A MISSION CONCEPT FOR MEASURING CHANGES IN APOPHIS DURING EARTH ENCOUNTER.

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Introduction: In 2029 the asteroid 99942 Apophis will make a close encounter with Earth and during the encounter it will experience torques and forces that could conceivably exceed the asteroid's material strength. The proposed concept describes a mission that would observe Apophis starting almost a year before encounter, through the encounter, and would subsequently monitor its behavior for up to several years.

The concept includes the launch of a small spacecraft to rendezvous with Apophis, deploy a simple passive tracking device on the surface and co-orbit the sun with the asteroid for several years conducting observations of the surface, its structure and rotation. The goal of the mission is to observe and improve understanding of the surface and internal constitution of the asteroid, as well as any dynamical response due to the encounter.

Science Objectives: The encounter with Earth at a distance of < 40,000 km will produce stresses in Apophis that are likely to disturb the surface, change its rotation, and possibly disrupt Apophis [1]. The science objectives address each of these possibilities in order to understand the physical processes involved and to inform on the future close encounters that could affect planet Earth: (1) determine the behavior of the asteroid as it approaches Earth encounter; (2) determine its structure and integrity during the encounter; (3) measure any dynamical changes as result of the encounter; (4) assess the overall long-term effect of the encounter with Earth on Apophis' orbit around the sun.

Science Measurements: (1) high-resolution imaging of the surface**; (**2) shape, topography and gravity; **(**3) structural properties and integrity of the body**; (**4) rotation and dynamics**; (**5) surface temperature**; (**6) detection of any outgassing**; (**7) measurement of Yarkovsky effect and other small forces**; (**8) determination of the evolution of Apophis' heliocentric orbit.

Baseline Mission Scenario: The proposed mission would launch in 2026, cruise for ~20 months and rendezvous with Apophis, conduct a preliminary optical, altimetry and gravity survey from a range of ~1.2 km for 2 months, descend to an altitude of ~500 meters for 1 month to obtain a detailed survey, deploy retro-reflector arrays to the surface, monitor the behavior and dynamical motion of the asteroid through the encounter in April 2029, follow and monitor Apophis from a stand-off location for the next several years.

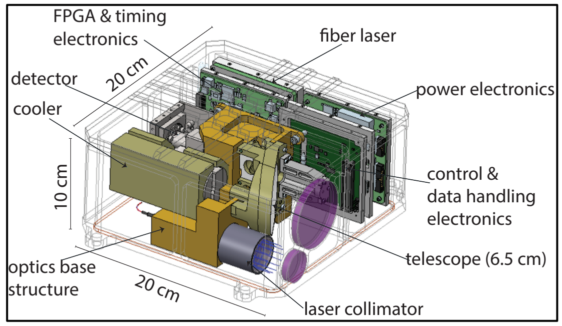

Figure 1. *Swath mapping lidar for small bodies.*

Science Instruments: The minimum instrument complement would include (1) an advanced small swath mapping lidar/ranger with fiber lasers, and PN code modulation for shape and structure assessment (Fig. 1); (2) a color imaging system able to characterize the surface morphology, detect any surface change, and for navigation; (3) a long-wavelength (thermal) infrared bolometer for characterizing surface temperature and aid in determining non-gravitational forces; (4) a set of small laser reflector arrays to be deployed to the surface for monitoring of Apophis' position and rotation (Fig. 2); and an X-band gravity investigation using the communication system.

The nominal design for the reflector arrays (Fig. 2) to be deployed to Apophis is a 5-cm-diameter dome containing eight 1.27-cm diameter corner cube retro-reflectors mounted on the dome shaped structure, with a total mass of 20 g. The complexity of the rotation of a tumbling Apophis suggests the deployment would be by spacecraft ejection and capture by Apophis for random deployment on the surface. The arrays will be detectable by a laser of the LOLA class from a distance of several hundred km.

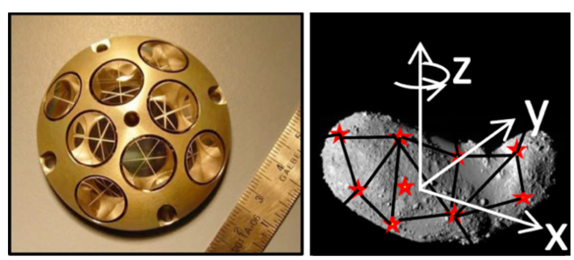

Figure 2. *Small laser reflector array and concept for distribution of several arrays on the surface of Apophis.*

The microwave tracking of the spacecraft would be at X-band with a nominal precision of 0.1 mm/s (1σ) at 10 sec rate. The tracking of the Apophis and its dynamical motion would be by laser ranging from the spacecraft with the laser altimeter/ranger. Primary downlink would be the X-band microwave link.

Summary and Conclusion: The close approach of Apophis to Earth provides a unique opportunity to observe the behavior of the asteroid under the extreme forces that occur during the close approach and include the possible breakup of Apophis. This is a once-in-a-lifetime opportunity and we need to maximize our understanding of the process of encounter and optimize our understanding of how to protect Earth from similar events.

References: DeMartini J.V. et al. (2019) *Icarus 328*, doi: 10.1016/j.icarus.2019.03.015.