A Radio Science Experiment for the RAMSES Mission to Asteroid 99942 Apophis

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Context: On April 13, 2029, the asteroid 99942 Apophis will have a very close encounter with the Earth, transiting the GEO ring. This flyby represents a unique opportunity for observing a well-known potentially hazardous asteroid being subject to strong tidal forces. The time-varying orbital and rotational environment can lead to changes in the surface slopes. Depending on the circumstances, this mechanism may drive significant property changes in the asteroid's internal structure and granular motion on its surface. In this context, characterizing the bulk density and its mass distribution within the asteroid nucleus, before and after the encounter, could represent a key step towards understanding the evolution history of near-Earth asteroids [1].

Aim: In this work, we present the outline of a possible Radio Science Experiment (RSE) onboard the Rapid Apophis Mission for SpacE Safety (RAMSES) proposed by the European Space Agency, which is expected to rendezvous with the asteroid in February 2029, right before the close encounter. The objectives of this experiment will include characterizing the overall mass, density, and porosity of the nucleus with an accuracy of less than 1%, determining its spin rate and orientation to less than 1% and 5°, respectively, estimating the extended gravity field and internal structure of the nucleus, and improving its heliocentric trajectory reconstruction.

Methods: To reach the outlined objectives, the radio science experiment will combine Earth-based radiometric measurements, namely Doppler, range, and ΔDOR, with optical images collected by the onboard narrow- and wide-angle cameras.

Furthermore, the RSE will exploit the radiometric measurements collected through the Inter-Satellite Link with the CubeSats released by the RAMSES spacecraft, allowing us to collect high-accuracy Doppler measurements at closer orbital distances from the target and after an eventual landing. In this regard, the mission might serve as the first deep space application for a new X-band Inter-Satellite Link Transceiver (ISL-T) for CubeSats, which is being developed in the framework of the INNOVATOR project founded by the Italian Space Agency [2].

Results: Building on the experience gained with the RSE onboard the HERA mission [3] [4] [5], this work will show that a HERA-like concept of operations, involving a radio link between RAMSES and two deployable CubeSats, is fully capable of satisfying the mission objectives of characterizing Apophis with high accuracy before and after the encounter. Furthermore, we will identify possible synergies with opportunity payloads to be embarked on either RAMSES or the CubeSats, and coordinated campaigns involving ground-based observatories and the OSIRIS-APEX mission [5].

References: [1] Findings from SBAG 29, July 11-13, 2023 (https://www.lpi.usra.edu/sbag/findings/). [2] Tortora P., et al. (2024), 4S Symposium, Abstract. [3] Zannoni M. et al. (2018), *Advances in Space Research, 62(8),* 2273–2289. [4] Gramigna E. et al. (2023), *Planetary and Space Science, submitted.* [5] Gramigna E. et al. (2022), IEEE 9th *Metrology for Aerospace*, 430–435. [6] Della Giustina, D. et al. (2023), *The Planetary Science Journal*, 4(10), 198.