**MASCOT on Hayabusa2: The plan to perform in-situ science operation of a nano-size landing package on NEA Ryugu.** T.M. Ho[1], S. Ulamec[2], V. Baturkin[1], J.P. Bibring[3], J. Biele[2], B, Cozzoni[2], C. Fantinati[2], M. Grott[4], J.T. Grundmann[1], D. Hercik[5], C. Krause[2], R. Jaumann[4], O. Küchemann[2], C. Lange[1], L. Lorda[6], M. Maibaum[2], A. Moussi[6], T. Okada[7], K. Sasaki[1], Y. Tsuda[7], F. Wolff[8], T. Yoshimitsu[7], [1]DLR Institute of Space Systems, Robert-Hooke-Str. 7, 28359 Bremen, Germany, [2]DLR Institute of Space Operations, 51147 Köln, Germany, [3]Institute d'Astrophysique Spatiale, 91405 Orsay cedex, France, [4]DLR Institute of Planetary Research, Berlin, [5]Technische Universität Braunschweig, 38106 Braunschweig, Germany, [6]CNES, 31400 Toulouse, France, [7]JAXA, Sagamihara-shi, Kanagawa 252-5210, Japan, [8]DLR Robotic and Mechatronics Center, 82234 Oberpfaffenhofen-Wessling, Germany

**Introduction:** Since over 4 years, the nano-size landing package MASCOT (Mobile Asteroid surface SCOuT) is flying on JAXA's Hayabusa2 (HY2) mission [1]. Once HY2 will arrive in June/July 2018 at Near-Earth asteroid (162173) Ryugu, MASCOT (MSC) will be separated about 3 months later (current baseline plan: early October, and two back up windows in February and May 2019) from its mother spacecraft to perform in-situ investigation of the asteroid with its four science instruments: the camera 'MASCAM' [2], the hyperspectral microscopic imager 'MMEGA' [3], the magnetometer 'MASMAG' [4] and the radiometer 'MARA' [5].

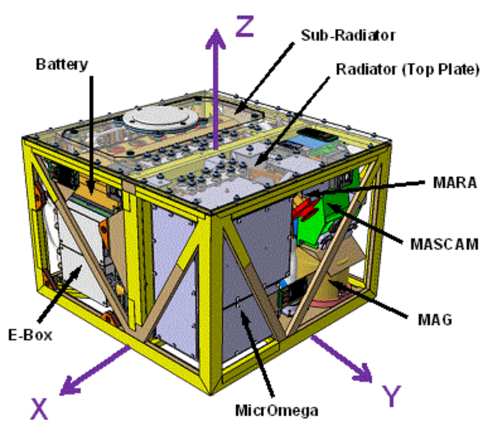


**Figure 1: Accomodation of subsystems and payloads of the MASCOT lander. Note: Radiators and closing foils on sides +X,-X, +Y, -Y –Z are not shown**

**System Requirements versus Operations Requirements**: To meet its requirements on volume and mass, i.e. 0.3 x 0.3 x 0.2 $m^3$ and 11 kg (incl. systems remaining on the Hayabusa2 spacecraft), and its tight development time of ~3 years (from Phase B until launch in 2014, Dec $4^{th}$), the MASCOT concept [6] has undergone several trade-off´s between science and system flexibility versus robustness. Finally, the assets of the MASCOT lander are the four full-fledged scientific instruments with a high payload to system mass ratio of 3:7, a mobility system to relocate on the asteroid, redundancy of most subsystems and a semi-active thermal control system to survive 4 years of cold cruise phase and operate on a "warm" asteroid. The drawbacks are a passive landing via free-fall and bouncing resulting in an unpredictable final resting orientation of MASCOT, a limited lifetime of about 16h based on primary batteries only and thermal operational limitations to survive the asteroid's surface temperature that are expected to vary between -80 to +50 °C.

Some of the challenges are coped directly by MASCOT's design such as the desired operational orientation of the lander, i.e. the bottom plate (-Z) facing the asteroid's surface, see Figure 1. This will be established by the detection of MASCOT's actual attitude via its optical proximity sensors (OPS) and photoelectric cell sensors (PEC), enabling the same mechanism that it is designed for hopping also to selfright the lander, in case it lays unfavorable on the surface. This process is managed by MASCOT's Autonomy Manager (MAM), a decision making program running on the on-board computer to optimize on-surface operations, taking into acount the uncertainties of MASCOT's final orientation after bouncing as well as its limited operational lifetime. Due to the TCTM round trip time of about 30 min, interaction with ground is very limited.

However, other challenges of MASCOT can only be overcome by a solid operational planning, which includes a carefully chosen landing site respecting HY2's own on-surface activities (i.e. sampling and cratering sites), in depth trajectories and bouncing simulations and thermal predictions. Some of the landing site (LS) selection criteria are:

- A daytime landing and transmission of data before the first sunset should be possible
- The LS should provide daylight between 50% and 70% of the asteroid rotation period (i.e. sphere, rotation period = 7.631 hrs).
- The asteroid surface temperature should be characterized by a maximum daily temperature of 50°C. A minimum night temperature between -80°C and -60°C is preferable.

Next to all engineering requirements, the lander's baseline science operational scenario has to be fulfilled:

1. Fully characterize the first landing site including night-time measurements
2. Upload all data including night-time data prior to first relocation
3. Visit a second site and characterize it
4. Upload all data from the second site prior to end of mission

**Baseline Asteroid Operation Planning:** The latest MASCOT baseline operation scenario in 2018 is divided into two phases: the pre- and post-separation. The former phase covers preparation flight events such as the upload of pre- and post-separation sequences, and "final-update" parameters for subsystems and payloads like OPS, Mobility or MASCAM once the actual properties (i.e. shape, surface roughness, illumination condition etc.) of Ryugu and the selected landing site for MASCOT are determined by remote measurements (e.g. with ONC [7], TIR[8] and/or NIRS3[9]) onboard HY2).

The actual MASCOT pre-separation operations will start with pre-heating and battery depassivation activities, followed by final checks and switch on of MARA and MASMAG. MARA requires thermal equilibriation for its sensor head to be prepared for the on-asteroid operation and MASMAG will perform magnetic field measurements during the approach phase. Meanwhile HY2 will have descended to about 60 m. Shortly prior to enabling separation, the MASCOT primary batteries will be connected. The pre-separation phase will end with the actual separation from the mother spacecraft.

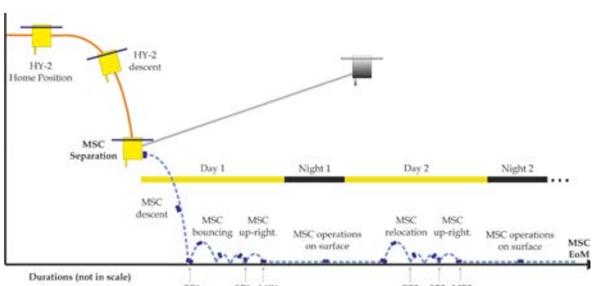


**Figure 2: MSC post-separation mission profile.**

Once separation has been executed successfully, i.e. when the lander module starts moving and the electrical connection between HY2 and MSC turns to OPEN, the post-separation phase starts, see Figure 2. At the currently planned release altitude of 60 m, the lander will touch the surface after about 9 min of descent. During the last phase of the descent, MASCAM will take panchromatic images of the landing site and its vicinity.

Depending on the surface properties, MSC might perform a bouncing phase after its first contact with the asteroid until it settles in a random attitude. If necessary MSC will execute its up-righting activity to reach the preferred orientation, see Figure 2.

At rest the first on-surface operations will start including operations during the first night. All four scientific instruments will perform measurements:

- Detailed multispectral and photometric investigation in high resolution of the asteroid surface.
- Continous measurement of the magnetic field.
- Continuous measurements of the surface brightness temperature
- Analysis of the asteroid soil to characterize structure and composition at grain-size level.

The data of the first science sequence will be uploaded the next morning. Once the upload to HY2 is finished, the lander will perform a relocation to a second location on the asteroid surface. During this hopping phase, three instruments will continue their measurements: MASMAG for magnetic field measurements, MARA for surface brightness temperature, and MASCAM to obtain wide angle imaging.

Once at rest again, and in the correct orientation after relocation, the second on-surface operation phase can start until the battery is depleted. This will define the end of the MASCOT mission.

**References:**

[1] Watanabe S. et al. (2017) *SSRv, 208*, 3–16. [2] Jaumann R. et al. (2017) *SSRv, 208*, 375–400. [3] Bibring J.P.. et al. (2017) *SSRv, 208*, 401-412. [4] Hercik D. et al. (2017) *SSRv, 208*, 433-449. [5] Grott M. et al (2017) *SSRv*, 208, 412-431. [6] Ho T. M. et al. (2017) *SSRv, 208*, 339–374. [7] Kameda S. et al. (2017), *SSRv*, 208, 17-31 [8] Okada T. et al. (2017) *SSRv*, 208, 255-286 [9] Iwata, T. et al. (2017) *SSRv*, 208, 317-337.

**Additional Information:** The MASCOT lander was developped and built by the German Aerospace Center (DLR) in cooperation with the Centre National d'Études Spatiales (CNES) and with a contribution of the Japan Aerospace Exploration Agency (JAXA). The scientific payloads have been provided by DLR, IAS and TU Braunschweig.