



RAMSES: A European rendezvous mission to study tidal effects on the Near-Earth Asteroid Apophis during its 2029 close encounter with the Earth

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Introduction

The ESA RAMSES (Rapid Apophis Mission for Space Safety) mission is designed to rendezvous with the Potentially Hazardous Asteroid (99942) Apophis prior to its extremely close approach to Earth on April 13, 2029, at a distance of about 30000 km, below that of geostationary satellites. The mission is part of ESA's Space Safety Programme and aims to characterize Apophis before, during, and after its encounter with Earth, with the goal of assessing the asteroid's response to terrestrial tidal forces. RAMSES builds on the heritage of ESA's Hera mission [1] and will include a main spacecraft and two CubeSats. The mission is scheduled for launch in spring 2028, with a direct trajectory enabling arrival at Apophis two months prior the closest approach. Its development is ongoing while the formal approval has to wait for the ESA Council at Ministerial Level (CMIN25) in November 2025.

ESA RAMSES mission logo

Scientific Objectives

RAMSES targets fundamental planetary defense and asteroid science questions. Its primary objectives are to determine the dynamical and physical state of Apophis prior, during and after Earth encounter. These include determining the asteroid's orbit, spin state, shape, surface and internal properties. Post encounter observations will refine the asteroid's orientation and rotation modes to better than 1% for the dominant component, and within 10% for secondary rotation components. RAMSES will perform high-resolution global imaging (≤ 10 cm/pixel) before and after the encounter to identify local surface movements, landslides, or morphological changes. Radio science will measure small-scale deformations. The mission will also explore whether Apophis undergoes internal restructuring as a result of tidal stress, through interior probing by a low-frequency radar and Radio Science which also measure the internal heterogeneity and porosity. Furthermore a landing CubeSat equipped with a seismometer, gravimeter, and magnetometer will provide, for the first time, seismic and magnetic measurements on an asteroid. Ramses aims to detect structural heterogeneities down

to meter scales and determine whether Apophis is a rubble pile, contact binary, fractured monolith or other complex structure. RAMSES includes TIRI, a thermal infrared imager, led by JAXA and based on heritage from Hera, to map temperature distribution and estimate thermal inertia. These measurements are key to understanding Yarkovsky-related orbital evolution and contribute to the assessment of post-encounter changes. The combination of imaging, radio science, and in-situ measurements will constrain Apophis' bulk density, internal heterogeneity, and porosity. The possible presence of dust clouds or levitated dust particles during the encounter, potentially triggered by Earth's tidal forces or interaction with its magnetosphere, will be monitored using high-resolution imagery and a plasma instrument. This may provide new insight into space weathering processes and surface refreshing mechanisms.

Mission Architecture and Instrumentation

RAMSES is derived from the design of ESA's Hera spacecraft [1], adapted for a direct transfer trajectory to Apophis. The spacecraft will operate in close proximity to Apophis throughout the Earth encounter phase. The core payloads comprise, as in Hera, two Asteroid Framing Cameras and the Radio Science experiment (for mass, gravity and tidal deformation measurements). Opportunity payloads are the thermal infrared camera TIRI (from JAXA) with Hera heritage and some new payloads selected by ESA in March 2025: a visible-near-infrared spectral camera, CHANCES and a visible-near-infrared hyperspectral imager, HAMLET, for mineralogical and compositional mapping. Two 6U-XL CubeSats will be included in the mothercraft: a **Lander CubeSat** equipped with a seismometer, gravimeter, and magnetometer. It will attempt surface landing before the flyby to record in-situ data during tidal stress; an **Orbiter CubeSat** that will carry a low-frequency radar for internal structure probing and the VISTA instrument for dust analysis. The two CubeSats will be released prior to Earth close approach and will operate autonomously, communicating with the main spacecraft acting as a relay with an Inter-Satellite Link that will also contribute to the asteroid gravity field determination. The Lander CubeSat represents a milestone, potentially enabling the first seismic detection on an asteroid.

RAMSES is part of a broader international effort to study Apophis during its 2029 close approach. It is expected to arrive after a possible flyby by JAXA's DESTINY+ mission and before NASA's OSIRIS-APEX, which will investigate long term post-encounter evolution. The synergy between those missions will provide a temporal baseline for observations, allowing pre-, peri-, and post-encounter characterization of Apophis by multiple space agencies.

Conclusion

RAMSES will be the first mission to observe in real-time the geological and dynamical response of an asteroid to natural tidal forces from a planetary encounter. It will provide unique scientific data on asteroid structure, mechanical properties, composition and space weathering processes, while also supporting ESA's planetary defense roadmap. Moreover, while asteroid Apophis makes its exceptionally close approach to Earth and RAMSES will feed in live real images of the asteroid, more than 2 billion people will have the rare opportunity to observe it with the naked eye. This will further enhance the impact of the United Nations' designation of 2029 as the International Year of Asteroid Awareness and Planetary Defense.

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