Automatic Yarkovsky effect determination at the ESA NEO Coordination Centre

M.Fenucci[1,2], L.Faggioli[1,3], F.Gianotto[1,3], M. Micheli[1,3], D. Oliviero[1,2], A. Porru[1,4]

[1]ESA ESRIN / PDO / NEO Coordination Centre, Largo Galileo Galilei, 1, 00044 Frascati, RM, Italy, Email: neocc@esa.int
[2]Elecnor Deimos, Via Giuseppe Verdi, 6, 28060 San Pietro Mosezzo, NO, Italy
[3]RHEA Systems, Via di Grotte Portella, 28, 00044 Frascati (RM), Italy
[4]Alia Space System Srl, Via San Giuseppe Calasanzio 15, 00044 Frascati (RM), Italy

Introduction

The Yarkovsky effect is the most important non-gravitational perturbation affecting the dynamics of asteroids smaller than about 30 km in diameter. It is a thermal effect caused by non-isotropic re-emission of heat, and it mainly produces a drift in the semi-major axis. Determining the Yarkovsky effect is fundamental to: 1) correctly evaluate the impact probability of near-Earth asteroids (NEAs); 2) constrain physical properties of NEAs; 3) determine the age of asteroid families. The Yarkovsky effect has been detected on many NEAs, however, the procedure has not been fully automatized yet. This is because the lack of knowledge about physical properties of NEAs makes the estimation of the expected Yarkovsky drift very difficult. Moreover, the results of the orbit determination can be affected by isolated bad astrometric positions.

We introduce here an automatic procedure for the determination of the Yarkovsky effect on NEAs. To estimate the expected drift, we use a statistical approach based on the most recent models and findings of the whole NEA population. Candidates for detection are selected according to the length of their observational arc and on the level of uncertainty in their orbit. Detections are finally accepted only if they are statistically compatible with the estimated expected drift. Accepted detections will be available on the NEOCC web page.

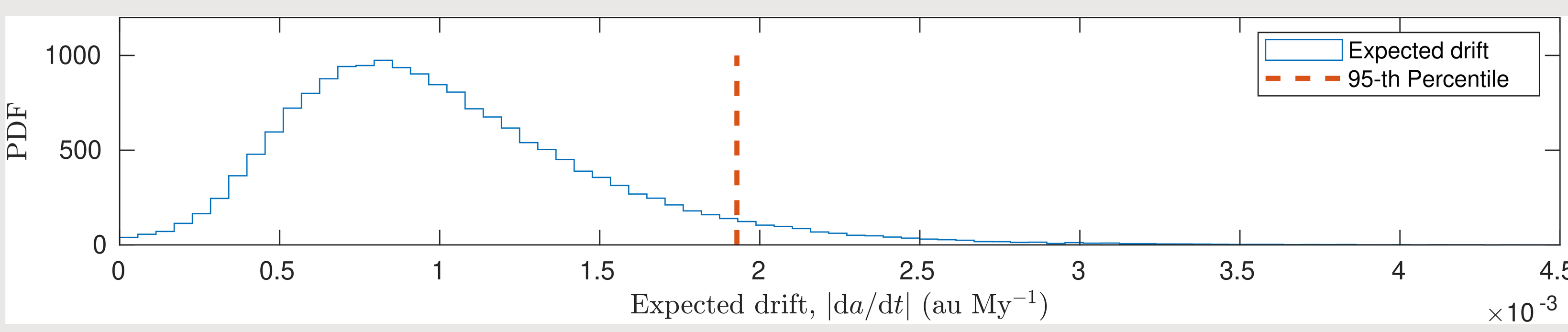
Methods

Expected Yarkovsky drift model and parameters

The expected Yarkovsky drift is computed by using a semi-analytical model [1]. Physical parameters entering the model are assumed to be either measured or modeled with a certain distribution. Data about the diameter D, the rotation period P, and the taxonomic complex, are retrieved from the `SsODNet` database [2]. When not present, the diameter D and the density ρ are modeled according to general properties of the NEA population [3].

Model Parameters	Value
D - Diameter	Population based *or* Measured
ρ - Density	Population based *or* From Taxonomy
C - Heat Capacity	800 J kg^{-1} K^{-1}
γ - Obliquity	0 / 180 deg
Γ - Thermal inertia	250 ± 100 J m^{-2} K^{-1} s$^{-1/2}$
P - Rotation Period	Estimated *or* P = 5 h x D/(1 km)

The distribution of the expected Yarkovsky semi-major axis drift $|\mathrm{d}a/\mathrm{d}t|$ is then determined by using a Monte Carlo method, and a maximum threshold can be computed.



Distribution of the expected Yarkovsky drift for (99942) Apophis.

Orbit determination

Dynamical model:

- Gravitational attraction of the Sun, the 8 planets, the Moon, the 16 most massive main-belt asteroids, and Pluto;
- Relativistic effects from the Sun, the planets, and the Moon;
- Yarkovsky effect as

$$\mathbf{a}_t = \frac{A_2}{r^2}\hat{\mathbf{t}},$$

where A_2 is a fit parameter, r is the distance from the Sun, and $\hat{\mathbf{t}}$ is the tangential direction;

Orbit determination: Orbits and parameters of the model are fitted by using a least square procedure that minimizes the observational residuals. Observational outliers are automatically rejected by using the procedure described in [4]. All the orbital computations are done with the ESA Aegis Orbit Determination and Impact Monitoring software [5].

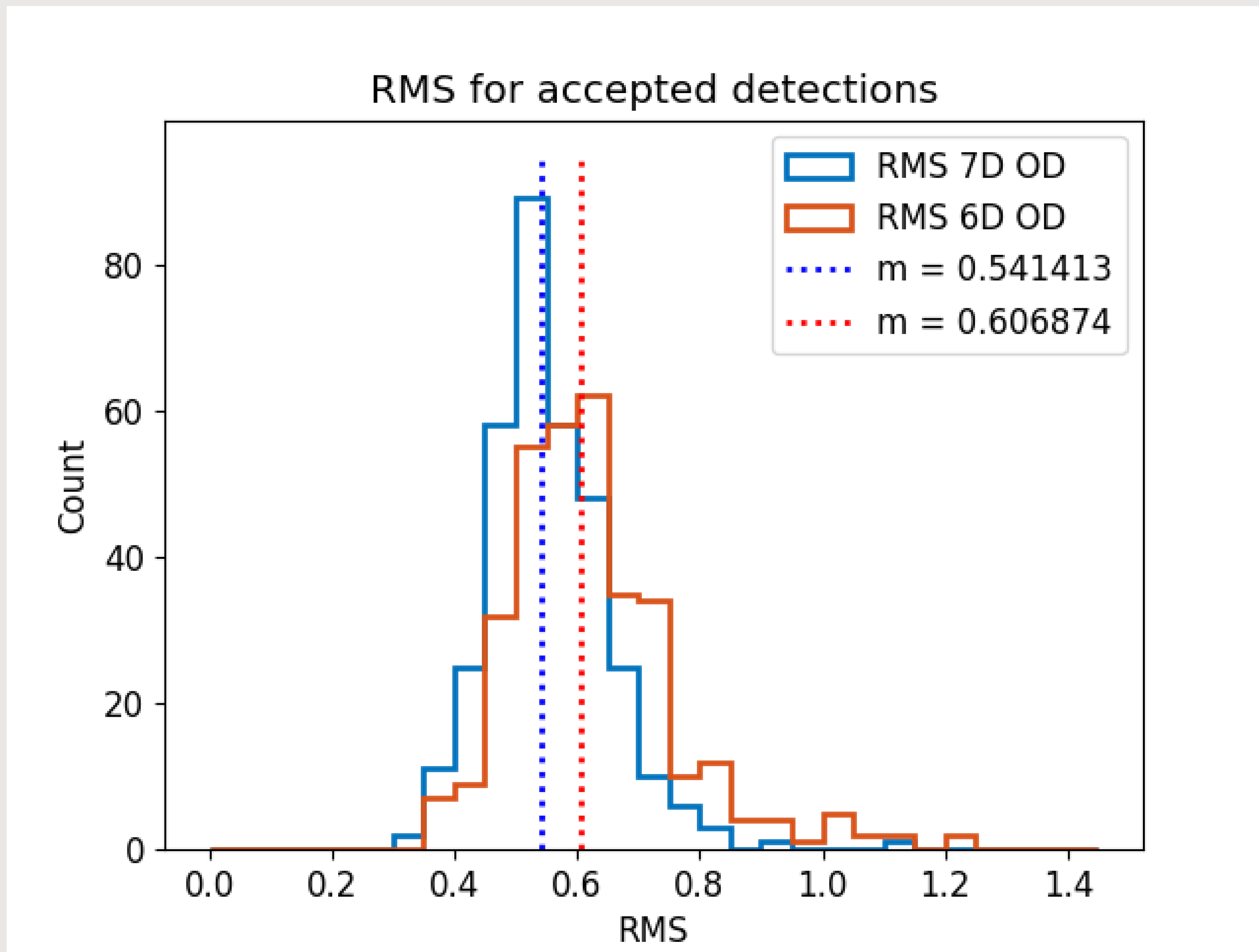
Automatic Yarkovsky effect determination

For each NEA, we perform the following steps:

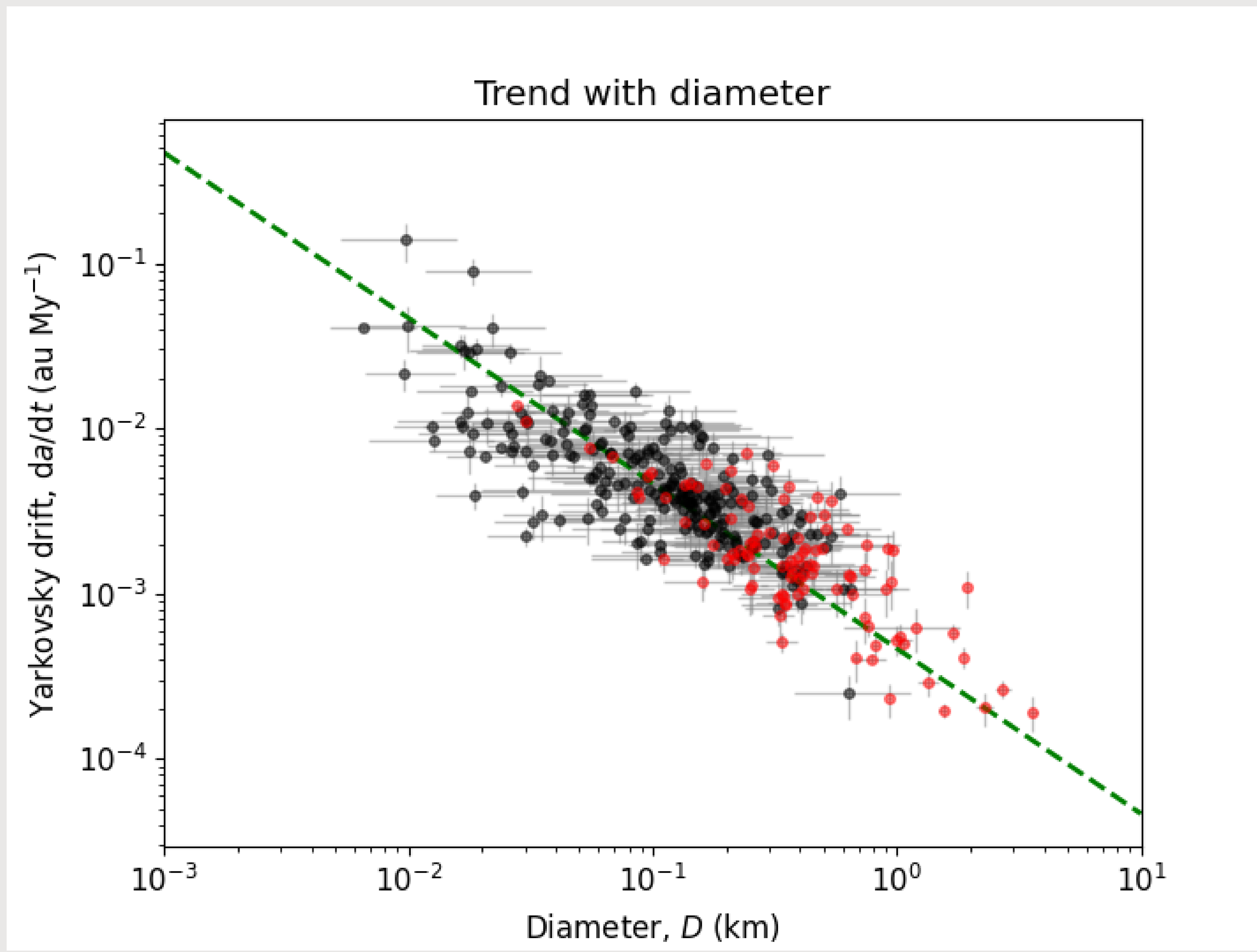
1. Determine Y_M = 95-th percentile of the $|\mathrm{d}a/\mathrm{d}t|$ distribution;
2. If $\sigma_a < Y_M \times \Delta T$ then **determine** A_2, otherwise discard the object;
3. Convert A_2 and $\sigma(A_2)$ in $\mathrm{d}a/\mathrm{d}t$ and $\sigma(\mathrm{d}a/\mathrm{d}t)$;
4. If SNR$(A_2) > 3$ and $|\mathrm{d}a/\mathrm{d}t|$ is statistically comparable with the expected drift then **accept the detection**, otherwise discard the detection.

Preliminary results

Number of positive detections: 337



Distribution of RMS of residuals from orbit determination, with Yarkovsky in the model (blue histogram) and without (red histograms).



Trend of the detected Yarkovsky drift with diameter. Red circles are NEAs with measured diameter, black circles are NEAs with estimated diameter. The green dashed line is the reference $1/D$ function.

Notable rejections:

- (433) Eros, (523599) 2003 RM
- 2006 RH120, 2009 BD, 2012 LA, 2012 TC4, 2015 TC25

References

▪ [1] Vokrouhlický D., et al. (2017), *AJ*, **153**, 270 ▪ [2] Berthier J., et al. (2023), *A&A* ▪ [3] Fenucci M., et al. (2021), *A&A*, **647**(A61) ▪ [4] Carpino M., et al. (2003), *Icarus*, **166**, 248 ▪ [5] Faggioli L., et al. (2022), *2nd NEO and Debris Detection Conference*

Scan the QR code to go to the **NEOCC web portal**