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APOPHIS: COMPLEX ROTATION AND HAZARD ASSESSMENT

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ABSTRACT

(99942) Apophis is one of the most remarkable near-Earth asteroids in terms of impact hazard. In 2004 the probability of an impact in 2029 reached a peak of 2.7%. With the data available today we know that Apophis will pass Earth safely in 2029 at about 38,000 km. However, despite the availability of a well observed arc and three radar apparitions, the 2029 Earth encounter has such a strong scattering effect on the trajectory of Apophis that post-2029 predictions are only possible in a statistical sense and impacts in the following decades are hard to rule out.
To predict the future ephemerides of Apophis the dominant source of uncertainty is the Yarkovsky effect, a small nongravitational perturbation that arises from the anisotropic re-emission at thermal wavelengths of absorbed solar radiation. Modeling the Yarkovsky effect acting on an asteroid is generally challenging, as we need a good knowledge of the asteroid's physical model or observable deviations from a purely gravitational trajectory. A further complication comes from the complex rotation state of Apophis. We use the available information on the physical properties of Apophis, e.g., shape, size, thermal inertia, and rotation state, to estimate the Yarkovsky effect acting on Apophis by solving the nonlinear heat transfer equation on a finite-element mesh of facets model of the shape of Apophis.
We find that the Yarkovsky perturbation significantly affects the trajectory of Apophis, thus contradicting the idea that a complex rotation state implies an insignificant

contribution of the Yarkovsky effect. We analyze the implications on the hazard assessment by mapping the orbital uncertainty to the 2029 close approach and computing the keyholes, i.e., the locations at the 2029 Earth encounter leading to a resonant impact at a future close approach. Whereas collisions with Earth before 2060 are ruled out, impacts are still possible after 2060 with probabilities up to few in a million.

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