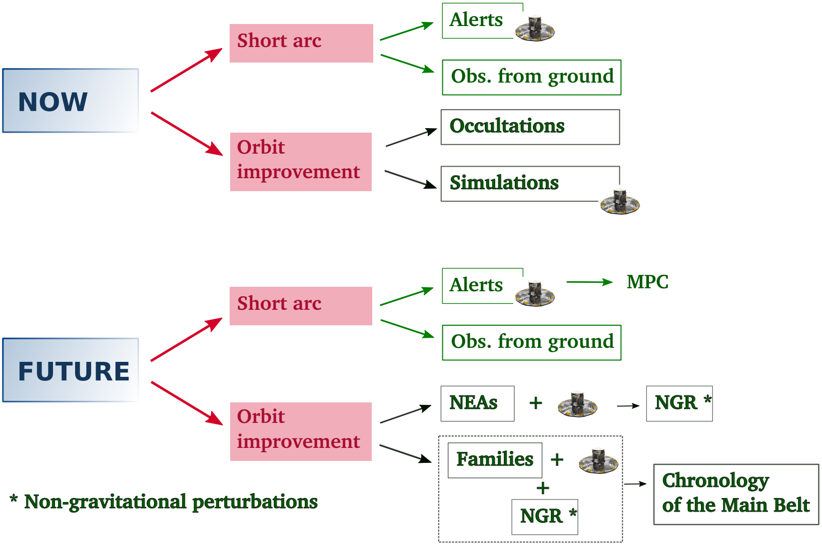
Observations

Systematic ranging

MPC archive
$\sigma \sim 500$ **mas**, 1000 **mas**

Gaia
$\sigma < 1$ **mas**

Outline



NOW

Short arc
- Alerts
- Obs. from ground

Orbit improvement
- Occultations
- Simulations

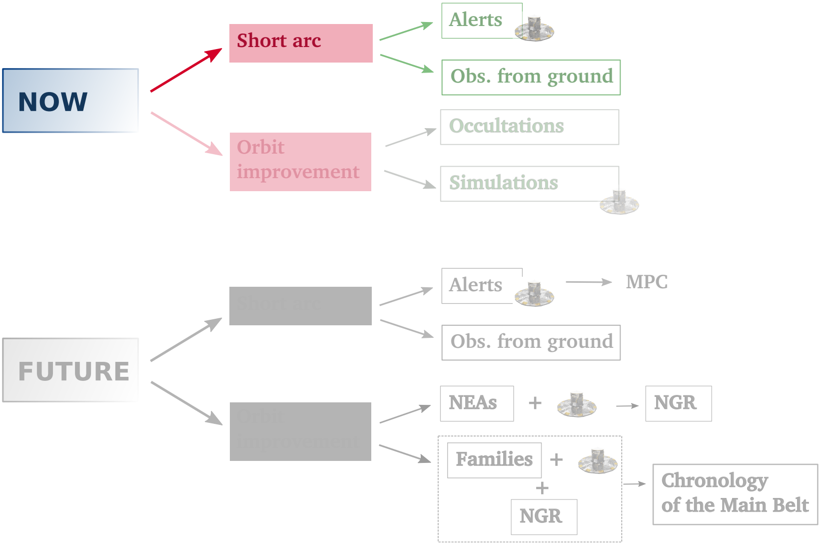
FUTURE

Short arc
- Alerts → MPC
- Obs. from ground

Orbit improvement
- NEAs + → NGR *
- Families + + NGR * → Chronology of the Main Belt

*** Non-gravitational perturbations**

Short arc



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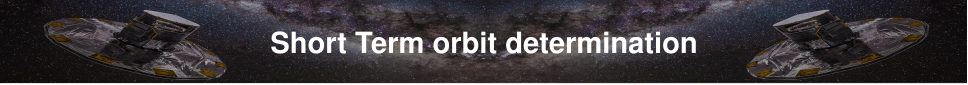


Short Term orbit determination

Problems

- **Few** astrometric observations over a **short** time span
- **Limited** amount of information to compute a full orbit

Approach

- Orbit determination with **short arcs**

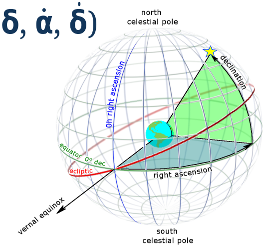
Methods

- Systematic ranging (Farnocchia et al. 2015)
- Random-walk statistical ranging (Muinonen et al. 2015)
- Admissible region + systematic ranging / cobweb (Spoto et al. 2017)

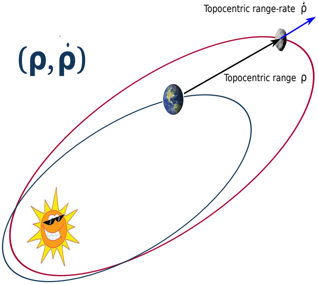
Attributable

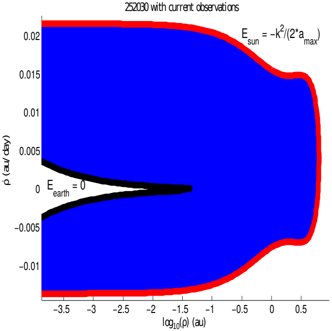
Attributable

$$A = (\alpha, \delta, \dot{\alpha}, \dot{\delta})$$

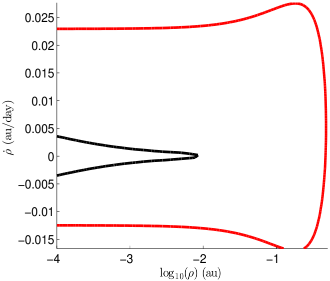


$(\rho, \dot{\rho})$

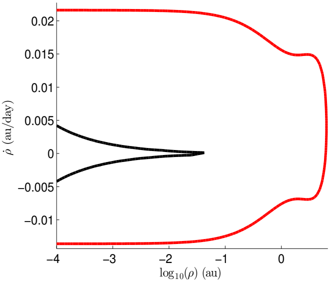




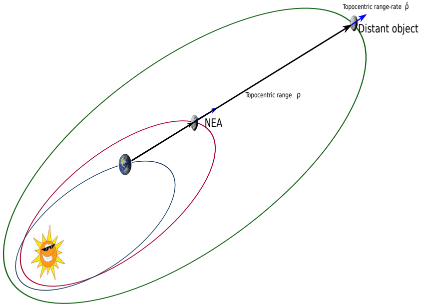
Systematic ranging: admissible region

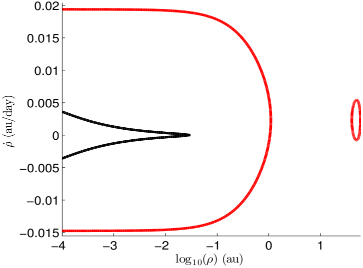


2014AA with current observations



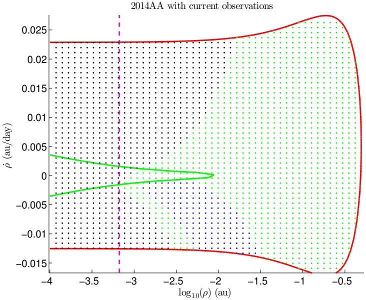
252030 with current observations

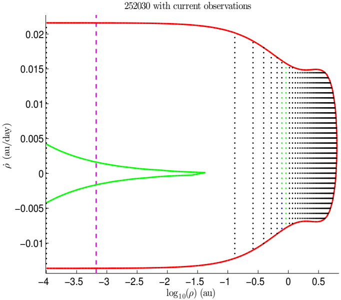




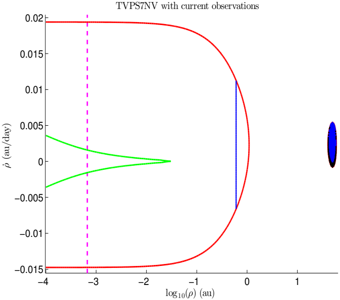
TVPS7NV with current observations

Systematic ranging: grid



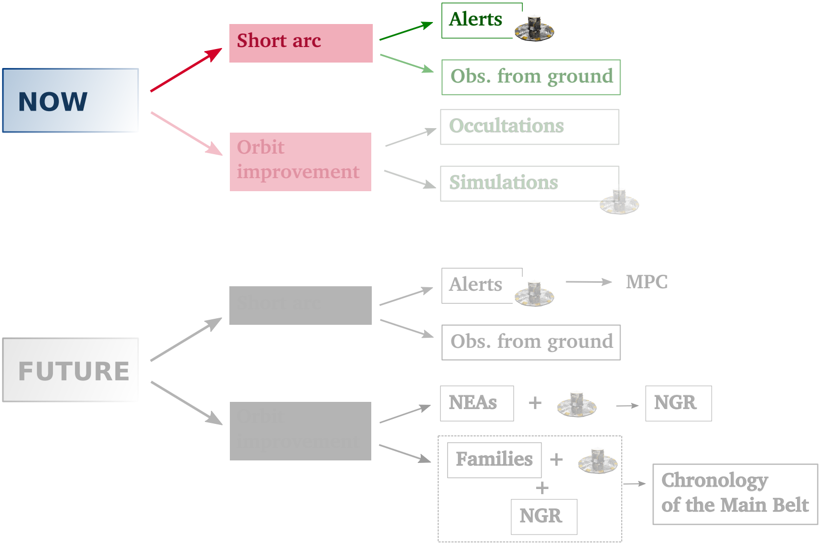


$$\chi = \sqrt{m|Q(\boldsymbol{X}) - Q(\boldsymbol{X}^*)|}$$



- **Blue**: $\chi \leq 2$
- **Green**: $2 < \chi \geq 5$
- **Black**: $\chi > 5$

Alerts



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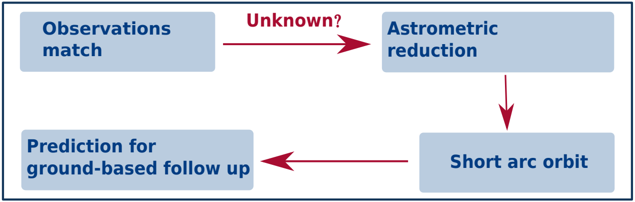
Alerts



Observations match

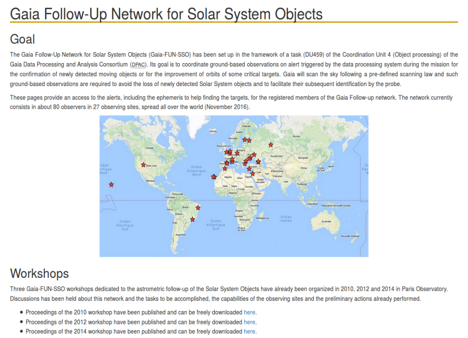
Unknown?

Astrometric reduction

Short arc orbit

Prediction for ground-based follow up

CNES



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 (DU459) of the Coordination Unit 4 (Object processing) of the Gaia Data Processing and Analysis Consortium (DPAC). 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 consists in about 80 observers in 27 observing sites, spread all over the world (November 2016).

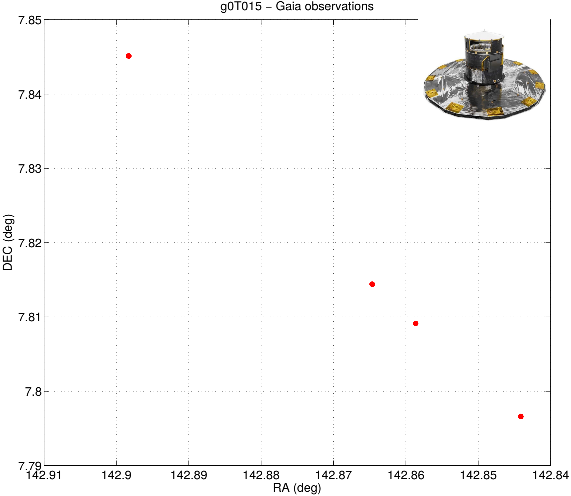
Workshops

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 has been held about this network and the tasks to be accomplished, the capabilities of the observing sites and the preliminary actions already performed.

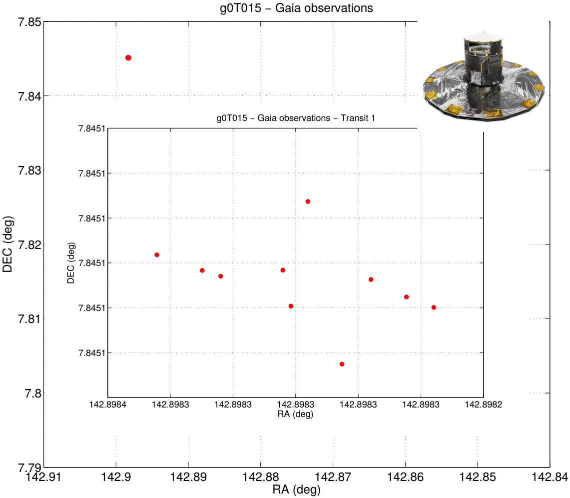
- Proceedings of the 2010 workshop have been published and can be freely downloaded here.
- Proceedings of the 2012 workshop have been published and can be freely downloaded here.
- Proceedings of the 2014 workshop have been published and can be freely downloaded here.

https://gaiafunsso.imcce.fr/index.php

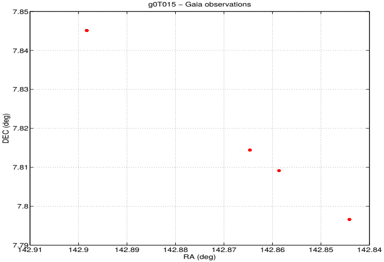
g0T015: Gaia observations

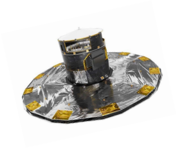


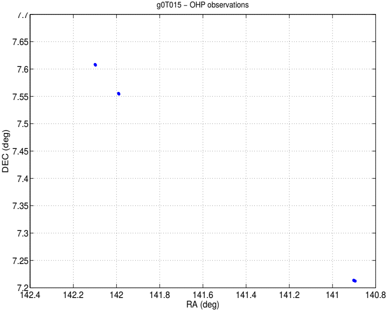
g0T015: Gaia observations



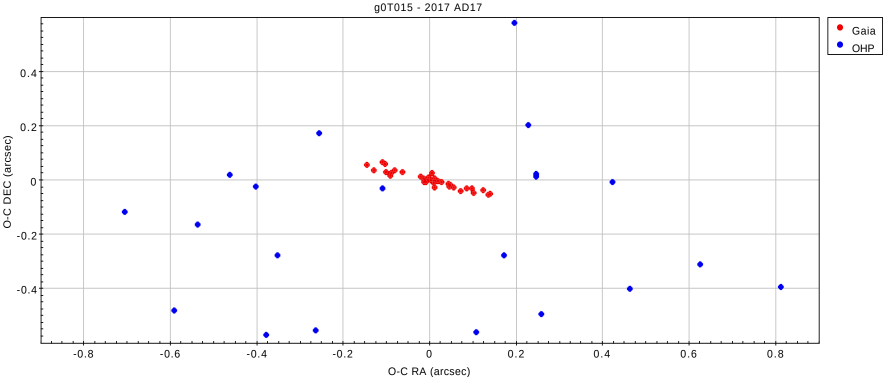
g0T015: Gaia + OHP observations



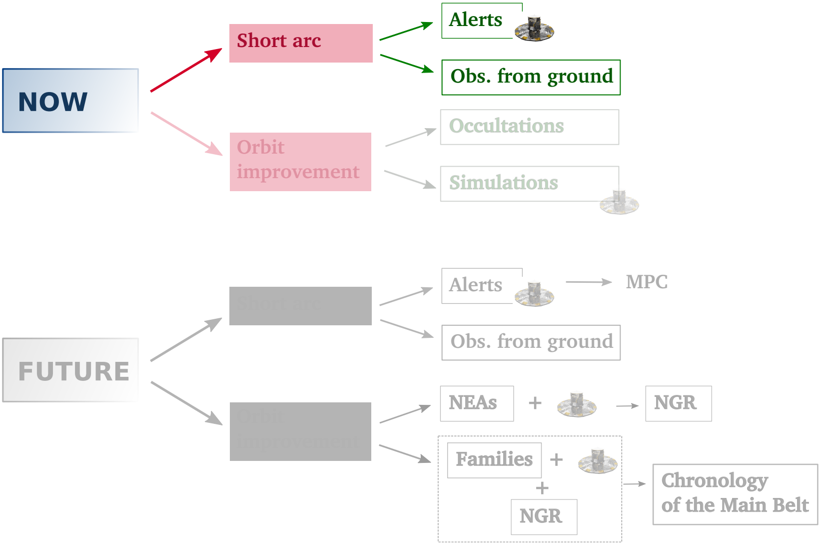




Residuals


g0T015 - 2017 AD17
Gaia
OHP
O-C DEC (arcsec)
0.4
0.2
0
-0.2
-0.4
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
O-C RA (arcsec)

GBOT



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GBOT : Gaia Based Optical Tracking

- **Ground Based Optical Tracking campaign** of Gaia.
- Standard procedure for satellite tracking is not sufficient.
- GBOT needs a level of absolute accuracy of **20 mas** on the satellite position determination.

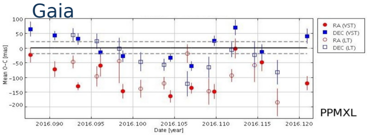
Asteroid observations

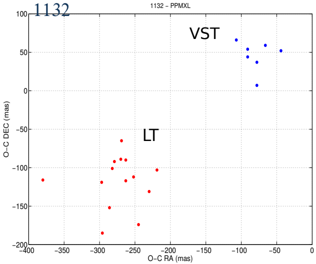
- **Two main telescopes**
  - Liverpool Telescope (LT) - La Palma
  - VLT Survey Telescope (VST) - Paranal

Data reduction

PPMXL

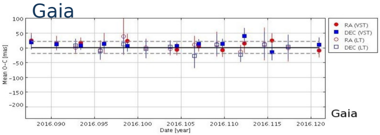
Reduction for North Data Block



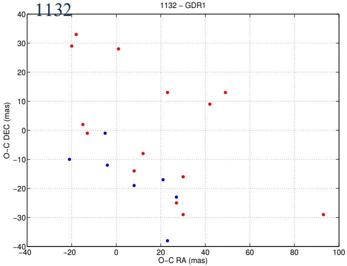


GDR1

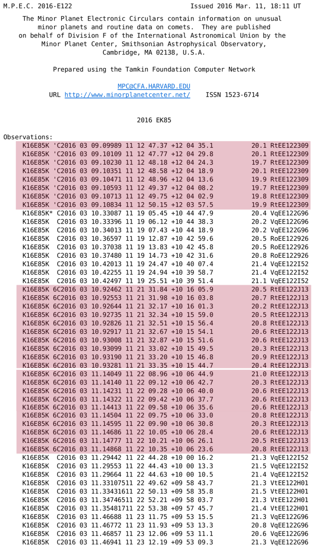
Reduction for North Data Block



Credit: S. Bouquillon (GBOT Team)



The case of 2016 EK_{85}: the discovery



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M.P.E.C. 2016-E122                              Issued 2016 Mar. 11, 18:11 UT

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          Minor Planet Center, Smithsonian Astrophysical Observatory,
                          Cambridge, MA 02138, U.S.A.

                   Prepared using the Tamkin Foundation Computer Network

                              MPC@CFA.HARVARD.EDU
          URL http://www.minorplanetcenter.net/    ISSN 1523-6714


                                   2016 EK85

Observations:
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     K16E85K 'C2016 03 09.10109 11 12 47.77 +12 04 29.8          20.1 RtEE122309
     K16E85K 'C2016 03 09.10230 11 12 48.18 +12 04 24.3          19.7 RtEE122309
     K16E85K 'C2016 03 09.10351 11 12 48.58 +12 04 18.9          20.1 RtEE122309
     K16E85K 'C2016 03 09.10471 11 12 48.96 +12 04 13.6          19.9 RtEE122309
     K16E85K 'C2016 03 09.10593 11 12 49.37 +12 04 08.2          19.7 RtEE122309
     K16E85K 'C2016 03 09.10713 11 12 49.75 +12 04 02.9          19.8 RtEE122309
     K16E85K 'C2016 03 09.10834 11 12 50.15 +12 03 57.5          19.9 RtEE122309
     K16E85K* C2016 03 10.33087 11 19 05.45 +10 44 47.9          20.4 VqEE122G96
     K16E85K  C2016 03 10.33396 11 19 06.12 +10 44 38.3          20.2 VqEE122G96
     K16E85K  C2016 03 10.34013 11 19 07.43 +10 44 18.9          20.2 VqEE122G96
     K16E85K  C2016 03 10.36597 11 19 12.87 +10 42 59.6          20.5 RoEE122926
     K16E85K  C2016 03 10.37038 11 19 13.83 +10 42 45.8          20.5 RoEE122926
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     K16E85K  C2016 03 10.42497 11 19 25.51 +10 39 51.4          21.1 VqEE122I52
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     K16E85K  C2016 03 11.46941 11 23 12.19 +09 53 09.3          21.3 VqEE122G96
```

VST

LT

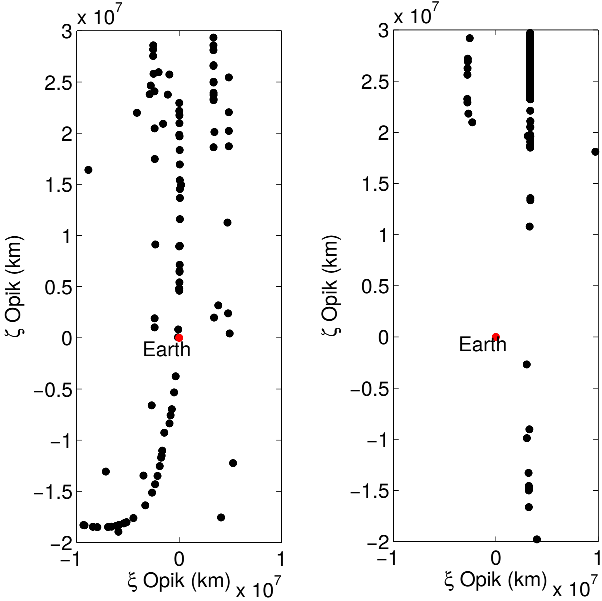
Past situation

- 48 observations (28 GBOT observations, covering 2 days)
- **Semi-major axis**: 2.482 au.
- **Possible impacts** with the Earth in 2102 and 2106.

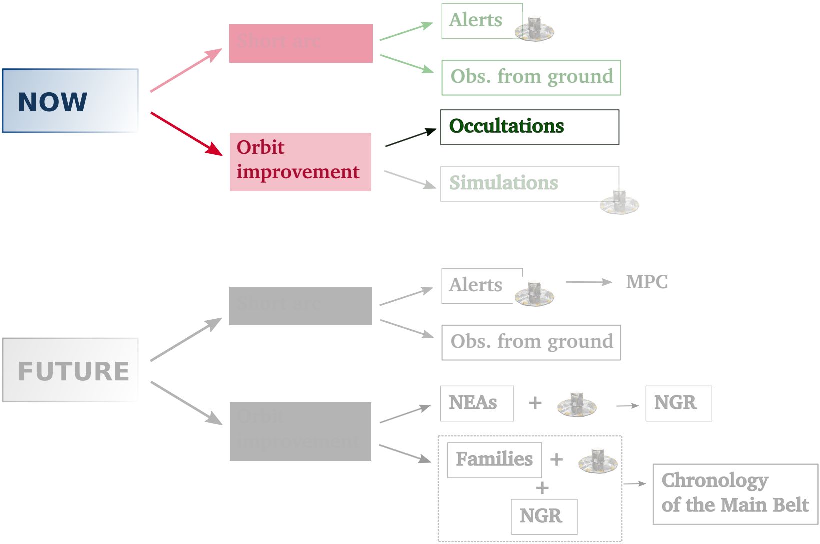
Current situation

- 74 observations, covering 27 days.
- **Semi-major axis**: 2.497 ± 0.005 au.
- **Removed** from the risk list (2016/03/23) after Mauna Kea observations.

The case of 2016 EK_{85} : the LoV



Occultations



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Orbit improvement

Alerts → MPC

Obs. from ground

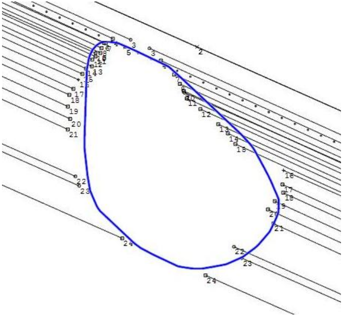
NEAs + → NGR

Families + + NGR → Chronology of the Main Belt

Occultations by asteroids

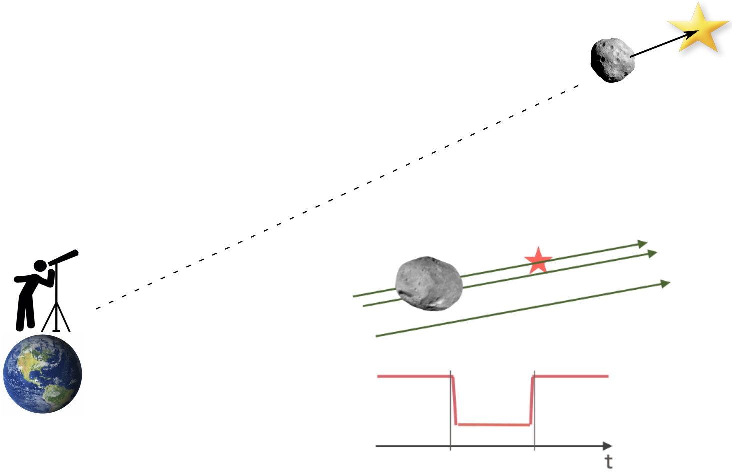
An occultation is an event that occurs when one object is hidden by another object that passes between it and the observer.

An occultation by an asteroid occurs when the asteroid passes in front of a star, temporarily blocking its light as seen from Earth.

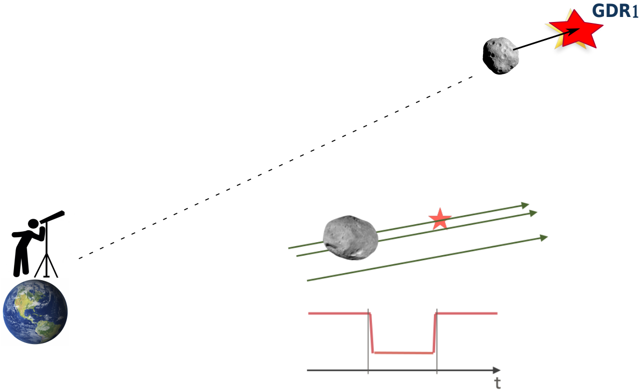


- Measuring size and position of asteroids.
- Precise occultation timing provide the asteroid position at the same level of accuracy of the occulted star astrometry.
- **Is it possible to fit a good orbit using occultations only?**

Occultations

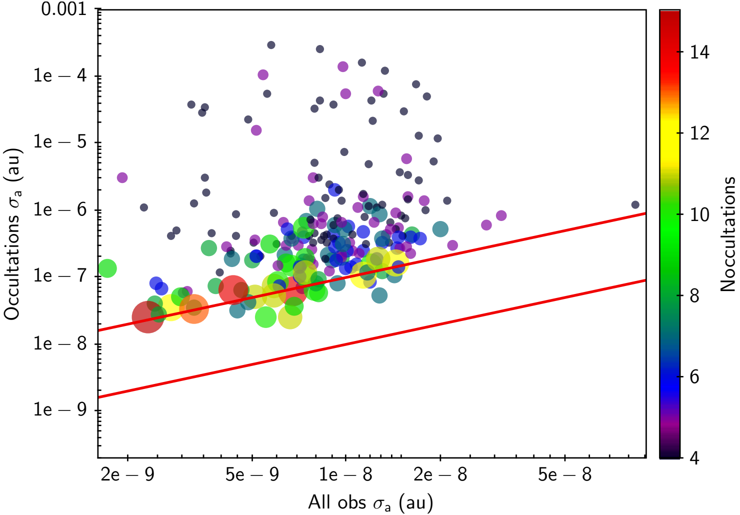


Occultations

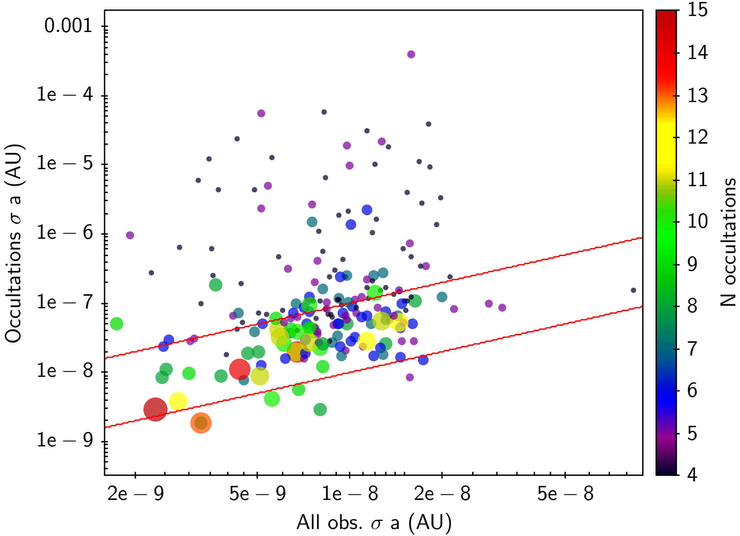


Stars in GDR1 → Re-reduction of occultation astrometry → Orbit determination with occultations

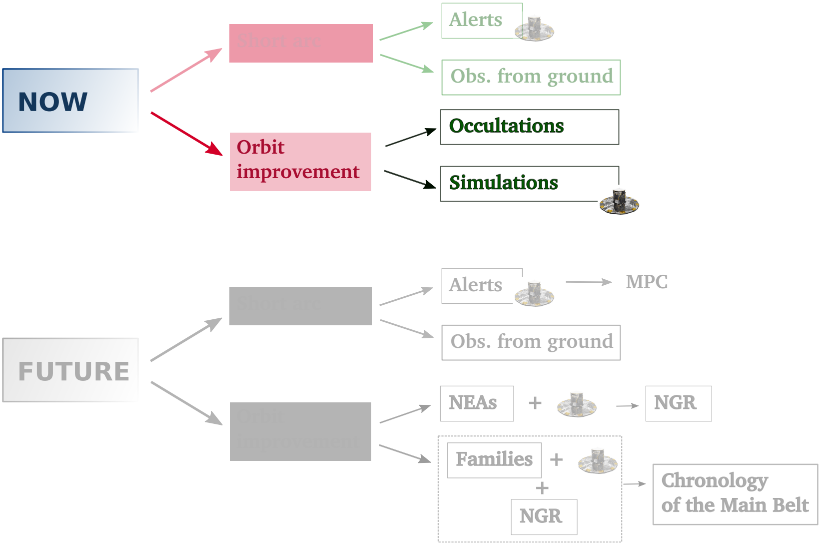
Occultations: before GDR1



Occultations: after GDR1



Simulations



NOW

Short arc

Alerts

Obs. from ground

Orbit improvement

Occultations

Simulations

FUTURE

Short arc

Alerts → MPC

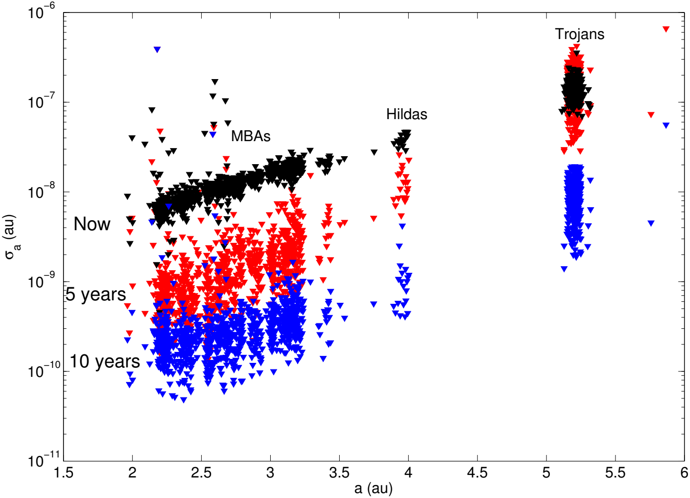
Obs. from ground

Orbit improvement

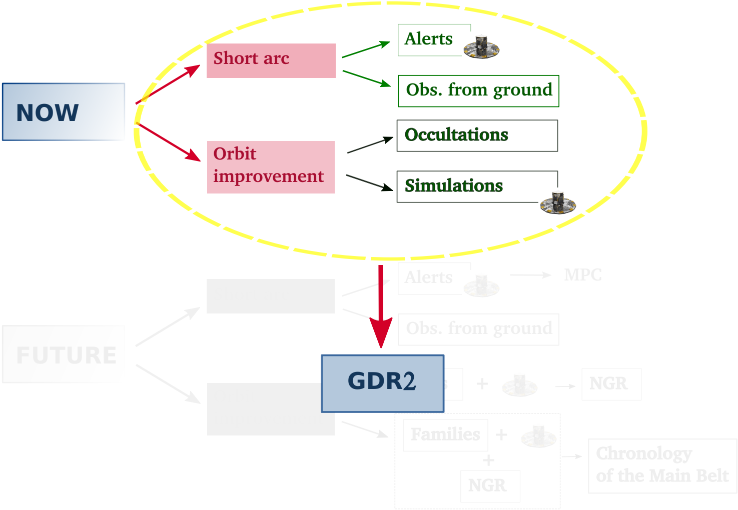
NEAs + → NGR

Families + + NGR → Chronology of the Main Belt

Orbit improvement



Outline - GDR2



NOW

Short arc

Orbit improvement

Alerts

Obs. from ground

Occultations

Simulations

GDR2

FUTURE

Alerts

MPC

Obs. from ground

+

NGR

Families

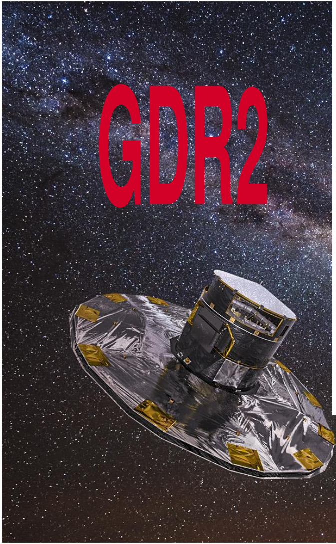
+

+

NGR

Chronology of the Main Belt

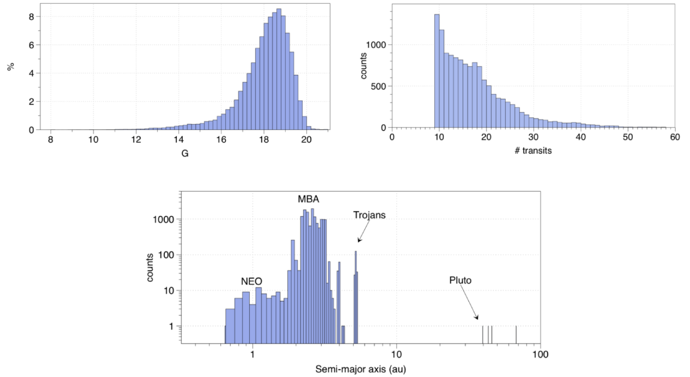
Save the date! / Réservez la date!



April 2018

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30					

Selection for GDR2

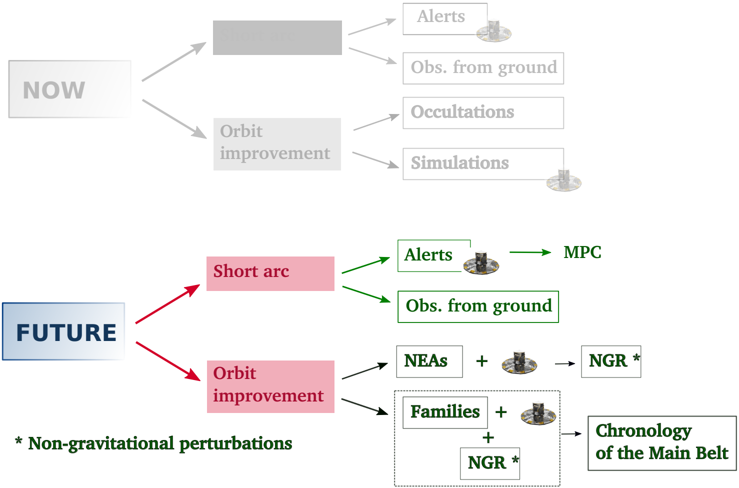


F. Mignard, OCA

- **Asteroid astrometry, per epoch, for well-known asteroids ($\sim$ 10000)**
- CCD level

To infinity and beyond

To infinity and beyond



NOW

Short arc

Alerts

Obs. from ground

Orbit improvement

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FUTURE

Short arc

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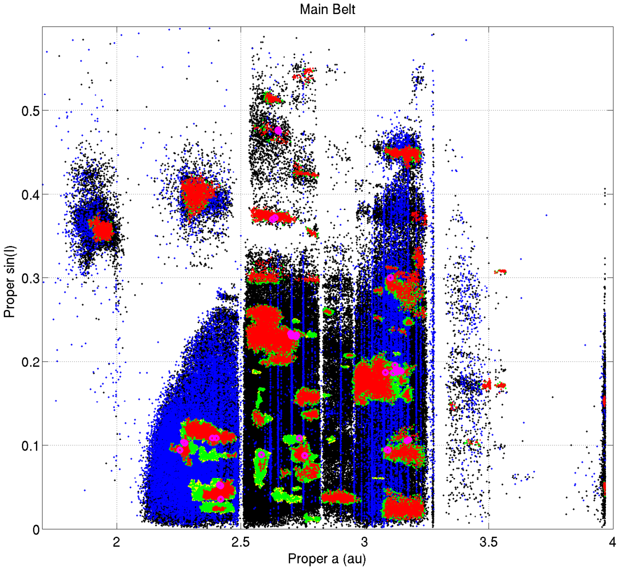
Orbit improvement

NEAs + → NGR *

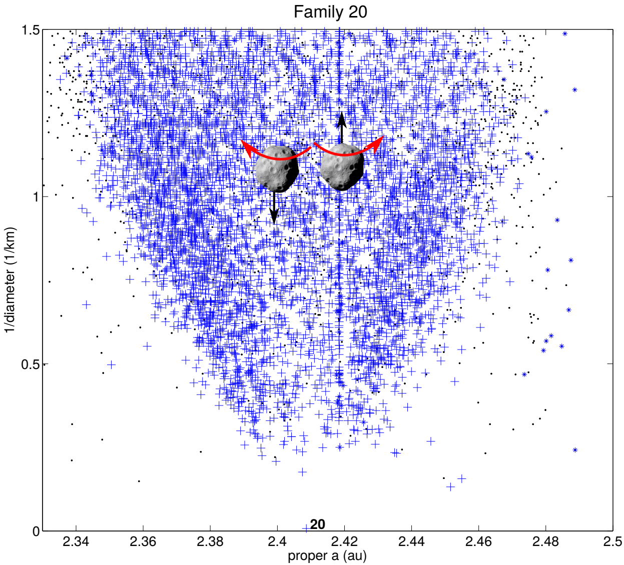
Families + + NGR * → Chronology of the Main Belt

* Non-gravitational perturbations

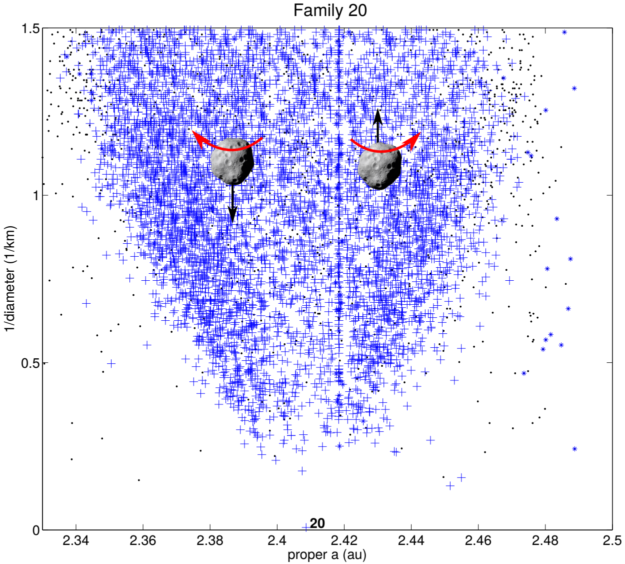
Asteroid families



V-shape


Family 20
1.5
1
0.5
0
1/diameter (1/km)
2.34
2.36
2.38
2.4
2.42
2.44
2.46
2.48
2.5
proper a (au)
20

V-shape



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2.34
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2.46
2.48
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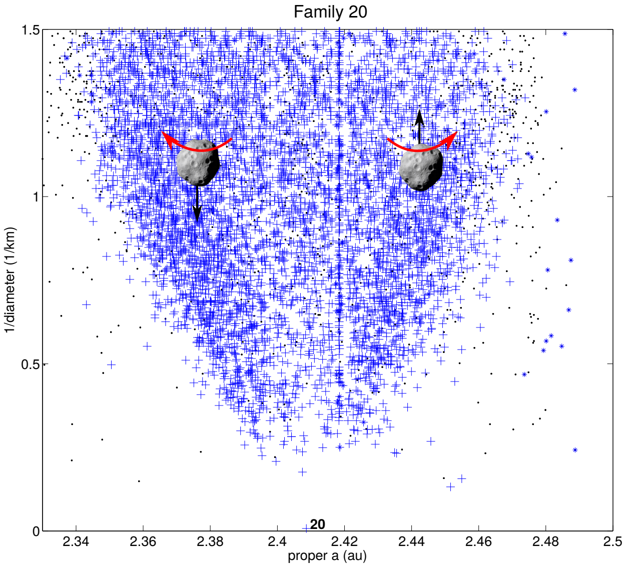
proper a (au)
20

V-shape


Family 20
1/diameter (1/km)
proper a (au)
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2.36
2.38
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2.42
2.44
2.46
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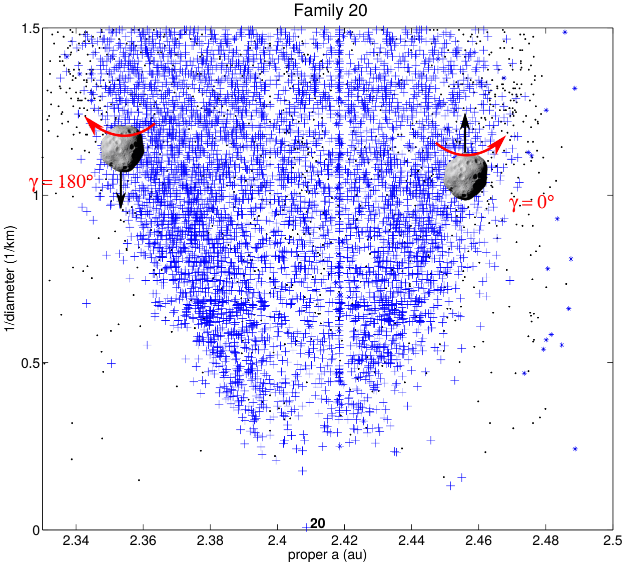
20

V-shape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1.5
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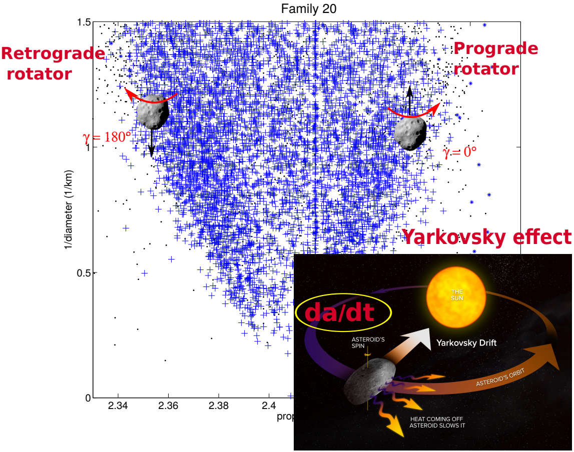
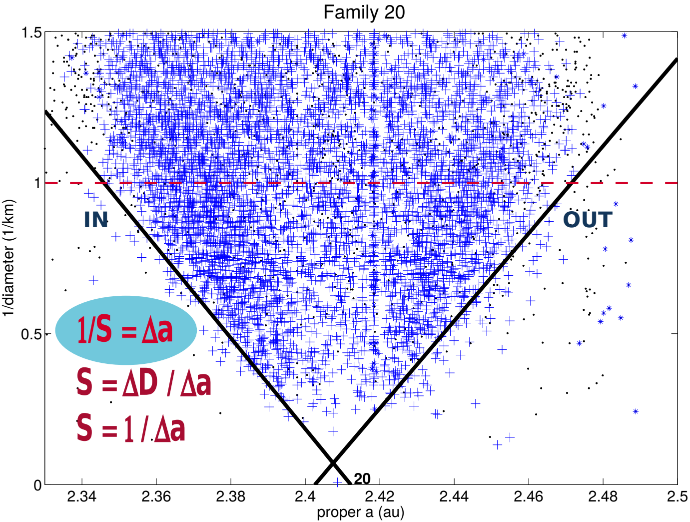
0.5
0
1/diameter (1/km)
2.34
2.36
2.38
2.4
2.42
2.44
2.46
2.48
2.5
proper a (au)
20
γ = 180°
γ = 0°

V-shape and Yarkovsky effect



- Typical values: $10^{-3} - 10^{-4}$ au/Myr
- Proportional on $1/D$
- **Unknown physical quantities**

Age computation

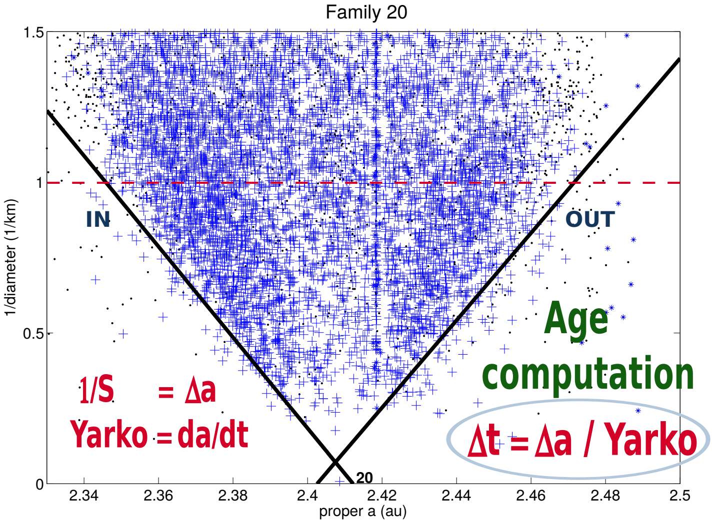


$1/S = \Delta a$

$S = \Delta D / \Delta a$

$S = 1 / \Delta a$

Age computation



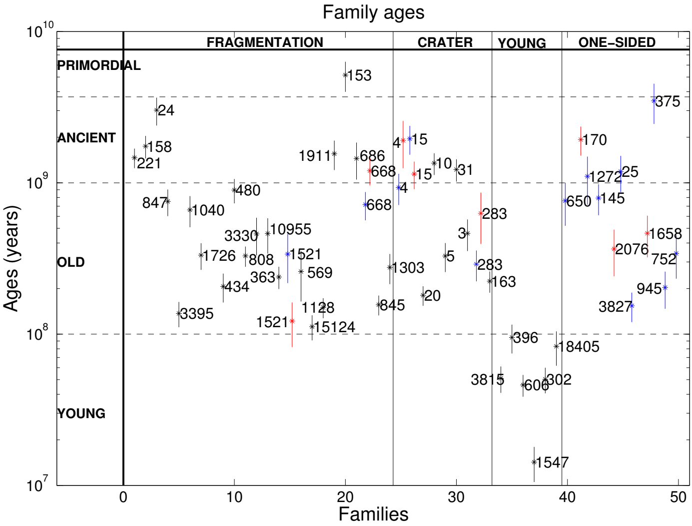
Age computation

1/S = Δa

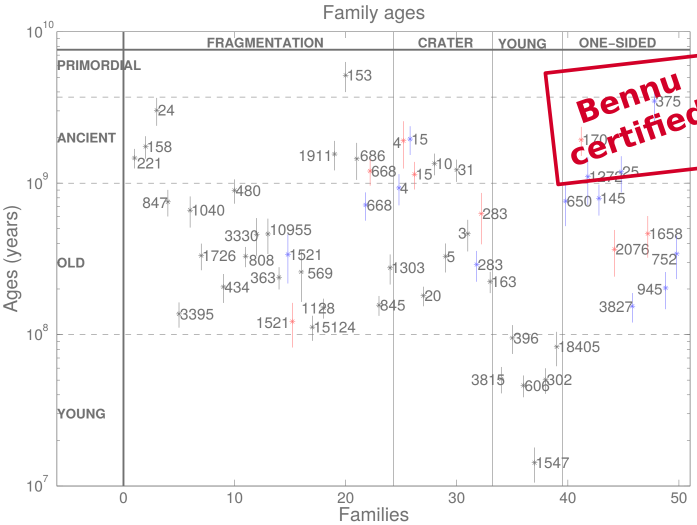
Yarko = da/dt

Δt = Δa / Yarko

Chronology of the Main Belt

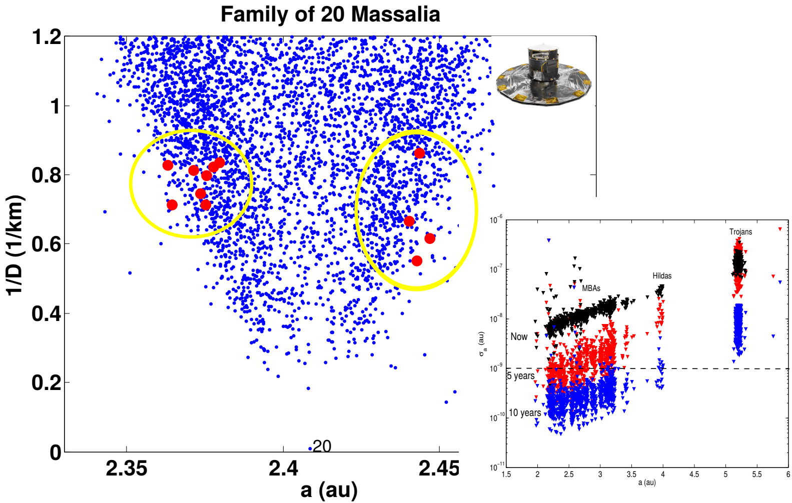


Chronology of the Main Belt

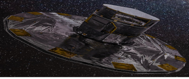


Bennu certified

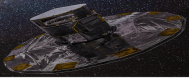
Gaia and the Chronology



Almost done



Conclusions



- **Alerts work**, but we need **more follow-up**
- **GDR1**: the accuracy is $\sim 20/30$ mas, but we know we **can do better**
- **Occultations** can be used for the astrometry which will have the same **precision of the stars**
- **Orbit improvement** due to Gaia will be crucial in the next years:
  - Computation of non-gravitational perturbations (Yarkovsky effect)
  - Chronology of the Main Belt

Enjoy GDR2 and following...

Thank you!

esa

gaia