

Asteroid data mining and precoveries in the Gaia era

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Asteroid data mining and precoveries in the Gaia era

Interest of ancient observations for asteroids?

Improvement of ...

- the orbital elements / ephemerides
- orbital characterization and identification
- observations connection
- predictions of events (stellar occ., ...)
- impact risk assessment (PHAs)

=> Strong interest for NEAs / PHAs science

Asteroid data mining and precoveries in the Gaia era

Outline

- Asteroid database and precision: global overview
- Data mining: what are the possibilities / what impact ?
- The 99 942 Apophis case

Asteroid database and precision: global overview

Asteroid Observations: global overview

From Minor Planet Center (<http://www.minorplanetcenter.net/>)

Astrometric measurements

code	type	number	percentage	timespan
C	CCD	82 849 054	93.74%	1986-2012
S/s	Satellite observation	4 006 902	4.53%	1994-2011
	<i>HST</i>	3 544	0.09%	1994-2010
	<i>Spitzer</i>	114	0.00%	2004-2004
	<i>WISE</i>	4 003 244	99.91%	2010-2011
A	Observations from B1950.0 converted to J2000.0	647 649	0.73%	1802-1999
c	Corrected without republication CCD observation	462 065	0.52%	1991-2007
P	Photographic	352 113	0.40%	1898-2011
T	Meridian or transit circle	26 968	0.03%	1984-2005
X/x	Discovery observation	16 706	0.02%	1891-2010
M	Micrometer	12 081	0.01%	1845-1954
H	Hipparcos geocentric observation	5 494	0.01%	1989-1993
R/r	Radar observation	1 602	0.00%	1968-2006
E	Occultations derived observation	1 571	0.00%	1961-2011
V	"Roving observer" observation	372	0.00%	2000-2010
n	Mini-normal place derived from averaging observations from video frames	93	0.00%	2009-2011
e	Encoder	16	0.00%	1993-1995

J. Desmars et al. 2012 in preparation

Asteroid Observations: global overview

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J. Desmars et al. 2012 in preparation

Asteroid Observations: global overview

From AstDyS-2 (<http://hamilton.dm.unipi.it/astdys/>)

type	name	number of measurement	percentage of accepted measurement	accuracy
C	CCD	73 938 542	99.48%	0.401 arcsec
S	Wise	1 497 360	99.89%	0.579 arcsec
S	Hubble Space Telesc.	867	96.54%	0.577 arcsec
S	Spitzer	48	33.33%	1.672 arcsec
A	B1950 to J2000	631 982	81.68%	1.175 arcsec
c	Corrected CCD obs.	419 070	99.68%	0.509 arcsec
P	Photographic	345 698	93.17%	1.088 arcsec
T	Meridian/transit circle	26 968	99.74%	0.288 arcsec
M	Micrometer	12 081	90.65%	1.896 arcsec
H	Hipparcos obs.	5494	100.00%	0.201 arcsec
E	Occultations	1570	100.00%	0.126 arcsec
R	Ranging	546	95.79%	5.695 km
R	Doppler	401	99.00%	7.128 km/s
V	Roving observer	356	49.72%	0.829 arcsec
e	Encoder	16	100.00%	0.557 arcsec

J. Desmars et al. 2012 in preparation

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J. Desmars et al. 2012 in preparation

Uncertainty parameters

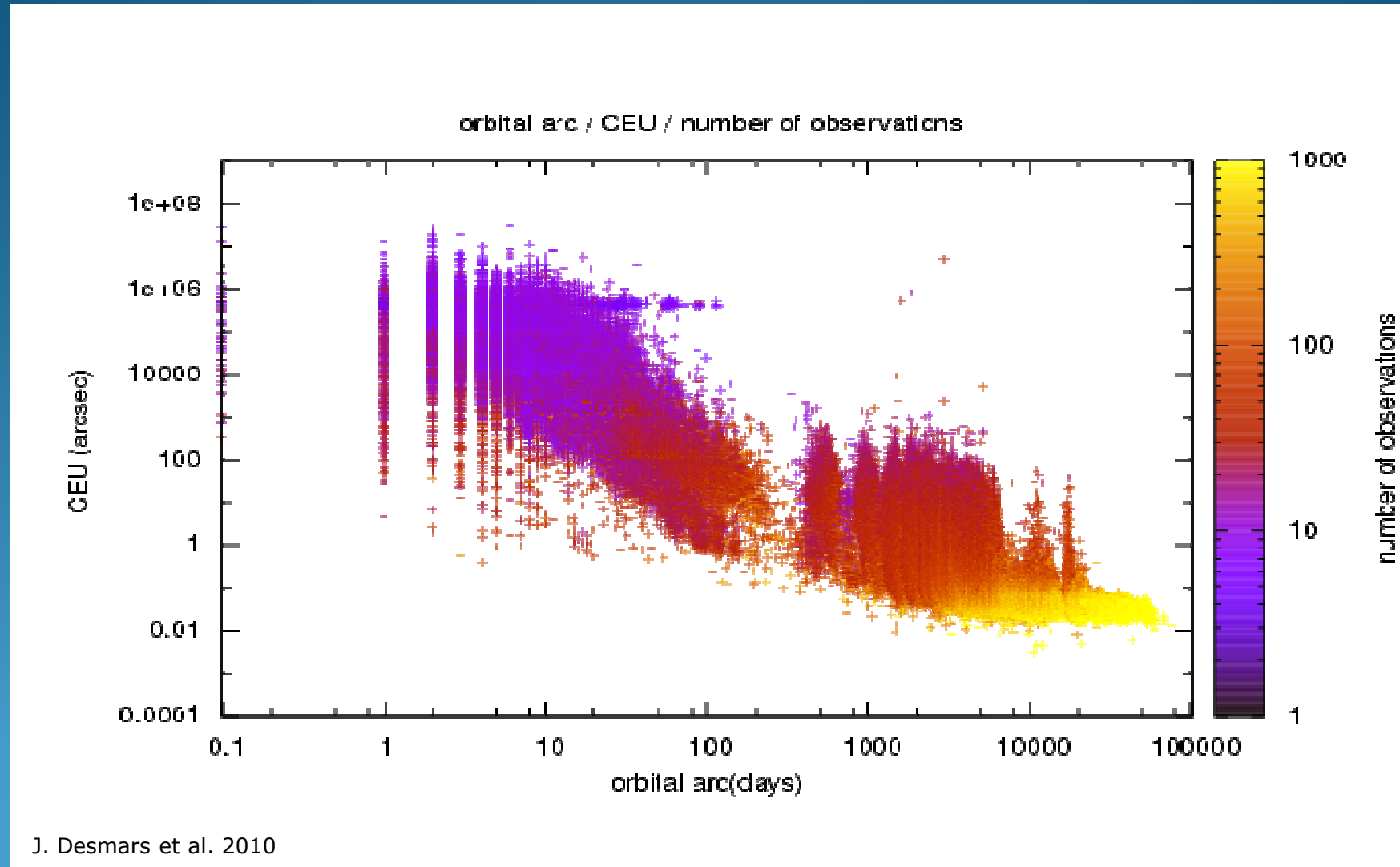
- From Lowell obs. (Bowell E.)
(<ftp://ftp.lowell.edu/pub/elgb/astorb.html>)
- ASTORB database provides five parameters measuring uncertainty

Sky plane
uncertainty at a
given date

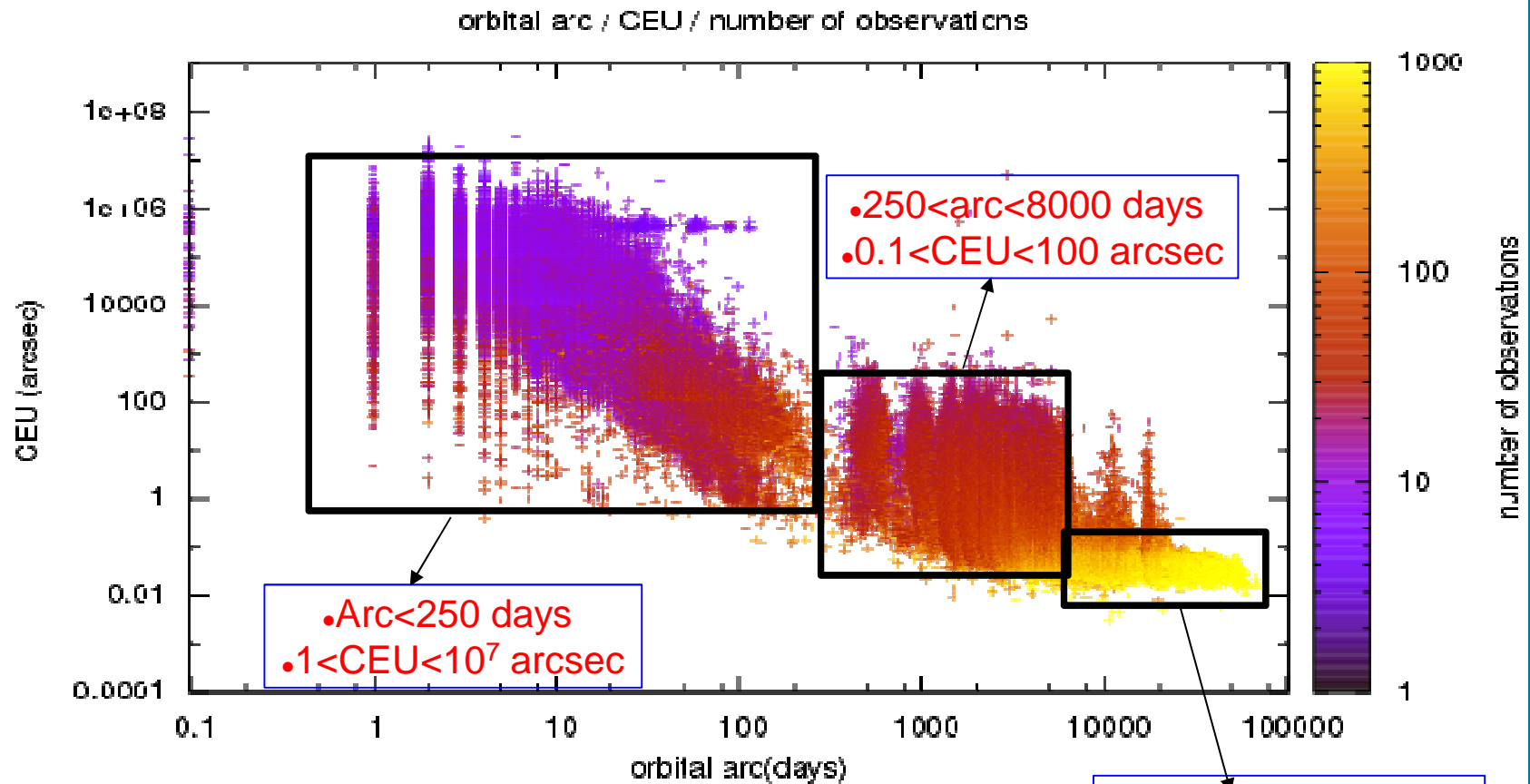


- **CEU** (arcsec): current 1- σ uncertainty
- **CEU rate** (arcsec/day)
- **Date of CEU**
- **PEU** (arcsec) : next peak uncertainty
- **Greatest PEU**: (arcsec) : 2 parameters:
(1):greatest PEU in 10 years from date of CEU
(2): greatest PEU in 10 years from date of PEU

ASTORB data base

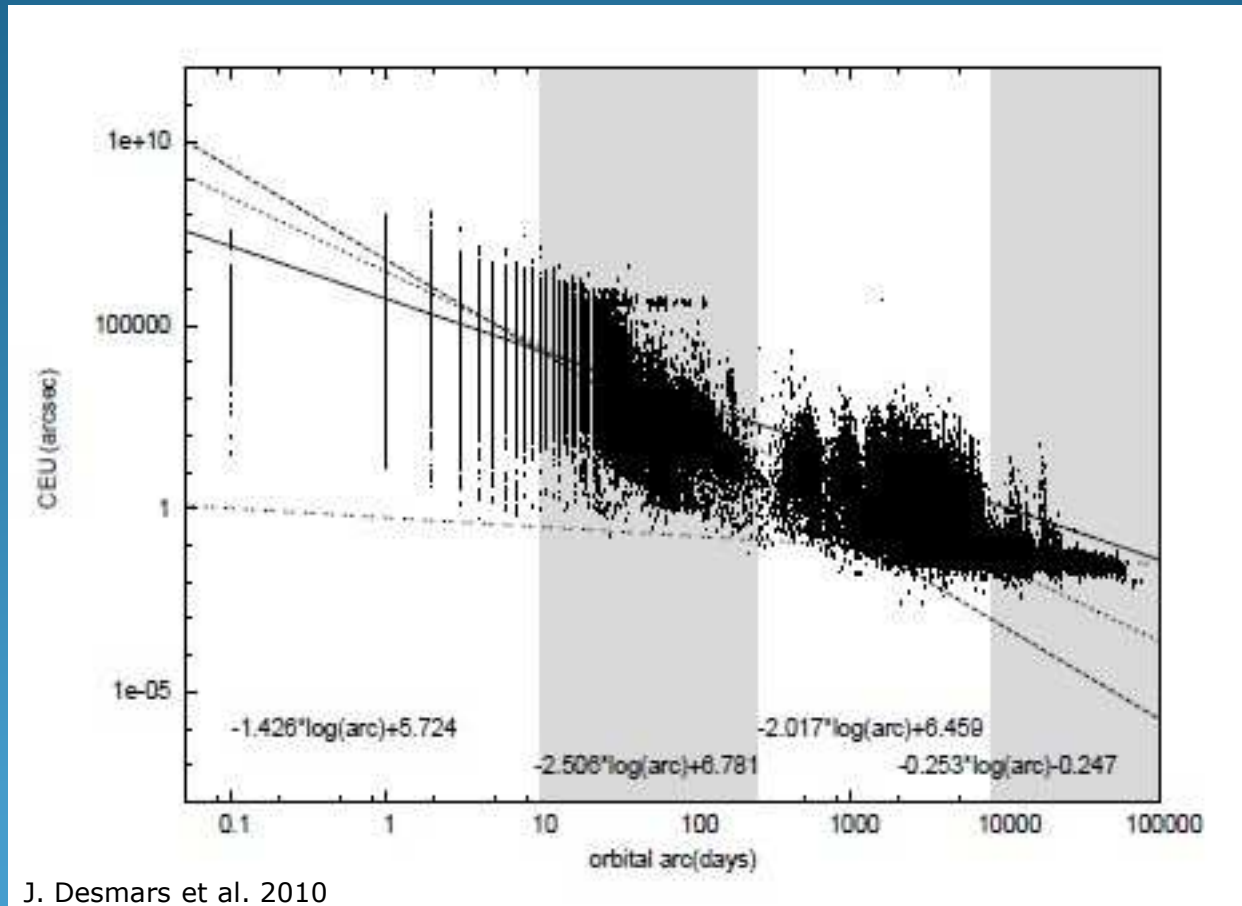


ASTORB data base



J. Desmars et al. 2010

Precision vs. Length of arc



Datamining: what are the possibilities / what impact ?

Data mining

Search for precovery data (pre-discovery recoveries) ?

➤ **Skybot web service (skybot.imcce.fr):**

pre-computed ephemeris (see talks by J. Berthier + M. Birlan)

➤ Different approaches:

✓ Intensive data mining of large source databases

✓ Mining of a survey catalogue > list of new obs. of asteroids

✓ Mining a collection of catalogues > to get astrom. of one peculiar target

➤ **Some limitations** for astrometry (timing, reduction, faintness, metadata,...)

Re-reduction

Method to use for extending the period of observation?

by applying **Re-reduction to:**

- priority objects : PHA, space mission targets,...
- selected CCD frames
- selected digitized photographic plates



- ✓ The best stellar astrometry possible
=> the best accuracy of asteroid positioning
- ✓ Impact of the future Gaia catalogue?



http://www.minorplanetcenter.net/

99 942 Apophis Discov.: 2004 June 19

MPCObs
Datamining
6 obs in
2004 March

June 20-22, 2012

MPC Operations Status

- Observer Services (NEOs)
 - NEO Services Overview
 - NEO Confirmation
 - NEO Confirmation (RA order)
 - NEO Ratings
 - NEO Page
 - NEO Observation Planning Aid
 - NEOChecker
 - NEOCMChecker
 - NEOCP Blog
- Observer Services
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 - Minor Planet & Comet Ephem.
 - Natural Satellite Ephemerides
 - New Object Ephemerides
 - MPCChecker
 - CMTChecker
 - Distant Artificial Satellites
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(99942) Apophis = 2004 MN4

Discovered at Kitt Peak on 2004-06-19 by R. A. Tucker, D. J. Tholen, and F. Bernardi.
(99942) Apophis = 2004 MN4

Also known as Apep, the Destroyer, Apophis is the Egyptian god of evil and destruction who dwelled in eternal darkness. As a result of its passage within 40 000 km of the earth on 2029 Apr. 13, this minor planet will move from the Aten to the Apollo class. [Ref: *Minor Planet Circ.* 54567]

Orbit

Orbit type: Aten
Potentially Hazardous Asteroid
Critical list numbered object.

Interactive Orbit Sketch Note: WebGL enabled browsers only (e.g. Firefox, Safari, Chrome, Opera), but not IE.

epoch	2012-03-14.0	semimajor axis (AU)	0.9222957	uncertainty	0
epoch JD	2456000.5	mean anomaly (°)	150.13477	reference	MPO 231943
perihelion date	2011-10-31.07810	mean daily motion (°/day)	1.11275310	observations used	1512
perihelion JD	2455865.57810	aphelion distance (AU)	1.09900	oppositions	2
argument of perihelion (°)	126.42424	period (years)	0.89	arc length (days)	2976
ascending node (°)	204.42933	P-vector [x]	0.87281527	first opposition used	2004
inclination (°)	3.33194	P-vector [y]	-0.46431986	last opposition used	2012
eccentricity	0.1910904	P-vector [z]	-0.15033488	residual rms (arc-secs)	0.40
perihelion distance (AU)	0.7460538	Q-vector [x]	0.48745844	perturburs coarse indicator	M-v
		Q-vector [y]	0.81419717	perturburs precise indicator	003Eh
		Q-vector [z]	0.31538427	first observation date used	2004-03-15.0
		absolute magnitude	19.2	last observation date used	2012-05-08.0
		phase slope	0.15	computer name	MPCW

Observations

1519 total observations over interval: 2004 03 15.10789 – 2012 05 08.27193
These data are available for [download](#) ([format description](#)).

« Previous 1 2 Next »

Date (UT)	J2000 RA	J2000 Dec	Magn	Location	Ref
2004 03 15.10789	04 06 08.08	+16 55 04.6		691 – Steward Observatory, Kitt Peak-Spacewatch	MPS 126394
2004 03 15.11039	04 06 08.58	+16 55 06.1		691 – Steward Observatory, Kitt Peak-Spacewatch	MPC 53585
2004 03 15.12365	04 06 11.75	+16 55 15.5		691 – Steward Observatory, Kitt Peak-Spacewatch	MPC 53585
2004 03 15.12628	04 06 12.40	+16 55 17.7		691 – Steward Observatory, Kitt Peak-Spacewatch	MPC 53585
2004 03 15.13723	04 06 14.90	+16 55 25.4		691 – Steward Observatory, Kitt Peak-Spacewatch	MPC 53585
2004 03 15.13998	04 06 15.58	+16 55 27.1		691 – Steward Observatory, Kitt Peak-Spacewatch	MPC 53585
2004 06 19.17015	09 44 29.658	+13 18 50.95		695 – Kitt Peak	MPC 54280
2004 06 19.17015	09 44 29.658	+13 18 50.95		695 – Kitt Peak	MPC 54280
2004 06 19.17015	09 44 29.677	+13 18 50.67		695 – Kitt Peak	MPS 298141
2004 06 19.17486	09 44 30.584	+13 18 46.78		695 – Kitt Peak	MPC 54280
2004 06 19.17486	09 44 30.604	+13 18 46.81		695 – Kitt Peak	MPS 298141
2004 06 19.17967	09 44 31.507	+13 18 42.91		695 – Kitt Peak	MPS 298141
2004 06 19.17968	09 44 31.494	+13 18 43.09	20.9 R	695 – Kitt Peak	MPC 54280
2004 06 20.15951	09 47 41.080	+13 05 24.97		695 – Kitt Peak	MPC 53585
2004 06 20.159514	09 47 41.116	+13 05 24.49		695 – Kitt Peak	MPS 298141
2004 06 20.164317	09 47 42.006	+13 05 20.50		695 – Kitt Peak	MPS 298141
2004 06 20.16432	09 47 42.018	+13 05 20.60	20.7 B	695 – Kitt Peak	MPC 53585



IAU Minor Planet Center



<http://www.minorplanetcenter.net/>

Toutatis
Discov.: 1989

MPCObs

Datamining:
2 obs in 1934
2 in 1976
5 in 1988
2 in 1989

June 20-22, 2012

- Processing (Info)
- ECS: Accessible
- MPC Status Page
- Observer Services (NEOs)**
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- Central Bureau for Astro. Tel.
- Cometary Science Archive
- Smithsonian Astro. Obs.

(4179) Toutatis = 1934 CT = 1989 AC

Discovered at Caussols on 1989-01-04 by C. Pollas.
(4179) Toutatis = 1989 AC

Named after the Gaulish god, protector of the tribe. This totemic deity is well known because of the cartoon series "Les aventures d'Asterix" by Uderzo and Goscinny. This tells the stories of two almost fearless heroes living in the last village under siege in Roman-occupied Gaul in 50 B.C., and whose only fear is that the sky may fall onto their heads one day. Since this object is the Apollo object with the smallest inclination known, it is a good candidate to fall on our heads one of these days... But as the chief of the village always says: "C'est pas demain la veille..." Citation written by the discoverer and A. Maury and endorsed by J. D. Mulholland, who with Maury obtained the discovery plates. [Ref: *Minor Planet Circ.* 16444]

Orbit

Orbit type: Apollo
Potentially Hazardous Asteroid

[Interactive Orbit Sketch](#)

Note: WebGL enabled browsers only (e.g. Firefox, Safari, Chrome, Opera), but not IE.

epoch	2012-03-14.0	semimajor axis (AU)	2.5294312	uncertainty	0
epoch JD	2456000.5	mean anomaly (°)	299.56644	reference	MPO 231432
perihelion date	2012-11-15.66551	mean daily motion (°/day)	0.24500210	observations used	3383
perihelion JD	2456247.16551	aphelion distance (AU)	4.12200	oppositions	21
argument of perihelion (°)	278.55539	period (years)	4.02	arc length (days)	13150
ascending node (°)	124.50744	P-vector [x]	0.73058074	first opposition used	1976
inclination (°)	0.44602	P-vector [y]	0.62950313	last opposition used	2012
eccentricity	0.6294330	P-vector [z]	0.26453276	residual rms (arc-secs)	0.44
perihelion distance (AU)	0.9373236	Q-vector [x]	-0.68279618	perturbbers coarse indicator	M-h
		Q-vector [y]	0.68885907	perturbbers precise indicator	003EH
		Q-vector [z]	0.29168167	first observation date used	1976-05-27.0
		absolute magnitude	15.3	last observation date used	2012-05-28.0
		phase slope	0.1	computer name	MPCLINUX

Observations

3501 total observations over interval: 1934 02 10.01990 – 2012 05 28.42983
These data are available for [download](#) ([format description](#)).

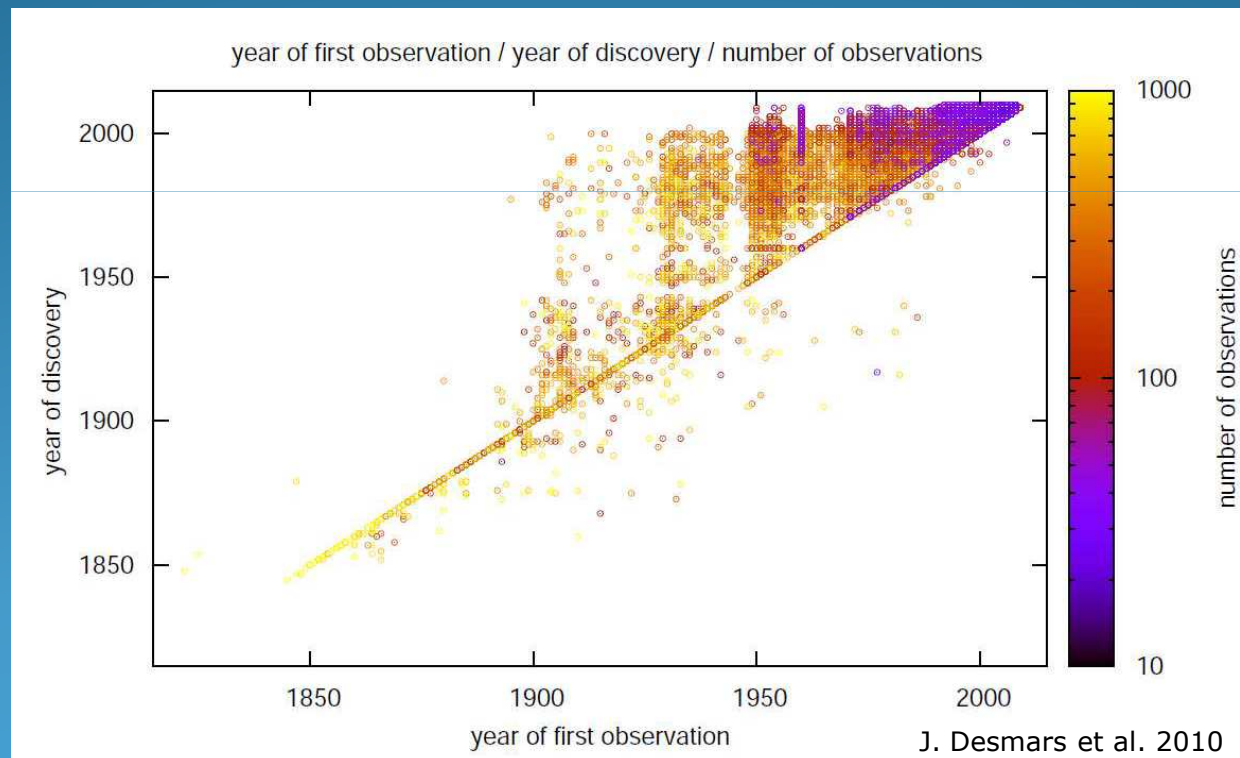
« Previous 1 2 3 4 Next »

Date (UT)	J2000 RA	J2000 Dec	Magn	Location	Ref
1934 02 10.01990	08 50 26.58	+18 13 36.1		012 – Uccle	RI 928
1934 02 14.89925	08 45 57.57	+18 32 14.2		012 – Uccle	RI 928
1976 05 27.66280	19 14 02.81	-21 58 05.4		260 – Siding Spring Observatory-DSS	MPS 55591
1976 05 27.69058	19 14 02.02	-21 58 07.1		260 – Siding Spring Observatory-DSS	MPS 55591
1988 07 12.34479	19 56 57.15	-20 28 48.4	16.8	675 – Palomar Mountain	MPC 14430
1988 07 13.24774	19 55 39.15	-20 32 37.9		675 – Palomar Mountain	MPC 14430
1988 07 16.36319	19 50 54.01	-20 46 19.2		675 – Palomar Mountain	MPC 16557
1988 07 17.35243	19 49 18.96	-20 50 47.9	17	675 – Palomar Mountain	MPC 14290
1988 07 17.38628	19 49 15.60	-20 50 56.2		675 – Palomar Mountain	MPC 14290
1989 01 03.21615	03 19 04.66	+16 26 27.0	11.5	675 – Palomar Mountain	MPC 14126
1989 01 03.22101	03 19 07.21	+16 26 39.6		675 – Palomar Mountain	MPC 14126
1989 01 04.81250	03 39 07.37	+17 48 54.2		010 – Caussols	MPC 14088
1989 01 04.85428	03 39 37.07	+17 50 51.3		010 – Caussols	MPC 14088
1989 01 04.87014	03 39 47.67	+17 51 33.8		010 – Caussols	MPC 14088
1989 01 04.91181	03 40 17.12	+17 53 28.6	12	010 – Caussols	MPC 14088
1989 01 06.09305	03 53 50.06	+18 44 10.6		801 – Oak Ridge Observatory	MPC 14129
1989 01 06.24111	03 55 26.35	+18 49 49.8		801 – Oak Ridge Observatory	MPC 14129

ASTORB data base: Data mining done

Year of discovery / year of first observation

380 000 : Global view of the data issued from data mining asteroids

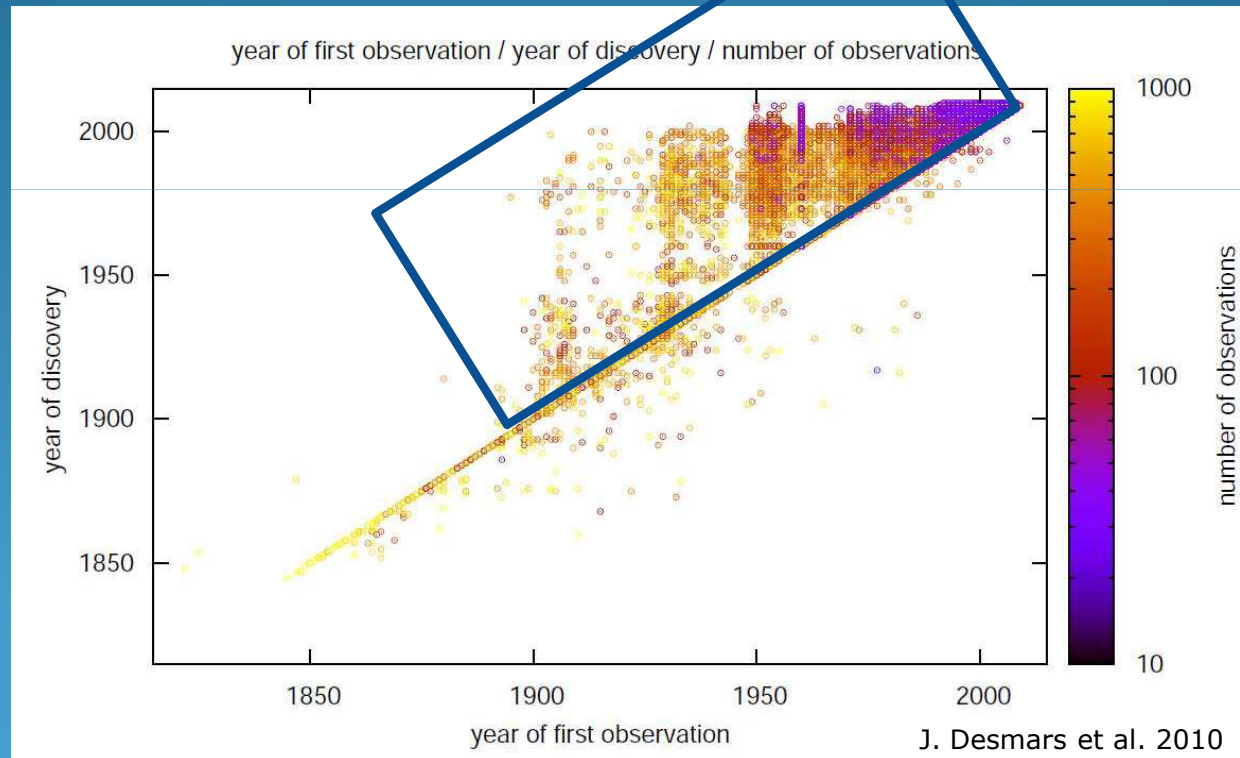


ASTORB data base: Data mining done

Date discovery > date 1st obs.
Measurements done through data mining:

380 000
asteroids

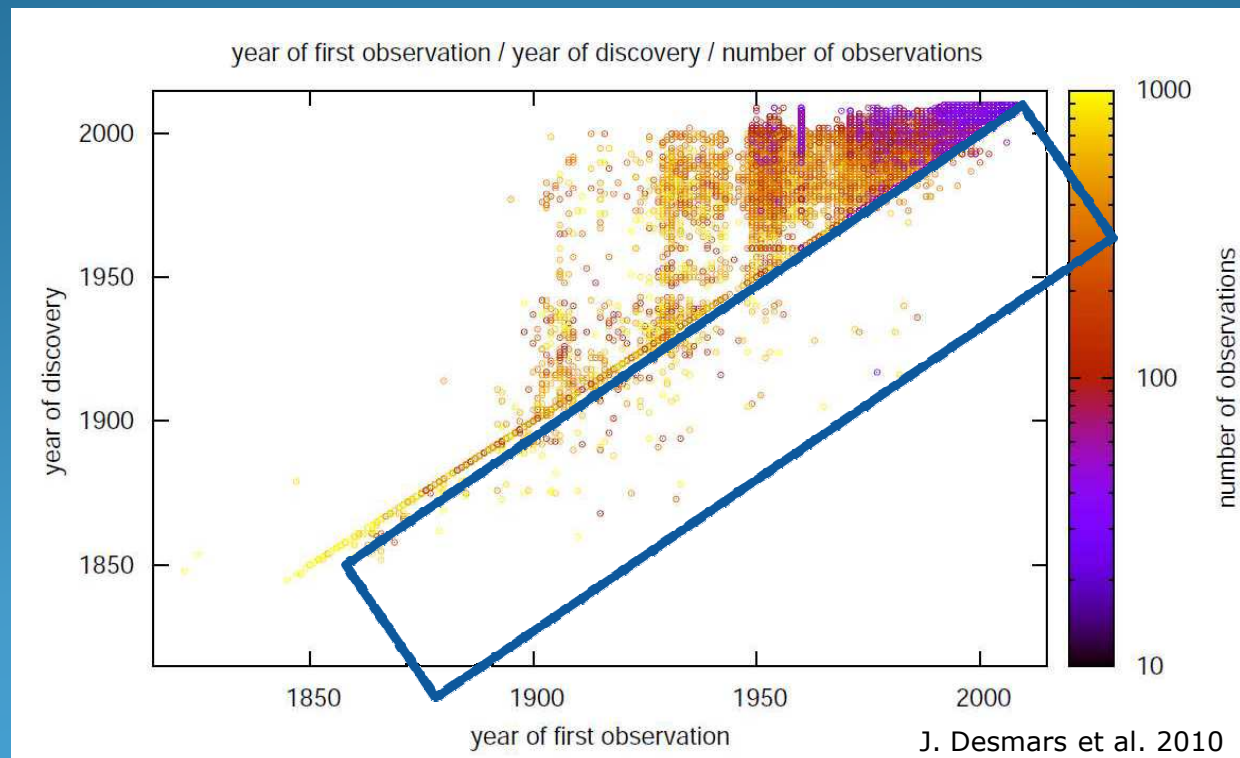
273 970 (71%)



ASTORB data base: Data mining done

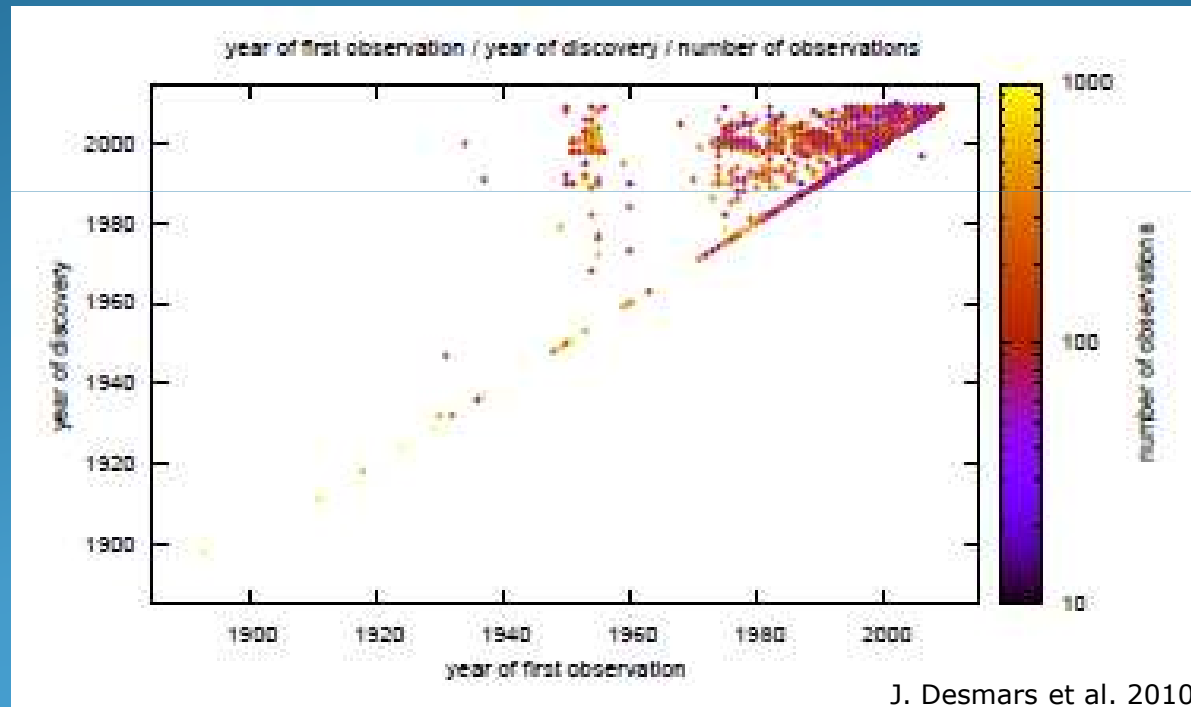
380 000
asteroids

Date discovery < date 1st obs.
1st observation too unprecise?
not registered as date of discovery



ASTORB data base: Data mining done

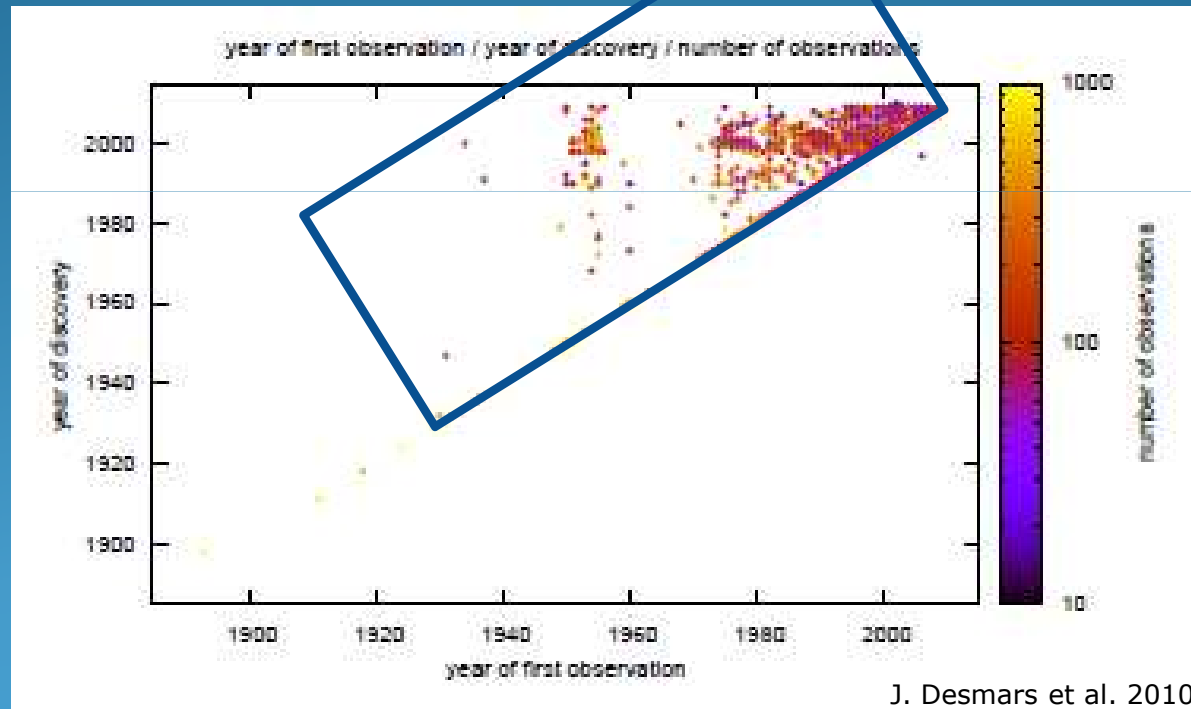
Only NEAs
2691



ASTORB data base: Data mining

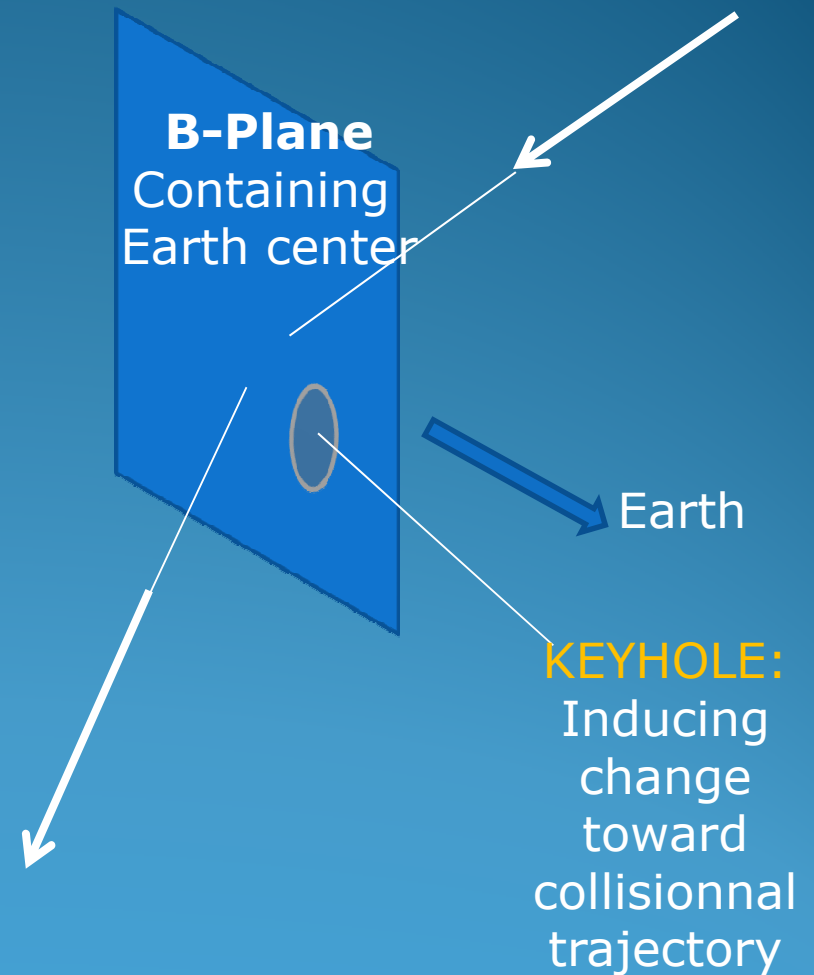
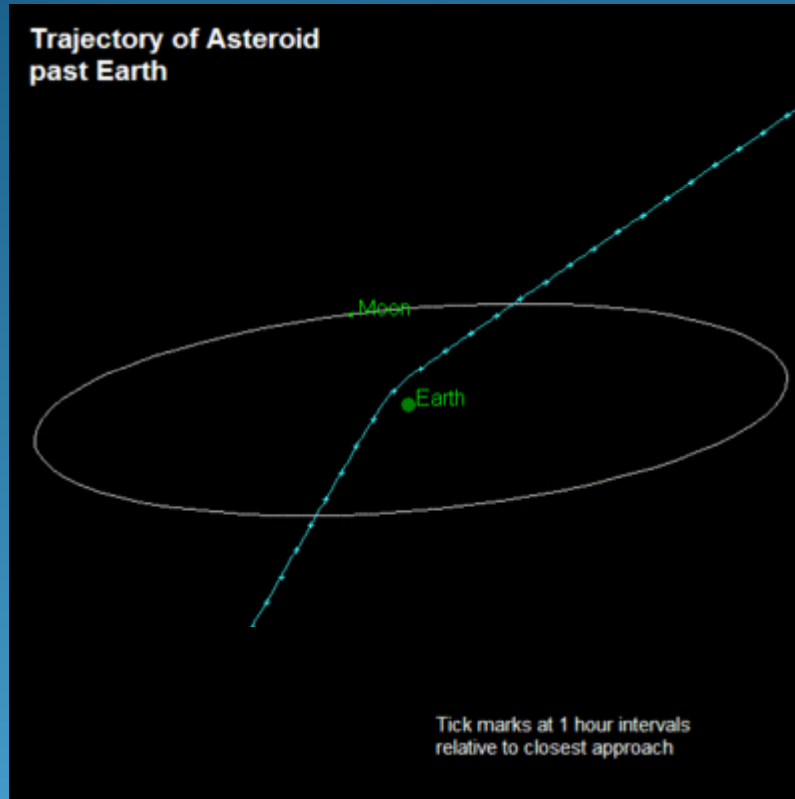
Only NEAs
2691

782 NEAs (29%)



Case of 99942 Apophis

Bessel plane / Keyholes



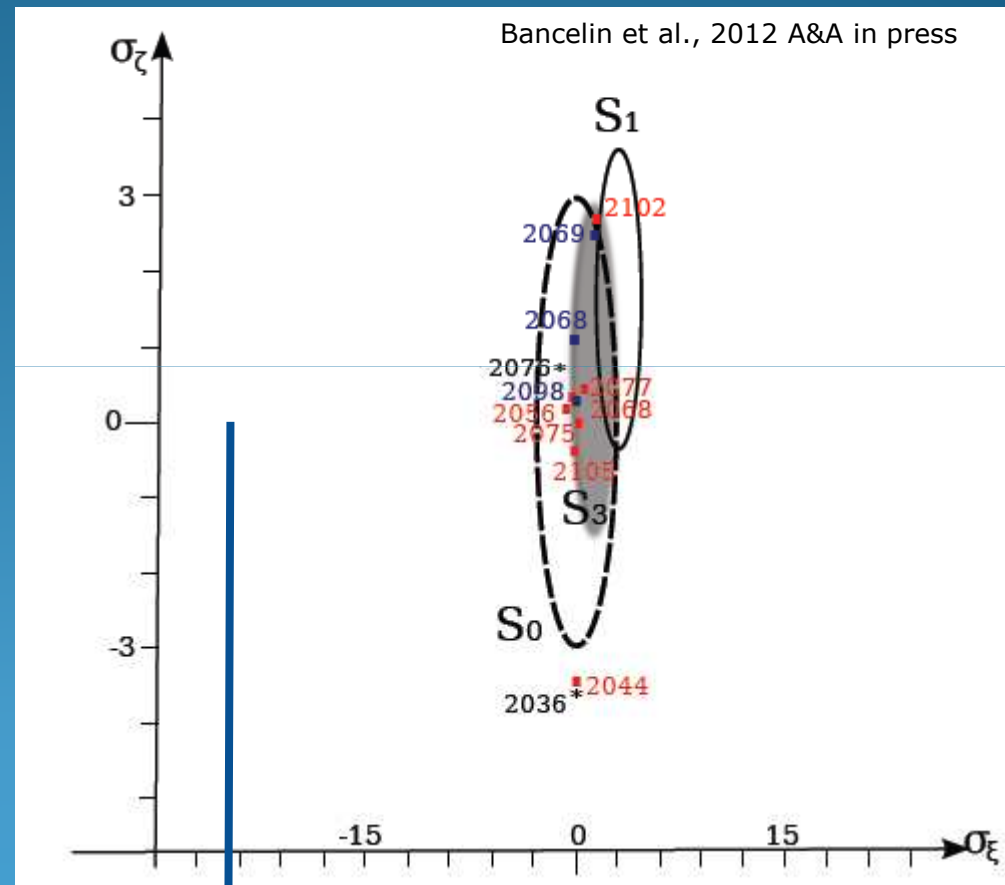
B-plane of 99942 Apophis

Apophis 2029 B-plane

- obs. 2004-2011
- 3σ uncertainty ellipses
- S0: 15 km x 350 km
- S3: 15 km x 245 km
- Keyholes

Year	Resonance	Keyhole size (m)
2034	5 : 4	560
2035	6 : 5	560
2036	7 : 6	610
2037	8 : 7	570
2046	17 : 15	660
2048	19 : 17	410

Chesley, 2006



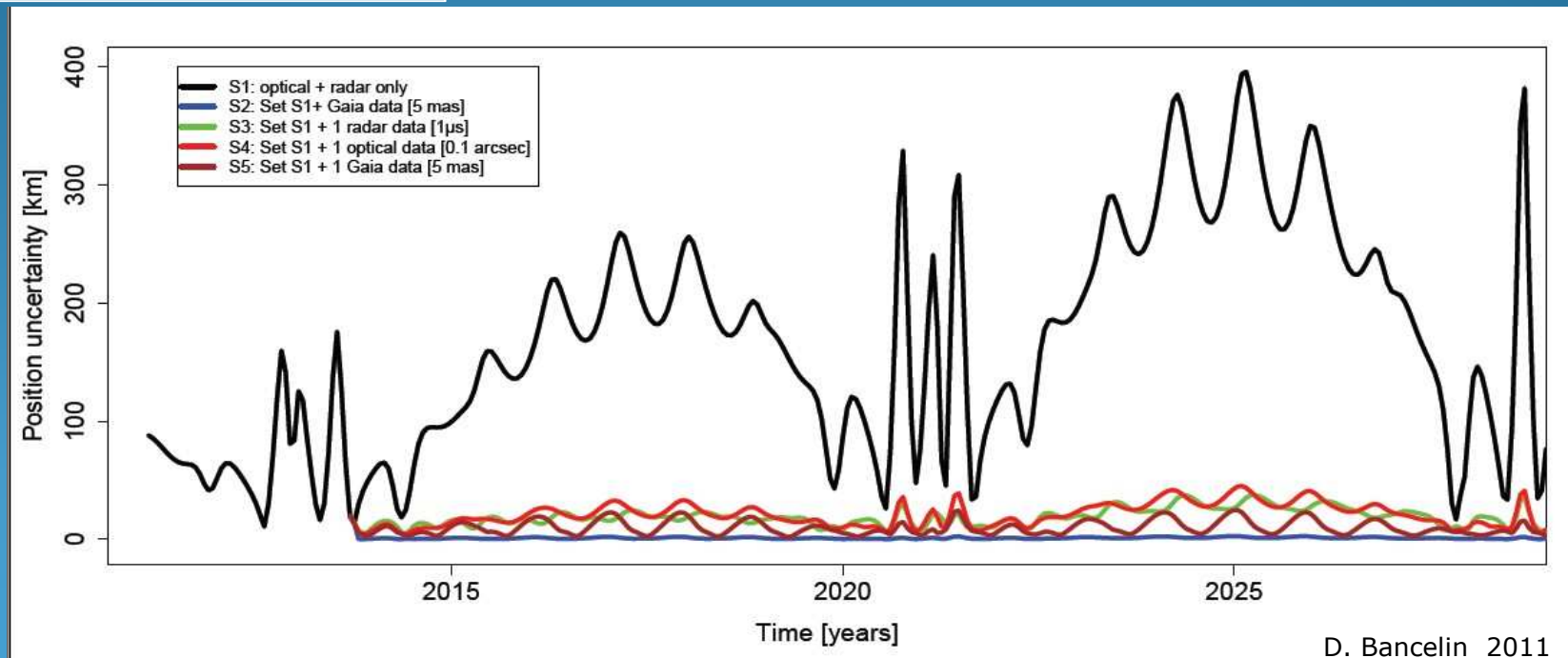
To the Earth : 38 080 km

Impact of direct Gaia observations on the orbital model of 99942 Apophis

- simul. **direct Gaia obs. of Apophis**
- Propagation of error
- covariance matr. Tech.

- Sets of observations
- S1: optical 2004-2011 + radar
- S2: S1 + 12 Gaia obs. (5mas)
- S3: S1 + 1 radar in 2013 (1 μ s)
- S4: S1 + 1 optical (100 mas)
- S5 : only 1 observation by Gaia (5 mas)

Position known to less than 50 km on the period



D. Bancelin 2011

Impact of the Gaia catalogue on the orbital model of Apophis

Current stellar catalogues :

- Systematic errors => impact on the asteroid orbital models
- Estimate of biases => Zonal corrections

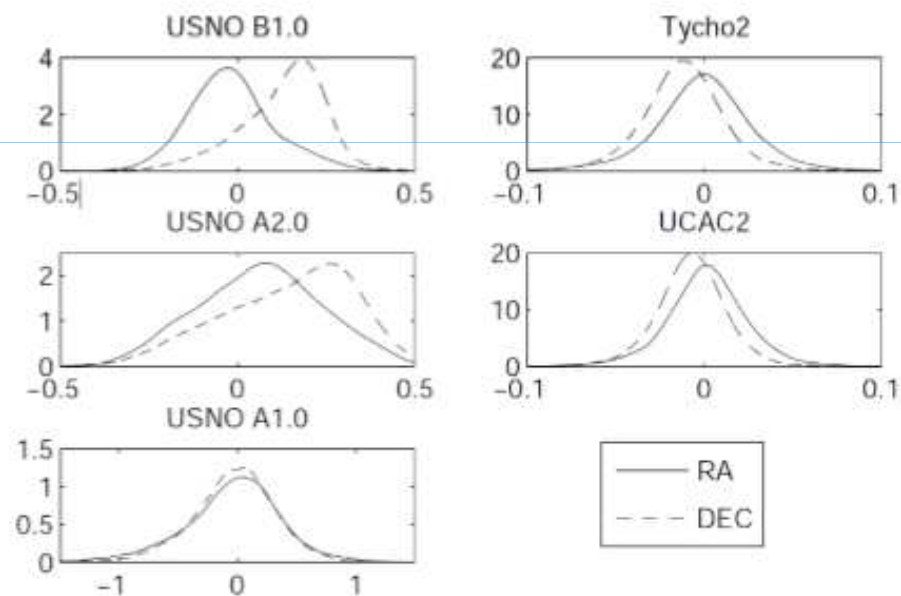


Figure 5.2: Probability densities of inter-catalogue systematic errors, as compared to the 2MASS catalog. For each plot, the abscissa is the difference in arcsec between the given catalogue and 2MASS and the ordinate is the associated probability density in arcsec^{-1} . Note that the plots are not all on the same scale (source: Chesley et al. (2009))

Impact of the Gaia catalogue on the orbital model of Apophis

D. Bancelin (2011, Phd Thesis)

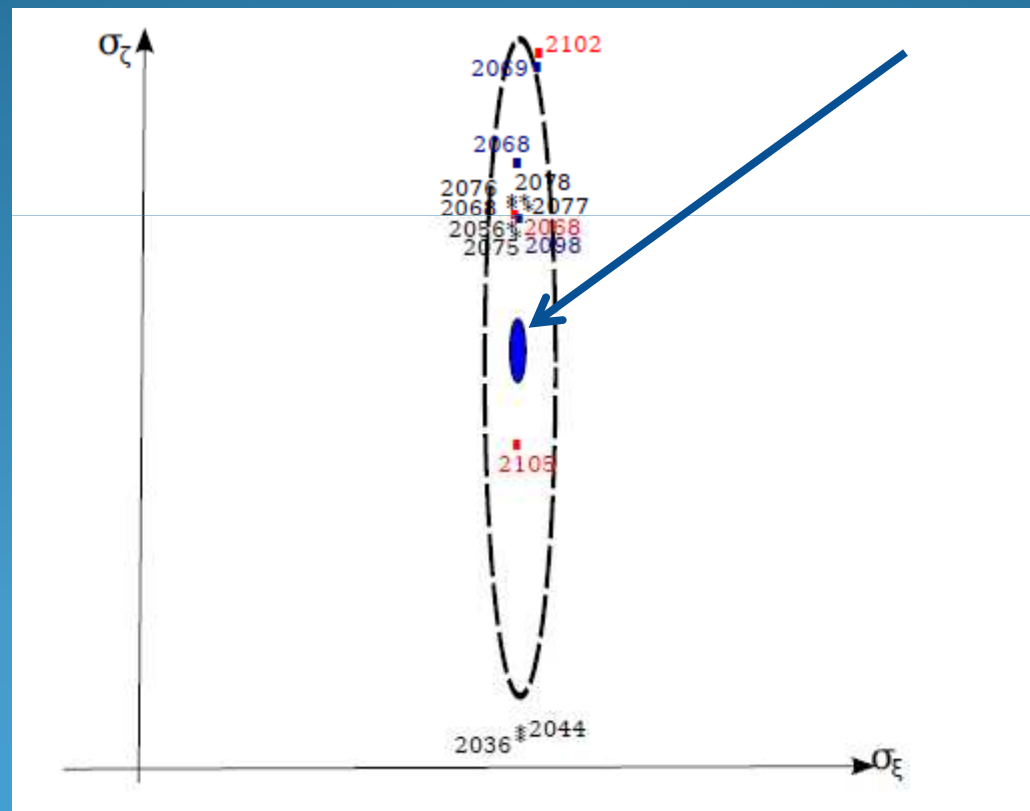
- Simulation of re-reduction with the Gaia catalogue (50 mas)
- improvement of uncertainty by 10 (a, e, Ω , M) and 100 (i)

	without	with Gaia cat.
a [UA]	1.3×10^{-08}	1.3×10^{-09}
e	5.7×10^{-08}	4.9×10^{-09}
i [°]	1.8×10^{-06}	9.9×10^{-09}
Ω [°]	8.0×10^{-05}	3.9×10^{-06}
ω [°]	8.0×10^{-05}	3.9×10^{-06}
M [°]	5.5×10^{-05}	5.6×10^{-06}

Impact of the Gaia catalogue on the orbital model of Apophis

D. Bancelin (2011, Phd Thesis)

- Simulation of re-reduction with the Gaia catalogue (50 mas)
- 2019 B-Plane of Apophis: uncertainty ellipse reduced by factor 10



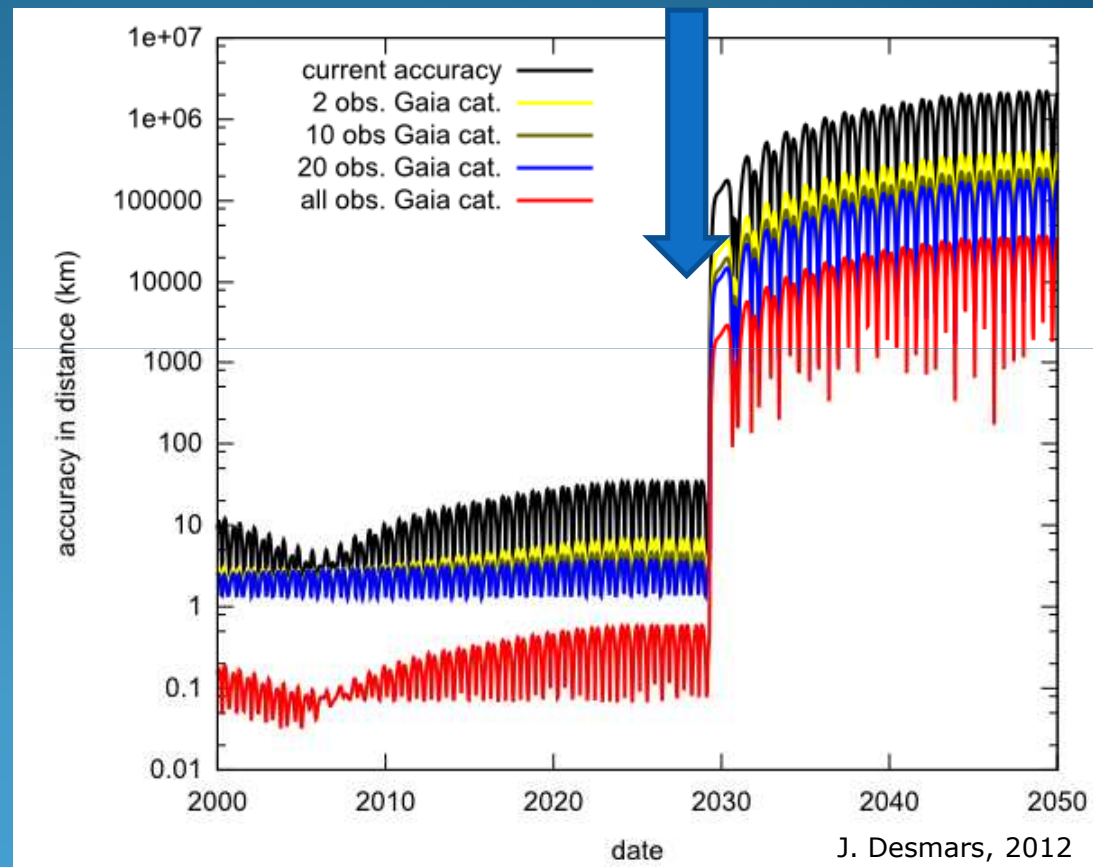
Impact of the Gaia catalogue on the orbital model of Apophis

Close approach 2029

- Accuracy in helioc. distance (km)
- **Error propagation** (covariance matrix techn.)
- NEODys obs (2004 to 2012)
=> nominal values

Simulation of re-reduction with the Gaia Catalogue (10 mas):

- ✓ All observations
- ✓ 20 (10 first and 10 last)
- ✓ 10 (5 first and 5 last)
- ✓ 2 (1st and last ones)



Strong improvement (/1000)

Thank you!

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