THE YARKOVSKY EFFECT ON APOPHIS: BULK DENSITY CONSTRAINTS AND ANTICIPATED OSIRIS-APEX SCIENCE. D. Farnocchia[1], D. Vokrouhlický[2], D. Čapek[3], S.R. Chesley[1], and D. N. DellaGiustina[4], [1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109, USA, Davide.Farnocchia@jpl.nasa.gov, [2]Charles University, CZ-180 00 Prague 8, Czech Republic, [3]Czech Academy of Sciences, CZ-251 65 Ondřejov, Czech Republic, [4]Lunar and Planetary Laboratory, University of Arizona, Tucson, AZ 85721, USA.

Introduction: Since its discovery in 2004, Apophis has been one of the most remarkable asteroids in the catalog. Initial calculations indicated that Apophis had a significant probability of Earth impact in April 2029. Although this impact was later ruled out thanks to precovery and radar observations [1,2], Apophis will nevertheless make an exceptionally close approach to Earth on 2029 April 13 at 38,000 km from the geocenter. This anticipated encounter at first caused substantial uncertainty about the orbit of Apophis and opened the possibility of impacts in later years, especially 2036 and 2068 [3,4]. However, as more tracking data were collected through 2021, any impact was ruled out, and the trajectory is now fully deterministic over the next century [5,6].

The 2029 encounter offers a singular scientific opportunity to study a small asteroid (340 m diameter) [7] coming so close to Earth [8]. Among other things, the spin state of Apophis may change [9], and resurfacing mechanisms could take place [10]. Ground-based campaigns [11] and space missions [12] are being planned to maximize the scientific return from this "natural experiment".

Spacecraft interactions with Apophis after the 2029 encounter will not materially alter the future trajectory of Apophis. On the other hand, before the 2029 encounter, only science-level interactions such as flybys and SmallSat impacts are generally safe, whereas a kinetic impact–class interaction could result in unwarranted and undesirable orbital perturbations [6].

The Yarkovsky effect: Given the well-constrained orbit and the scattering effect of the 2029 encounter, the Yarkovsky effect [13] has been a key consideration for modeling the future trajectory of Apophis [1,2,3,4]. Thanks to the tracking data collected from 2004 to 2021, the semimajor axis drift caused by the Yarkovsky effect on Apophis is now well measured as -199 ± 1 m/yr [6].

The high signal-to-noise ratio of this detection, together with other measured physical properties of Apophis, allows us to derive constraints on its bulk density. A similar approach was successfully used to estimate the mass of Bennu prior to the arrival of the OSIRIS-REx mission [14,15]. Apophis has a diameter of 340 ± 50 m, a visible albedo of 0.29 ± 0.03, and a slope parameter 0.24 ± 0.11 [12]. By adopting these physical parameters and the non-principal axis rotation state and shape derived from photometric observations [16], we computed the Yarkovsky drift as a function of thermal inertia as in [4] and in turn derived the bulk density needed to match the measured drift, as shown in Fig. 1. Even though the constraints are not as tight as they were for Bennu [14], the density range is consistent with Apophis's Sq-type taxonomy [12,17]. The only possible discrepancy may arise towards the lower end of the estimated range of thermal inertia [12], which favors a low bulk density.

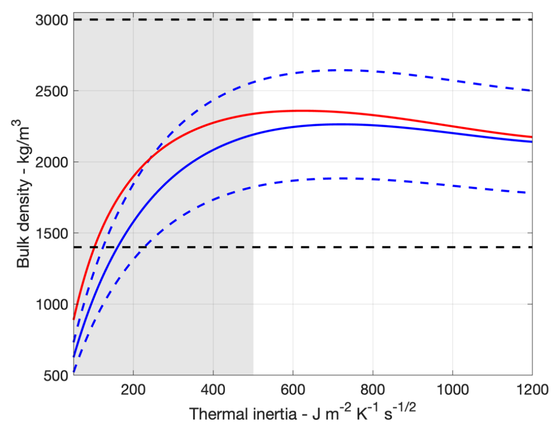

Figure 1. Bulk density of Apophis as a function of thermal inertia. The solid blue curve represents the case with a smooth surface, and the blue dashed lines show the ±1-σ error due to uncertainties in the Apophis physical parameters. The red curve represents the case with 100% surface roughness, using as a proxy a Yarkovsky-enhancement model developed for Bennu [14]. The shaded area corresponds to the estimated range of thermal inertia for Apophis [12]. The dashed black lines encompass the plausible range of densities based on Itokawa as an analog [12].

Yarkovsky science with OSIRIS-APEX: The OSIRIS-APEX mission will visit Apophis after the 2029 encounter [12]. Among the science goals of the mission is measuring the post-encounter Yarkovsky effect. In fact, any change to the rotation spin state of Apophis during the encounter would cause a change in the Yarkovsky effect. OSIRIS-APEX could allow the first measurement of a Yarkovsky effect change, which could also be compared to models and measurements of the spin state of Apophis before, during, and after the 2029 encounter.

While in orbit, OSIRIS-APEX will measure the position of Apophis to 2 m precision using spacecraft ranging, like OSIRIS-REx at Bennu [18]. The longer the spacecraft stays in orbit, the better the post-encounter Yarkovsky effect can be measured. The current mission profile would enable a 1-σ detection of a 4% change in the Yarkovsky effect (see Fig. 2). If the mission were extended beyond November 2030, there could be an improvement of up to an order of magnitude.

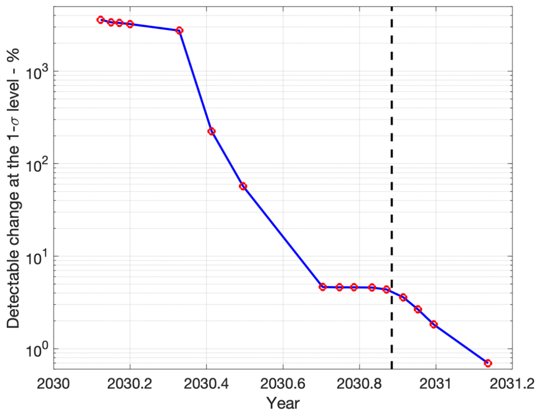

Figure 2. Detectable change in the Yarkovsky effect as a function of the length of the mission, currently scheduled to end in November 2030 (dashed black line). The red dots correspond to simulated ranging points during orbital phases of the mission.

Acknowledgments: We thank B. Rozitis for helpful discussions. The OSIRIS-APEX mission is supported by NASA Contract NNM10AA11C. Part of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with NASA.

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