99942 Apophis : Gaia-FUN-SSO campaign

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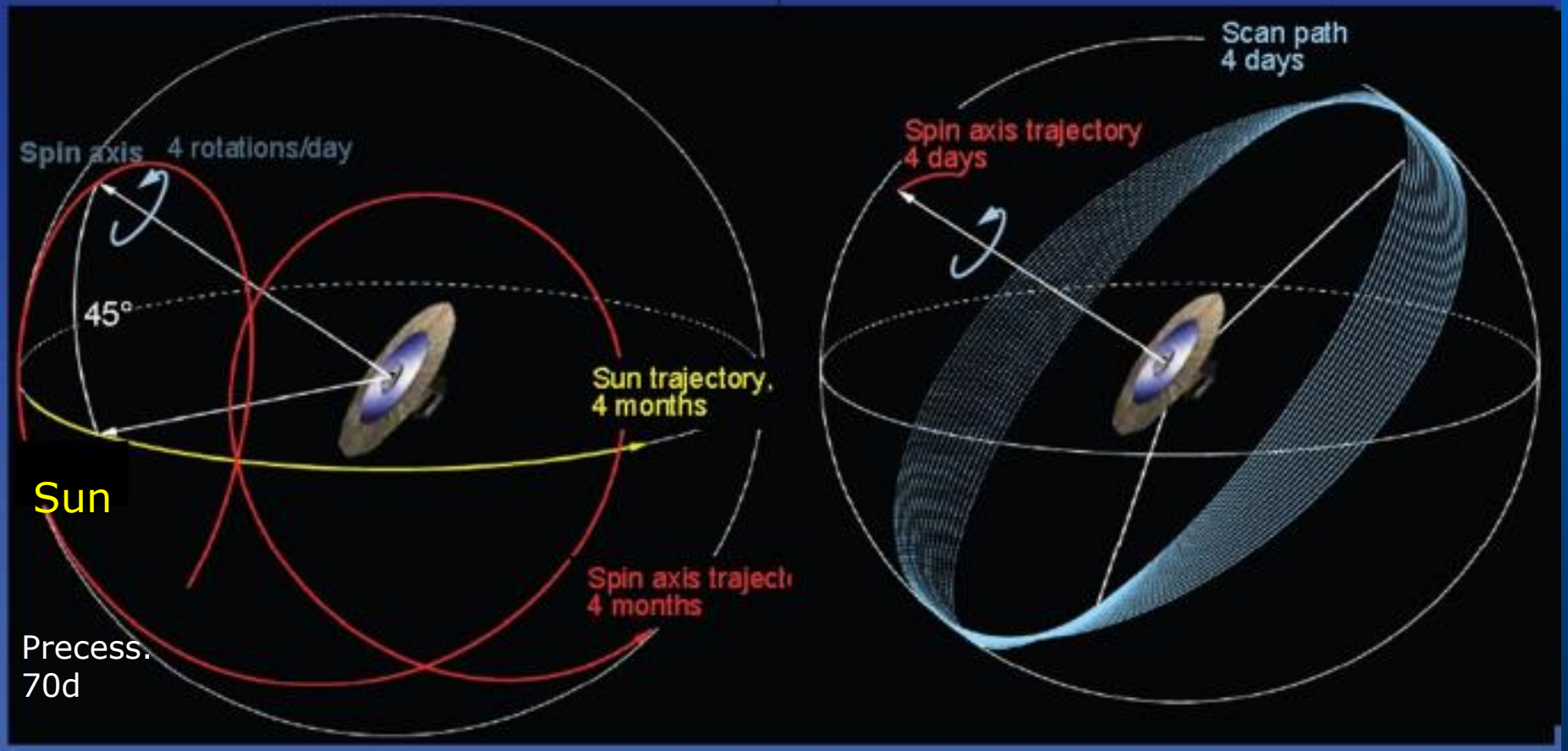
Gaia and the NEAs

- Gaia launch 19 December 2013
- Solar System Objects will be observed
- > 300 000 asteroids
- Detection of NEAs
- Scanning mode of observation
- Alerts will be triggered
- Ground-based network required

The scanning law

Rotation axis movement

Scan path in 4 days

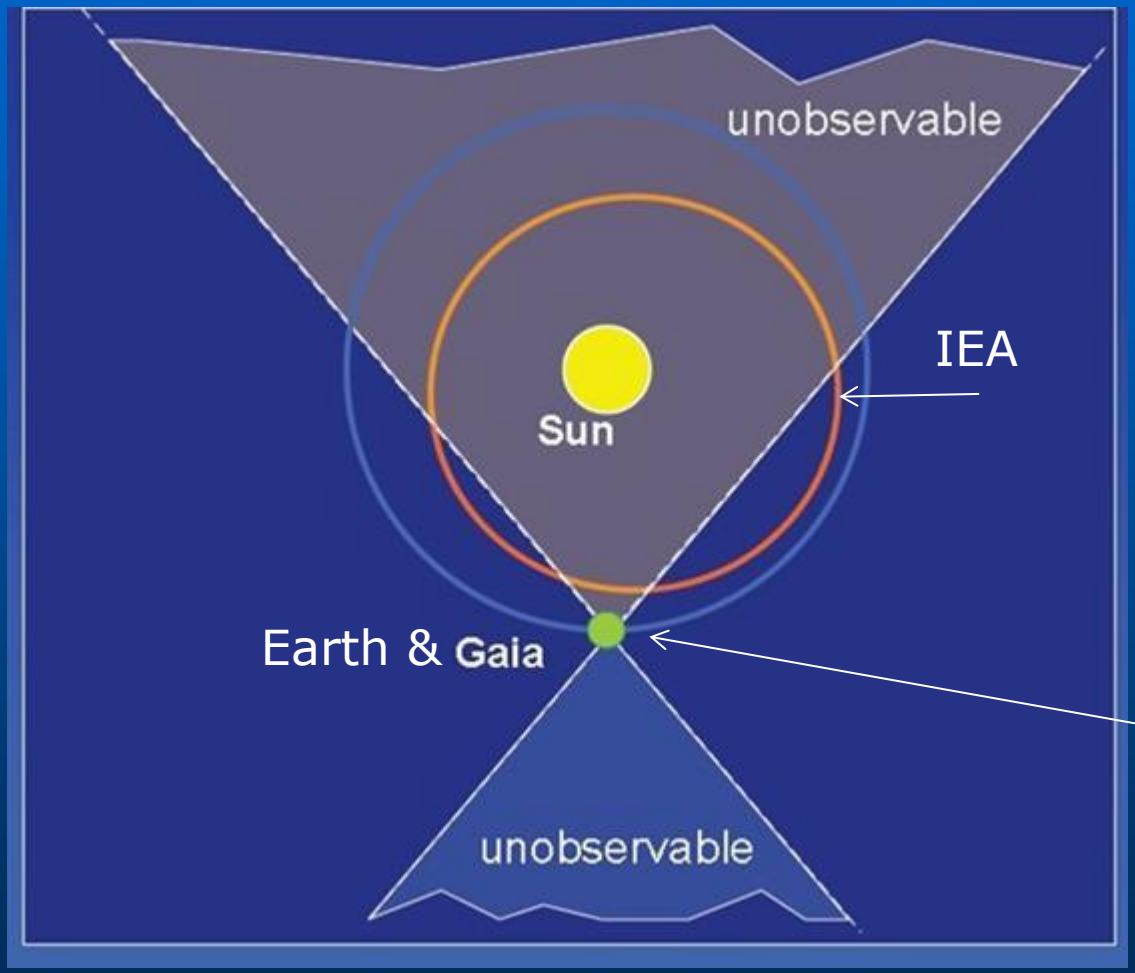


Sun

Precess.
70d

Figure courtesy Karen O'Flaherty

Observable region in ecliptic



Gaia will observe at low Solar elongation ~ 45 deg.

Detection of Inner Earth Asteroids possible

Earth
+ Gaia at L2
(1.5 Mkm)

Need of ground-based observations for Gaia

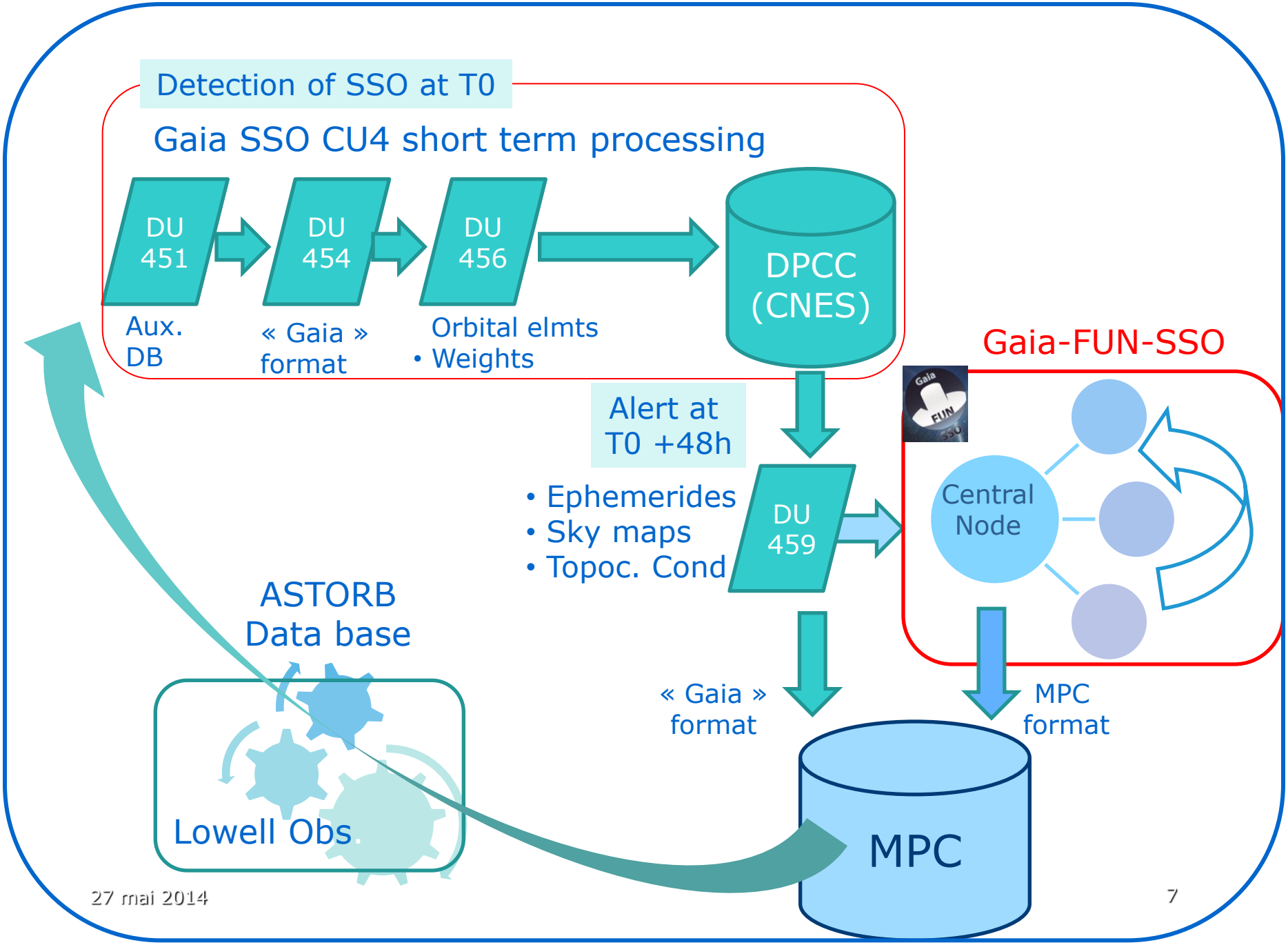
3 ground-based networks

✓ GBOT network: Ground Based Optical Tracking for Gaia observation of the probe itself in order to guarantee the best orbital positionning. No alert – astrometry of the probe

✓Science alerts network: GREAT activity for complementary ground-based observation of transients. Photometric & spectroscopic alerts ➔5th GREAT workshop in Warsaw - September 2014

✓Gaia-FUN-SSO : Gaia Follow-Up Network for ground-based observation of peculiar/critical Solar System Objects

➔ astrometry alerts for Solar System Objects


Detection of SSO at T0
Gaia SSO CU4 short term processing
DU 451
DU 454
DU 456
DPCC (CNES)
Aux. DB
« Gaia » format
Orbital elmts
• Weights
Gaia-FUN-SSO
Alert at T0 +48h
• Ephemerides
• Sky maps
• Topoc. Cond
DU 459
Central Node
ASTORB Data base
Lowell Obs.
« Gaia » format
MPC format
MPC

Gaia-FUN-SSO


Nunaat (Greenland)
Ísland (Iceland)
Suomi (Finland)
Sverige (Sweden)
Norge (Norway)
Россия (Russia)
Canada
United Kingdom
España (Spain)
Italia (Italy)
Казахстан (Kazakhstan)
Монгол Улс (Mongolia)
中国 (China)
日本 (Japan)
South Korea
North Atlantic Ocean
México (Mexico)
States
الجزائر (Algeria)
ليبيا (Libya)
مصر (Egypt)
العراق (Iraq)
ایران (Iran)
افغانستان (Afghanistan)
پاکستان (Pakistan)
السعودية (Saudi Arabia)
India
ประเทศไทย (Thailand)
Mali
Niger
تشاد Tchad (Chad)
السودان (Sudan)
Nigeria
ኢትዮጵያ (Ethiopia)
Venezuela
Colombia
Kenya
DR Congo
Tanzania
Indonesia
Papua New Guinea
Perú (Peru)
Brasil (Brazil)
Bolivia
Angola
Namibia
Madagasikara (Madagascar)
Indian Ocean
South Atlantic Ocean
South Africa
Australia
Argentina
New Zealand
Registered
Not confimed
In project

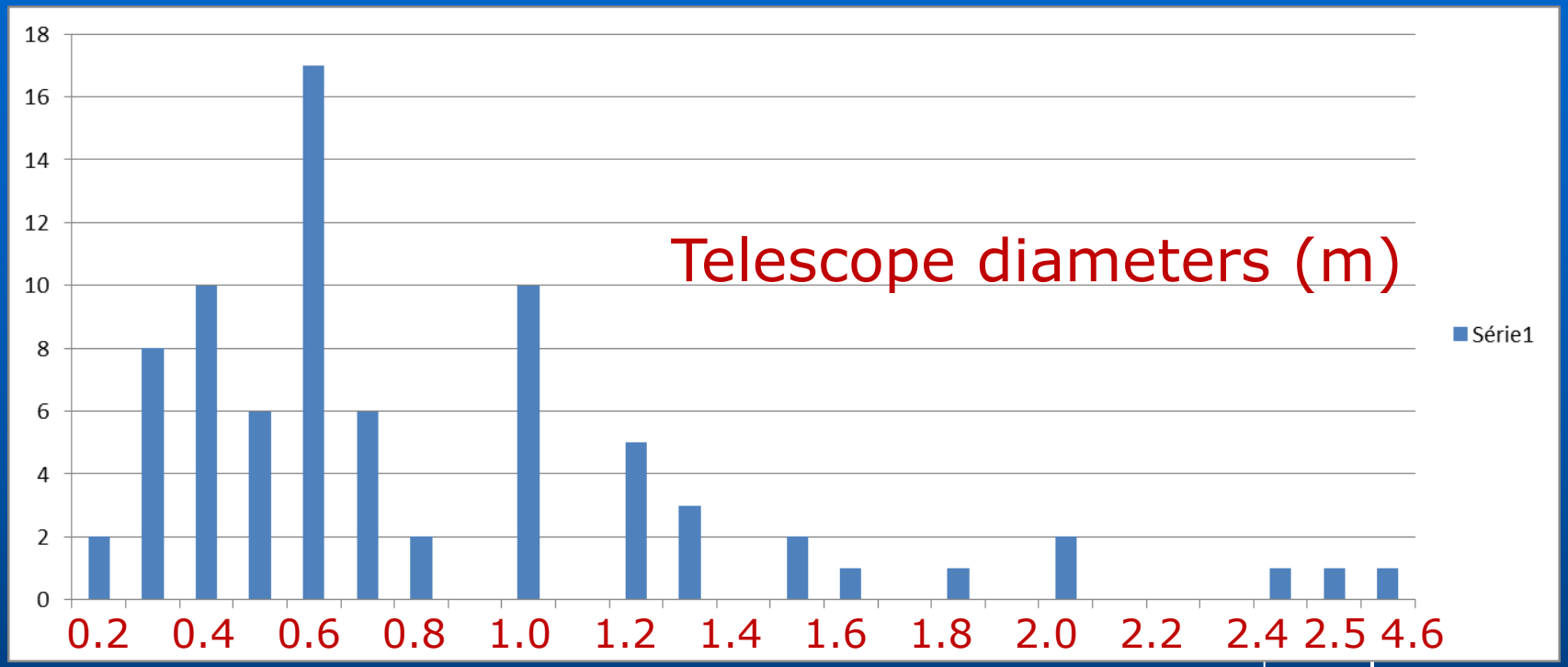
Gaia-FUN-SSO

- 54 observing sites
- 75 operating instruments
- Volunteering base
- Wiki https://www.imcce.fr/gaia-fun-sso/
- Pipeline + web (starting from June 2014)

- Major part : 0.6 & 1m-class
- 6 Schmidt tel. :

  Rozhen / Xuyi / Konkoly / Tatenburg / Kourovskaya / Xinlong
- 4 robotic tel. : Tarot 1 & 2 / Zadko / ESA-OGS
- 2 remote tel. : NM-Mayhill / Tubitak

Gaia-FUN-SSO



Tarot 1 & 2

- MPC 071-NAO Rozhen, Smolyan, (Bulgaria)

- MPC B18 Terskol Russia

MPC O44
Yunnan Observatory
Lijiang station (China)

+ Target of Opportunity on:
ING-WHT/IAC
Roque de los Muchachos Obs.,
Isaac Newton Group
+2.5m
+ 4.2m

Gaia-FUN-SSO

- Training campaigns

- 2005 YU55: 15 nov. 15 dec. 2011
- 1996 FG3: Feb. – March 2012
- 99 942 Apophis: Feb.-March 2012
- 99 942 Apophis: Dec. 2012 - Apr. 2013
- 2012 DA14: Feb. – March 2013
- 2002 GT June -Aug. 2013
- 2013 TV135: oct. 2013 –Jan. 2014
- 2007 HB15 : Apr. 2014
- 2014 HQ124: June 2014 (triangulation)

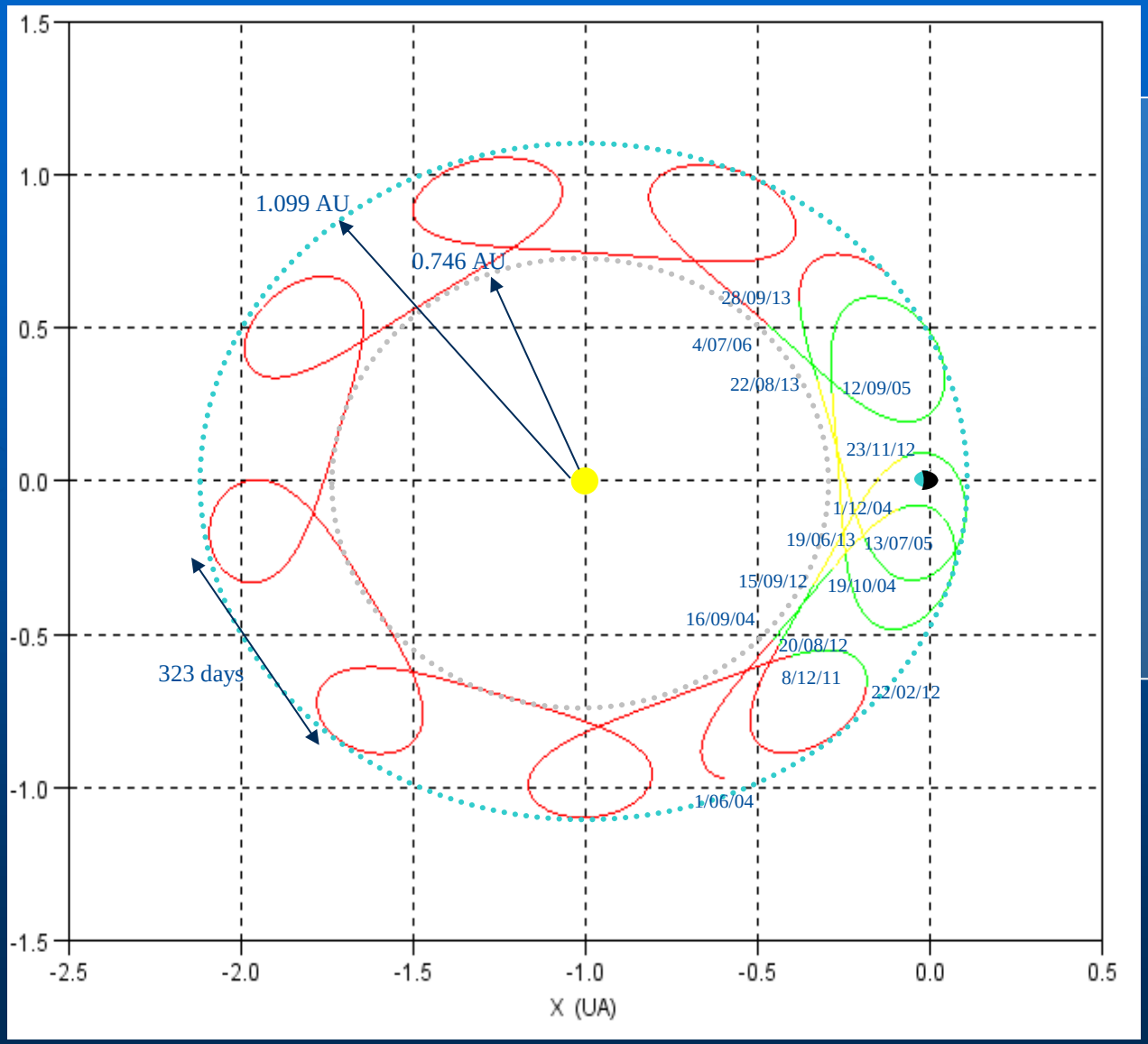
Gaia-FUN-SSO

- Apophis campaigns

- 99 942 Apophis: Feb.-March 2012
- 99 942 Apophis: Dec. 2012 - Apr. 2013

- Impact probability studies
- Gravitational effects during close approaches
- Tumbling asteroid (Pravec et al, 2014)
- Yarkovsky effect on orbit
- 2029 close app.: space missions (CNES WG: APEX project)

99 942 APOPHIS: Observation possibilities for the 2004-2013 time frame



Not visible from the Earth

Distance < 0.7 AU
but solar elongation <45°

Visible from the Earth

Dates format day/month/year

APOPHIS trajectory plotted in an Earth-Sun rotating frame (courtesy J.Y. Prado)

Apophis campaign

- Increasing length of orbital arc => accuracy improvement

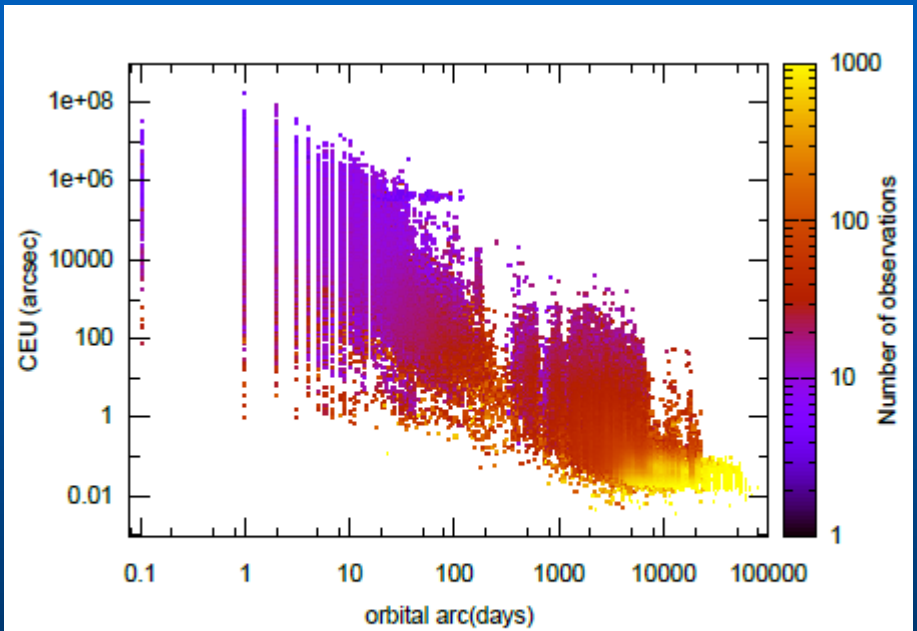


Fig. 4. Relation between the length of the orbital arc, CEU and the number of observations for all asteroids.

Desmars et al., 2013

Apophis campaign

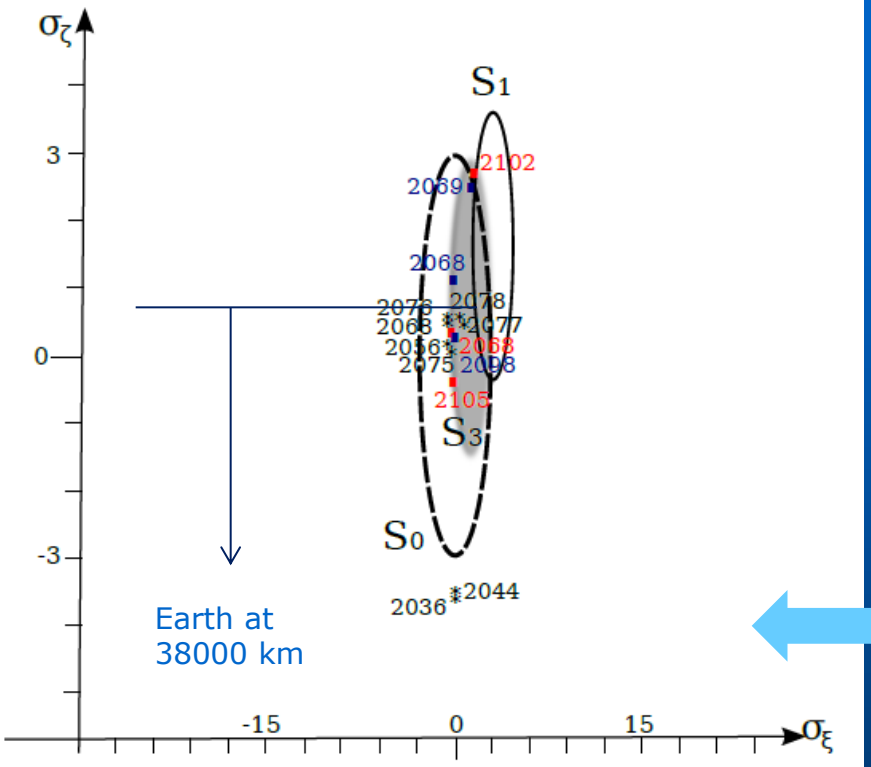


Fig. 2. 2029-b-plane of Apophis. The dotted 3σ ellipse is computed using solution S_0. The solid 3σ ellipse is computed using solution S_1 and the blurred one with solution S_3. For completeness, the center of primary (★) and secondary keyholes leading to collision at ascending node (■) and descending node (■) are also represented. The figure is centered on the dotted ellipse and axis are expressed in sigma units of the S_0 solution.

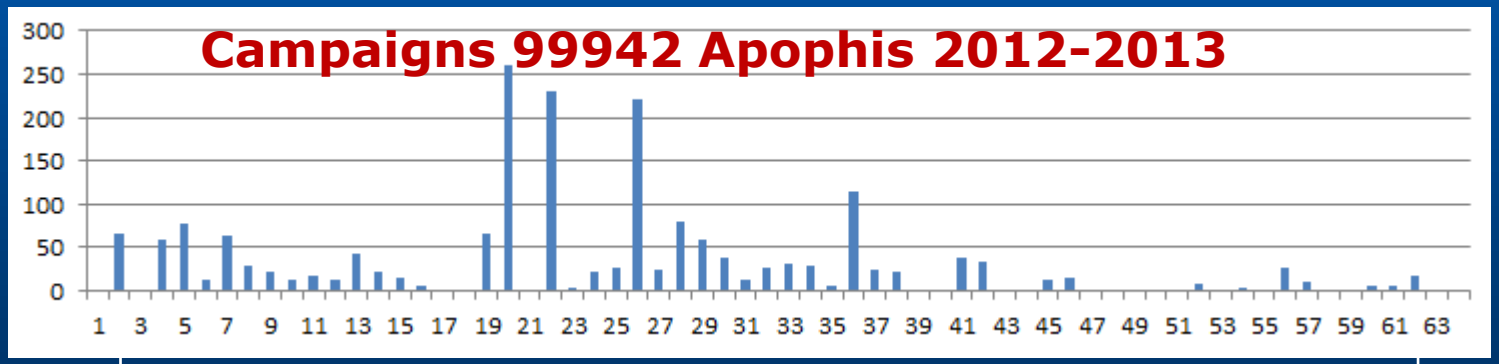
PHA (2004 MN4 / 99 942)

Mueller et al, 2014
Diam.: 375 m
Albedo 0.33
Mass 4.4-6.2 10^6 kg

- Bancelin et al., 2012
- 2029 b-plan
- Impact of astrometry
- Uncertainty ellipse
- Size + position
- Keyholes

Apophis campaigns : new results

- Gaia-FUN-SSO campaign (Feb-March 2012 + Dec. – Apr. 2013)
- Thuillot, Bancelin , Eggl, Desmars et al., 2014, to be submitted
- 19 observing sites
- Collecting images => Homogenous astrometric reduction
- PRAIA software (Valongo obs., Brazil)
- 2700 astrometric observations (major part not yet in MPC database)



14/12/2012

13/3/2013

Apophis campaign

MPC code	Observatory	Country	Tel. diam. m.	FOV arcmin	pixel arcsec.
010	C2PU telescope Cote-d'Azur obs.	France	1.00	40x40	0.17
071	NAO Rozhen institute of astronomy	Bulgaria	0.70	73.7x73.7	1.08
089	Nikolaev astronomical obs.	Ukraine	0.50	42x42	0.84
119	Abastunami obs.	Georgia	0.70	45x30	0.87
188	Maidanak obs.	Uzbekistan	1.50	18x18	0.21
300	Bisei Spaceguard center	Japan	1.00	72x139	1.06
511	Haute-Provence obs.	France	1.20	12x12	0.68
585	Astronomical obs. of Kyiv university	Ukraine	0.70	17x17	0.95
586	Pic-du-Midi observatory	France	1.05	8x8	0.44
950	Isaac Newton telescope	Canaries Isl., Spain	2.50	34x34	0.33
A84	TUBITAK obs.	Turkey	1.00	21.5x21.5	0.39
B04	OAVdA	Italy	0.81	16.5x16.5	0.96
B17	Evpatoria obs.	Ukraine	0.70	45x45	1.76
B18	Terskol obs.	Russia	0.80	10.7x10.7	1.24
C01	Lohrmann obs.	Germany	0.60	51.4x51.4	0.75
C20	Kislodov station of Pulkovo obs.	Russia	0.50	21x21	1.19
D20	Zadko obs.	Australia	1.00	23.5x23.5	1.38
O44	Lijiang station Yunnan obs.	China	2.40	9x9	0.28
Z20	Mercator telescope	Canaries Isl., Spain	1.20	9.4x14.1	0.55

Apophis campaign

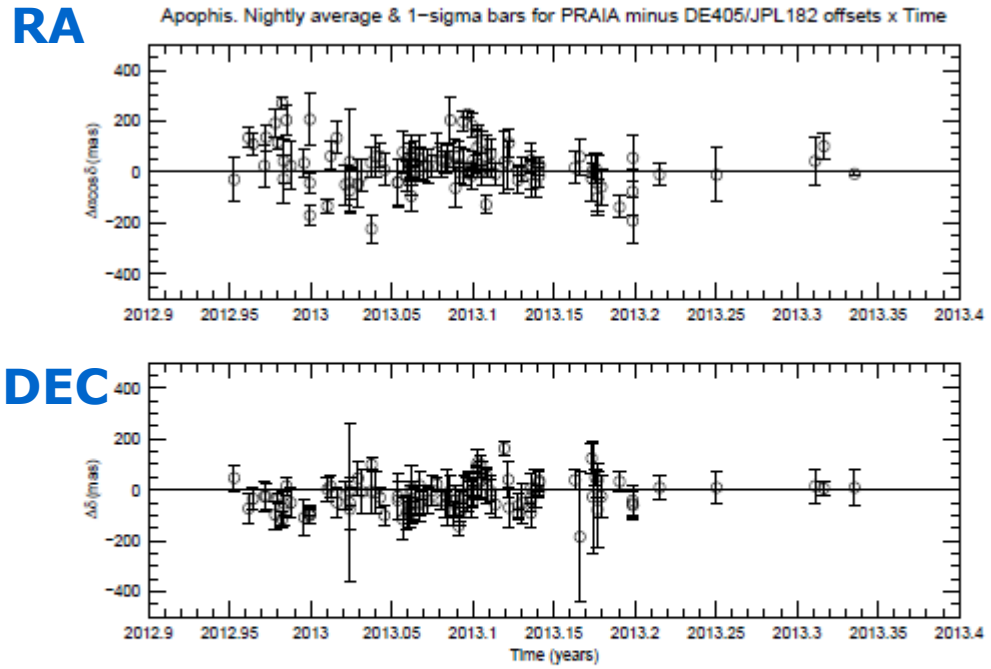


Fig. 1. Nightly average and 1 sigma bars for PRAIA measures minus DE405(JPL182) offsets in right ascension and declination versus time

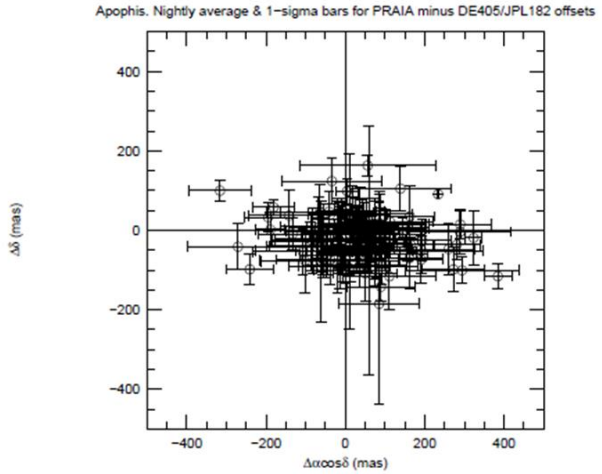


Fig. 2. Nightly average and 1 sigma bars for PRAIA measures minus DE405(JPL182) offsets in right ascension and declination

Apophis campaign

Preliminary results

Table 2. Astrometric information about the (α, δ) reductions for each observatory set.

IAU code	S. D. to JPL σ_α mas	S. D. to JPL σ_δ mas	No. nights	No. pos.	UCAC4 stars	Mean errors σ_α mas	Mean errors σ_δ mas
010	48	49	1	137	94	61	63
071	69	53	11	114	1336	57	56
089	101	137	5	80	540	56	62
119	99	64	2	7	621	59	58
188	85	52	1	22	20	52	52
300	48	34	4	13	528	60	60
511	43	50	1	7	83	56	53
585	69	63	3	15	180	57	56
586	58	59	6	960	36	63	66
950	47	25	1	5	24	72	50
A84	23	29	15	154	155	57	55
B04	227	210	4	22	110	60	62
B17	39	34	6	22	738	63	64
B18	67	71	4	126	71	60	58
C01	68	186	2	7	1822	58	62
C20	60	62	18	664	210	61	62
D20	48	46	22	147	247	62	56
O44	27	38	5	70	102	58	60
Z20	48	53	4	160	16	62	62

Mean errors are the r.m.s. in the (O−C) residuals from the (α, δ) reductions with the UCAC4 catalog. S. D. regards to the (α, δ) standard deviations about the nightly average offsets with respect to the JPL reference ephemeris, after the elimination of discrepant positions (see text). Detailed telescope data for each observatory is given in Sect. 2 (Observations).

First step:

- Collecting images
- PRAIA reduction
- Filtering
- Iteration with observers
- Astrometric data base

Further…:

- More on grav. effects
- Non grav. Effects
- Impact of tumbling spin

Apophis campaign

Preliminary results

- $S_1 = [2004\text{-}2014]_{MPC}$ + radar
- $S_2 = [2004\text{-}2014]_{MPC}$ - D_{MPC} + D_{PRAIA} + radar
- $S_3 = S_2 + S_{NEW}$
- $S_4 = S_1 + S_{NEW}$
- $S_5 = S_{NEW} + D_{PRAIA}$ + radar

$[2004\text{-}2014]_{MPC}$: all MPC data

S_{NEW} : New data (2099 obs.)

D_{PRAIA} : Duplicated MPC reduced with PRAIA(627 obs.)

D_{MPC} : MPC data (627 obs.) (various catalogues)

	Total residual (arcsec)	b-plane uncertainty (km)	Δ_i - $\Delta_1(km)$
S_1	0.425	2.994	0
S_2	0.422	2.940	1.5
S_3	0.367	2.423	3
S_4	0.357	2.446	3
S_5	0.386	3.609	4.5

Table 4. Orbital accuracy information – fit residuals and b-plane uncertainty – computed with different sets of observations. We also computed the difference in b-plane distance for each set Delta i with the distance obtained with S i)

Thank you