APOPHIS 2029 PLANETARY DEFENSE MISSION OPTIONS. A. F. Cheng[1], R. T. Daly[1], O. S. Barnouin[1], J. B. Plescia[1], D. C. Richardson[2], J. V. DeMartini[2], N. C. Schmerr[2], J. M. Sunshine[2], C. M. Ernst[1], B. W. Denevi[1], and J. T. S. Cahill[1]. [1]Johns Hopkins University Applied Physics Laboratory, Laurel, MD, USA (andy.cheng@jhuapl.edu), [2]University of Maryland, College Park, MD.

Introduction: The Potentially Hazardous Asteroid (PHA) 99942 Apophis will make an extremely close approach to Earth on 13 April 2029, within ~0.1 lunar distance or ~37000 km. This apparition provides a rare opportunity to visit Apophis with a spacecraft and to make vital measurements to inform and formulate a planetary defense. Through 2200, no other PHA will approach as close to Earth. The close flyby of Earth by Apophis raises the possibility of observing any tidally induced resurfacing and possible reshaping of the body as well as possible modifications of the unusual spin state of the body. Further important measurements to be made by an Apophis 2029 mission include: determinations of the Apophis future impact hazard and Yarkovsky drift; physical properties relevant to mitigation, like strength and porosity; and internal structure.

Apophis in 2029: Apophis is an Sq-type near-Earth asteroid [1] and is elongated and asymmetric with a mean diameter 340 m as measured by radar [2]. Apophis is in a tumbling, non-principal axis rotation state [3, 2] where the strongest light curve amplitude is at a period of 30.56 hr.

Tidally induced resurfacing, during Earth close approaches, may explain the apparently fresh and unweathered surfaces of Q and related type NEAs [4]. Apophis in its 2029 apparition will come to about 6 R_E from Earth, which is well outside the classical Roche limit (for density 2.4 g/cm^3, the Roche limit is at 3.2 R_E). Hence tidal disruption or drastic reshaping of Apophis are not expected from the 2029 flyby of Earth, but small-scale surface mass motions or boulder displacements may be triggered [5]. In addition, substantial changes in the spin state of Apophis may be induced by the Earth flyby [6, 7]. Tidally driven stress build-up may also create seismic activity [8].

Apophis 2029 Planetary Defense Mission (PDM): To be able to observe the changes that may be induced by the close approach to Earth, the Apophis 2029 PDM must rendezvous with Apophis some months in advance of the close approach on 13 April 2029 and then remain in rendezvous with Apophis for several months afterwards. Chemical mission opportunities have been identified that could launch in late 2027 and arrive at Apophis in late 2028, with a medium launch vehicle and total post-launch Δv <1800 m/s.

Mission objectives are summarized in Table 1. The objectives fall into three main goal areas: impact hazard risk assessment for the long-term future after 2029; determinations of physical properties that would greatly reduce risk for any future mitigation; determinations of asteroid interior structure. Apophis 2029 PDM will map the entire surface before and after the Earth flyby, and it will emplace seismometers and monitor seismic activity induced by the Earth flyby as well as activity from micrometeorite impacts and thermal fracturing. It will conduct an active seismic experiment and perform radar tomography to characterize internal structure, and it will observe and measure changes in the Apophis spin state from the Earth flyby.

Table 1. Apophis 2029 Mission Objectives

Mission Objectives	Measurement objectives	Techniques
Impact risk assessments	Orbit determination and propagation after 2029	Radiometric tracking
	Yarkovsky drift determination	Radiometric tracking, TIR imaging
Physical properties relevant to mitigation	Observe and measure changes in surface features and shape/morphology	Narrow angle Vis imaging, VNIR and TIR spectral imaging
	Determine geotechnical properties, including strength and porosity	Seismometers, active impactor experiment, RF gravity or gravimetry
	Observe and measure changes in Apophis spin state	High-resolution visible imaging
Interior Structure	Characterize subsurface interfaces, layers, blocks, or voids	LF radar, seismometers, RF gravity or gravimetry
	Observe any changes from flyby or from active impactor experiment	LF radar, seismometers, RF gravity or gravimetry

The mission concept uses a rendezvous spacecraft with one or more 6U CubeSats that may be close-in orbiting or landed experiment packages. Mission implementation options include accommodation of particular experiments on the main rendezvous spacecraft or on CubeSats. The rendezvous spacecraft will carry a narrow-angle camera for optical navigation and for performing the high-resolution imaging needed to determine shape and size, to observe any changes in Apophis from the Earth flyby, and also to measure the spin state before and after the flyby. This camera should have 10 cm resolution from 20 km range. The rendezvous spacecraft maintains a home position, where it is tracked by and communicates with Earth. Many of the other instruments can be carried on 6U CubeSats that are tracked by and communicate with the rendezvous spacecraft. In particular, VNIR spectral imaging, thermal spectral imaging, a gravimetry experiment, a Low-Frequency radar for tomography, and seismometers can be on CubeSats.

One or more of these experiments (e.g., thermal imager, active impactor) may alternatively be accommodated on the rendezvous spacecraft. The active impactor experiment would have two objectives: to create a small crater or craters and to provide artificial seismic stimuli, and can be accommodated on the rendezvous spacecraft. Gravity field determinations may be from a dedicated gravimeter in close orbit or landed on Apophis, and/or from Radio-Frequency tracking of CubeSats from the rendezvous spacecraft. An altimeter on the rendezvous spacecraft may further contribute to size, shape and gravity determinations.

In conclusion, the 2029 Apophis Earth flyby is a unique opportunity to obtain vital information for planetary defense by studying Apophis, determining its internal structure, and observing possible changes due to tidal effects from the Earth flyby.

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