Science objectives of RAMSES: ESA's Rapid Apophis Mission for SpacE Safety. P. Michel[1], M. Lazzarin[2], M. Küppers[3], S. Green[4], P. Tortora[5], S. Ulamec[6], J.B. Vincent[7], P. Abell[8], S. Sugita[9], P. Martino[10], [1]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Lagrange Laboratory, CS34229, 06403 Nice Cedex 4, France, michelp@oca.eu, [2]Padova University, Vicolo dell'Osservatorio 3, 35122 Padova, Italy, monica.lazzarin@unipd.it, [3]ESAC/ESA, Camino bajo del Castillo S/N, Urbanización Villafranca del Castillo, 28692 Villanueva de la Cañada, Madrid, Spain, Michael.Kueppers@esa.int, [4]The Open University, Milton Keynes MK7 6AA, UK, [5]University of Bologna, Department of Industrial Engineering, Via Fontanelle 40, I-47121, Forlì (FC), Italy, [6]German Aerospace Center (DLR), RB-MUSC, Linder Höhe 1, 51147 Cologne, Germany, [7]DLR Institute of Planetary Research, Berlin, Germany, [8]NASA Johnson Space Center, 2101 NASA Parkway, Mail Code XI, Houston, TX 77058-3696, USA, [9]University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo 113-0033, Japan, [10]ESTEC/ESA, Keplerlaan 1, 2201 AZ, Noordwijk, The Netherlands, Paolo.Martino@esa.int.

Introduction: The Rapid Apophis Mission for SpacE Safety (RAMSES) is the candidate mission of the European Space Agency (ESA) to rendezvous with the asteroid Apophis prior to its closest approach to Earth on April 13, 2029 (see the mission logo, Fig. 1). Its development is ongoing while the formal approval for launch in spring 2028 has to wait for the ESA Council at Ministerial Level (CMIN25) in November 2025.

Fig. 1: logo of the ESA RAMSES mission.

The year 2029 has been officially defined by the UN as the international year of asteroid awareness and planetary defense. Thus, the asteroid close approach itself, the missions sent to observe the asteroid during the approach at close distance, the science return from these missions, and the experience felt by people around the world will remain in the collective memory.

Objectives and requirements: The objectives of RAMSES are to measure the initial characteristics of Apophis before its closest approach to Earth and to observe the effect of Earth's tidal forces on those characteristics during the approach. While more than 2 billion people in Europe and Africa will be able to see the light of the asteroid with the naked eye, images obtained by RAMSES will be fed in live to the public, allowing for the first time a direct connection between the visible light of a small asteroid and its actual geological characteristics.

Similarly to the Hera mission [1] on which RAMSES' design is based, tincluding a main spacecraft and two cubesats, the mission requirements are split into two categories: core requirements and requirements for opportunity payload. The selection of opportunity payload on the main spacecraft will be announced in mid-March 2025. Below we only mention core requirements that rely on the already fixed core payload that includes two Asteroid Framing Cameras and Radio Science. Some requirements for opportunity payload are mentioned when related to core ones.

Core requirements are the primary mission objectives. They are related to the key planetary defense objectives to characterize the asteroid's dynamical and physical properties before, during and after the tidal encounter and to investigate possible changes of Apophis' morphology due to the Earth's tidal forces during the close flyby.

The orbit of Apophis during and after the close approach shall be determined. As an opportunity, determination of the thermal inertia would permit predictions of orbit changes as a result of the Yarkovsky thermal effect that plays a role in the trajectory of small asteroids.

The orientation of Apophis before the Earth flyby shall also be determined and followed during the flyby. After the flyby, a first determination of the rotational modes shall be made, giving initial input for Earth-based observations that may later refine the spin state with long-term campaigns spanning several years. The orientation of Apophis (orientation of principal axes in space) before Earth flyby is expected to be determined also from Earth-based observations but shall be refined by RAMSES. After the flyby, the dominant component of the spin state shall be determined to within 1 % and any secondary rotation components to within 10 %.

The shape of Apophis and possible surface changes shall also be measured. Global shape changes are not expected during the flyby, based on the current knowledge of its shape from radar observations [2]. However, this depends on its actual shape and structure (e.g., whether it is a contact binary), which needs to be measured as the presence and magnitude of local material movement depend on the overall shape. From current estimates, depending on shape and surface cohesion, local material movement may occur up to meter-scale. To investigate those changes due to Earth's tidal forces, a resolution of 10 cm is required. Apophis' tidal deformations due to the interaction with the Earth's gravity will also be measured by means of the radio science experiment. As an opportunity, for the investigation of smaller scale changes, the albedo and color of the surface of Apophis should be mapped before and after the flyby. RAMSES provides the unique possibility to observe surface changes while they are ongoing, allowing us to better understand the mechanical properties of such an asteroid and how they respond to a natural external action.

The internal homogeneity of Apophis on a global scale shall also be measured. For an asteroid of the size of Apophis (approx. 340 meters, with an elongated, asymmetric shape, suggesting possibly a bifurcated object, based on radar observations), it is, a priori, not clear if it is a rubble pile (reaccumulated from impact ejecta, as predicted by numerical simulations of asteroid disruptions, [3]), a fractured fragment, a contact binary or an intact irregularly shaped fragment. As a goal, heterogeneities down to a scale of a few meters shall be determined. The measurement shall be done before and after closest approach, to be able to measure any internal modifications or restructuring. As an opportunity, internal structure probing through a low-frequency radar onboard an orbiting cubesat and seismic measurements by means of a geophone onboard a landing cubesat on the surface would greatly improve the understanding of the interior structure. The latter would offer the first seismic studies of an asteroid, decades after such studies have taken place on the Earth, the Moon and Mars.

The possible detection of particle clouds through images would also provide insight into dust particle levitation mechanisms that may be active while Apophis passes through Earth's magnetosphere, with implications on the possible refreshing of surfaces and asteroid space weathering studies. As an opportunity, higher resolution imaging or measurements with a dust detector could further improve the detection.

Finally, mass, density and bulk porosity shall also be determined to within 1%.

Conclusion : RAMSES is the second mission of the Space Safety Program of ESA to characterize a near-Earth asteroid, which is part of the planetary defense roadmap while offering a great science return by measuring for the first time the response of a low-gravity body to external forces offered by nature itself through Earth's tidal forces. It will take place in the framework of an international cooperation. The JAXA DESTINY+ mission is currently planned to perform a flyby of Apophis shortly before the arrival of RAMSES and may be joined by the CNES CASPER mission, depending on launcher constraints, which is also planned to perform a flyby. Having one or several flybys of Apophis before the arrival of RAMSES will provide early images to extend the pre-encounter time base and offer the possibility to have a more robust shape model of the asteroid to inform the rendezvous phase. Furthermore, the NASA OSIRIS-APEX mission [4] will arrive at Apophis a few weeks after the closest passage of the asteroid to the Earth to study its post-encounter properties and possible long-term changes. Space agencies and scientists involved in those projects will offer to the world a demonstration of international cooperation, which is at the heart of planetary defense, by defining together a high science and operational synergy between those missions.

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