**Multi-Scale Imaging of (99942) Apophis.** N. Schmitz[1], J.B. Vincent[1], K. Otto[1], K. Stephan[1], M. Grott[1], F. Preusker[1], S. Walter[2], S. Schröder[3], P. Michel[4], T. Kouyama[5], S. Sugita[6], B. Gundlach[7], C. Güttler[7], S. Ulamec[8], G. Portyankina[1] and H. Rauer[1],[2] [1](nicole.schmitz@dlr.de) German Aerospace Center (DLR), Institute of Planetary Research, Berlin, Germany, [2]Freie Universität Berlin, Berlin, Germany, [3]Department of Computer Science, Electrical and Space Engineering, Luleå University of Technology, Kiruna, Sweden, [4]Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, Nice, France, [5]Digital Architecture Research Center, National Institute of Advanced Industrial Science and Technology (AIST), Aomi, Koto, Tokyo, Japan, [6] Department of Earth and Planetary Science, School of Science, University of Tokyo, Tokyo 113-0033, Japan, [7]Institut für Planetologie, University of Münster, Münster, Germany, [3]German Aerospace Center (DLR), MUSC, Cologne, Germany

**Introduction:** (99942) Apophis is a potentially hazardous asteroid that will closely approach the Earth on April 13, 2029. This close encounter represents a unique opportunity for planetary science and defense.

A number of missions to reach Apophis before its closest encounter with Earth have been proposed, like e.g. ESA's RAMSES (Rapid Apophis Mission for SEcurity and Safety) [1]. RAMSES is based on the Hera bus (an ESA mission to investigate the Didymos system, [9]), however additional payload is under consideration like e.g. a small lander or landed cubesat. A combination of remote sensing and in-situ camera observations would deliver a unique view of the asteroid on scales ranging from the dm-scale from orbiter remote sensing down to sub-mm scales from in-situ observations, combining different vantage points.

In-situ imaging on small bodies was successfully demonstrated e.g. by the ROLIS camera on the Rosetta lander Philae at 67P/Churyumov-Gerasimenko [2], or the multispectral camera MASCam aboard the Hayabusa2 lander MASCOT [3]. MASCOT landed on the surface of C-type asteroid (162173) Ryugu as a DLR/CNES contribution to the JAXA sample return mission Hayabusa2 [4]. MASCam images were acquired during descent and bouncing, and at multiple times during a full diurnal cycle while resting on the surface [3]. The in-situ observations of MASCam were complementary to those taken by the ONC imager [5] on the Hayabusa2 spacecraft and offered a unique opportunity for multi-scale science. Here we highlight the relevance of descent and in-situ camera observations for a potential mission to asteroid (99942) Apophis, e.g., RAMSES.

**Science Objectives:** The scientific goals of such an investigation are to provide ground truth and to complement remote sensing observations, to provide context for measurements by other lander instruments, and to characterize the geological context, compositional variations and physical properties of the surface (e.g. rock and regolith particle size distributions). With a MASCam-like imager, the asteroid can be observed on multiple scales from a hovering position, during descent and on the surface. During daytime, clear filter images would be acquired. During night, illumination of the dark surface can be performed, e.g. by an LED array equipped with monochromatic light-emitting diodes (LEDs) working in different spectral bands. Multi-band imaging will allow color imaging and thus the identification of spectrally distinct surface units. Continued imaging during the surface mission phase and the acquisition of image series at different sun angles over the course of an asteroid day will contribute to the physical characterization of the surface and also allow for the investigation of time-dependent processes and to determine the photometric properties of the regolith. Descent and close-up imaging will reveal surface features over a broad range of scales [6], allowing an assessment of the surface diversity and closing the gap between the remote sensing observations from the spacecraft and those made by potential in-situ lander instruments.

**Multi-Scale Observation Potential:** The scientific potential of combined remote sensing, descent and in-situ imaging has been demonstrated by the imaging investigations on Hayabua2 and its lander MASCOT.

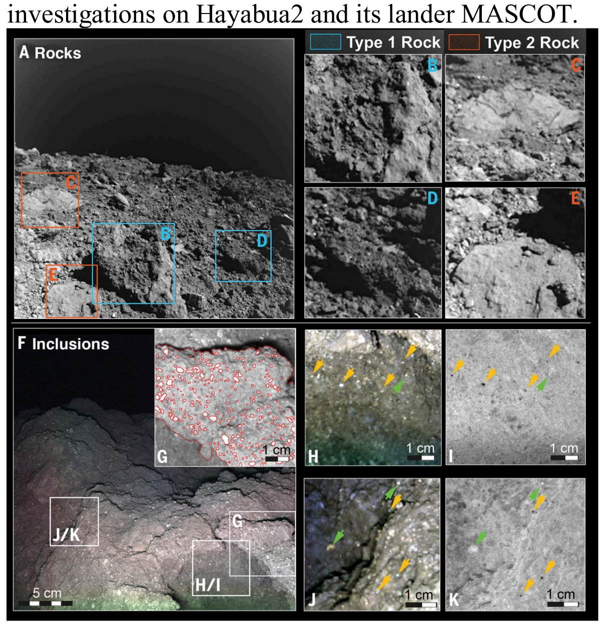


***Figure 1****: (A to E) MASCam images acquired during descent showing two types of rocks. (F to K) Color images (0.465, 0.523, and 0.633 μm) of a type 1 rock*

*taken during the second night revealing bright inclusions. [3]*

The Hayabusa2 orbiter was also equipped with the ONC telescopic camera, that allowed a cross interpretation of MASCOT MASCam and ONC images spanning multiple spatial scales [4], and in 2D and 3D (ONC shape model and MASCam stereo from motion).

The MASCam images acquired during descent and bouncing revealed a surface covered with rocks and boulders of different lithologies. Four types of rock have been identified in ONC images (Sugita et al. 2019). Two of these types are readily identified in MASCam images (Fig. 1): dark and rough (type 1) and bright and smooth (type 2) [3].

In addition, MASCam provided close-up fine-scale texture identification. Based on ONC data, [5] suggested that the rugged surfaces and edges of the type 1 boulders showed uneven layered structures that could be related to the inclusion of coarse-grained clasts. This assumption is supported by the high-resolution MASCam images, in which the mm-size structure of type 1 boulder results in a granular friable surface texture [3].

Schröder et al. (2021) also investigated the reflectivity in the visible wavelengths of the type 1 rock in front of MASCam (Fig. 1) and found that the reflectance of the rock is in agreement with ONC observations. Based on the low reflectivity, the flat spectral slope in the visible wavelengths, and the inclusions, the rock appears to be similar to carbonaceous chondrites [3,6,7]. ONC global data hints at thermally metamorphosed carbonaceous chondrites as an appropriate meteorite analogue given the dark nature of Ryugu's regolith [5].

In summary, MASCam and ONC acquired multispectral images of Ryugu's surface from meter to millimeter scale, and the integrated results significantly contributed to understanding the nature of Ryugu's surface and surface materials, characteristics of a potential parent body and proved invaluable for placing the returned samples into context [6]. High-resolution, multicolor images from MASCam played a critical role.

**Heritage Design and Future Options:** The MASCam camera (Figure 2 left) was designed to operate both, during descent, and on the surface and even imaging of the asteroid's surface from the home position of the mother spacecraft would be possible [8]. The hyperfocal optics allows focusing to large distances, by applying the Scheimpflug principle to ensure that the entire scene along the camera's depth of field (150 mm to infinity) is in focus.

MASCam uses a 1024×1024 pixel CMOS sensor and has a square field-of-view of 54.8°. Together with the f-16 optics with a focal length of 14.8 mm, this yields a nominal ground sampling distance of 150 µm/px at 150 mm distance (diffraction limited). For color and night-time imaging, the camera is equipped with LEDs in 4 wavelengths (R, G, B, IR). When used as an orbiter camera, the ground sampling distance is 1 m at a distance of 1 km to the target, and resolution could be enhanced using a deployable lens as employed on the ROLIS camera for the Rosetta Philae lander [2].

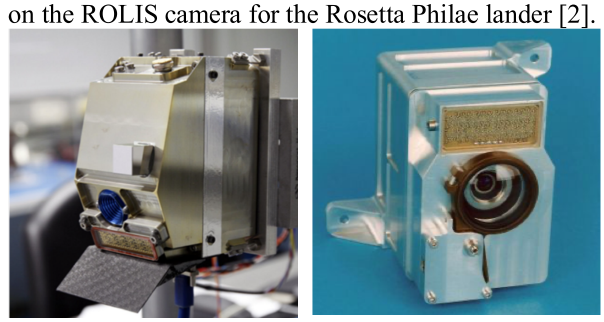

***Figure 2**: Flight models of the MASCam (left) and ROLIS (right) cameras*

A camera for an Apophis cube-sat or lander would use a modern state of the art CMOS sensor, which is available at a pixel pitch of 3.45 µm. Such sensors have up to 4096x3000 pixels and using an f-6 optics with a focal length of 10 mm would result in a field of view of 70.5° x 54.7° and a ground sampling distance of 100 µm/px at a distance of 280 mm. A Scheimpflug optics will be needed to get the near field into focus. At an altitude of 1 km above Apophis, ground sampling distance would be 0.35 m, which could be further enhanced using a deployable lens.

**RAMSES Lander Camera:** Geological context derived from a combination of orbital, descent and surface vision, including range, resolution, stereo, and multispectral imaging, is commonly regarded as a basic requirement for investigating and eventually understanding the nature of the surface of any planetary body. For a potential Apophis lander or cubesat, we therefore propose the addition of a hyperfocal descent and lander camera based on MASCam and ROLIS in order to observe the surface of (99942) Apophis on multiple scales and in multiple color bands.

**References**: [1] M. Kueppers et al. (2023) *DPS55 abstracts,* Vol 55, Issue 8, [2] S. Mottola et al. (2007 Space Sci Rev 128, 241–255, [3] R. Jaumann et al., (2019) Science, Vol 365, Issue 6455, [4] Ho, T.-M. et al. Planetary and Space Science 200, 105200 (2021), [5] S. Sugita et al. (2019) Science, Vol 364, Issue 6437, [6] K. Otto et al., Earth Planets Space 75, 51 (2023), [7] S. Schroeder et al.(2021) A&A666:A164, [8] R. Jaumann and N. Schmitz et al. (2016) Space Science Reviews, 208, pp 375-400, [9] P. Michel et al., (2022) Planet. Sci J. 3:160