APEX - ASTEROID PROBE EXPERIMENT. J. B. Plescia[1], O. Barnouin[1], D. Richardson[2], N. Schmerr[2], D. Lawrence[1], B. Denevi[1], C. Ernst[1], and H. Yu[3] [1]Applied Physics Laboratory, Johns Hopkins University, Laurel, MD, [2]University of Maryland, College Park, MD, [3]Arizona State University, Tempe, AZ.

Introduction: The Asteroid Probe Experiment (APEX) is a mission concept to determine the interior structure of an asteroid. The mission employs a small spacecraft (Discovery or Deep Space Small Sat) that can rendezvous with an asteroid, deploy a suite of seismometers and then conduct a passive and possibly active seismic experiment. Determining the interior structure of an asteroid is critical to understanding their origin and evolution. Knowledge of the interior structure is also vital to understanding the hazard a near-Earth object (NEO) impact would pose to the Earth.

While any NEO could serve as a target, we focus here on Apophis. Apophis is a particularly intriguing object that will be influenced by tidal forces during its close approach to the Earth in April 2029, and that has an extremely small probability of impacting the Earth in 2036. Apophis is also characterized by a slowly tumbling rotation state thought to be excited by tidal forces each time the asteroid encounters the Earth. An impact of a 300 m diameter object, similar to Apophis, would have continental-scale implications releasing about 2,000 MT of energy.

APEX would be the first mission to directly explore the interior structure of an NEO, while also characterizing its rotational and surface properties.

Apophis: Discovered in 2004, Apophis is an Sq-type asteroid ~325 m diameter. Apophis has an orbit-geometry similar to that of the Earth and became an object of considerable interest in 2004 when initial observations suggested that it had a 2.7% chance of impacting the Earth in 2029. Subsequent radar data collected in 2005 [1] led to a correction of the 2029 approach, indicating an encounter of only 0.000245 ± 0.000060 AU (36,700 ± 9,000 km or 5.7 ± 1.4 Earth radii, 3σ uncertainties), which is just below geosynchronous orbit and 28,000 km closer than predicted by the pre-radar ephemeris. An impact at a future date remains possible [2-4]. Apophis' approach to Earth in 2029 is expected to be sufficiently close that its surficial properties and rotational period and axis might change [5-6].

Mission Description: The APEX mission has the following set of baseline objectives: (1) determine the rotational dynamics, (2) establish the physical dimensions, (3) determine the topography, (4) determine the interior structure, and (5) define the surface morphology. Additional objectives include the chemical and mineralogic composition and the surface physical properties. The mission will also provide data needed to calibrate interpretations of Earth- and space-based astronomical observations and Earth-based radar observations of NEOs.

Two of the most important science aspects are the level of tidal stresses and the seismic response of Apophis to those stresses. Apophis will approach the Earth to <5.7 ± 1.4 radii. The classical Roche limit for a cohesionless fluid body (ρ = 2.4 g cm^{-3}) to escape disruption by tidal forces is 3.22 Earth radii, hence Apophis is not expected to disrupt, as did Shoemaker Levy 9. However, it is expected that deformation and reorientation will occur and will be sufficient to excite seismic signals in the interior. The characteristics of those signals can be used to understand the interior structure.

Spacecraft: One version of the spacecraft (Fig. 1) has dimension of 0.65 x 0.65 x 1.1 m and has a total mass of 191 kg (including the sensors) with an average margin of about 11%. Power is supplied by two solar-array-panels. When deployed, an arm to deploy the seismic sensor is 3.3 m long (excluding the sensor package). Arms are mounted to the side of the spacecraft. During flight, arms are folded and stowed against the spacecraft. Upon arrival at the target body, once a survey has been made to identify appropriate locations, an arm is unfolded. The spacecraft then navigates up to the body and presses the instrument package against the surface. The package has an anchor on the bottom to ensure mechanical coupling between the sensor and the body. The arm releases the instrument package via a connector at the top.

Conops: The mission's concept of operation includes an initial rendezvous with Apophis prior to its encounter with the Earth to characterize the body, followed by deployment of the seismometer on the surface. The spacecraft then conducts station-keeping or orbits to collect information about the asteroid as it encounters the Earth and undergoes tidal deformation. Following the encounter, the spacecraft will continue observations to fully characterize the rotational dynamics and any surface changes.

Arrival must be early enough that the surface can be mapped and rotational parameters determined with confidence before Earth encounter. Any changes to the body as the result of tidal forces will occur over a few hours during closest approach. After encounter, the surface will be remapped and observed to determine if any changes have occurred in the surface character or rotational parameters.

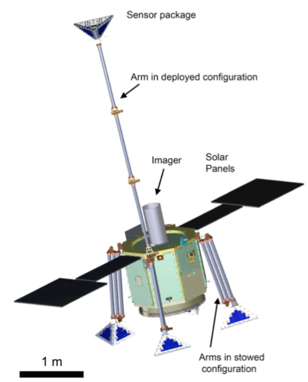

Fig. 1. Solar powered spacecraft with arms to deploy seismometers onto the surface.

Station keeping or orbiting a small body, in the near-Earth environment, is challenging as the spacecraft will be small and subject to orbit perturbations, the spacecraft will possibly need to navigate to within a few meters of the surface to deploy the seismometer and the distance between the spacecraft and Apophis held as constant as possible for uniform mapping.

The mission will observe Apophis before, during and after its encounter with the Earth in 2029 to define it characteristics and to understand how the tidal forces of the encounter influence the body, its surface and its rotational states. The tidal forces will induce deformation that will provide the seismic sources for measuring the asteroid's internal structure. These objectives are specifically cited by the NRC [7] study as required to fully characterize an NEO and provide the information necessary to determine mitigation efforts.

Payload: The baseline payload includes a panchromatic imager and a seismometer; additional candidate instruments include a multiband imager, a thermal imager, and a gamma ray spectrometer.

Panchromatic imaging: Defining the rotational period, precession, and pole for Apophis requires imaging of the entire body over a sufficient period of time to fully define those aspects. The instrument required to produce this data can be a simple panchromatic framing camera. Given that the spacecraft will be in close proximity to Apophis, the IFOV can be modest and still produce high-resolution images. Complete coverage, in stereo, is required to define the shape model and local topography.

Seismometer: A seismometer is the most critical instrument as it provides the data necessary to understand the tidal effects and the internal structure. The seismometer concept is one that has been developed by Hongyu Yu at Arizona State University with. This instrument senses seismic displacement via electrolyte flow through sensor plate. The seismometer has high performance, similar to that of a terrestrial seismometer. Because there are no moving parts, the sensor is orientation independent (i.e., it does not need to be leveled) greatly simplifying deployment. An additional aspect of the seismic experiment would to be to prove an active source (e.g., explosive) such that the internal velocity could be determined.

Multi-color imaging: In order to assess the composition of surface, images at a range of wavelengths are necessary. A hyperspectral instrument is inconsistent with the scale of this mission. However, a color imager could fit within the constraints and provide the necessary data. A simple three-wavelength observation could be sufficient to define space weathering. Such an instrument would replace the panchromatic imager noted above.

Thermal imaging: The surface thermal properties are important in terms of understanding how materials endure thermal fatigue and how processes such as YORP modify Apophis' orbit. Here, a simple bolometer to measure surface temperature will be considered.

Surface composition: Elemental composition of a NEO is important data to understand its origin and evolution. Gamma-ray spectroscopy is a standard technique for obtaining elemental composition measurements. To obtain robust composition measurements, a gamma-ray spectrometer (GRS) needs to be located within 0.5 body radii for at least tens of hours. This would require close-proximity operations either by the main spacecraft.

Summary: APEX would be the first mission to directly explore the interior structure of a NEO, while also characterizing its rotational and surface properties. It will investigate Apophis, a particularly intriguing object that will be influenced by tidal forces during its close approach to the Earth in April 2029. Apophis is also characterized by a slowly tumbling rotation state thought to be excited by tidal forces each time the asteroid encounters the Earth.

References: [1] Giorgini, J. D. et al. (2008) Icarus, 193, 1-19. [2] Chesley, S. R. (2005) Asteroids, Comets, Meteors, IAU Symposium 229. [3] Chesley, S.R., et al. (2013) Amer. Astron. Soc., DPS Meeting, abstract 106.08 [4] Vokrouhlický, D. et al. (2015) Icarus, 252, 277-283. [5] Scheeres, D. J. et al. (2015) Asteroid Interiors and Morphology, in, Asteroids IV, University of Arizona Press, pp. 745–766. [6] Yu, Y., et al., 2014, Icarus, 242, 82-96.4 [7] NRC, 2010. National Research Council, Defending Planet Earth, Near-Earth-Object Surveys and Hazard Mitigation Strategies, National Academies Press, 133 pp.