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Estimation of Yarkovsky acceleration using datamining in the perspective of Gaia

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Abstract : The Yarkovsky effect is a weak non gravitational force that can modify the semi-major axis of asteroid. It has an important effect on the long term evolution of Near Earth Asteroids. The aim of this paper is to detect secular drift in the semi-major axis of some asteroids. The datamining can help to detect such a drift by extending the orbital arc. Finally the Yarkovsky effect is also considered in the Gaia mission context.

Introduction

The Yarkovsky effect was discovered in the early 20th century by the Russian engineer Igor Yarkovsky. It is a weak non gravitational force associated with an anisotropic emission of thermal radiation. It affects mainly small Near Earth Asteroids (from 10 cm to 10 km). Despite its small magnitude, it has an important effect in the dynamical evolution of NEAs. One of the main effects is to modify the semi-major axis of the asteroids.

Öpik (1951) first discussed the possible importance of the effect in the meteoroid motions. The Yarkovsky effect was first measured thanks to radar measurements by Chesley et al. (2003) for asteroid (6489) Golevka. In 2008 Vokrouhlicky et al. measured the Yarkovsky effect by using only astrometrical observation for asteroid (152563) 1992BF.

In the first section, we deal with the modeling of the Yarkovsky effect. Then we present some cases of detection of drift in semi-major axis using observations. Finally, we present the detection of Yarkovsky effect in the context of datamining and in the Gaia mission context.

1. Modeling the Yarkovsky effect

The Yarkovsky effect can be modeled by different methods. Vokrouhlicky et al. (2000) presented a detailed modeling by solving the surface heat diffusion problem. With a linear method, the rate of change of the semi-major axis can be related to the obliquity of the spin axis, the bulk density, the diameter and the diurnal thermal parameter.

Chesley et al. (2008) proposed a simple modeling. The Yarkovsky effect can be modeled as a transverse force depending on orbital elements, heliocentric distance and the drift in semi-major axis.

In our study, we used the same modeling. The dynamical model of the asteroid motion takes into account the gravitational perturbations of the planets, Pluto and the Moon, the gravitational perturbations of the three main asteroids (Ceres, Pallas and Vesta), the relativistic effects and the Yarkovsky effect.

The equations of motion and the equations of variation are numerically integrated and the initial parameters (initial position and velocity and drift in semi-major axis) are determined by least-square method giving also the covariance matrix of the parameters.

2. Detection of Yarkovsky effect

In order to validate our model, we tried to detect secular drift in semi-major axis for asteroids for which the drift was already detected. 1992BF is one of these asteroids. It was discovered in 1992 and four precovery observations in 1953 are available. They allow to measure a drift in semi-major axis. Vokrouhlicky et al. (2008) measure a drift in semi-major axis:

da/dt= (-10.7+/-0.7).10^-4 AU.My-1

In our study we have :

da/dt= (-11.66+/-0.77).10^-4 AU.My-1

Actually, the best accuracy for residuals and O-C of 1953 observations is obtained by fitting the dynamical model to 1953-2011 period of observations and by including the Yarkovsky effect in the model.

According to Chesley et al. (2008), we detected a drift in semi-major axis for other NEAs. Table 1 gives the value and the accuracy of the drift in semi-major axis for some NEAs. The ratio signal on noise, the observational period and the absolute magnitude are also indicated.

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

The drift values are negative. It means that asteroids have a retrograde rotation which is consistent with La Spina et al. (2004). Moreover, 10^-4 AU/My seems to be a typical and accurate value to detect drift because a drift smaller than 10^-4 AU/My is still hard to detect.

3. Yarkovsky effect in the datamining context

The previous asteroid is a good example for the interest of datamining. Indeed the four precovery observations in 1953 help to detect drift in semi-major axis. Generally, the drift in semi-major axis can be detected with a large period of observations. Datamining is useful to extend the period of observations and to detect Yarkovsky effect.

In this section, we deal with the accuracy of the drift in semi-major axis related to the date of precovery observations and to the accuracy of the precovery observation.

In this context, we considered the case of 1992BF but without the four precovery observations in 1953, it means with only 1992-2011 observations and their own accuracy, and we assume just one precovery for a date t and an fixed accuracy.

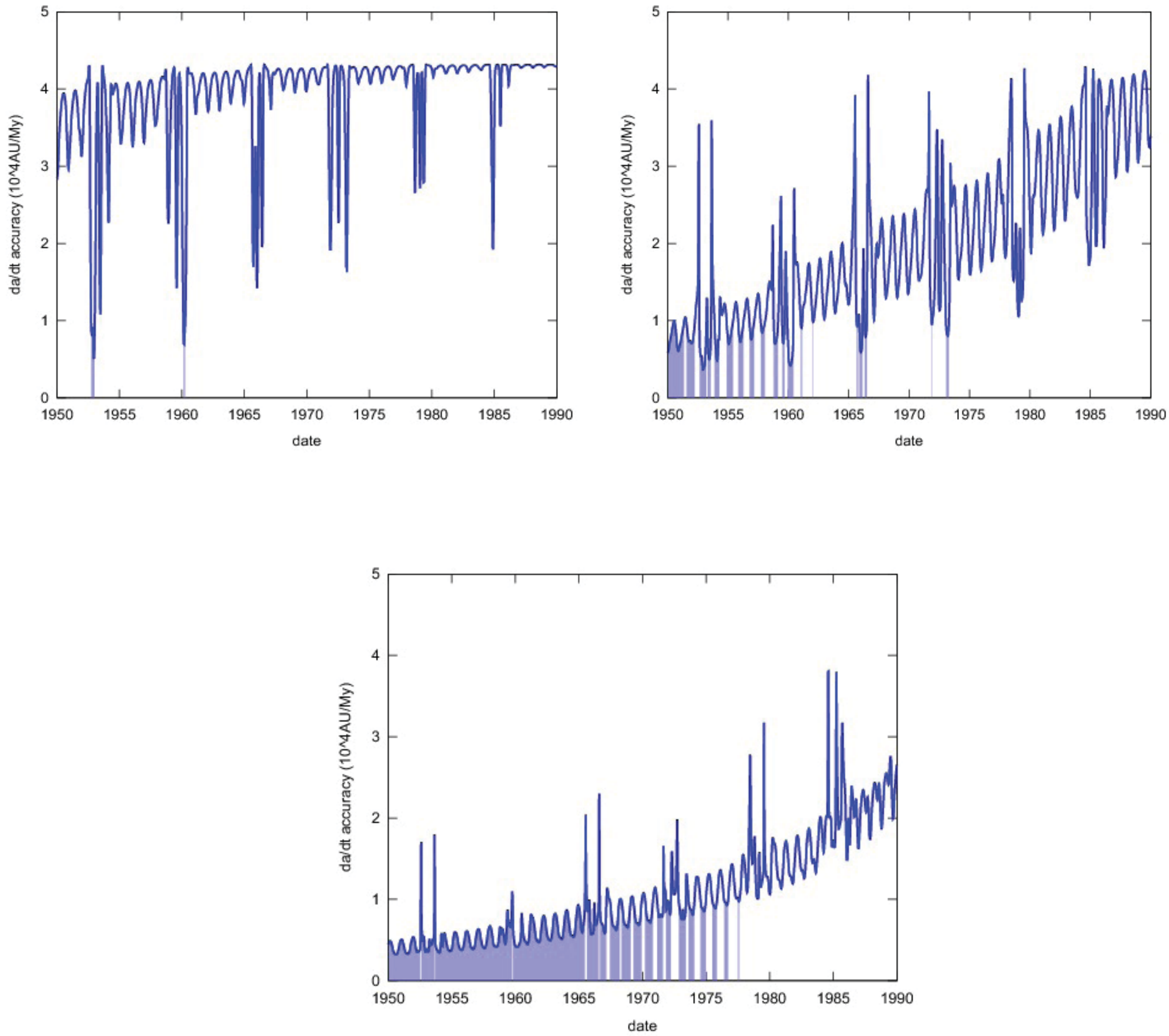

Figure 1. Relation between accuracy of the drift in semi-major axis for 1992BF and date of precovery observation from 1950 to 1990. (A) is with an accuracy of 1 arcsec for the precovery observation, (B) 0.1 arcsec and (C) 10mas.

Fig. 1 represents the accuracy of the drift in semi-major axis for asteroid 1992BF in relation with the date and the accuracy of the precovery observation. Color under the curve indicates that the accuracy is less than 10^-4AU/My. The first plot reveals some short period (also favourable period of visibility) during which the precovery observation allow a good accuracy in the drift of semi-major axis, even if the accuracy of the precovery observation is not so accurate (1 arcsec). One can see that January 1953 is one of these periods. With an accuracy of 0.1 arcsec for the precovery observation, the drift can be detected with a good accuracy during a longer period. Finally, if we assume that the accuracy of the precovery observation is 10 mas (e.g. reduced with the Gaia stellar catalogue) then the drift can be detected with a good accuracy whatever the period before 1975.

For other asteroids such as (99942) Apophis, the situation is quite different. The accuracy of the drift decreases while the accuracy of the precovery observation improves but it is still larger than 10^-3AU/My. This is due to the current large value of the drift accuracy (6.10^-3AU/My using 2004-2012 observations).

Finally, datamining can help to detect a drift in semi-major axis by extending the length of the observational period.

4. Yarkovsky effect in the Gaia context

The Gaia stellar catalogue will be very helpful for astrometry. The positions of stars brighter than magnitude 20 will be available with a very good accuracy (about tens of micro-arcseconds). With this catalogue, it will be possible to reduce observations, in particular old observations with a very good accuracy. Process of reduction will probably need to be improved but an accuracy of 5-10 mas is expected for the position of asteroids. In this context, some observations could be reduced again with this catalogue in order to improve the accuracy of observations and then the quality of asteroid orbit. For most of the asteroids, all the observations could not be reduced again but only a few part of them. For some specific asteroids (Potentially Hazardous Asteroids), it will be important to reduce all the observations.

To measure the impact of Gaia stellar catalogue on the accuracy of the drift in semi-major axis, we computed the accuracy of the drift in semi-major axis for 1212 numbered NEAs and for five different kinds of reduction. For all the case, we used the current observations of these asteroids.

In the first case, we assumed the current accuracy of the observations. In the second case, we assumed that the first and the last observations could be reduced with the Gaia stellar catalogue and the others have their current accuracy. The first five and the last five could be reduced in the third case and first ten and last ten for the fourth case. Finally in the fifth case, all the observations could be reduced again with Gaia stellar catalogue.

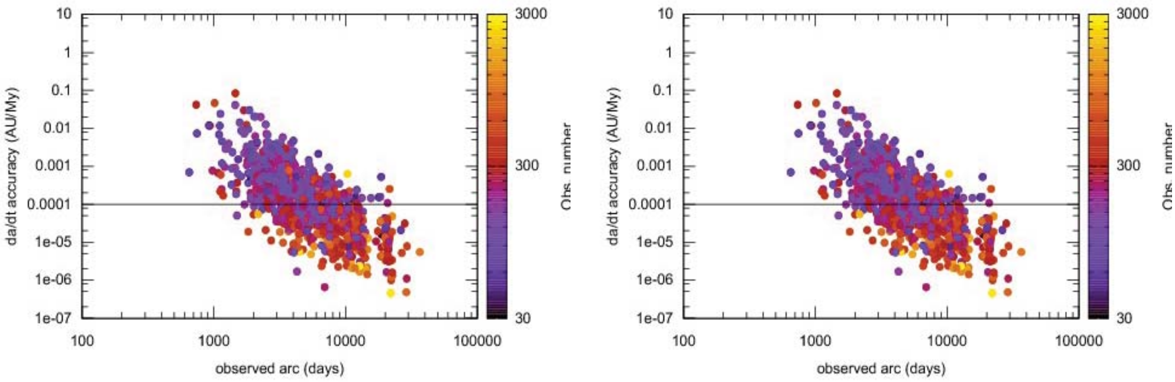

Figure 2. Relation between accuracy of the drift in semi-major axis, observed arc and number of observation for 1212 numbered NEAs and by using current accuracy for asteroid observations (left) and by assuming that all observations have been reduced with Gaia stellar catalogue (right)

Fig. 2 shows the accuracy of the drift in semi-major axis for 1212 numbered NEAs according to their observed arc and the number of observations. The values have been computed assuming the current accuracy of asteroid observations (left figure corresponding to first case) and by assuming that all observations have been reduced with Gaia catalogue i.e. with an accuracy of 10 mas(right case corresponding to last case). There is a correlation between accuracy of the drift and observed arc. In particular, asteroids for which the drift can be determined with a good accuracy (less then 10^-4 AU/My) have a large period of observations (more than 6000 days) and a large number of observations.

Table 2 shows the number among the 1212 numbered NEAs for which the drift in semi-major axis can be determined with a good accuracy (less than 10^-4 AU/My) and with a very good accuracy (less than 10^-5 AU/My) for the different cases of reduction with Gaia catalogue.

TAB. 2 – Number of astroid and accuracy of drift in semi major axis for different cases of reduction with Gaia catalogue

	NEAs with $\sigma_{\dot{a}} \leq 10^{-4}$AU/My	NEAs with $\sigma_{\dot{a}} \leq 10^{-5}$AU/My
current	6 (0.5%)	0 (0.0%)
first and last 1	29 (2.4%)	0 (0.0%)
first and last 5	96 (7.9%)	4 (0.3%)
first and last 10	150 (12.4%)	10 (0.8%)
all	536 (44.2%)	114 (9.4%)

Currently, only six NEAs have a good accuracy. But by reducing only 2 observations (the first and last ones), 29 can be determined with good accuracy. As the number of reduced observations with Gaia catalogue increases, the number of asteroids for which the drift in semi-major axis can be determined with a good accuracy also increases. Finally, if all NEA observations could be reduced with Gaia stellar catalogue, drift in semi-major axis of 536 asteroids can be determined with a good accuracy (whom 114 with a very good accuracy).

Conclusion

The Yarkovsky effect is weak non gravitational force that can have important impact in dynamical evolution of small asteroids, especially NEAs. The effect can be determined with observations (astrometrical and radar) for only few asteroids with well known orbit (ie asteroids with a large orbital arc). Simple modeling such as Chesley et al (2008) allows to determine a drift in semi-major axis of asteroids.

In this context, we determined drift in semi-major axis for NEAs. We showed that datamining can help to improve the accuracy of the drift by extending the orbital arc.

Moreover, Gaia stellar catalogue will allow a new reduction of astrometrical observations with an accuracy of about 10 mas. By reducing some or all the current observations with Gaia catalogue, it will be possible to determine the drift for about 44% of 1212 numbered NEAs with a good accuracy whereas currently only 0.5% have this accuracy.

According to Vokrouhlicky et al. (2000) model, physical parameters of the asteroid such as bulk density or spin obliquity can be deduced from the knowledge of the drift in semi-major major axis.

The Yarkovsky effect can also be determined with radar measurements or with Gaia observations themselves (Mouret & Mignard 2011) but datamining and in particular Gaia catalogue remain good opportunities in detection of the Yarkovsky effect.

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