POTENTIAL MISSION CONCEPTS FOR CHARACTERIZING THE POTENTIALLY HAZARDOUS NEAR-EARTH ASTEROID (99942) APOPHIS. C. A. Raymond[1], J.F. Bell III [2], R.S. Park[1], D. Landau[1], S.R. Chesley[1], K. Reh[1], P.W. Chodas[1], and M. Brozovic[1],[1]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA (carol.a.raymond@jpl.nasa.gov), [2]Arizona State University, School of Earth & Space Exploration, Tempe, AZ, USA.

Introduction: The near-Earth asteroid (99942) Apophis will make an extremely close pass by the Earth on April 13, 2029, providing an unprecedented opportunity for up-close study of a Potentially Hazardous Asteroid (PHA). This ~350 m diameter object will pass through the Earth-Moon system at a closest approach altitude to our planet of less than five Earth radii. This close flyby provides a unique opportunity to study potential tidal distortion and/or surface mass wasting effects on the asteroid that could provide unique insights into its interior structure and other physical properties. The encounter will allow characterization of a highly-representative member of the approximately 2,000 PHAs at a variety of mission scales, from ground-based assets to in-situ spacecraft observations. As such, it provides an easily accessible target for a dry run of a rapid response characterization of a hypothetical potential Earth impactor.

Here we summarize three main objectives of an Apophis encounter mission for planetary science as well as for planetary defense. These intertwined goals define a suite of mission and payload concepts that would characterize Apophis from orbit, as well as demonstrate the capability to obtain information needed to inform the design of deflection or other mitigation missions for a real impact threat.

Background and Mission Objectives: (99942) Apophis is an Sq-type asteroid that qualitatively matches LL ordinary chondrite meteorites [1]. Its spectrum is well-matched by a mixture of olivine and pyroxene that has been space-weathered (i.e., reddened). The size and rough shape of Apophis has been determined using ground-based radar, yielding an equivalent diameter of 340±40 m [2]. From the inferred composition and rough size, an upper bound on the mass is obtained as 6.1×10^{10} kg, with an estimate of 2.0×10^{10} kg if its porosity is similar to Itokawa's (~40%) [1]. Radar observations indicate non-principal axis rotation about the short-axis [3]. Little is known about the internal structure of Apophis.

Mission Objective #1 is to map the geology, composition, and mineralogy of Apophis to confirm its taxonomic type and meteoritic analogs, and its affinity to other small near-Earth asteroids also studied by deep space missions, e.g., (25143) Itokawa, (101955) Bennu, or (162173) Ryugu. This information is important to confirm the expected grain density for comparison to the mean density and thus to understand bulk porosity. It also provides a basis to link Apophis to other asteroids and meteorites in general.

Mission Objective #2 is to measure the asteroid's mass, shape and spin state. Mass is arguably the most important property of any PHA from a deflection or impact mitigation standpoint.

Mission Objective #3 is to understand the asteroid's internal structure and regolith properties. Regolith depth, and the distribution of porosity in the interior, provide information on the strength of the object and on the asteroid's origin and evolution – important intrinsic science information, but also additional data with which to inform deflection or other potential impact mitigation strategies.

Flyby Missions: A flyby mission with multispectral cameras and/or a VIS-IR spectrometer could address MO #1. A thermal IR spectrometer could also reveal regolith properties (grain size, roughness) to address MO #3. A second in-tandem spacecraft could also potentially enable the determination of mass and thus bulk density from such a flyby to partially address MO #2. A flyby mission would need to provide information superior to ground-based radar, which will achieve resolutions of down to a few meters during the asteroid's 2029 Earth flyby [4]. Flyby missions can be carried out using traditional spacecraft chemical propulsion systems, and several opportunities exist in advance of the 2029 close encounter, as shown in Figure 1.

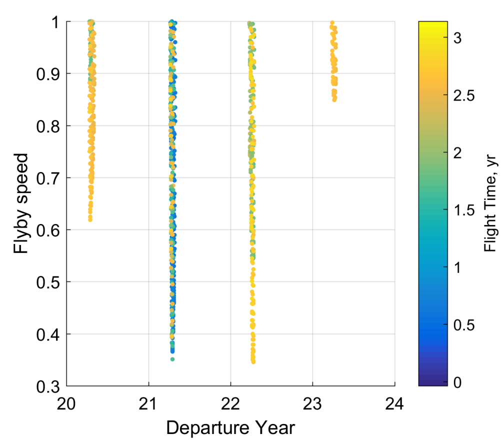

Figure 1. Examples of ballistic flyby opportunities (launch C_3 < 30 km^2/s^2) that would reach Apophis before close encounter. Flyby speed in km/s.

Rendezvous Missions: A more ambitious rendezvous (orbital) mission could achieve all of objectives with substantially improved accuracy, and potentially information on internal strength, by combining spectral measurements with gravity mapping. Also, a rendezvous mission would allow, for the first time, a real-time monitoring of tidally-induced dynamic changes of a PHA before, during, and after the extremely close approach to Earth. Rendezvous missions enable mapping of the body at multiple phase angles to fully determine composition and its heterogeneity at all scales, photometric and thermophysical properties of the regolith, the mass to <1%, gravity field to degree 3 or 4, and rotation pole and rate to <1%, and detailed shape to 10-cm resolution.

Such a rendezvous could be conducted either with traditional chemical propulsion technologies, or with novel ion propulsion systems that would provide better mass delivery and lower overall mission complexity. Such a rich science return as detailed above can be realized using a small, ESPA-class solar-electric propelled spacecraft bus with capable small instruments. An example trajectory is shown in Figure 2. The nominal mission design would encounter Apophis before the encounter and escort it through closest approach. A SEP mission would allow long-term observations beyond the encounter. A terminator orbit at 2-3 body radii would allow determination of GM to <1% in ~1 month of observations, while also providing few-cm imaging resolution. Surface changes due to tidal forces, either body distortions or landslides, could be detected, although tidal distortion is not expected to produce perceptible change.

The nominal payload for a rendezvous mission would include a capable narrow-angle (multispectral) camera, and IR and thermal IR spectrometers. A recently-developed 2U combined short-wave infrared and mid-infrared point spectrometer would enable accommodating this payload suite on a small spacecraft. Combining DSN tracking obtained using the IRIS radio flown on MarCO with optical navigation data would permit recovery of the gravity field and measure the moment of inertia in the body is tumbling, as has been reported by [3]. Finally, a low-frequency radar might be feasible given that close proximity to the target would reduce system mass, volume and power and allow a detailed look at the internal structure. Demonstration of such a capable flight system would provide an important demonstration of capabilities needed for characterizing any PHA, and blaze the trail to achieving a rapid response capability.

Outlook: Detailed assessments of the expected science and planetary defense returns from this range of possible mission concepts must be performed soon, however (and optimally be included among the highest priorities of the next National Academy of Sciences Planetary Decadal Survey) in order to allow enough time for the detailed development, launch, and operation of one or more missions that can exploit this once-in-a-millennium opportunity.

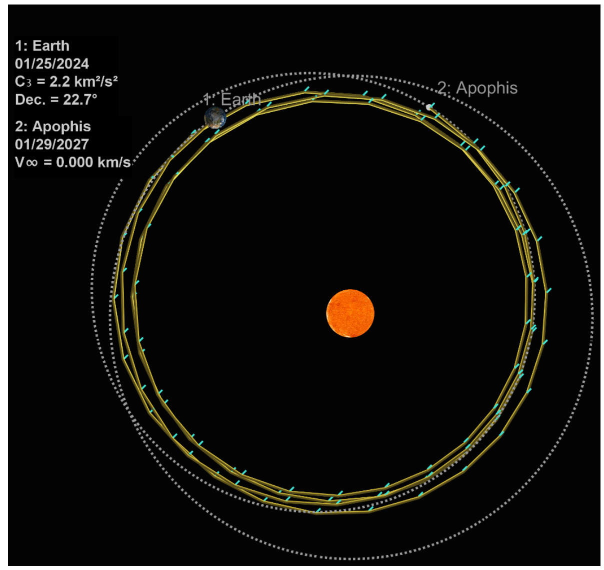

Figure 2. Example of a solar-electric propulsion trajectory that would deliver of order 70 kg mass to a rendezvous orbit around Apophis.

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References:

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[4] Brozovic M. et al. (2020), this meeting.