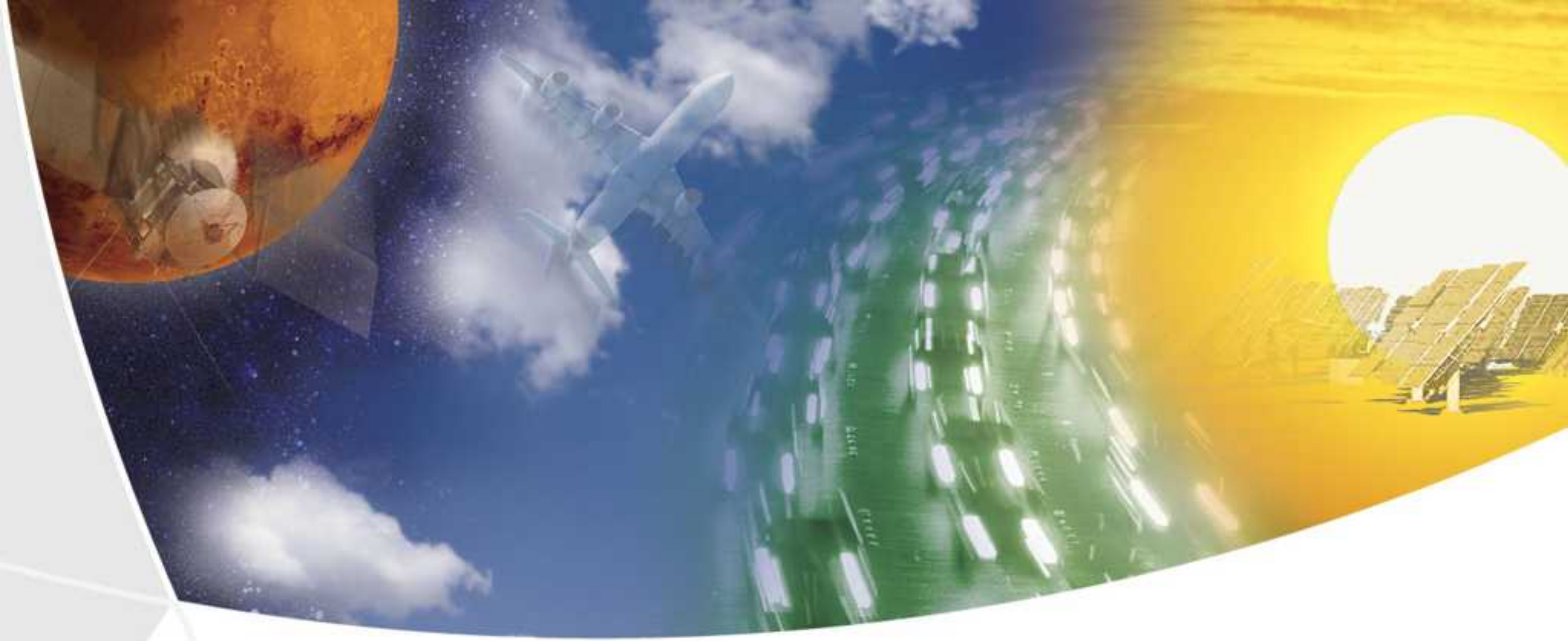
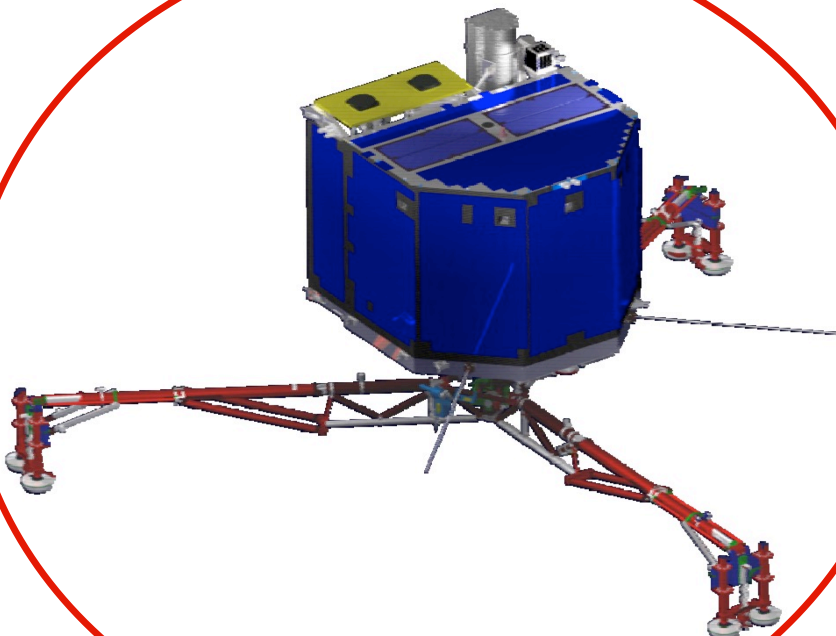


Designs of mobile landers for small bodies

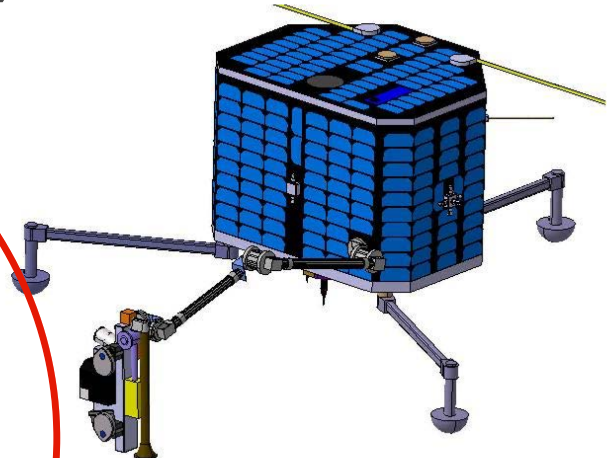
J.Biele, S. Ulamec, Th. Grundmann, M. Deleuze, P.-W. Bousquet, Ph. Gaudon, K. Geurts, T.-M. Ho, C. Krause, R. Willnecker, L. Witte and the Philae and MASCOT teams.

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

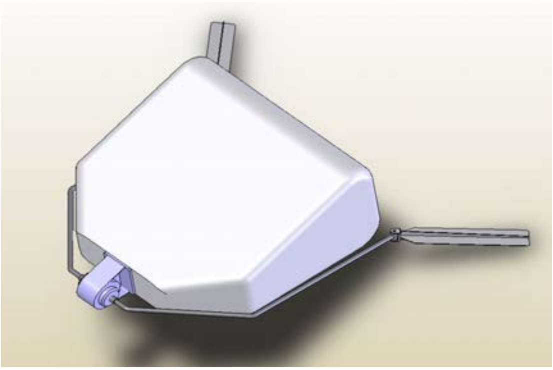
Designs studied (DLR)



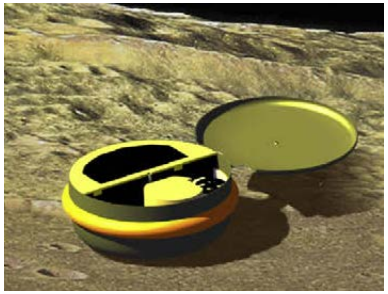
Philae (100 kg)



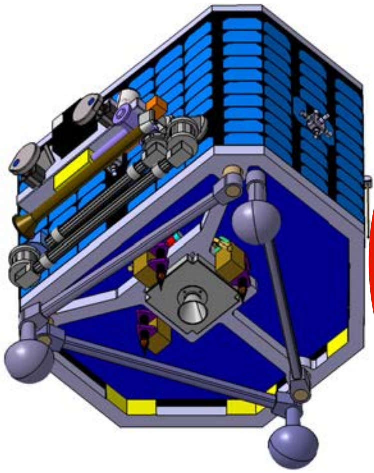
MASCOT (30, 70 kg)

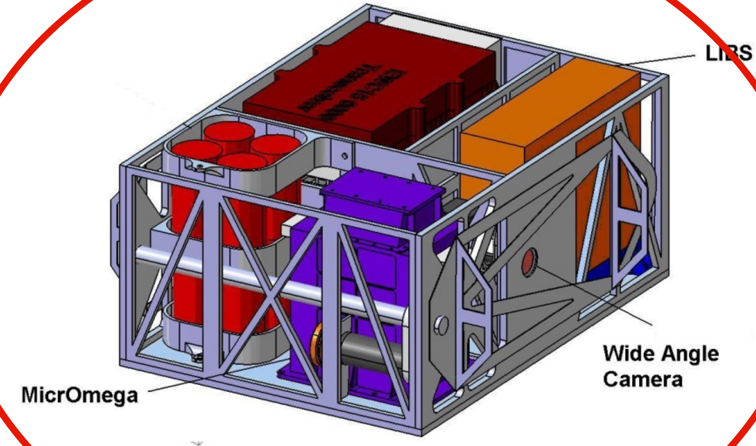


Hopper(10-25 kg)



Leonard

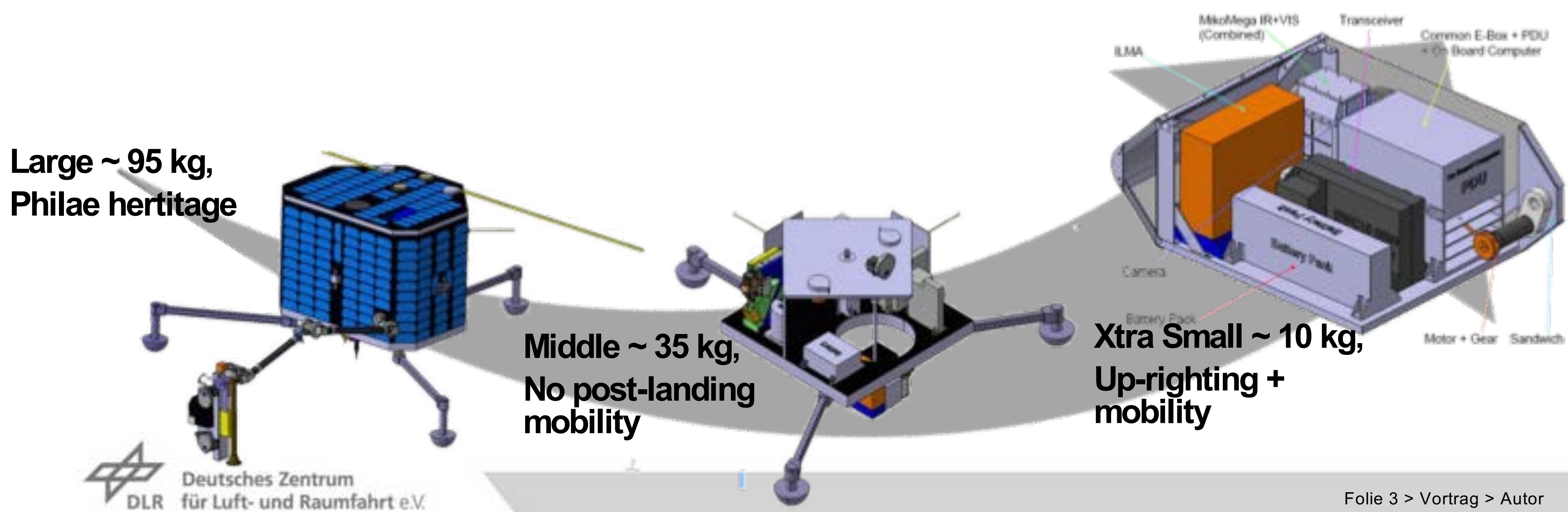




MASCOT (10 kg)

Study Flow of MASCOT („how to shrink a lander..“)

- December 2008 – September 2009: feasibility study, with CNES, in context of Marco Polo and Hayabusa-2, with common requirements:
  - 3 iterations of different mass (95kg, 35kg & 10kg) and P/L
- Settled on 10 kg lander package including 3 kg of P/L
- Current design of MASCOT < 10 kg (incl. P/L and support structure)

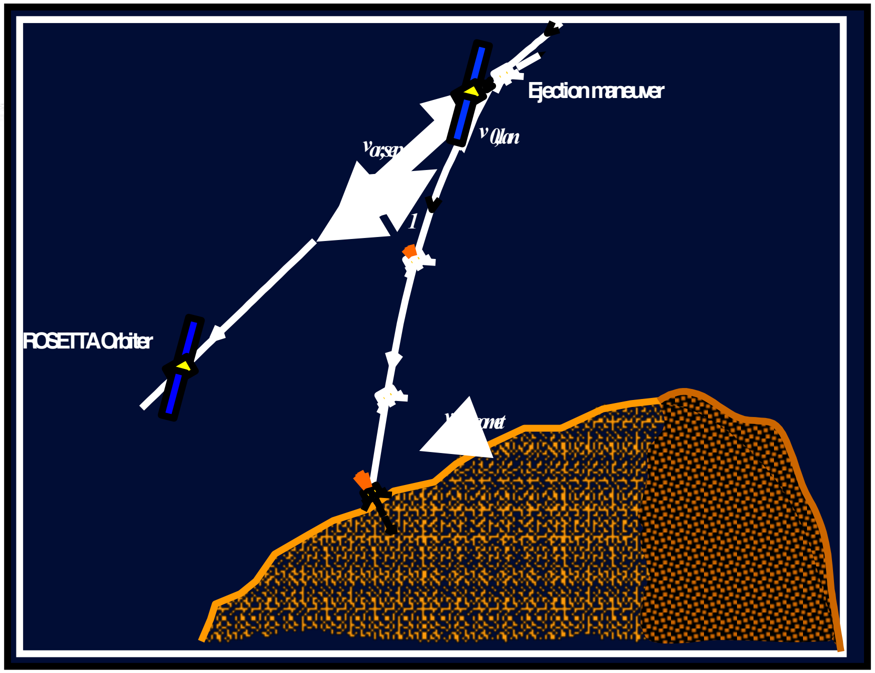


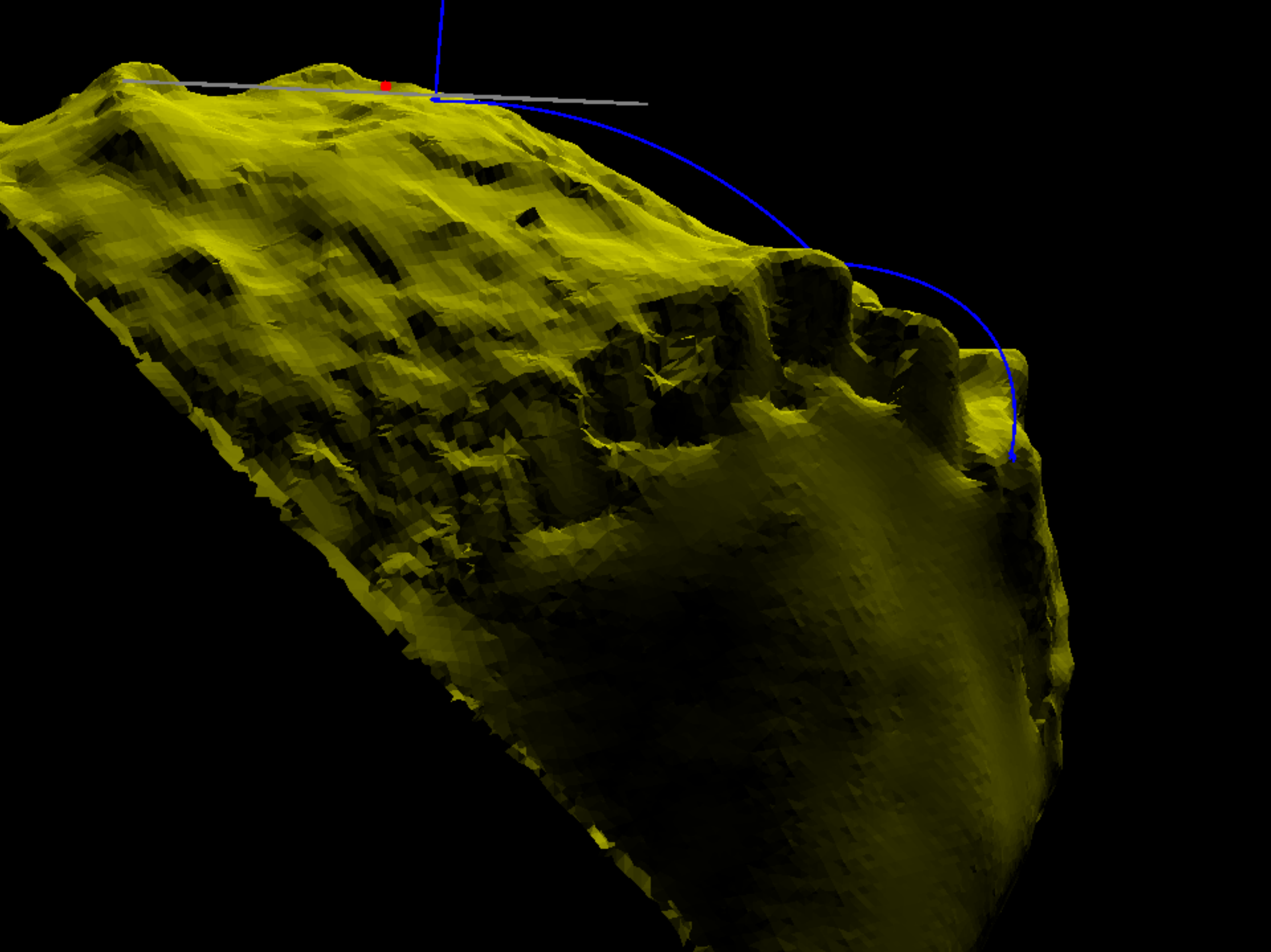
Considerations for different scales

- **Small Lander (10kg)**
  - Maximum heritage from MASCOT
  - Funding by national agencies highly probable
  - Offers capability to operate payload with about 3kg on surface of asteroid
  - Can be "upgraded" to longlived version with solar generator
- **Up-scaled MASCOT**: (11 to ~40kg)
  - Heritage of MASCOT can be used
  - Extended payload capability (typically 25%-30% of overall mass)
  - Funding would probably require larger consortium or significant ESA contribution
- **Down-scaled Philae** (45 to 90 kg):
  - Considerable modifications recommended (technology of the 90ies)
  - Maximum science capabilities
  - Not cheap….

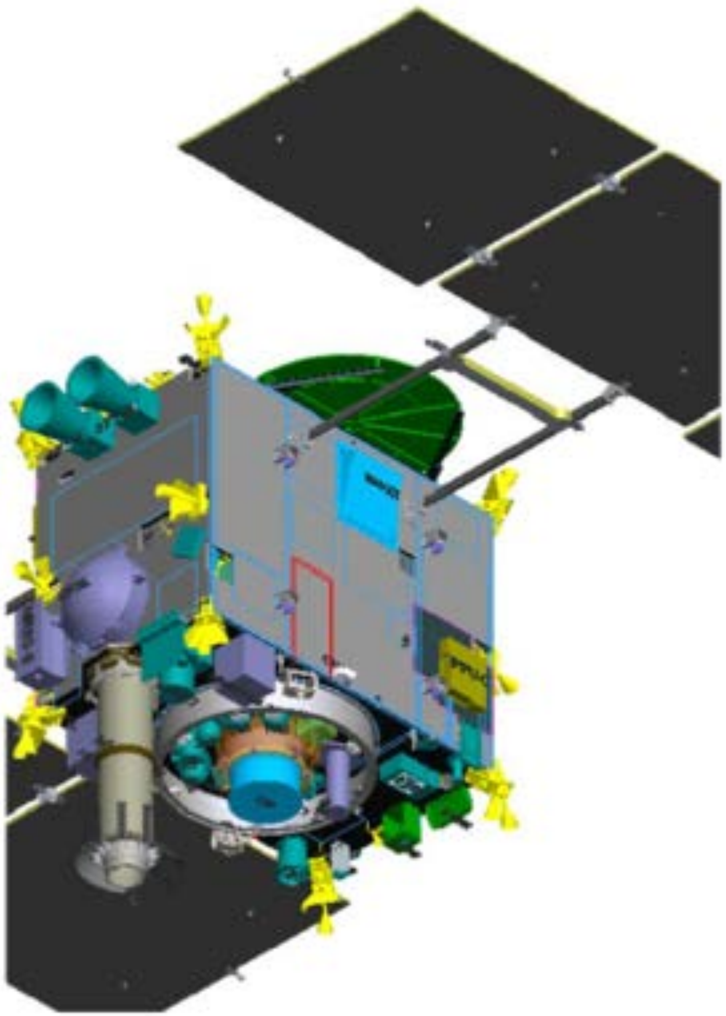
Landing Scenario

- Eject from Orbiter
- Descent (ballistic)
- Optional activation of comt gas system (ADS)
- Stabilization with flywheel
- Anchoring (harpoons)

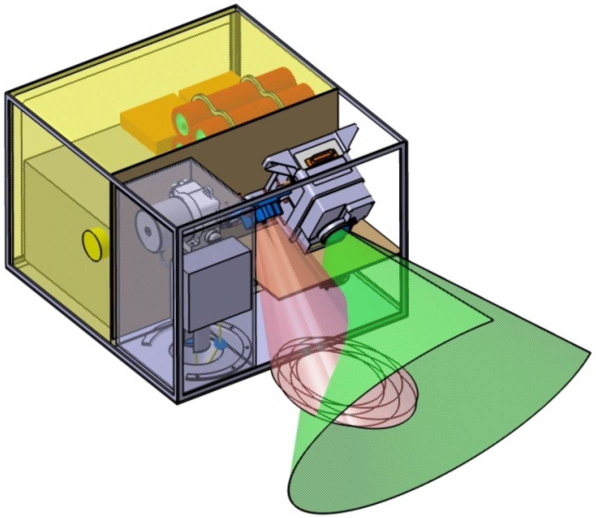


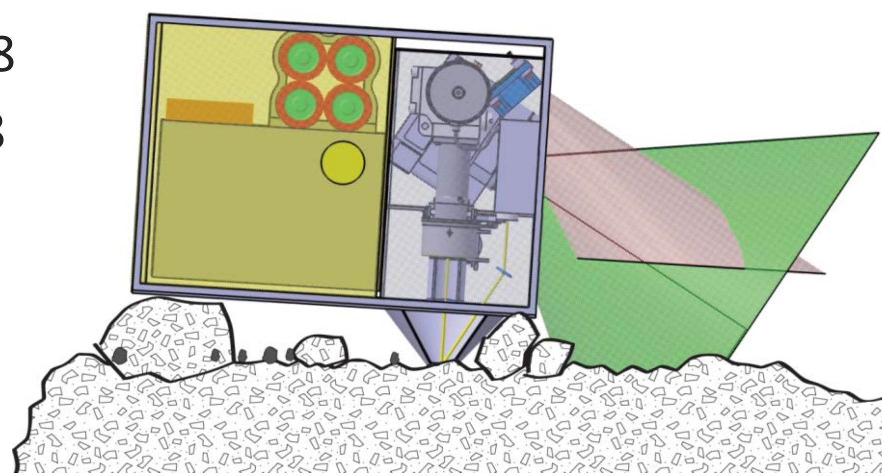


MASCOT – Hayabusa 2 - Overview



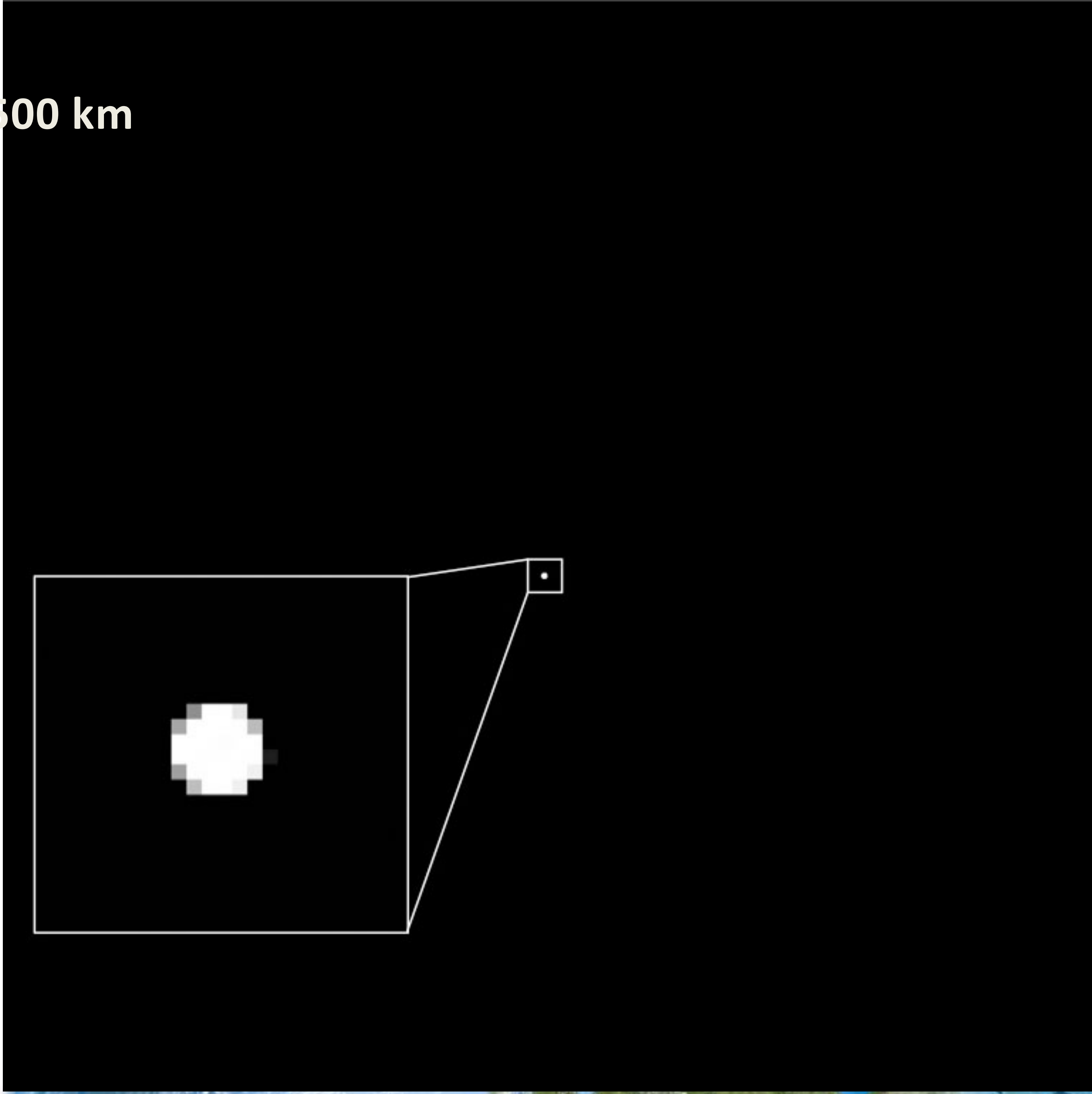
- MASCOT is a small Lander, containing 4 scientific instruments
- It will be delivered by Hayabusa 2 and is contributed to JAXA by DLR (German Aerospace Agency) and CNES (French Space Agency)
- Launched Dec, 2014
- Arrival June 27, 2018
- Landing Oct 3., 2018





Rygu from 1500 km

Ryugu imaged with the ONC-T. The photograph was taken on June 10, around 12:50 JST. The field of view is 6.3 degrees x 6.3 degrees and the exposure time is about 0.09 seconds.
Ground observation team: JAXA, University of Toyko, Kyoto University, Japan Spaceguard Association, Seoul National University.
ONC team: JAXA, University of Tokyo, Kochi University, Rikkyo University, Nagoya University, Chiba Institute of Technology, Meiji University, University of Aizu and AIST.



Hopping

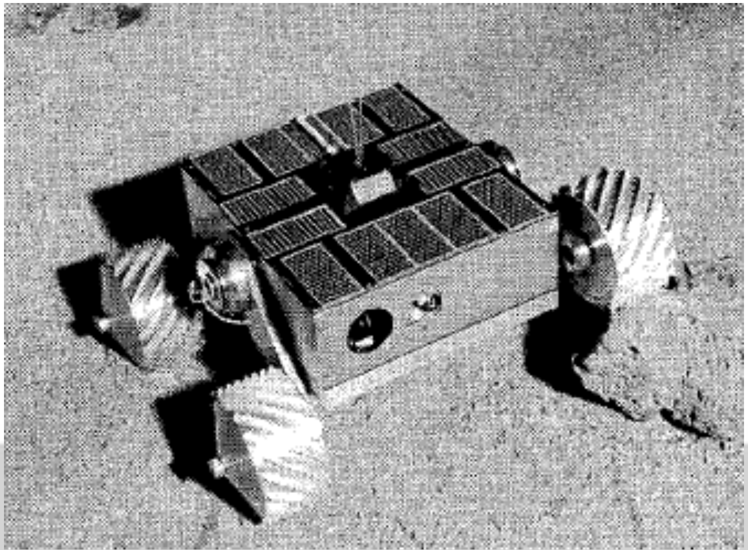
- Rough planar, homogeneous g model
- Trajectory launched at 45° (maximum distance)
- Distance for 1 hop: sm=v0^2/g, time of hop T=2*v0/g
- Example: v0=5 m/s (safe wrt. escape). sm=4 km, T=0.5 h.
- MASCOT-1 had v0=5 cm/s, would hop on Phobos only 0.4 m; but energy from torquer to kinetic is only 0.013 J.
- For the 5 m/s, one would need (m=13 kg) 163 Ws = 0.05 Wh, negligible for energy consumption, but high power in short (<1 s) time; maybe more elegant to store in a spring device or supercap.
- Detailed studies see Ulamec et al., Hopper concepts for small body landers, Advances in Space Research 47 (2011) 428–439 and Liu et al., Hopping trajectory optimization for surface exploration on small bodies, Advances in Space Research 60 (2017) 90–102

Roving

- Hayabusa-1 „MUSES-CN“ rover [Jones 2000] (for Itokawa, $g=(0.56 - 4.5)x10^{-4}$ m/s²): 1.3 kg, 14x14x6cm, max 1.5 mm/s speed, unclear operations to control possible frequent flip-overs, manage obstacles etc.

"The surface gravity on 1989ML is expected to be 8 to 80 µg and the escape velocity will be 0.2 to 1 m/s. With this low gravity, the gravitational force on a 1300-gram rover would be less than 0.13 grams of force. Depending on the model used for the surface properties of the asteroid, this low, normal force could imply certain mobility problems for conventional wheeled vehicles. If the surface is modeled as having conventional friction (e.g. coulombic friction), then the mobility characteristics of a vehicle in the asteroid environment will be a slow-motion version of the dynamics of an off-road vehicle on Earth. If the vehicle hits a 0.5 cm bump on the surface of the asteroid, computer simulations show that it will go more than one vehicle length into the sky and frequently overturn. For this reason, as well as the desire to be ejected from the host spacecraft at an altitude of a few tens of meters, the rover has been designed to be self-righting and to be able to operate upside down." [Wilcox 2000]

- Regolith under µg may show surprising effects when stirred by a wheel (→ mobility number)
- Operations may be very heavy
  → use autonomy
- Detailed simulations and design now performed jointly CNES&DLR



Mobility Options summary

- μ-gravity scales linearly with radius and bulk density
- DidyMoon: g~5e-5 m/s², close to lower limit with conventional (spring) release mechanisms and delivery altitudes
- Ryugu: 1.5E-4 m/s² (GM=32), ideal for easy hopping (MASCOT)
- Milli-gravity (Phobos 0.005 m/s²): roving with wheels becomes a viable possibility, though very slowly (order of mm/s). Hopping still good (Russian Hopper being the grandfather!) but needs other gears, motors, longer excenter arms and/or higher masses than MASCOT to cover reasonable distances (100 m per hop goal)

➔

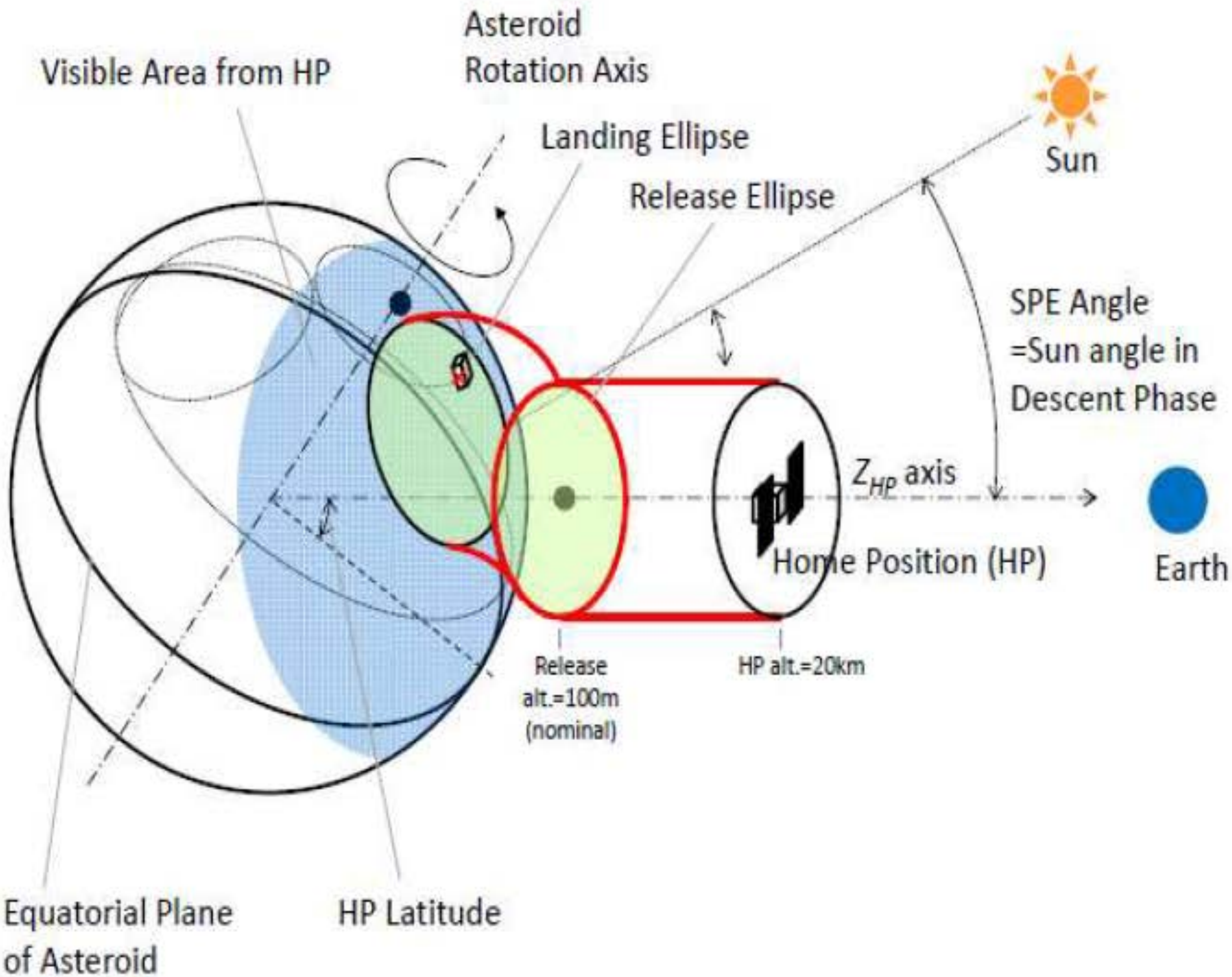
- Hopping:
  - Lower end: constrained by landing safely - dispersion of eject mechanism and S/C state vector
  - High end: constrained by mobility, by motor, gears, mass and length of excenter arms
- Roving on wheels:
  - Lower end constrained by traction while accelerating but more by loosing ground contact when driving over a pothole or a bump too fast
  - High end: N/A

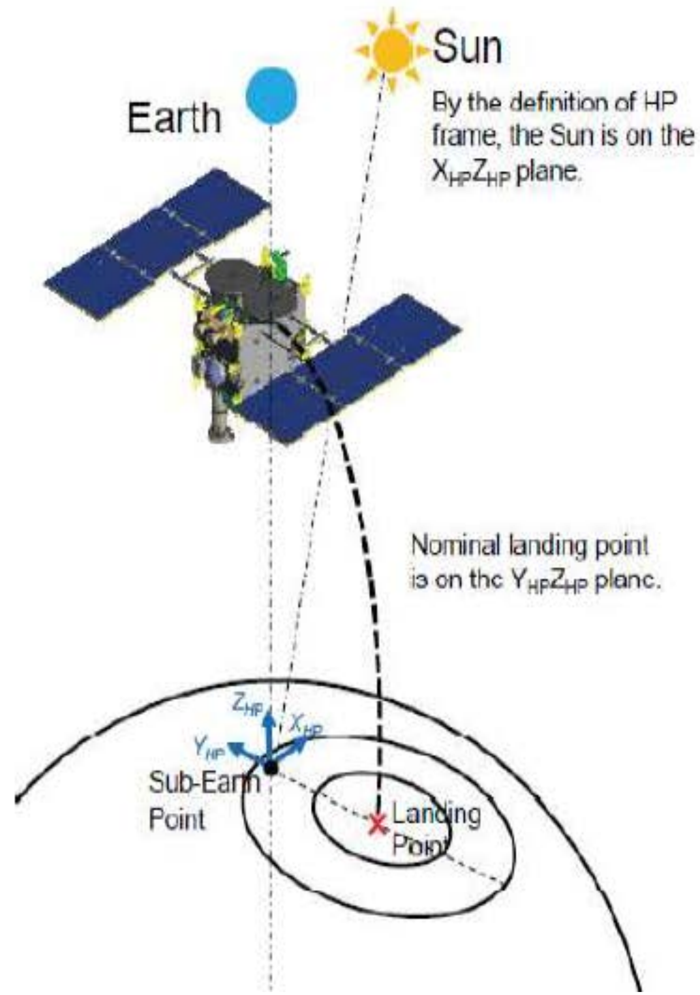
Thank you!

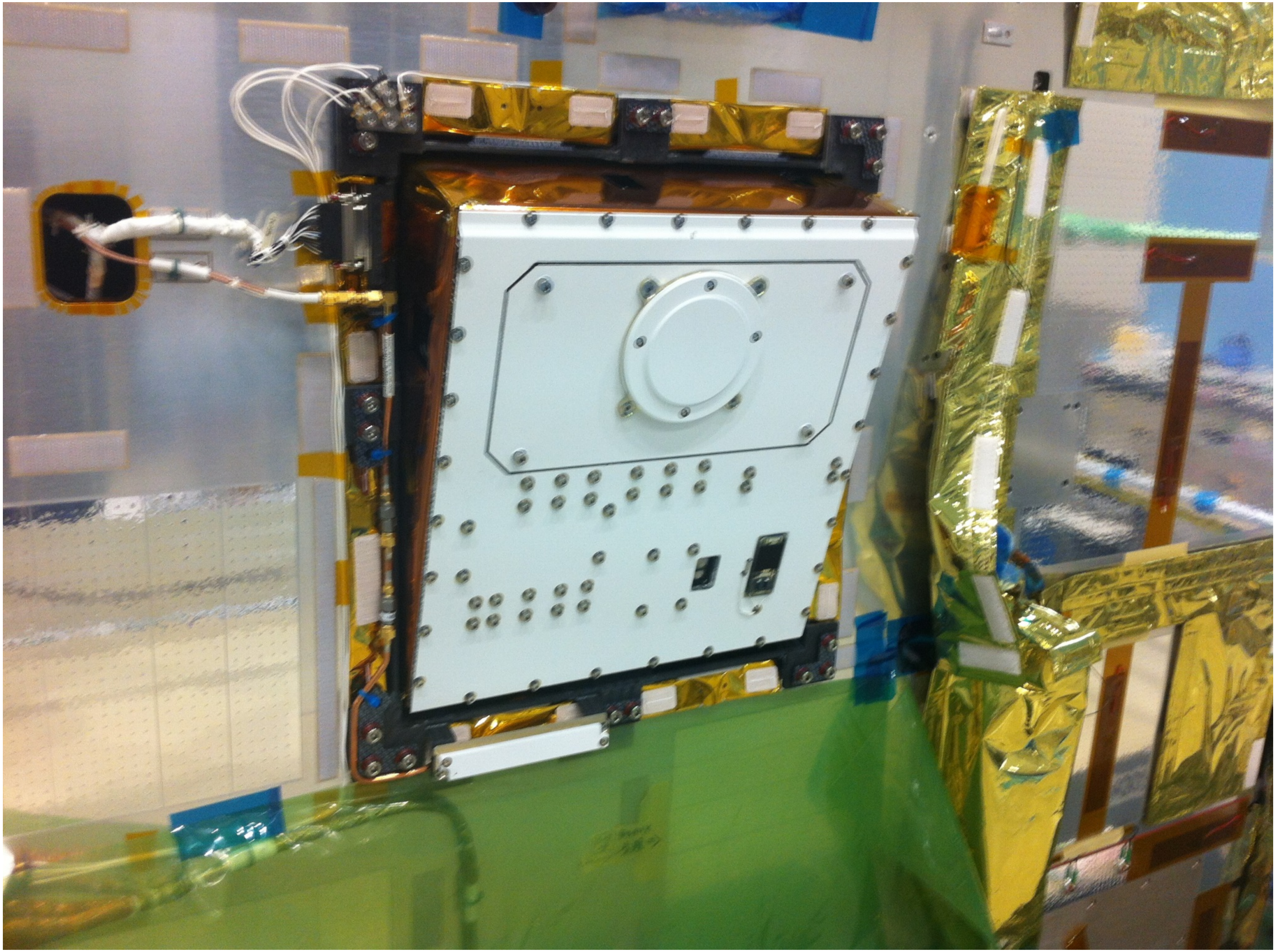
MASCOT Payload

Instrument	Science Goals	Heritage	Institute; PI/IM	Mass [kg]
MAG	magnetization of the NEA → formation history	MAG of ROMAP on Rosetta Lander (Philae), ESA VEX, Themis	TU Braunschweig K.H. Glassmeier / U. Auster	0,15
µOmega	mineralogical composition and characterize grains size and structure of surface soil samples at µ-scale	ESA ExoMars, Russia Phobos GRUNT, ESA Rosetta, ESA ExoMars rover 2018, Rosetta / Philae / CIVA/MI Infrared hyperspectral microscope	IAS Paris J.P. Bibring / M. Berthé	1,9
MARA	map NEA's surface temperature to determine the thermal inertia → Yarkovsky & Yorp effects	MUPUS-TM on Rosetta Lander (Philae); MERTIS-RAD on BepiColombo	DLR PF (Berlin) M. Grott / J. Knollenberg	0,12
CAM	multispectral images of the landing site and provide geological context	ExoMars PanCam heads, Rosetta-ROLIS head, ISS-RokViss head	DLR PF (Berlin) R. Jaumann / N. Schmitz	0,4

Delivery

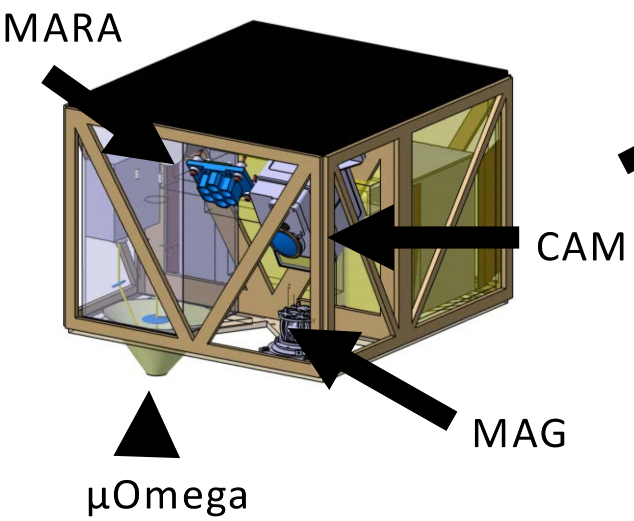

Asteroid
Rotation Axis
Visible Area from HP
Landing Ellipse
Release Ellipse
Sun
SPE Angle
=Sun angle in
Descent Phase
Z_{HP} axis
Home Position (HP)
Earth
Release
alt.=100m
(nominal)
HP alt.=20km
Equatorial Plane
of Asteroid
HP Latitude


Earth
Sun
By the definition of HP
frame, the Sun is on the
$X_{HP}Z_{HP}$ plane.
Nominal landing point
is on the $Y_{HP}Z_{HP}$ plane.
Z_{HP}
Y_{HP}
X_{HP}
Sub-Earth
Point
Landing
Point



MASCOT+ – Proposed Lander Packages

- On the basis of MASCOT (a ~10kg lander for the Hayabusa 2 mission), landers with various instrument complements have been studied

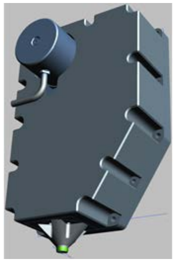


MASCOT

MAPOSSI

- LIBS,
- APX
- Thermal Mapper,
- Mößbauer Spectrometer,
- IR-spectrometer (MicrOmega),
- Camera,
- optional elements

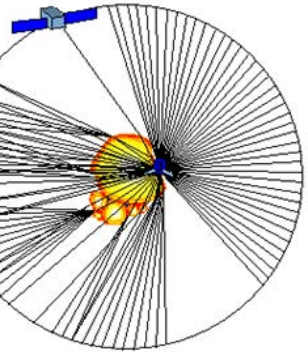
LIBS for ExoMars
© DLR



MicrOmega
for MASCOT
© IAS

FANTINA

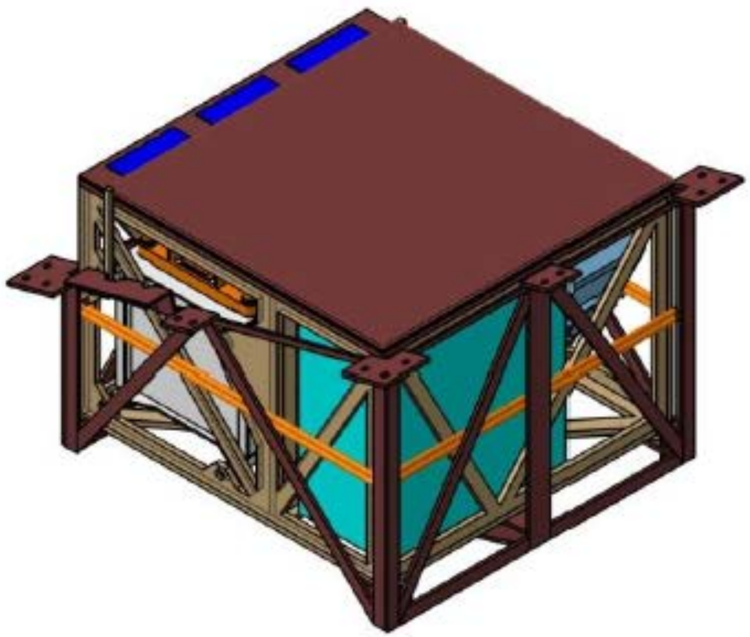
- Radar Tomographer
- Camera
- optional elements

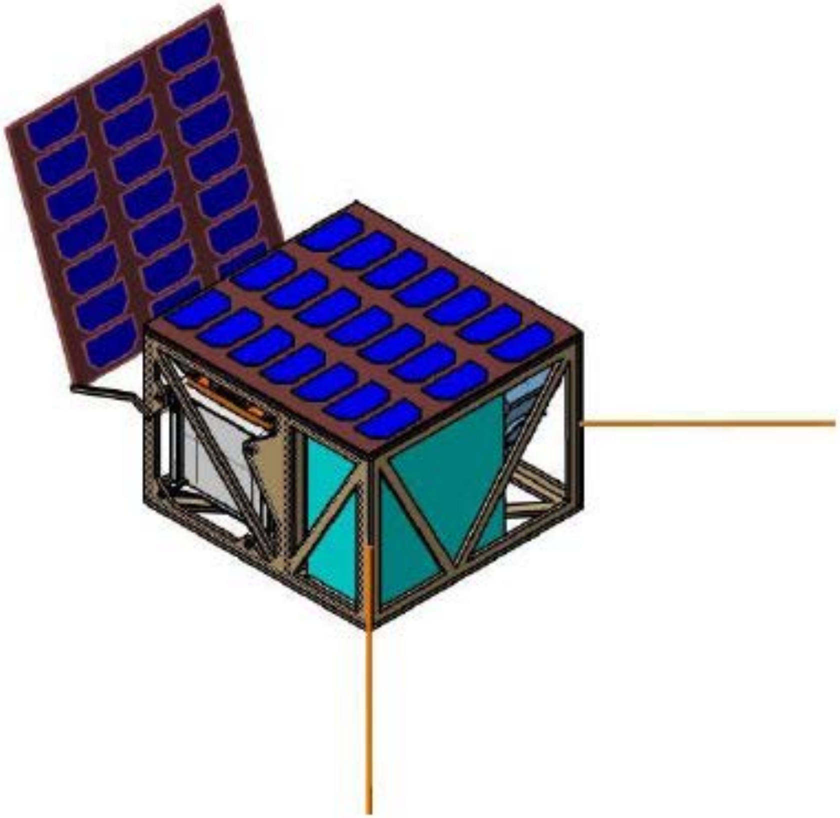


Concept of
Radar Tomogapher
Image: IPAG

Bus Design / Power System longevity – MASCOT-2 (AIM)

- Unfoldable solar generator cover
- Supports orientation and protects solar cells during touch-down
- Active area 0,127 m²
- Energy output: ~23 Wh/T_{rot}





Payload Considerations

- **Analytical Payload**
  - Context measurements
  - Analysis of in-situ composition and detection of possible modifications during sampling, and return
  - EGA´s, LIBS, APX, etc…
- **Analysis of global properties**
  - Added scientific aspect as compared to sample return science
  - Radar, Magnetometer, Seismics (tbc)
- **Physical properties**
  - Added scientific aspect, as physical properties of surface material will be corrupted during sampling
  - Thermal measurements, surface strength, density
- **Surface variability**
  - Make use of mobility
  - Camera + all above

Reconnaissance of Asteroid and Comet Interiors

- (Bistatic) Radar (CONSERT on Philae, Fantina ASSERT proposal using MACOT) – viable for bodies <~5 km diameter.
- Regolith structure of larger bodies by monostatic radar
- Seismic package(s) (precursor: acoustic sensors, e.g. SESAME-CASSE on Philae)

- Other payloads (collection)
  - Seismic package(s) (both active and passive)
  - RF sounding
  - Laser reflector
  - Various analytical instruments
  - Cameras, and Thermal mappers
  - Accelerometers, Dust monitors…

Lessons learnt (Philae, Mascot)

- Energy: never enough, in particular for primary battery landers. Plan with ample margin (units always consume more than promised, battery systems have always more losses than anticipated)
- Tradeoff primary/secondary battery cells (energy density vs. full capacity control9
- Ample redundancy and cruise test possibilites for one-shot devices and mechanisms, in particular motors (permanent magnets, brushes..). Pyros: mind the vacuum for ignition!
- Housekeeping fast and accurate enough (can never have too much HK!)
- Mechanical interaction with surface material is partly unpredictable. → Robostness !