Past and present missions:
Mobile Asteroid Surface Scout (MASCOT)
Jens Biele
Who am I?

- After some fun with chemistry (<18), became clear to study physics
- (Experimental) physics 1985-93 Univ. K-Town/Germany, Imperial College/London, Diploma (~masters), laser spectroscopy&molecular physics. Some hesitation what to do next..
- PhD 1995-98 at AWI institute, Potsdam/Berlin (polar atmospheric research in the Arctic, LIDAR, expeditions and all)
- Some hesitation what to do next..
- Moved to Cologne. Found job at DLR by chance: payload manager for Rosetta/Philae, liked it, stayed on, moved to other projects like MASCOT..
- Broad range of interests and, luckily, quite some freedom to pursue scientific interests even if not immediately necessary for project task at hand

- Explorations and science mission specialist for the business development group of the DLR-RB institute.
- Key experience and focus: testing and operations of science instruments in space, Solar system exploration in general, geophysics (atmosphere, solar system ices), thermodynamics, systems and subsystems for small spacecraft and surface science packages.
- Thesis supervisor for several master and diploma theses at DLR
- Occasional lectures at the University of Cologne, Department of Geophysics (Celestial mechanics and Coordinate Systems; Geodynamics/Rotation of the Earth)
MASCOT

= Mobile Asteroid Surface Scout with a suite of 4 scientific instruments onboard Hayabusa2
Target Object: NEA Ruygu/1999JU3 (C-Typ)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean volume-equivalent diameter (km)</td>
<td>0.87±0.03</td>
</tr>
<tr>
<td>Bulk density (kg/m³)</td>
<td>1300</td>
</tr>
<tr>
<td>Spin period (hrs)</td>
<td>7.63±0.01</td>
</tr>
<tr>
<td>Spin axis (J2000), positive pole</td>
<td>( \lambda_{ecl} = 73.1° )</td>
</tr>
<tr>
<td></td>
<td>( \beta_{ecl} = -62.3° )</td>
</tr>
<tr>
<td>Obliquity</td>
<td>151.6°</td>
</tr>
<tr>
<td>( V_{esc} ) (m/s)</td>
<td>0.37±0.03</td>
</tr>
<tr>
<td>Thermal inertia (global average) (Jm⁻² s⁻⁰.⁵ K⁻¹)</td>
<td>Notional: 400</td>
</tr>
<tr>
<td>Emissivity</td>
<td>0.9 (assumed)</td>
</tr>
<tr>
<td>( g ) (m/s²)</td>
<td>( 1.5 \times 10^{-4} )</td>
</tr>
<tr>
<td>Surface fraction covered with craters</td>
<td>0.4 – 0.9</td>
</tr>
</tbody>
</table>

JAXA Design Reference
MASCOT will serve as ground truth tie point between sample science ($10^{-3}$-$10^{-6}$m) & remote sensing sciences ($10^{3}$–$10^{-3}$m)
The MASCOT Concept, Requirements and Technical Realization

**Top Level Requirements:**

- The maximum mass is 11 kg
- The maximum volume is $0.3 \times 0.3 \times 0.2 \text{m}^3$
- Separation & descent during a sampling dress rehearsal
- Operation during two asteroid rotations
- Autonomous operations on asteroid surface
- Self right and relocation ability via mobility

... that have implication on the system design & development
⇒ Shared communication with Minerva Rovers (via CCOM & OME-A Antenna)
⇒ During cruise: „wireless“ communication with MESS antenna
⇒ On asteroid: shared communication with OME-A
MASCOT Concept

- Agile, light & compact nano-lander for in-situ asteroid research
- Total mass: ~10 kg
- PLs: MASCAM, μOmega, MARA, MASMAG
- Developed by DLR in collaboration with CNES for the Hayabusa 2 Mission
- On-Asteroid ops: ~Oct 3, 2018
Hayabusa2 (HY2)

= Hayabusa Immediate follow-on Asteroid Sample Return Mission (JAXA/ISAS)

- Launch: Dec 2014
- Arrival + Ops: 2018/2019
- Return to Earth: 2020
- Mass ~ 600 kg
- Dimensions of main structure: 1.0m x 1.6m x 1.4m (Paddle span: 6.0m)
- PL: Four orbiter experiments, impactor, sampler, 3 Minerva rovers + MASCOT (DLR/CNES)
MASCOT Baseline Design - Summary

- **Configuration/Structure**: highly integrated carbon-fibre composite structure with separate payload and warm compartment (including common E-box for all instrument electronics)
- **Power**: Primary battery only; redundant power supply from main-S/C during cruise
- **Communication**: common communication based on Minerva transceiver, on MASCOT: omnidirectional, redundant link with one antenna on each side
- **DHS/OBC**: Redundant on-board computer, Mascot Autonomy Manager (MAM)
- **Mechanisms**: uprighting and hopping using motor/drive/excenter
- **GNC (attitude)**: using proximity sensors (baseline optical + backup)

- **Thermal**: semi-active;
- **Cruise**: active (heater power and control from HY2)
- **On surface**: passive (MLI and coatings)
- **MESS**: physical interface to HY2
Payload Accommodation
MASCOT Science Payload

Camera (MasCam)/DLR PF
- *Ground truth* for orbital measurements of the HY2 instruments and the in-situ MSC sensor suite
- Geological context of the samples

Radiometer (MARA)/DLR PF
- Surface brightness temperature for a full asteroid rotation
- Surface inertia and spectral slope in the IR

Magnetometer (MasMag)/TU Braunschweig
- Observe the magnetic field profile during descent and hopping
- Identification of global and local magnetization of asteroid and reconstruct the coordinate system of the magnetic field vector

IR Hyper-Spectral Imager (MicrOmega)/IAS Paris
- Composition of the asteroid’s surface, at grain scale in terms of minerals (pristine, altered), ices/frosts, organics
- Microscopic structure of the soil, and the relation between the various phases of distinct compositions.
The Mass and Volume Requirements

- Maximum mass (incl. MESS) ≤ 11 kg!
- Maximum volume (incl. antenna, etc.) ≤ 0.3x0.3x0.2 m³!

⇒ Lander structure (CFRP) ≈ 0.56 kg
⇒ MESS structure (CFRP) ≈ 0.7 kg
⇒ Payload/System Mass Ratio ≈ 3:7

<table>
<thead>
<tr>
<th>MASCOT Lander</th>
<th>Mass [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility</td>
<td>0.52</td>
</tr>
<tr>
<td>GNC</td>
<td>0.26</td>
</tr>
<tr>
<td>OBC</td>
<td>0.49</td>
</tr>
<tr>
<td>Communication</td>
<td>0.52</td>
</tr>
<tr>
<td>Power (Batteries and PCDU)</td>
<td>1.82</td>
</tr>
<tr>
<td>Structure (incl. Ebox)</td>
<td>2.13</td>
</tr>
<tr>
<td>Thermal</td>
<td>0.41</td>
</tr>
<tr>
<td>Harness</td>
<td>0.55</td>
</tr>
<tr>
<td>Payload</td>
<td></td>
</tr>
<tr>
<td>MicrOmega</td>
<td>2.1</td>
</tr>
<tr>
<td>MAG</td>
<td>0.24</td>
</tr>
<tr>
<td>MARA</td>
<td>0.26</td>
</tr>
<tr>
<td>MASCAM</td>
<td>0.46</td>
</tr>
<tr>
<td>MASCOT MESS</td>
<td>1.23</td>
</tr>
<tr>
<td>Total</td>
<td>11.02</td>
</tr>
</tbody>
</table>
⇒ High integration density:
  − Most harness is replaced by a backplane
  − E-box (Al, thickness ≈ 1.5 mm) contains nearly all PCBs & Mobility S/S
Separation and Landing

- MASCOT will be separated during a ‘Touch and Go’ maneuver of HY2 at an altitude of ~100m and free fall on asteroid surface.
⇒ MASCOT will be ejected via separation mechanism (NEA, push plate, spring) from HY2 & MESS
  - Relative separation velocity \( \approx 5 \text{ cm/s} \)
  - \( V_{\text{impact}} < 50\% \) then asteroid escape velocity (\( \approx 32 \text{ cm/s} \))
Operational Requirements

- The landing package shall operate at least during two complete asteroid rotations
- The landing package shall autonomously perform nominal operations when ground intervention is not possible

⇒ Primary batteries (i.e. LSH20 SAFT; Philae/Rosetta)
⇒ MSC Autonomy Manager: State Machine as App on On-Board Computer

Degree of Autonomy

Level 0
- Automatic system, i.e. monitoring of parameters and autonomous
- Mode switching in failure cases

Level 1
- Low level intelligent functions identify errors
- Voting mechanism & logic-based function

Level 2
- Flexible, knowledge-based fault diagnosis

Level n
- Knowledge-based reactive on-board planning & operations optimization
Mobility

- Upright capability & change of surface site
  - Upright and hopping mechanism via mobility s/s (motor/control electronics/excenter arm)
  - OPS to detect asteroid surface
  - Redundancy via PEC to detect Sun vector
Thermal Requirements

- Temperatures during cruise (4 years): \(-30 < t < +60 \, ^\circ C\)
  - Max. heat transfer between MSC & HY2 ~ 5W
- Temperatures on the asteroid surface: \(-60 < t < +77 \, ^\circ C\)
- Warm compartment (Ebox, batteries) \(\Leftrightarrow\) Cold compartment (PL)
  \(\Rightarrow\) Semi-active Thermal Control System
Passive Thermal Control Part

⇒ Super-insulation (MLI) on MESS
⇒ E-box & batteries in super-insulating layers (MLI)
⇒ SLI: Insulated sides to reduce heat input from ground (landed) or heat exchange to HY2 (cruise)
⇒ Radiator & Heat Pipes (Main Actor during In-flight switch on)
Thank you for your attention!
Thermal Control via HY2 S/C

⇒ Redundant heater on MASCOT for thermal control of batteries (+ Ebox and MMEGA)
  − grant survival temperature of batteries during cruise
  − preheat MASCOT before commissioning phases & shortly before landing.

<table>
<thead>
<tr>
<th>S/C Requirements: Heat Transfer to the S/C</th>
</tr>
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<tbody>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Cold Case</strong></td>
</tr>
<tr>
<td>Maximum Heat Transfer</td>
</tr>
</tbody>
</table>
Hayabusa2 Mission Baseline

Dec 3, 2014: Launch
HY2 will fly once around the Sun
(Note: similar to Earth’s orbit)

End of 2015: Earth swing-by
- After the swing-by HY2 goes into an orbit similar to NEA Ryugu.
- ~ 2 rounds around the Sun to arrive at NEA Ryugu.
Summer 2018: Arrival at the asteroid – Stay there for about 18 months.

- Remote observation incl. Near InfraRed Spectrometer (NIRS$_3$) and Thermal Infrared Imager (TIR).
- Separation of small rovers “MINERVA“ and small lander “MASCOT“.
- Sampling surface of the asteroid.
- Small Carry-on Impactor (SCI) separation → artificial crater, touch down & sampling
Materials:

• MASCOT2 – A small body lander to investigate the interior of 65803 Didymos’ moon in the frame of the AIDA/AIM mission. Acta Astronautica 149 (2018) 25–34

Questions?