**SMALL STEPS ON DISTANT ROADS – NANO LANDING, SAILING, GOING TOGETHER TO APOPHIS.**

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**Introduction:** 2527 days to go until Friday, April 13th, 2029, 21:45 UT, when every informed and curious naked eye, lens, mirror or dish within the horizon will stand and stare at (99942) Apophis for an once-in-a-dozen lifetimes opportunity. Time is getting short, at least on the scale of spaceflight projects: 8 years is the typical delay between first significant budget release and Flight Model (FM) delivery. Clearly, if a visit to Apophis is intended, whether in passing or as a rendezvous brief or long, it is time.

**MASCOT:** 10½ years before Apophis' fly-by on Friday, April 13th, 2029, the Mobile Asteroid Surface Scout, MASCOT, successfully completed its 17-hours mission on the ~km-sized C-type potentially hazardous asteroid (162173) Ryugu, scouting the rugged landscape together with two MINERVA-II landers, before its surface was sampled by its mothership, HAYABUSA2. MASCOT was developed by DLR in collaboration with the French space agency, CNES. It is shoebox-sized 10 kg asteroid nanolander carrying four full-scale science instruments, and provides them with relocation capability. [1-5]

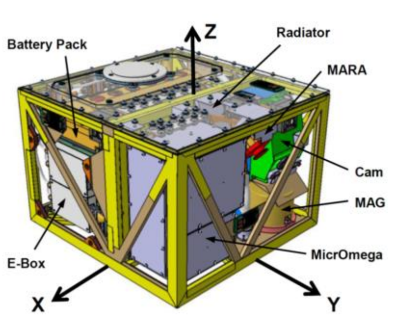


*Fig.1 – The MASCOT Landing Module*

After a phase of studies initiated by ESA's MARCOPOLO mission study, the full-scale hardware development of MASCOT for HAYABUSA2 was released in conjunction with its Preliminary Design Review on June 6th, 2012 – the day of the Venus transit. The Flight Model (FM) was delivered to JAXA mid-June 2014 and was launched towards Ryugu aboard HAYABUSA2 on December 3rd, 2014. [6,7]

**MASCOT2 for AIM in AIDA:** So far closest to flight came MASCOT2, developed for the AIM spacecraft which until 2016 was the partner mission of the recently launched DART spacecraft in the joint NASA-ESA AIDA mission to perform and study a kinetic impact on Dimorphos, the moonlet of binary NEA (65803) Didymos. [8] MASCOT2 was designed to land, position and operate the surface element of the bistatic low-frequency radar on AIM, LFR. It was based on extensive re-use of MASCOT technologies with tailored capability upgrades in the details of many subsystems. Many more lessons learned from MASCOT's and the MINERVAs' flight as well as from many other studies and projects have since been incorporated into the development of future MASCOT nanolanders, keeping pace with the growing knowledge in the highly dynamic field of small solar system body science.

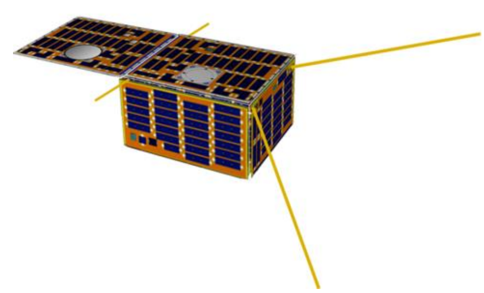

*Fig. 2 - The MASCOT2 nanolander for AIM*

Since the cancellation of MASCOT2 when time ran out for AIM to make it to Didymos in time for DART's impact, the MASCOT team is pursuing a wide range of

MASCOT nanolander options, from maximum as-is re-use incarnations for near-term missions to entirely new developments of the MASCOT concept. Many studies took one of the many middle roads of tailored re-use with optimization in detail, similar to MASCOT2. [9]

**Sailing together:** Small interplanetary probes designed to fit the 'mini' and 'micro' rideshare payload slots on launch vehicles can benefit from resource-sharing concepts when carrying a MASCOT. These have been developed based on technologies qualified in the GOSSAMER-1 solar sail deployment demonstrator project, itself a small 'micro' spacecraft composed of 5 independent 'nano' spacecraft. [10,11,14-16]

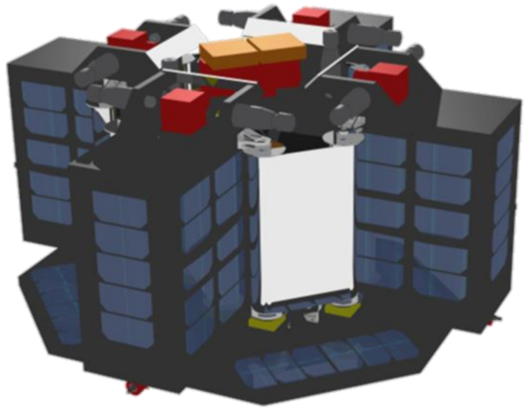

*Fig.3 – Un pour tous, tous pour un – the shared resources multi-sub-spacecraft design of GOSSAMER-1*

These concepts enable mutual support of the mission's main spacecraft and the MASCOT nanolander aboard during cruise up to lander separation. Options include photovoltaic power redistribution, shared batteries, thermal control support, more data handling and communication capabilities including radio networks, and additional instruments and viewing angles.

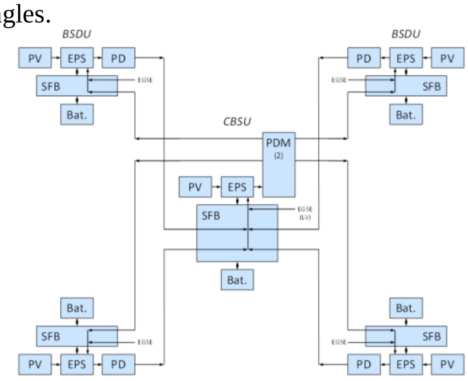


*Fig. 4 - The GOSSAMER-1 Charging Network sharing all power resources of 5 nanospacecraft*

In particular, a wireless communication network can be shared between all participating spacecraft, possible even different missions to the same target, Apophis. The lander communication system of HAYABUSA2 was also shared for the three MINERVA-II landers and MASCOT, and the GOSSAMER-1 system applied a similar concept for synchronized membrane deployment. Recent studies add self-transfer propulsion to the MASCOT portfolio, allowing the main spacecraft to stay at a safe distance from the unknown unknowns of the asteroid. [12,13,17]

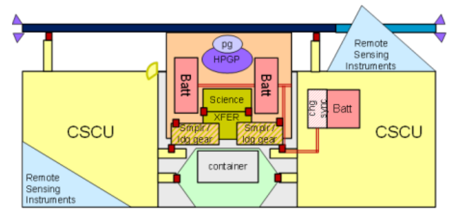


*Fig.5 – Notional accommodation of a sample-return lander integrated organically with its carrier.*

**Conclusion:** The experience with fast-paced and organically integrated complex small spacecraft projects accumulated in the development lines beginning with MASCOT and the GOSSAMER-1 Roadmap suggests that small spacecraft approaches and tightly integrated teams are the way to go and arrive in time at Apophis, for a variety of mission and to stay.

**Acknowledgments:** The authors acknowledge the work of the MASCOT, MASCOT2, GOSSAMER-1, GOSOLAR, and follow-on study teams and the support for these studies by the CEF team at DLR Bremen.

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