THE PLANETARY DEFENSE AND SCIENCE CASE FOR A MISSION TO STUDY APOPHIS BEFORE, DURING, AND AFTER ITS CLOSEST EARTH APPROACH IN 2029. R. T. Daly[1], O. S. Barnouin[1], A. F. Cheng[1], J. B. Plescia[2], D. C. Richardson[2], J. V. DeMartini[2], N. C. Schmerr[2], J. M. Sunshine[2], C. M. Ernst[1], B. W. Denevi[1], J. T. Cahill[1], A. K. Davis[1], N. C. Chabot[1], and D. S. Lauretta[3]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (terik.daly@jhuapl.edu), [2]University of Maryland, College Park, MD, [3]University of Arizona, Tucson, AZ, USA.

Introduction: In April 2029, the asteroid 99942 Apophis will pass within ~36,700 km (5.7 Earth radii) of the Earth—a distance comparable to geosynchronous orbit (~36,000 km). Apophis' close approach in nine years does not, in and of itself, justify a sending a spacecraft. Two factors, however, compellingly motivate a mission to Apophis.

First, according to impact risk data from the Sentry program, Apophis is among the top three potentially hazardous asteroids (PHAs), as rated by the Palermo scale [1]. Characterizing key properties (e.g., mass, detailed shape, topography, and internal structure) of Apophis and refining its orbital properties and spin state will improve predictions for future Earth flybys and aid the planning of successful mitigation efforts, should the need arise. Furthermore, Apophis provides a unique test of models, physical assumptions, and remote inferences about PHAs that will help inform mitigation efforts for any future hazardous object.

Second, the 2029 Earth encounter provides a rare opportunity to observe active tidal forces on a ~340-m diameter asteroid. Tidal forces will not be strong enough to break apart Apophis, but may trigger measurable changes in asteroid rotational dynamics, surface morphology, exposure of space weathered materials, and seismic activity [2–8]. The 2029 close passage of Apophis is the best near-term opportunity to study these tidal disturbances, which also affect other Solar System objects that encounter tidal stresses.

Here we focus on the science and planetary defense motivations for a dedicated mission that targets Apophis in time for its 2029 Earth encounter. Potential mission concepts are discussed elsewhere [e.g., 10–12]. A mission that takes fullest advantage of the science and planetary defense opportunities presented by the Apophis flyby will study the asteroid before, during, and after its closest approach.

Why Apophis in 2029: The evolution of small asteroids (<5 km) is influenced by YORP driven spin-up, impact processes (including impact-induced seismicity), thermal fragmentation processes, and tides, when in close-enough proximity to a planet. The 2029 Apophis apparition is uniquely suited for studying how planetary tides affect asteroids, while also providing insights into impacts and thermal fragmentation. By studying the surface, interior seismicity, and rotational state of Apophis leading up to, during, and after its closest approach, we can learn about each of these processes. The Apophis Earth flyby also provides an opportunity to test the idea that tidally induced resurfacing from close encounters with Earth may explain the presence of unweathered surfaces on Q-type asteroids [3].

Although models predict that Apophis will not be reshaped at large scales by tidal forces during the encounter, they do suggest that smaller-scale motion or displacements may occur, processes that could trigger seismic activity [e.g., 8]. Apophis has surface slopes as steep as 45° (Figure 1); such slopes should be close to failure.

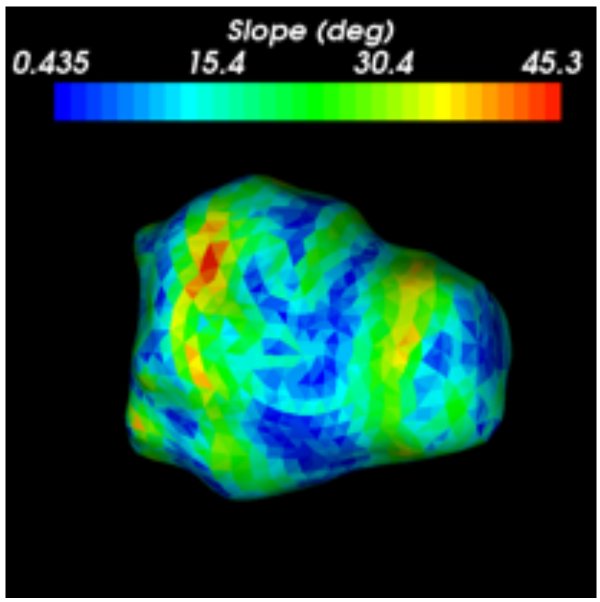

Figure 1. Radar-based shape model of Apophis [13], colored by surface slope.

It would be wise, however, to remember that missions often yield results at odds with pre-encounter models or predictions. Every asteroid visited by spacecraft has surprised the scientific community (e.g., Itokawa, Bennu, Ryugu, Eros, Mathilde, etc.), with observations that have defied pre-encounter predictions and models. For instance, OSIRIS-REx has observed multiple particle ejection events at Bennu [9]. No pre-encounter models predicted that Bennu would be ejecting particles as large and as often as it does. The extent to which features on Apophis will be reshaped, the interior structure adjusted, and the asteroid's spin state modified by the Earth encounter in 2029 should be viewed as open questions—questions that can only be answered by a rendezvous mission that characterizes Apophis before (to establish a baseline for reference), during, and after Earth closest approach. A mission that studied Apophis only *after* closest approach would not provide the crucial before-and-after comparisons required to fully characterize the effects of the Earth encounter.

Relevant instruments on an Apophis rendezvous mission could include a high-resolution color camera, seismometers, and/or a radar sounding instrument, among others [10–12]. The impactor flux in near-Earth space, and therefore at Apophis, is reasonably well-understood. The flux is such that, within a year, a natural impact should occur that produces seismic signals that could be detected by a seismometer on the surface.

A null result (e.g., no detectable change in the spin state, surface, or interior of Apophis) would still provide useful information. It would serve as a point of reference for validating tidal deformation models and bound the values of properties critical to planetary defense, such as the bulk strength, porosity, and internal structure of Apophis and, by extension, other similar near-Earth asteroids.

Additional Advances in Asteroid Science and Planetary Defense: From remote sensing, Apophis is relatively well-understood at global scales geologically, compositionally, and dynamically [2–8; 13–16], which makes it an ideal target for characterizing surface changes and asteroid interior structure. In addition to the unique science that can only be done because of Apophis' close approach, an Apophis mission could advance a range of asteroid science and planetary defense topics, including the effects of micrometeoroid and meteoroid bombardment, thermal fracturing, and asteroid interior structure.

An appropriately instrumented Apophis mission could produce first-of-a-kind observations of an asteroid's interior structure. This result could be achieved using seismometers deployed on the surface (an active seismic source could be brought, in case micrometeorites or tidal sources were insufficient to measure the deep interior structure) or radar sounding. Asteroid internal structure is poorly understood [17], yet will significantly affect the outcomes of asteroid deflection attempts. Apophis in 2029 is, for the next few decades, our sole chance to study the effects of Earth tides on PHAs. We maximize our ability to interpret the tidal effects and prepare for a future deflection attempt (should the need materialize) if we determine the structure of Apophis' interior.

If a mission to Apophis were executed, Apophis and Bennu (which is also one of the top 3 PHAs on the Palermo scale [1]) would become the best-characterized PHAs. The two bodies have very different compositions and properties, which makes them useful endmembers for considering how the diverse properties of PHAs could affect asteroid deflection efforts (if needed at a future time), since the specific type of PHA requiring deflection is not known in advance.

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