The Camera of the MASCOT Asteroid Lander on Board Hayabusa 2 – Science Objectives, Imaging Sequences and Instrument Design. N. Schmitz[1], R. Jaumann[1], A. Koncz[1], S. Schroeder[1], F. Trauthan[1], S. Mottola[1], H. Hoffmann[1], H. Michaelis[1], K. Otto[1], S. Sugita[2], L. Perez-Prieto[3] .[1]DLR, Institute of Planetary Research, Berlin, Germany, Nicole.Schmitz@dlr.de, [2]Dept. of Earth and Planetary Science, University of Tokyo, Japan, [3]Airbus DS, Munich, Germany.

Introduction: JAXA's Hayabusa 2 asteroid sample return mission has been launched to asteroid (162173) Ryugu on Dec 3rd, 2014. It is scheduled to arrive at Ryugu in April 2018, and return samples to Earth in 2020. On-board is the Mobile Asteroid Surface Scout (MASCOT), developed by the German space agency (DLR) with major contributions by the French space agency (CNES) [1]. MASCOT will be ejected towards the surface in October 2018 to land around noon local time. Ryugu is of the rare spectral type Cg, with reflective properties of both the C and G-type asteroids [2]. The MASCOT mission at Ryugu is to study the surface of this small, enigmatic asteroid up-close with its four instruments. Images acquired by the MASCOT camera will contribute to this goal by characterizing the physical and reflective properties of the regolith at high spatial resolution, providing the ground truth for the remote observations by the Hayabusa 2 instruments, and providing context and guidance for the Hayabusa 2 sampling effort.

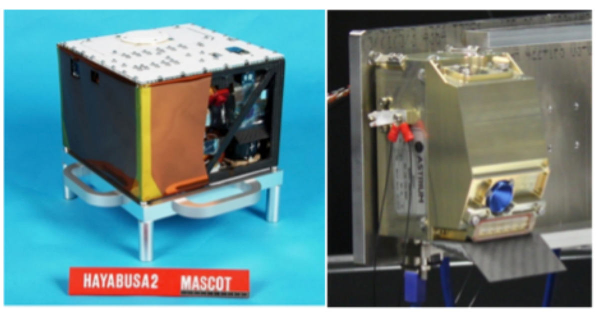

Figure 1. Left: MASCOT lander (camera mounted in the upper left corner). Right: MASCOT Camera flight model.

Science Objectives and Imaging Sequences: The scientific goals of the camera investigation are to: a) provide the ground truth for the orbiter remote sensing observations, b) provide context for measurements by the other lander instruments (radiometer, spectrometer), and the orbiter sampling experiment, and c) characterize the geological context, mineralogy and physical properties of the surface. The MASCOT mission is expected to last about two asteroid days and nights, depending on the on-board battery performance. Several mission phases can be distinguished: (1) descent, landing, and uprighting, (2) afternoon of day 1, (3) night 1, (4) day 2, (5), night 2, and (6) day 3. Immediately after separation, CAM will start its fully autonomous imaging sequence. Imaging during the 10 minute descent consists of two phases: (1) 6 minutes of low cadence imaging, and (2) 4 minutes of high cadence imaging at closest approach.

The detection of the SURFACE state by the MASCOT Autonomy Manager (MAM) will initiate the CAM surface science phase, which includes both day and night imaging. The day imaging sequence includes a photometry sequence, a HDR sequence, and calibration images. The photometry sequence consists of single image acquisition and shall be repeated every 8 minutes until MAM signals the end of day (beginning of night) or until a certain maximum number of images has been acquired. The acquisition of images at different sun angles over the course of a day will contribute to the physical characterization of the asteroid surface by allowing to characterize time-dependent processes and the photometric properties of the regolith.

During the night, illumination of the dark surface by means of a 4-band LED illumination device will permit color imaging. This may allow to identify minerals, organics, and, possibly, ices. The night sequence consists of three sequences of LED-illuminated images and calibration images (dark, bias).

The MASCOT camera observations, combined with the MASCOT hyperspectral microscope and radiometer observations, will cover a wide range of observational scales and serve as a strong tie point between Hayabusa-2's remote sensing science (10^3 - 10^{-3}m) and sample science (10^{-3} -10^{-6} m). [3]

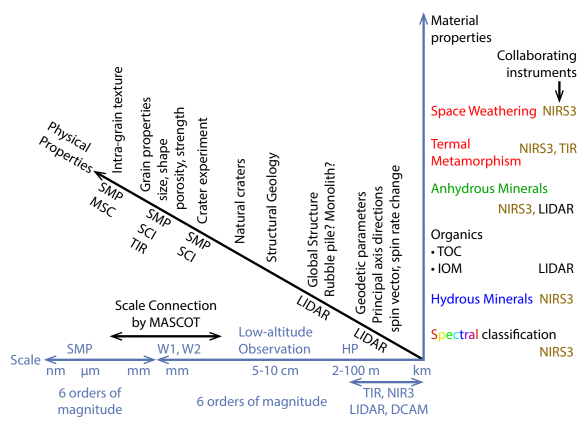

Figure 2. Hayabusa 2/MASCOT combined measurement scales.

Instrument Design: The MASCOT camera, a highly compact wide-angle CMOS camera, is designed to cover a large part of the surface in front of MASCOT. It is mounted inside the lander slightly tilted, such that the center of its 54.8° square field-of-view is aimed at the surface at an angle of 22° with respect to the surface plane. This is to ensure that both the surface close to the lander and the horizon are in the FOV, when the lander rests on an even surface.

Table 1. MASCOT Camera instrument characteristics [3]

Key Characteristics
• Highly compact CMOS imaging system • Mounted inside MASCOT lander, upper left corner. Boresight calibrated with MASCOT MARA (radiometer) • Boresight direction (optical axis): azimuth: 0° (±180°), elevation: -(22 ± 0.5)° • Illumination Unit (4 x 36 LEDs) for colour imaging • 77 x 96 x 114 mm (without alignment cube, LED baffle) • Mass: 0.403 kg • Typical power consumption: 1.5W panchromatic, 6.5 W multiband nighttime imaging • Onboard calibration target (shared with MASCOT MARA)
Optics
• Double gauss lens system • Fixed focal length • 14.8 mm focal length, f/16 system • FOV (square): 54.8° x 54.8° • Depth of Field: 150 mm to ∞ • Pixel footprint @ 150mm: 0.15 mm • Optical Performance: Diffraction-limited, PSF <30 µm • <1% f tanθ geometric distortion
Illumination Unit
• 4x36 LEDs in 4 colours, centered at: 470 nm (Blue), 530 nm (Green), 640 nm (Red), 805 nm (NIR)
Image Sensor
• 1024 x 1024 CMOS imaging sensor (ON Semiconductor) • 15 micron square pixels • Quantum efficiency x fill factor: 30% (between 450 nm and 750 nm) • Spectral range: 400 nm - 1000 nm • Full well (within 5% linearity): 135 Ke- • Average dark signal @ 22 ± 3°C: 1173.9 e-/s

The camera is designed according to the Scheimpflug principle, so that the entire scene along the camera's depth of field (150mm to infinity) is in focus, if the lander rests on an even surface. The camera utilizes a 1024x1024 pixel CMOS sensor sensitive in the 400-1000 nm wavelength range, peaking at 600-700 nm. Together with the f/16 optics of 14.8mm focal length, it yields a nominal ground resolution of about 150 micron/px at 150 mm distance (diffraction limited). An LED array, equipped with 4x36 LEDs of 4 different colors (cf. table 1) is available to illuminate the surface at night for color imaging.

Camera calibration: The camera flight model has undergone standard geometric and radiometric calibration both at component and system (lander) level. Geometric calibration at Airbus DS included focus stability tests, geometric distortion, distortion stability, in- and out-field straylight. The radiometric calibration pipeline for images contains the following steps: bias subtraction, dark field substraction, light fixed pattern correction and correction for non-linearity. A piece of the Murchison meteorite has been used for spectral cross-calibration between the camera, MASCOT MicrOmega (hyperspectral microscope) and Hayabusa-2's ONC-T camera. [3]

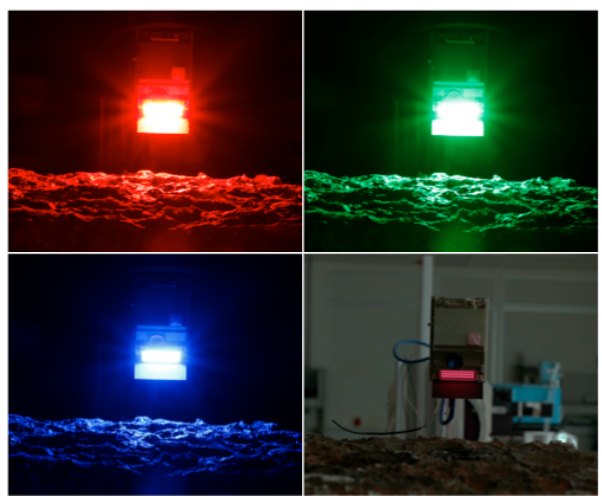

Figure 3. MASCOT Camera spectral characterization during radiometric calibration of the flight model.

References: [1] Ho, T.-M. et al. (2016), SSR, DOI 10.1007/s11214-016-0251-6, [2] Binzel, R. P. et al. (2002), in Asteroids III, ed. W. F. Bottke et al., 255, [3] Jaumann, R., et al. (2016), SSR, DOI 10.1007/s11214-016-0263-2