RECONNAISSANCE OF APOPHIS (RA): A MISSION CONCEPT FOR EXPLORING THE POTENTIALLY HAZARDOUS ASTEROID APOPHIS DURING ITS 2029 EARTH ENCOUNTER. B. W. Barbee[1], L. F. Lim[2], S. Aslam[2], B. Sarli[2], J. Lyzhoft[2], T. Hewagama[3,2], J. Nuth[2], A. Liounis[2], R. Nakamura[4], K. Hughes[2], L. Purves[2], R. Lewis[2], [1]NASA/Goddard Space Flight Center (GSFC), Code 595, 8800 Greenbelt Road, Greenbelt, MD, 20771, brent.w.barbee@nasa.gov, [2]NASA/GSFC, [3]University of Maryland, [4]JAXA

Introduction and Background: The ~325-meter size [1] Potentially Hazardous Asteroid (PHA) designated 99942 Apophis (2004 MN_4), hereinafter referred to simply as Apophis, will make a historic close approach of Earth on April 13th, 2029, depicted in Fig. 1. On that date, Apophis will pass within ~31,346 km of Earth's surface, which is ~4,439 km closer than our geosynchronous orbit satellites.

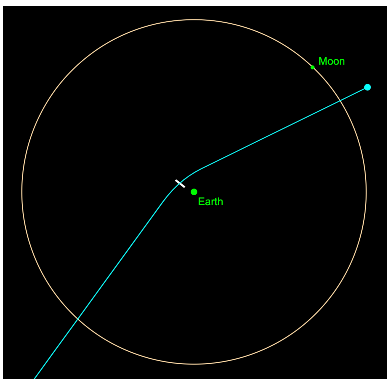

Fig. 1. April 2029 Close approach of Apophis to Earth. (credit: CNEOS)

The 2029 close approach to Earth by Apophis presents an unparalleled opportunity for collecting data on a several hundred meter size asteroid of Apophis' spectral type (Sq, corresponding to LL chondrite meteorites [2]) while it undergoes heretofore unobserved processes due to effects from Earth's gravitational field throughout the close approach event.

The uniqueness of the opportunity presented by the 2029 Apophis/Earth encounter cannot be overstated. We know of no other similarly close Earth encounter by a similarly sized asteroid of any spectral type within the next century. Further, we are fortunate that our mission concept for availing ourselves of this singular opportunity can be accomplished with our proposed Reconnaissance of Apophis (RA) mission for a small, low-cost spacecraft utilizing minimal instrumentation. That eases mission implementation and reduces risk, compared to interplanetary missions of larger size/cost class.

Apophis' extraordinarily close encounter with Earth provides a truly unique opportunity to observe planetary encounter effects on a minor planet. These observations are best performed in situ via spacecraft. Apophis' closest approach occurs during daytime in Hawaii and Chile, and the circumstances of the Earth approach preclude finer than ~75 m spatial resolution near-infrared imaging via ground-based assets. By contrast, imaging of Apophis via our planned onboard spacecraft instrumentation is expected to achieve ~15 m spatial resolution at an asteroid distance of ~100 km, as a point of reference. Finer resolutions will be available at shorter distances from the asteroid, achievable during post-rendezvous proximity operations. Additionally, the central region of the 2.7-micron hydroxyl (OH) band (2.5 to 2.85 microns) is not observable from the ground due to the opacity of Earth's atmosphere. An example of this for the asteroid 433 Eros is provided in Fig. 2. The significance of collecting data at this wavelength is made clear in the next section.

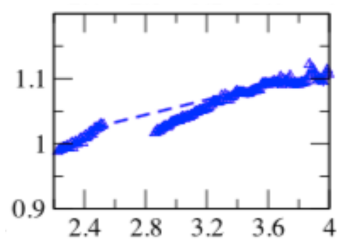

Fig. 2. Ground-based Infrared Telescope Facility (IRTF) spectrum of S-type asteroid 433 Eros in the hydroxyl (OH) region [3]

Apophis Science Opportunities: At present, little is known regarding how minor planet regolith material will respond to the gravitational effects of a close planetary approach. Those effects may reconfigure the regolith in a way that serves to essentially "reset" the effects of space weathering on the regolith material. Such resetting would affect interpretation of remote spectroscopic observations of minor planets in terms of their ages, formation processes, and migration histories.

The OH band (2.7 microns) has been observed on the Moon in spite of the largely anhydrous lithology of the lunar rocks, as shown in Fig. 3.

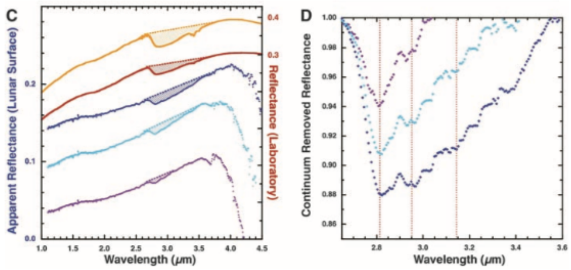

Fig. 3. Lunar spectra from EPOXI showing the hydroxyl (OH) feature at ~6—10% band depth at 2.8 microns [4]

The dominant hypothesis is implantation of hydrogen by solar wind. However, the rates and amounts involved are unclear. Searching for this signal on Apophis before and after Earth encounter may shed light on the effects of solar wind in this regard, as well as on the influence of the Earth encounter and environment on that phenomenon.

The RA mission will also map Apophis' thermal inertia, which provides key parameters for Yarkovsky acceleration models necessary for understanding Apophis' dynamical evolution and future orbital and rotational motion, particularly out to distant time horizons. Ground-based CanariCam and Herschel PACS data have provided a global average estimate of 50 to 500 for the thermal inertia of Apophis. [5] The large uncertainty in that estimate will be substantially reduced by the data collected by our mission. As one of the most potentially hazardous among the PHAs, accurate modeling of Apophis' heliocentric orbit and possible future Earth encounters is essential (just as it is for the PHA Bennu, for which the OSIRIS-REx spacecraft mission is currently providing key data, including thermal inertia).

In addition to the foregoing particular science tasks unique to the Apophis/Earth encounter, our mission will perform the perhaps more commonly expected asteroid science observation tasks, including searching for and characterizing any natural satellites of Apophis that might be present, and measuring Apophis' mass, bulk density, gravitational field, crater and boulder populations, and detailed shape.

Finally, the OSIRIS-REx mission has observed unexpected surface particle ejection events on the Bennu [6], raising the question of how common this behavior is for minor planets in general, as well as whether those events can occur on a largely anhydrous object such as Apophis. Our mission will attempt to detect whether Apophis exhibits such particle ejection processes.

RA Mission Overview: The RA spacecraft will have an initial mass of approximately 180 kg and is designed to launch in early 2024, utilizing low-thrust solar electric propulsion to intercept Apophis for a ~1 km/s relative speed close flyby in late 2026, and then come to rendezvous with Apophis in August of 2028, approximately eight months prior to the historic Earth close approach in April 2029. The spacecraft will remain in close proximity to Apophis from eight months before Earth close approach until at least several months after, thereby providing detailed monitoring of Apophis before, during, and after the Earth close approach event. A rendering of an exemplar mass-optimized RA mission trajectory design is provided in Fig. 4.

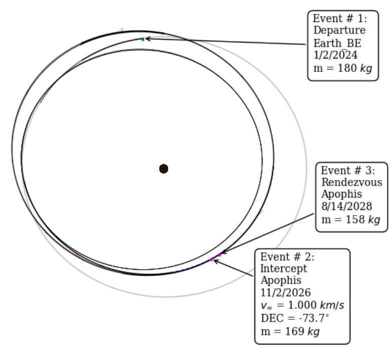

Fig. 4. Exemplar mass-optimal RA mission trajectory.

The preliminary design of the RA spacecraft is shown in Fig. 5. As noted previously, RA will carry only two instruments. One is the Apophis Thermal Camera (APTCam), currently under development at NASA's Goddard Space Flight Center (GSFC), and the second is a visible wavelength camera by Malin Space Systems, inc. (notionally, TTCam).

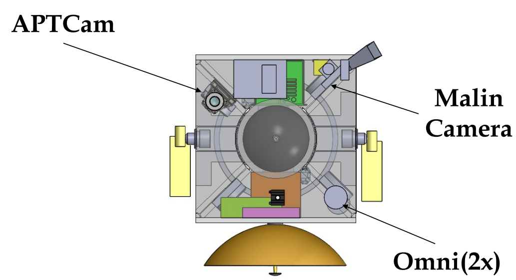

Fig. 5. Preliminary RA spacecraft design.

References: [1] Brozovic M. et al. (2018) *Icarus Vol. 300*, 115—128. [2] Reddy V. et al. (2018) *AJ* 155 , 140 [3] Rivkin A. et al. (2018) *Icarus Vol. 304, 74—82.* [4] Sunshine J. et al. (2009) *Science Vol. 326, 565—568.* [5] Licandro J. et al. (2016) *A&A VOL. 585, A10.* [6] Lauretta D. S. et al. (2019) *Science Vol. 366, Issue 6470.*