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Introduction: The European Space Agency (ESA) is currently studying several mission ideas for an in-situ investigation of the Potentially Hazardous Asteroid (PHA) (99942) Apophis before, during, and after its close encounter with Earth in April 2029[1]. One, very promising approach is the RAMSES mission concept based on an adaptation of the Hera spacecraft design. As part of the mission architecture there are two 6U-XL CubeSats planned, which will be released in proximity of Apophis before the close encounter. This paper outlines a potential German CubeSat contribution to the RAMSES mission.

Measurement and Science: Due to the tidal forces during the Earth closest approach (ECA) phase a change in the asteroid dynamic state is expected as well as small-scale surface mass motions and/or boulder displacements. Recent studies [2] estimate that tidal forces at ECA can change the effective surface slope by a couple of degrees, which could be sufficient to trigger regolith motions in areas already close to their maximum angle of repose. These surface changes may lead to long term alteration of the asteroid spin state and orbit, through the YORP and Yarkovsky effects. Such processes present a significant source of uncertainty in evaluating the future risk of collision between Apophis and the Earth. Monitoring changes during ECA will help determine the surface slope and gravity, hence gain insight on the internal structure of the asteroid. It will also improve our capability to predict further spin and orbital evolution.

Mission Statement and Mission Objectives: The mission aims to support the science objectives of the RAMSES mission by providing valuable insights into the physical characteristics and possible changes in pre- and post- Earth closest approach (ECA) phase of (99942) Apophis. In addition, it aims to characterize the magnetization of (99942) Apophis and the plasma interactions as it passes through the Earth's magnetosphere.

Mission Objectives:

1. Support the science objectives of RAMSES mission by observation of the internal composition, shape, and dynamic state of (99942) Apophis and its changes before, during, and after the flyby of Earth in April 2029
2. Investigation of the magnetization of (99942) Apophis and its plasma interaction during the flyby through the Earth's magnetosphere

Contributions to the RAMSES Mission: The CubeSat will be designed to operate in close proximity to the asteroid. In contrast to RAMSES S/C, the CubeSat will approach Apophis at a distance of several hundred meters, which corresponds approximately to the size of the asteroid's semi-major axis. This will give unique scientific opportunities which directly support the RAMSES mission objectives. In tab. 1 an overview of the planned measurements for the CubeSat mission is provided, highlighting how these align with and contribute to the preliminary scientific objectives of the RAMSES mission [3]. In addition to the primary measurements outlined here, secondary Radio Science measurements via the Inter-Satellite Link (ISL) between the CubeSat and RAMSES are potentially feasible, similar to the measurements between Juventas and Hera [4].

Optical Observations	Secondary measurements: Complementary observations from various angles alongside RAMSES observations.
Radar Measurements	Unique measurements as a direct contribution to the scientific objectives of RAMSES
Magnetometer	Distinct measurement beyond RAMSES scientific objectives, not covered by OSIRIS-APEX [5]

Tab. 1 Scientific Contributions to the RAMSES mission

Payload Overview: For observing the orbit, spin state, and orientation, a *scientific on-board camera* is a crucial payload instrument. In addition, the camera will be used to scan the surface of the asteroid before and after the fly-by to create a global shape model at a resolution of at least 50 cm per pixel and to observe surface changes. The camera is also used to provide optical navigation capabilities. A camera with the necessary heritage for reliable and rapid integration into the CubeSat will be based on the very successful *MASCAM* [6,7]. A *set of magnetometers* mounted on a deployable structure like a boom, or a deployable solar array will provide the continuously measurements of the magnetic fields experienced by the CubeSat [8]. By varying the distance between the asteroid and the spacecraft during several mission phases, the magnetization of the celestial body itself, as well as the interactions with the Earths magnetosphere will be quantified. The third main scientific payload is *a Low Frequency Radar (LFR)* which is inherited from the Radar JURA on the Juventas CubeSat of the HERA Mission [9]. The LFR is a BPSK coded radar at 60MHz carrier frequency and 20MHz bandwidth in the nominal mode, and 30 MHz in the extended mode. The Radar will consist of a 1U electronic box and a deployable cross dipole antenna for fully polarimetric operations. The total mass of the electronic box plus antenna is about 1.3 kg. A monostatic and bistatic (CubeSat/RAMSES) mode should be implemented to enable a tomographic analysis of the inner structures of Apophis. Monostatic operations will analyse the subsurface down to a depth of more than 100m. The aim of the analysis of monostatic and bistatic measurements is the construction of a tomographic model of the interior of Apophis in a spatial resolution of about 5m.

CubeSat Platform: The CubeSat bus needs to be capable of handling the deep-space environment, as well as operations in the close proximity of an asteroid. Here, the 6U+ SONATE-2 bus, developed and build inhouse at the University of Würzburg, can be a potential contribution [10]. The bus has already been designed with future use in space exploration missions in mind, with a particular focus on mission autonomy and operating AI and advanced image processing hardware in space environment [11]. This will be a sustainable basis for the necessary optical navigation system. The integration of a novel multi-camera star-sensor and a propulsion system additionally increases the suitability of the bus as a basis for the necessary adaptations for a reliable and flight-proven platform as part of a potential CubeSat contribution to the RAMSES mission.

Acknowledgments: The work on the evaluation of extraterrestrial CubeSat mission ideas is funded by the Federal Ministry for Economic Affairs and Climate Action (BMWK) through the German Aerospace Center (DLR) based on a decision of the German Bundestag (Grant No. 50OO2222).

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