**RECONNAISSANCE OF APOPHIS (RA): A RENDEZVOUS MISSION CONCEPT FOR EXPLORING THE POTENTIALLY HAZARDOUS ASTEROID APOPHIS DURING ITS 2029 EARTH ENCOUNTER.** L. F. Lim[1], B. W. Barbee[2], B. J. Bos[2], C. Brambora[2], T. Hewagama[2,4], K. Hughes[2], T. A. Hurford[2], M. Jhabvala[2], R. Lewis[2], A. Liounis[2], R. Lynch[2], J. Lyzhoft[2], P. Mainwaring[2], R. Nakamura[3], J. Nuth[2], K. Parker[2], L. Purves[2], D. C. Richardson[4], B. Sarli[2], A. Shahid[2], J. Swenson[2], CK Venigalla[2], K. Yienger[2], [1]NASA/Goddard Space Flight Center (GSFC), Code 691, 8800 Greenbelt Road, Greenbelt, MD, 20771, lucy.f.lim@nasa.gov, [2]NASA/GSFC, [3]JAXA, [4]University of Maryland

**Introduction and Background:** The ~325-meter diameter [1] Potentially Hazardous Asteroid (PHA) designated 99942 Apophis (2004 $MN_4$), hereafter 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 satellites.

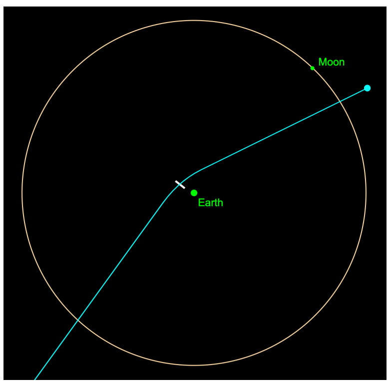


**Fig. 1. April 2029 Close approach of Apophis to Earth. (credit: CNEOS)**

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, VNIR spectrum consistent with LL chondrite meteorites [2]) while it undergoes heretofore unobserved processes due to effects from Earth's gravitational field throughout the close approach event.

The effects of Earth's gravity on Apophis' physical structure are of great interest but challenging to predict for lack of information about the asteroid's physical nature (it has not yet been studied by spacecraft, only via remote observations). The effects of the 2029 close Earth encounter on the asteroid's heliocentric orbit, however, are somewhat more predictable, albeit with some significant uncertainties. Orbital dynamics modelling predicts that the Earth close approach will transform Apophis from an Aten type near-Earth asteroid (NEA) (semimajor axis, $a$, <1.0 au) to an Apollo type ($a$ >1.0 au) and decrease its heliocentric orbit inclination by approximately 1.1°. However, substantial uncertainty remains in the predicted closest approach distance between Apophis and Earth during the subsequent 2036 Earth encounter, predicted to be between ~8.4 million km and ~62.2 million km.

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. That eases mission implementation and reduces risk, compared to interplanetary missions of larger size/cost class.

Apophis' close encounter with Earth provides a truly unique opportunity to observe planetary encounter effects on a minor planet [3]. Possible changes that could be observed include spin state, mass wasting, color and spectral changes, and particle ejections, especially near the "neck" if the object is truly a contact binary as suggested by the latest radar analysis.

The science deliverables will include: multispectral (visible and near-infrared) maps of Apophis; thermal inertia maps of Apophis before/after Earth encounter; bulk density of Apophis; shape models of Apophis before/after Earth encounter; and ejected particle populations and trajectories (e.g., [4]), if any.

**RA Mission Overview:** The RA spacecraft will have an initial mass of approximately 180 kg and is designed to launch no later than December 2026. RA will use low-thrust solar electric propulsion to intercept Apophis for a rendezvous in 2028, several months before the historic Earth close approach in April 2029. The spacecraft will then remain in close proximity to Apophis until at least several months after Earth close approach, thereby providing detailed monitoring of Apophis before, during, and after the Earth close approach event.

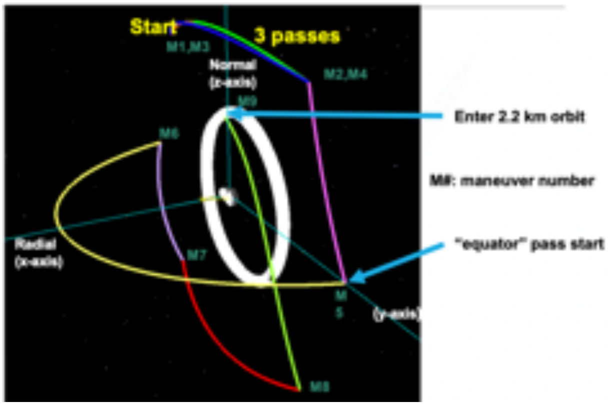


**Fig. 2. A preliminary survey of slow hyperbolic flybys will establish the GM (mass) of Apophis**

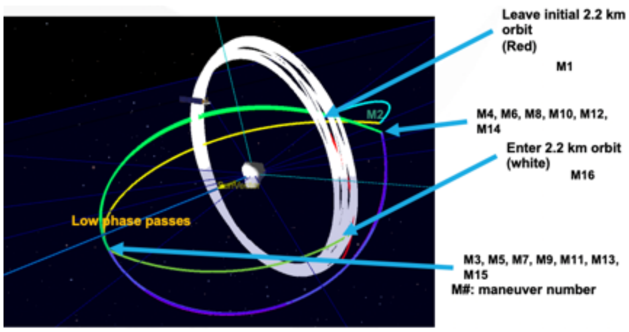


**Fig. 3. Spectral, albedo, and color imaging data sets will be acquired during low phase angle excursions from orbit. Exemplar low-phase-angle RA proximity operations trajectory.**

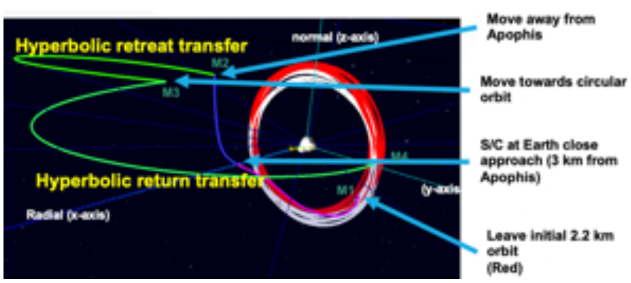


**Fig. 4. The RA spacecraft can safely follow Apophis during the Earth close encounter at a distance of <5 km from the asteroid's surface.**

The survey will determine the mass of Apophis (**Figure 2**) and will include asteroid-wide mapping campaigns with color photometry and spectroscopy (**Figure 3**) both before and after the Earth close approach. The main spectral and color imaging data sets will be acquired from low phase angle excursions from orbit at a distance of less than ~5 km from the asteroid's surface. Choices for proximity operations strategies and trajectory designs (station-keeping, close slow flybys, captured orbits, etc.) have been informed by heritage from the OSIRIS-REx, Hayabusa, and Hayabusa2 missions, two of which are operating successfully at the time of this writing. Our analysis indicates that the RA spacecraft can safely follow Apophis through Earth encounter (**Figure 4**) to collect data during the encounter. More important is that identical surveys will be conducted both before and after the encounter to identify any changes induced by the Earth flyby or to set limits on such effects.

**Conclusion:** The Reconnaissance of Apophis (RA) spacecraft mission concept is under development and would launch by December 2026 to survey the PHA Apophis during its April 2029 extremely close approach to Earth. That 2029 Apophis/Earth close approach presents a unique opportunity for unparalleled scientific observations that are unavailable outside the singular circumstances created by the close planetary encounter with Earth. Such an opportunity is unlikely to be available again for at least a century.

**References:** [1] Brozovic M. *et al.* (2018) *Icarus 300*, 115—128. [2] Reddy V. *et al.* (2018) *AJ* 155 , 140 [3] DeMartini *et al.* (2019) *Icarus* 328, 93—103 [4] Lauretta D. S. *et al.* (2019) *Science 366, 6470.*