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The Asteroid Probe Experiment (APEX): Seismology at 99942 Apophis

N. C. Schmerr[(1)], V. Lekic[(1)], A. Mautino[(1)], J. B. Plescia[(2)], O. Barnouin[(2)], M. Paul[(2)], D. C. Richardson[(1)], L. Dai[(3)], J. V. DeMartini[(1)]
[(1)]University of Maryland, College Park, MD (nschmerr@umd.edu)
[(2)]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD 20723
[(3)]Arizona State University, Tempe, AZ

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ABSTRACT

The ~400 m diameter asteroid 99942 Apophis will make a close approach to Earth on April 13, 2029, passing at a distance of only 36700 ± 9000 km – closer than geosynchronous satellites. While the approach is not close enough to disaggregate the asteroid, it is expected to produce changes in the rotational state, solid body shape, and surface morphology. Apophis' encounter with the Earth presents a unique opportunity for a detailed study of a Near-Earth Asteroid with a small spacecraft. We carried out a study for a mission concept called APEX (Asteroid Probe Experiment) to characterize the internal structure, rotational dynamics, and surface morphology as Apophis passes the Earth in 2029. A major task of this mission would place a seismometer on the surface to monitor seismic signals generated during the Earth/asteroid encounter.

The seismometer mission requirements for APEX were to record seismic energy on 3 orthogonal components and across a range of high frequencies (10–500 Hz), and amplitudes (> 10–100 ng), spanning several weeks. Defining the internal structure of a small body is critical to understanding its origin and geologic history as well as its potential effects should it impact the Earth. A body composed of a loose

aggregate of particles might disaggregate due to tidal forces as it encounters the Earth and be further dispersed upon entry into the atmosphere. A single solid object could survive tidal forces and pass through the atmosphere more easily. Models of asteroid interiors suggest a range of possible conditions from solid massive objects to collections of relatively small particles (rubble piles). There is no direct data constraining the interior structure of Apophis. Its 27-hour rotation period would place Apophis among the slow rotators that have been interpreted as rubble piles, but a monolith object could also rotate slowly.

To investigate the internal structure of Apophis and determine how to best use seismic waves to study asteroid interiors, we constructed a linear tetrahedral mesh of the asteroid shape model and used the mesh to perform isoparametric Finite Element Modeling of seismic waves. Our models focused on a rock-like propagation speed through the asteroid (V_p = 2,000 m/s), although the model allows for arbitrarily layered and heterogeneous media like lunar regolith. The modeling shows that a 1 kg object striking the surface at 1 m/s (1 Ns) results in a ground motion of 0.4 m/s^2 at the source (enough to loft particles off the surface in the microgravity of the asteroid), and waves propagate with amplitudes > 10^{-5} m/s^2 within the asteroid, well above the sensitivity of most seismic instrumentation (1–10 ng or greater). We predict that peak ground shaking takes place at the pinched interface between the two nodes of the asteroid and at the antipodes to the source. The highest likelihood of strong ground motion is modeled to be in proximity to this local low region on the asteroid, and/or at topographic highs. A preliminary recommendation for APEX was that seismic instrumentation be placed in the vicinity of the neck or away from topographic peaks.