Estimation of Yarkovsky acceleration using datamining in the perspective of Gaia

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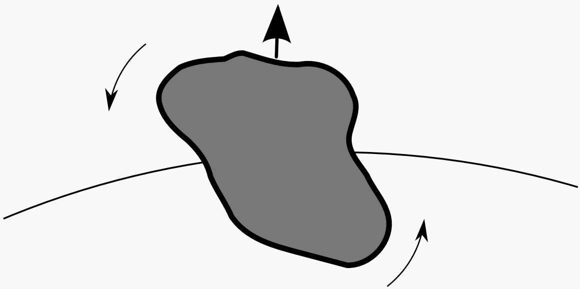
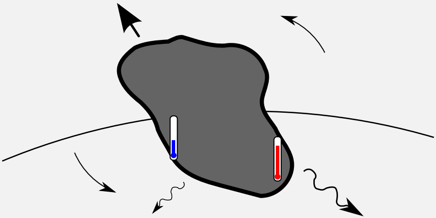
Yarkovsky effect



Yarkovsky effect

- The Yarkovsky effect is a weak non gravitational force associated with anisotropic emission of thermal radiation
- It affects mainly small NEAs (about 10 cm to 10 km in diameter)
- Despite its small magnitude, it has important effect in dynamical evolution of NEAs
- One of the main effects is to modify the semimajor axis



Aim : Detect the rate of change of asteroid semimajor axis by using observations

Brief story of Yarkovsky effect

- **∼1900** The effect was discovered around 1900 by I.O. Yarkovsky, a Russian engineer
- **1951** E.Öpik discussed the possible importance of the effect in meteroids motions
- **2003** S.Chesley et al. →first measure of Yarkovsky effect on a asteroid (6489 Golevka) using radar measurements
- **2006** D.Vokrouhlický et al. →first measure of Yarkovsky effect on a asteroid (152563 1992BF) using astrometrical observations

Igor O. Yarkovsky

Modelling the Yarkovsky effect

Complex Modelling

- Vokrouhlický et al. (2000) modeled the force by solving the surface heat diffusion problem.
- They used linear and finite element methods
- With linear method, the rate of change of semimajor axis **da**/**dt** depends on γ obliquity of spin axis, ρ_b bulk density, D diameter and Θ diurnal thermal parameter

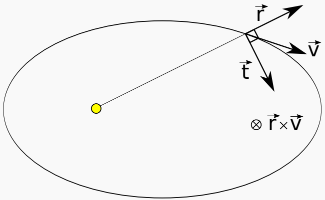
$$\frac{da}{dt} \propto \frac{\cos\gamma}{\rho_b D} \frac{\Theta}{1+\Theta+0.5\Theta^2}$$

Simple Modelling

According to Chesley et al. (2008), the Yarkovsky effect can be modeled as a transverse force, depending on orbital elements, the heliocentric distance and on a drift in semi major-axis $\dot{a} = \frac{da}{dt}$

$$\mathbf{F_Y} = \frac{n}{2}\frac{a^2(1-e^2)}{r^2}\left(\frac{da}{dt}\right)\mathbf{t}$$

where n is mean motion, a semi-major axis, e excentricity and $\mathbf{t} = \frac{(\mathbf{r}\times\mathbf{v})\times\mathbf{r}}{|(\mathbf{r}\times\mathbf{v})\times\mathbf{r}|}$ the transverse vector.



Dynamical model

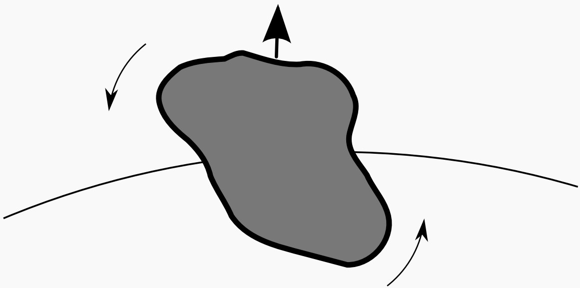
The dynamical model takes into account :

- gravitational perturbations of planets + Pluto + Moon
- gravitational perturbations of 3 main asteroids (Ceres, Vesta, Pallas)
- relativistic effects
- Yarkovsky acceleration ($\mathbf{F_Y}$)

Computation

- Numerical integration of the equations of motion and equations of variations
- Determination of initial parameters (initial position & velocity + semi-major axis drift rate $\dot{a}$) by least-square method, giving also the covariance matrix of the parameters

Detection of Yarkovsky Effect



152563 (1992BF)

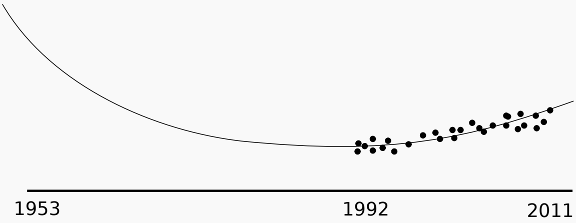
- Asteroid was discovered on 1992
- 4 precovery observations on January 1953 are available.
- Vokrouhlický et al. AJ 135, (2008) detect a drift in semimajor axis using observations from 1992 to 2008 and 1953 precovery observations.

$$\frac{da}{dt} = -(10.7 \pm 0.7) \times 10^{-4} AU.Myr^{-1}$$

Astrometry (with 1953-2011 observations)

222 observations (1992-2011) + 4 observations (1953) ; 2 unusable obs.

1. 1992-2011 observations and no Yarkovsky effect
2. 1953-2011 observations and no Yarkovsky effect
3. 1953-2011 observations and Yarkovsky effect



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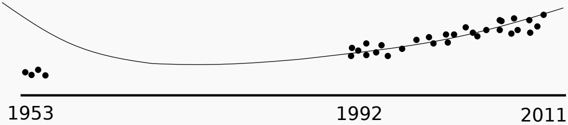

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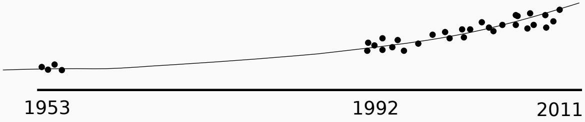

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Residuals

date	1		2		3	
	α	δ	α	δ	α	δ
1953 01 10.136810	+7.535	+3.089	+5.556	+2.479	**-0.138**	**+0.439**
1953 01 10.143750	+7.524	+0.831	+5.546	+0.222	**-0.148**	**-1.819**
1953 01 12.136810	+7.294	+2.224	+5.446	+1.650	**+0.100**	**-0.235**
1953 01 12.143750	+7.492	+2.898	+5.644	+2.325	**+0.300**	**+0.440**

	rms_α	rms_δ	rms_α	rms_δ	rms_α	rms_δ
1953-2011	1.243	0.707	1.141	0.674	**0.728**	**0.634**
1992-2011	0.749	0.634	0.875	0.630	**0.734**	**0.626**

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Rate of change of semimajor axis for 1992 BF

Vokrouhlický et al. AJ 135, (2008) (with 1953-2008 observations) :

$$\frac{da}{dt} = -(10.7 \pm 0.7) \times 10^{-4} AU.Myr^{-1}$$

This work (with 1953-2011 observations) :

$$\frac{da}{dt} = -(11.66 \pm 0.77) \times 10^{-4} AU.Myr^{-1}$$

Tab. 1: Estimated semimajor axis drift rate for some NEAs

Ast.Num.	**Ast.Name**	**da/dt**	$\sigma_{\dot{a}}$	**S/N**	**Observed arc**	**H.Mag.**
152563	1992BF	-11.658	0.772	15.1	1953-2011	19.7
85953	1999FK21	-10.600	1.452	7.3	1971-2011	18.0
1862	Apollo	-2.527	0.428	5.9	1930-2008	16.0
1620	Geographos	-2.380	0.543	4.4	1951-2012	15.2
2100	Ra-Shalom	-5.758	1.332	4.3	1975-2010	16.1
2340	Hathor	-13.532	3.372	4.0	1976-2012	20.0
54509	YORP	-30.826	7.990	3.9	2000-2005	22.6
101955	1999RQ36	-15.382	5.677	2.7	1999-2012	20.6
1685	Toro	-1.286	0.488	2.6	1948-2010	14.3
1865	Cerberus	-5.539	3.392	1.6	1971-2007	16.5
2063	Bacchus	-3.495	2.524	1.4	1977-2007	17.1

Note : **da/dt** & $\sigma_{\dot{a}}$ are in 10^{-4}AU/My

Negative values mean retrograde rotation (consistent with La Spina et al., 2004)

Some remarks

- The drift da/dt=$\dot{a}$ needs real data to be determined
- The accuracy of the drift $\sigma_{\dot{a}}$ only needs accuracy of the data to be determined

In the next slides...

- In the context of simulated observations, we will determined only the accuracy of the drift $\sigma_{\dot{a}}$
- 10^{-4}AU/My will be considered as a typical (accurate) value for accuracy of the drift in semimajor axis

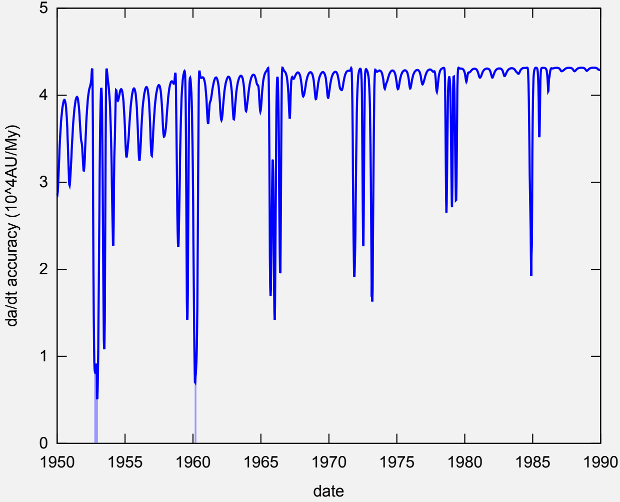
Yarkovsky effect in the datamining context

Influence of precovery observation for (152563) 1992BF

- What is happen if there is no precovery observations on 1953 but on other period ?
- What is the influence of the precovery observation's date on the accuracy of the rate of change of semimajor axis ?
- What is the influence of the precovery observation's accuracy on the accuracy of the rate of change of semimajor axis ?

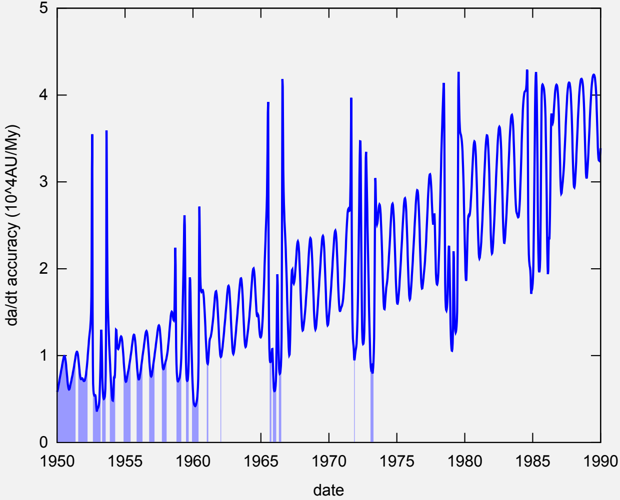
Influence of precovery observation for (152563) 1992BF

Precovery observation with accuracy $\sigma = 1.0$ arcsec



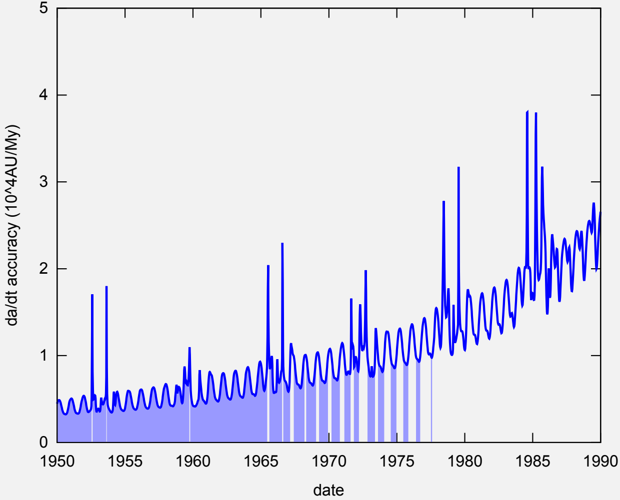
Influence of precovery observation for (152563) 1992BF

Precovery observation with accuracy $\sigma = 0.1$ arcsec



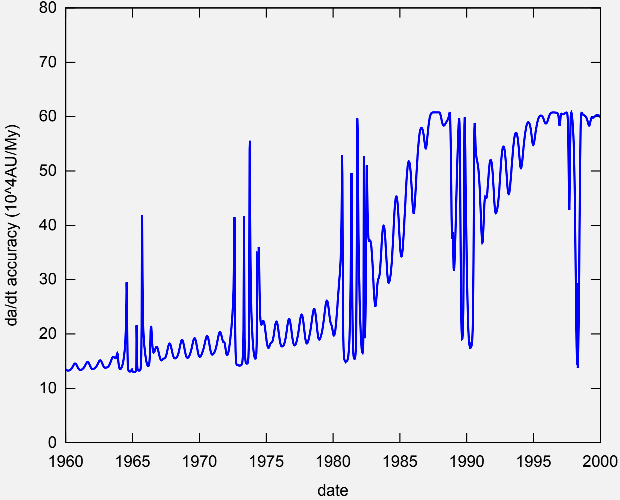
Influence of precovery observation for (152563) 1992BF

Precovery observation with accuracy $\sigma = 10$ mas –Gaia reduction–



Influence of precovery observation for (99942) Apophis

Precovery observation with accuracy $\sigma = 1.0$ arcsec



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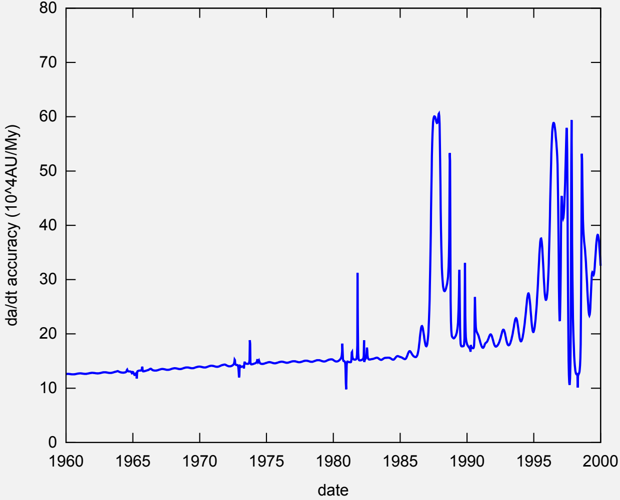

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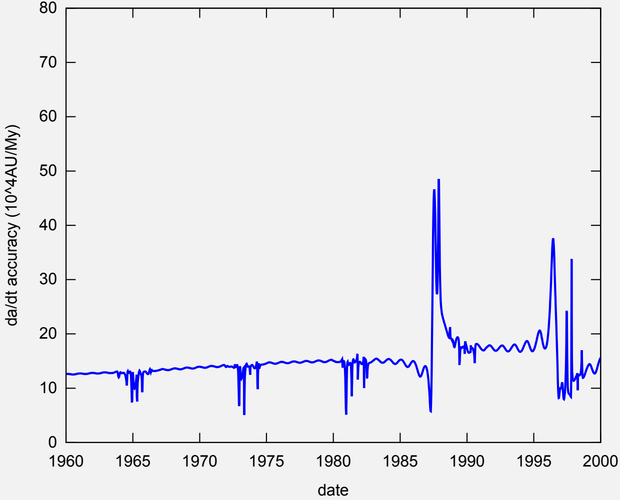
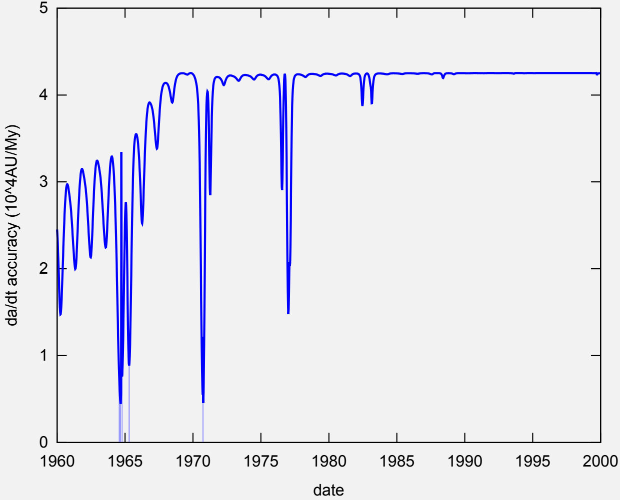


Influence of precovery observation for (101955) 1999RQ36

Precovery observation with accuracy $\sigma = 1.0$ arcsec



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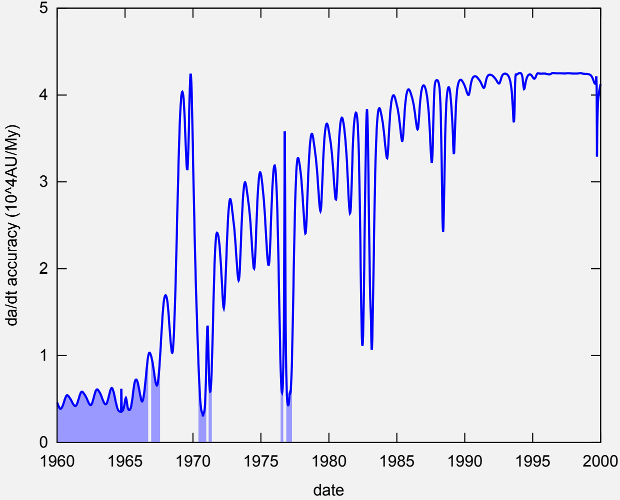

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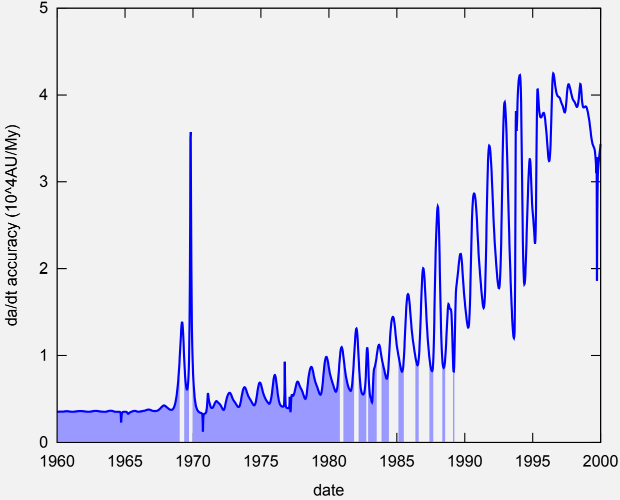
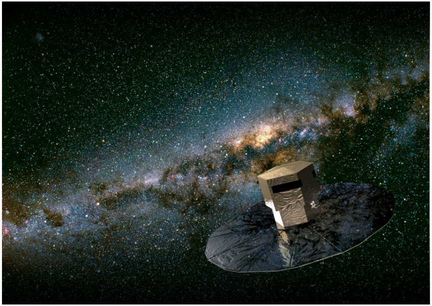


Yarkovsky effect in the Gaia context

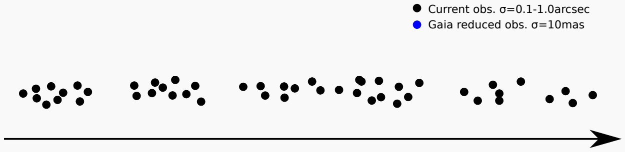


Gaia stellar catalogue

- Gaia stellar catalogue will allow to reduce old photographics or CCD frames with an accuracy of 5-10 mas
- What is the improvement in detection of Yarkovsky effect with Gaia stellar catalogue ?

Reduction with Gaia stellar catalogue

1. Current observations (no reduction with Gaia catalogue)
2. Only the first and the last observation can be reduced with Gaia catalogue
3. Only the first 5 and the last 5 observations can be reduced with Gaia catalogue
4. Only the first 10 and the last 10 observations can be reduced with Gaia catalogue
5. All observations can be reduced with Gaia catalogue



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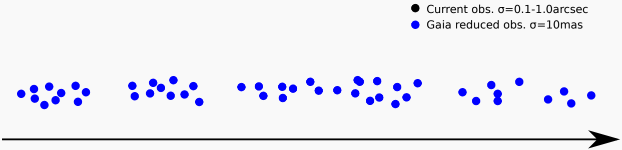
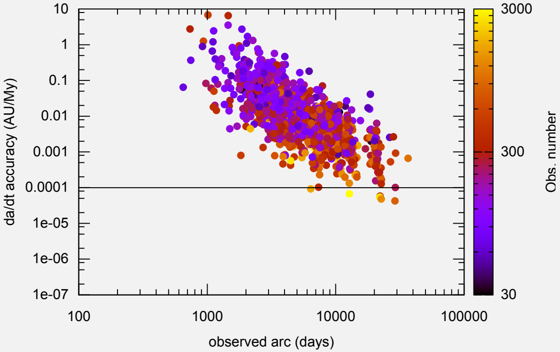


Accuracy of da/dt for 1212 numbered NEAs

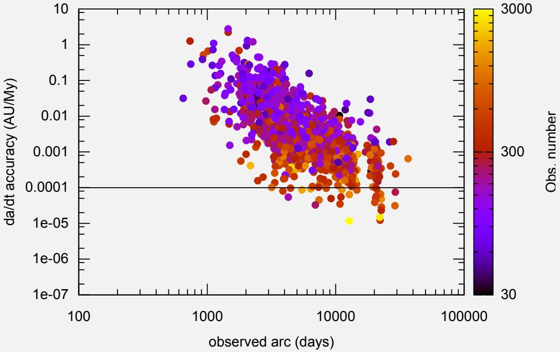
1. Accuracy with current observations – no reduction with Gaia catalogue –



$\mu_{\sigma_{\dot{a}}}$	NEAs with $\sigma_{\dot{a}} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot{a}} \leq 10^{-5}$AU/My
661.1 10^{-4}AU/My	6 (0.5%)	0 (0.0%)

Accuracy of da/dt for 1212 numbered NEAs

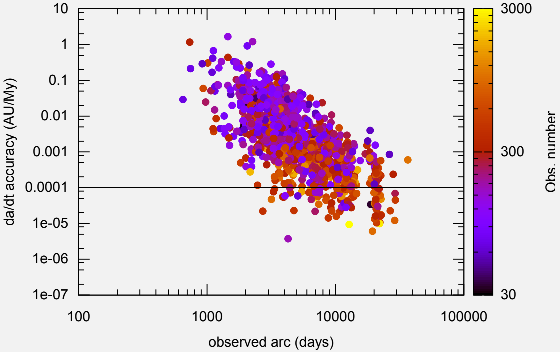
2. Accuracy with first and last obs. reduced with Gaia



$\mu_{\sigma_{\dot{a}}}$	NEAs with $\sigma_{\dot{a}} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot{a}} \leq 10^{-5}$AU/My
337.5 10^{-4}AU/My	29 (2.4%)	0 (0.0%)

Accuracy of da/dt for 1212 numbered NEAs

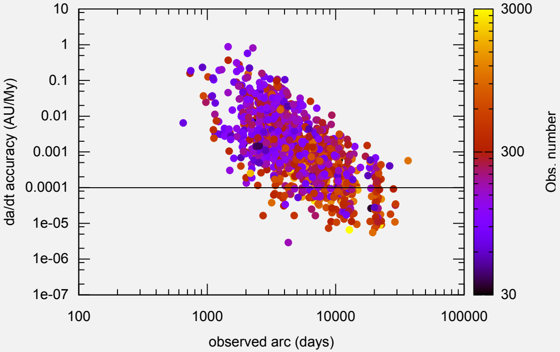
3. Accuracy with 5 first and 5 last obs. reduced with Gaia



$\mu_{\sigma_{\dot a}}$	NEAs with $\sigma_{\dot a} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot a} \leq 10^{-5}$AU/My
196.4 10^{-4}AU/My	96 (7.9%)	4 (0.3%)

Accuracy of da/dt for 1212 numbered NEAs

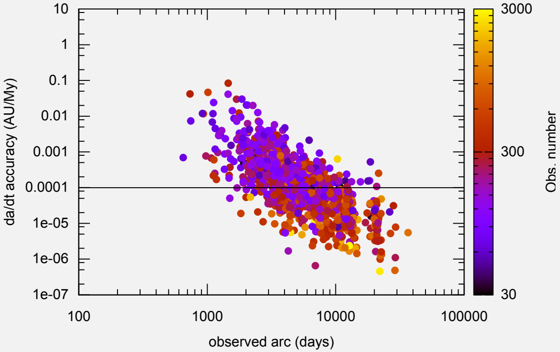
4. Accuracy with 10 first and 10 last obs. reduced with Gaia



$\mu_{\sigma_{\dot{a}}}$	NEAs with $\sigma_{\dot{a}} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot{a}} \leq 10^{-5}$AU/My
114.0 10^{-4}AU/My	150 (12.4%)	10 (0.8%)

Accuracy of da/dt for 1212 numbered NEAs

5. Accuracy with all observations reduced with Gaia



$\mu_{\sigma_{\dot{a}}}$	NEAs with $\sigma_{\dot{a}} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot{a}} \leq 10^{-5}$AU/My
8.2 10^{-4}AU/My	536 (44.2%)	114 (9.4%)

Conclusion

- Despite its weakness, the Yarkovsky effect can produce a secular drift of semimajor axis.
- Currently this effect (drift in semimajor axis) can be detect with good accuracy for only few objects.
- Datamining, by extending the orbital arc, can help to decrease the accuracy of the drift (even with poor observations), but not for all NEAs (see Apophis)
- Gaia stellar catalogue will allow new reduction of astrometric observations with an accuracy of about 10 mas
- Currently the determination of drift with an accuracy less than 10^{-4}AU/My can be realized for only 6 NEAs
  - by reducing 2 observations with Gaia catalogue, 29 NEAs
  - by reducing 10 observations with Gaia catalogue, 96 NEAs
  - by reducing 20 observations with Gaia catalogue, 150 NEAs
  - by reducing all observations with Gaia catalogue, 536 NEAs

Conclusion

- Other possible solutions in order to increase accuracy of the drift :
  - radar measurements (for Apophis in 2013 $\sigma_{\dot{a}}$ 60.10^{-4}AU/My $\rightarrow\sim 10.10^{-4}$AU/My)
  - Gaia observations (Mouret & Mignard 2011 for 64 NEAs)
- With the knowledge of the drift and some assumptions, we can deduce from Vokrouhlický model, the spin obliquity or the bulk density.

Thank you for your attention !