SATIS MISSION STUDY FOR APOPHIS: Science objectives and mission definition. Ö. Karatekin[1], B. Ritter[1], B. Gundlach[2], C. Güttler[2], M. Patzek[2], F. Cabral[3], D. Catisanu[3], V. Fogliano[4], P. Holsters[4], R. Walker[5], R. Moissl[5] and the Satis Team
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Introduction: Satis is an ESA Phase A Planetary Defence mission study targeting Apophis, a Potentially Hazardous Asteroid (PHA). It consists of a stand-alone 12U-XL CubeSat that aims to rendezvous with Apophis prior to its Earth Closest Approach (ECA) at a distance from Earth's surface of 31,500 km on Friday, 13th April 2029. Here, we present the overall mission planning, spacecraft design and mission timeline, and introduce the science objectives. Instrumentation and proximity operations will be presented in the accompanying study [1]. The mission study aims to provide a Mission Definition Review and a Preliminary Requirements Review upon the completion of Phase A.

Science Objectives: The flyby of Apophis in April 2029 will be a unique opportunity to observe a PHA closely. Its gravitational encounter with Earth will enable the direct observation of changes in the asteroid's rotation, possible surface changes, as well as its long-term orbit. Satis will observe these parameters to assess the effects of an ECA on the evolution of asteroids.

Apophis is a tumbling body or a non-principal axis (NPA) rotator. The gravitational forces on Apophis during the ECA will likely change Apophis' rotational speed significantly, by more than 30%, and cause a wobble in the rotation [2-6]. These changes in rotation will allow us to infer the ratios of moments of inertia and provide information on internal mass distribution and structure. The interior structure of an asteroid carries the imprint of its collisional and accretion history and is important for planetary defence mitigation attempts and Hypothetical impact assessment [7].

The tides and strong rotational forces have the potential to cause changes in the surfaces due to geophysical processes, such as landslides. Understanding how the surfaces of asteroids evolve and how often they are resurfaced is important for interpreting present observations and their evolution. Surface strength and cohesion are the main drivers for surface geophysical processes and are also critical for planetary defense, as they dictate the response of the asteroid to kinetic impacts.

The orbital perturbation from Earth's gravity on the Apophis orbit is likely to increase and change the orbit by increasing the semi-major axis and the perihelion distance. The change in the orbit due to ECA is expected to be large, but exact predictions are not possible due to uncertainties in the asteroid's initial orientation. Flyby-induced changes to Apophis' spin state and surface will also affect the asteroid's Yarkovsky acceleration, which is a relatively small perturbation but relevant for long-term orbit and planetary defense.

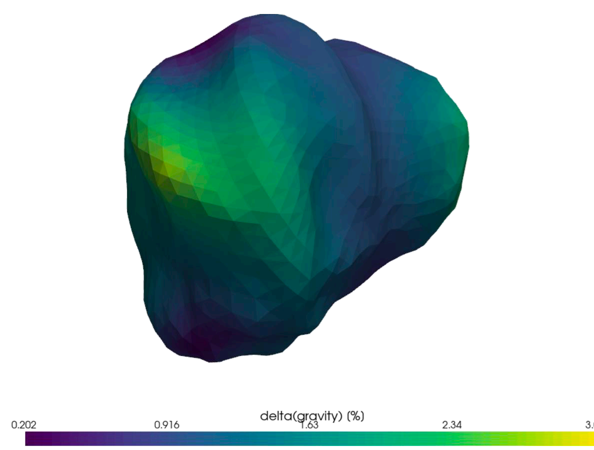

Fig. 1: The modelled changes in Apophis' gravity field due to ECA [2]

Mission definition: The feasibility of the Satis mission concept was studied by an ESA CDF study [8]. The mission is designed to observe the asteroid before, during, and after the ECA in order to detect any changes induced by the effects of Earth's gravity on this PHA, thus providing unique data for Planetary Defence purposes.

The mission starts with an April 2027 launch on a dedicated micro-launcher equipped with a kick stage. The kick stage will be used to inject the CubeSat onto the required escape velocity vector. Following commissioning, the CubeSat will use a highperformance miniaturized electric propulsion system for the 2-year interplanetary transfer to achieve the rendezvous with Apophis. Communication and navigation will be performed using a miniaturized X-band transponder interfacing with ESTRACK deep space ground stations. Upon arrival, the CubeSat will co-fly with Apophis and perform proximity observations using its scientific payloads [1].

References: [1] Gundlach. B. et al. (2024) Apophis T-5 Years Workshop April 22-23, 2024, Noordwijk. [2] Noiset, G. et al. (2023) 8th IAA Planetary Defence Conference, 3-7 April, 2003, Vienna. [3] Benson et al., 2023) Icarus, 390, 115324. [4] Scheeres, D. J. et al., (2006), Science, 314 (5803) [5] Souchay, J. et al (2018), Astronomy and Astrophysics, 617, 1–11. [6] Souchay, J. et al., (2014) Astronomy and Astrophysics, 563, 1–6. [7] Senel C. and Karatekin Ö. 8th IAA Planetary Defence Conference, 3-7 April, 2003, Vienna. [8] Satis CDF study (2022) ESA-TECSYE-HO-2022-003030.