Miniaturised Asteroid Remote Geophysical Observer (M-ARGO): A stand-alone deep space CubeSat system for low-cost science and exploration missions

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Presenter Philipp Hager, Ph.D (2)

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(2) Thermal Engineer, Thermal Control Section
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Miniaturised – Asteroid Remote Geophysical Observer (M-ARGO) Mission Concept

• Mission objectives:
  - rendezvous with an asteroid
  - characterise the physical properties of asteroid (shape, surface, mass)
  - assess potential for resource exploitation (composition, hydration)

• Mission phases:
  - piggyback launch on Sun-Earth L2 transfer (astronomy mission)
  - parking in Sun-Earth L2 halo orbit
  - interplanetary transfer using low-thrust solar electric propulsion
  - close proximity operations for 6 months of remote sensing

• Ground segment:
  - 15/35 m ESA ESTRACK stations + Sardinia Radio Telescope (64 m)
  - Mission Operations Centre with flight dynamics, Science Ops Centre

• Programmatic:
  - Budget (1st mission incl. NRE): <25 MEuro ROM
  - Schedule: launch 2021
# M-ARGO System Overview

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Specification</th>
</tr>
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<tbody>
<tr>
<td><strong>S/C volume</strong></td>
<td>• 12U form factor (226x226x340 mm)</td>
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<tr>
<td><strong>Payload volume</strong></td>
<td>• 1U available</td>
</tr>
<tr>
<td><strong>Propulsion</strong></td>
<td>• µRIT Gridded Ion Engine, gimbal, PPU, neutraliser</td>
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<td></td>
<td>• 2 Xenon propellant tanks &amp; feed system (Max. 2.8 kg)</td>
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<tr>
<td><strong>Communications</strong></td>
<td>• X-band DS transponder with ranging/doppler (2 Rx, 3 Tx channels)</td>
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<td></td>
<td>• 4x patch antennas for omni-directional TT&amp;C</td>
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<td></td>
<td>• Deployable HGA reflect-array for P/L data</td>
</tr>
<tr>
<td><strong>Power</strong></td>
<td>• Single body mounted panel (6U face) + Li-ion battery</td>
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<td></td>
<td>• 2-wing deployable solar array with solar array drive mechanism (SADM)</td>
</tr>
<tr>
<td><strong>Power to EP @ 1 AU</strong></td>
<td>93 W (6 panels)</td>
</tr>
<tr>
<td></td>
<td>120 W (8 panels)</td>
</tr>
<tr>
<td><strong>Thrust @ 1 AU</strong></td>
<td>1.7 mN</td>
</tr>
<tr>
<td></td>
<td>2.4 mN</td>
</tr>
<tr>
<td><strong>Isp @ 1 AU</strong></td>
<td>3050 s</td>
</tr>
<tr>
<td></td>
<td>3180 s</td>
</tr>
<tr>
<td><strong>S/C wet mass (w/ margins)</strong></td>
<td>21.6 kg</td>
</tr>
<tr>
<td></td>
<td>22.3 kg</td>
</tr>
<tr>
<td><strong>AOCS</strong></td>
<td>• Sensors: visnav camera, star tracker, 6 sun sensors, IMU</td>
</tr>
<tr>
<td></td>
<td>• Actuators: 3 reaction wheels, 8 Xe cold gas RCS thrusters</td>
</tr>
<tr>
<td><strong>Data handling</strong></td>
<td>• Modular avionics with payload data processing</td>
</tr>
<tr>
<td><strong>Thermal control</strong></td>
<td>• Passive with radiators &amp; heaters</td>
</tr>
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M-ARGO Spacecraft Configuration
Science rationale

- All asteroids visited so far are >300 m in size

- For asteroids with a size <100 m, models predict a compact monolithic body which has no regolith and is fast spinning

-> New science!

Other mission scenarios were also considered.
## Multi-Spectral Imager

<table>
<thead>
<tr>
<th>ASPECT Multi-spectral imager (VTT, Finland)</th>
<th>VIS channel 500 – 900 nm</th>
<th>NIR channel 900 – 1600 nm</th>
<th>SWIR channel 1600 – 2500 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Field of View [deg]</td>
<td>6° x 6°</td>
<td>5.3° x 5.3°</td>
<td>5° circular</td>
</tr>
<tr>
<td>Spectral res. [nm]</td>
<td>&lt; 20 nm</td>
<td>&lt; 50 nm</td>
<td>&lt; 25 nm</td>
</tr>
<tr>
<td>Spectral bands (tunable in flight)</td>
<td>~ 14</td>
<td>~ 24</td>
<td>~ 30</td>
</tr>
<tr>
<td>Image size [pixels]</td>
<td>614 x 614</td>
<td>256 x 256</td>
<td>1 pixel</td>
</tr>
<tr>
<td>Pixel size (µm)</td>
<td>5.5</td>
<td>30</td>
<td>1000</td>
</tr>
<tr>
<td>Focal length (mm)</td>
<td>32.3</td>
<td>81.5</td>
<td>11.7</td>
</tr>
<tr>
<td>F/#</td>
<td>3.3</td>
<td>5.04</td>
<td>0.9</td>
</tr>
<tr>
<td>GSD at 500 m</td>
<td>9 cm</td>
<td>18 cm</td>
<td>44 m</td>
</tr>
<tr>
<td>SNR at phase angle &lt;20°</td>
<td>&gt;40 (t_{int} = 50 ms) at 500-800nm</td>
<td>&gt;40 (t_{int} = 15 ms) at 900-1500nm</td>
<td>&gt;100 (t_{int} = 10 ms) at 1600-2500nm</td>
</tr>
</tbody>
</table>

Mass: 950g  
Power: 7 W  
TRL 6, Aalto-1 heritage (space qualified)
LASER Altimeter

DLEM 20 (Jenoptik, Germany):
- Up to 5 km measurement range
- Measurement accuracy 0.5-1 mm
- Mass < 33g
- Dimensions: 50 mm x 22 mm x 34 mm
- Power on < 1.8 W
- Operational Temp.: -40 °C to +80 °C
- COTS (not space qualified)

100 ms measuring time
Up to 1500 m measuring distance
(Acc. ±0.5 m up to 1000 m)
NEO Target Screening

MPCORB database (23/1/2017)
725,896 objects

Pre-filtering
(3-impulse chemical)

63 objects (<2.6 km/s, n>80, V<28.1)

Low-thrust trajectory optimisation tool

30 objects (mp <2.5 kg)

Assumptions

Starting from Earth-Sun L2 with no initial C3
Spacecraft initial mass 20 kg
Maximum thrust of 1.7 mN, specific impulse of 3000 s
Launch window: between 2020 and 2023 (included)
Maximum time of flight: 3 years
Maximum propellant mass: 2.5 kg
Sun Beam to Ion Beam Optimisation

- **Final power into EP [W]**
  - Sun distance [AU]: 0.8 to 1.2
  - 6 panels and 8 panels

- **Thrust [mN]**
  - Sun distance [AU]: 0.8 to 1.2
  - 6 panels, 8 panels, and Constant

- **Isp [s]**
  - Sun distance [AU]: 0.8 to 1.2
  - 6 panels, 8 panels, and Constant
## Mission Analysis of Potential Targets

<table>
<thead>
<tr>
<th>Designation</th>
<th>$a$ [AU]</th>
<th>$r_a$ [AU]</th>
<th>$r_p$ [AU]</th>
<th>$e$</th>
<th>$i$ [°]</th>
<th>$H$</th>
<th>$\Delta V$ [km/s]</th>
<th>$m_p$ [kg]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012 UV136</td>
<td>1.008</td>
<td>1.148</td>
<td>0.868</td>
<td>0.14</td>
<td>2.21</td>
<td>25.5</td>
<td>3.17</td>
<td>2.2</td>
</tr>
<tr>
<td>2014 EK24</td>
<td>1.006</td>
<td>1.077</td>
<td>0.935</td>
<td>0.07</td>
<td>4.81</td>
<td>23.3</td>
<td>3.92</td>
<td>2.50</td>
</tr>
<tr>
<td>1996 XB27</td>
<td>1.189</td>
<td>1.258</td>
<td>1.120</td>
<td>0.06</td>
<td>2.47</td>
<td>21.7</td>
<td>3.62</td>
<td>2.32</td>
</tr>
<tr>
<td>YORP</td>
<td>1.006</td>
<td>1.238</td>
<td>0.775</td>
<td>0.23</td>
<td>1.60</td>
<td>22.7</td>
<td>6.74</td>
<td>4.10</td>
</tr>
<tr>
<td>2013 BS45</td>
<td>0.992</td>
<td>1.075</td>
<td>0.909</td>
<td>0.08</td>
<td>0.77</td>
<td>25.9</td>
<td>1.88</td>
<td>1.31</td>
</tr>
<tr>
<td>2016 FU12</td>
<td>1.003</td>
<td>1.170</td>
<td>0.836</td>
<td>0.17</td>
<td>2.06</td>
<td>26.9</td>
<td>2.7</td>
<td>1.88</td>
</tr>
<tr>
<td>2011 MD</td>
<td>1.056</td>
<td>1.095</td>
<td>1.017</td>
<td>0.04</td>
<td>2.45</td>
<td>28.0</td>
<td>3.19</td>
<td>2.17</td>
</tr>
</tbody>
</table>

### Notes:
- **YORP**: orbital elements seem promising but from 2020 on, YORP is getting away from the Earth.
- **2014 EK24**: all orbital elements are in the good ranges but inclination is too high.
- **1996 XB27**: at rendezvous the range to Earth is too large for communication.
Mission Analysis

- Variable thrust & Isp vs. sun distance
- 8 panels option
- Delta-v: 3.17 km/s
- Xe mass: 2.2 kg
- Thrust-on: 395 d
- Sun distance <1.2 AU
- Earth range: <0.8 AU
- SAA during thrust-on phases 75-175 deg
Science rationale and asteroid assessment

- All asteroids visited so far are >300 m in size

- All 4 accessible targets are <50 m

- For this size, models predict a compact monolithic body which has no regolith and is fast spinning

-> New science!
Close Proximity Operations

Target 2012 UV136, 7 day repeat cycle
Communications

X-Band P/L Data Rates COMM3

- 25 kbps @ 1 AU
  15 W RF power
  64 m Sardinia

- 7 kbps @ 1 AU
  15 W RF power
  35 m ESTRACK
Science Data Return

24 h/week (35 m)

Science data return per week [Mb]

8 h/week (35 m)

Science data return per week [Mb]

Total science data in 90 days [Gb]

Total science data in 180 days [Gb]

Total G/S hours (35 m) per week
Thermal Design

Thermal design Drivers:
- Distance from Sun, spacecraft attitude, dissipation modes (EPROP, COM, Science), Sensitive Equipment

Thermal Control:
- Passive thermal design plus heaters
- Kapton foil thermal straps (increase TRL for miniaturized thermal straps)
- Heaters, thermistors, optical coatings,
- 44 W - maximum required heater power

Option: deployable radiators
- Free structural area for other equipment
- Reduce heater power in cold modes
Alternative L5 Space Weather Mission

**Departure date (from SEL2)**: 2024/2/6

**Earth encounter**: N/A

**Asteroid arrival date**: 2025/9/22

**Delta-V**: 2.62 km/s

**Propellant mass (without margin)**: 1.70 kg

**Thrust-on time**: 342 days

**Range of distance from Sun**: 0.99-1.15 AU

**Range of distance from Earth**: 0-1.02 AU

**Range of SAA value during thrust-on**: 80-135 deg

20-month transfer
Stand-Alone Deep Space Cubesats

• High potential to cut the entry-level cost of space exploration by an order of magnitude
• Piggyback launch options to near Earth escape:
  o Lunar transfer/orbit, Sun-Earth L1/L2 transfer, outer planet
• 12U CubeSat with enabling miniaturised technologies:
  o high specific impulse electric propulsion system & cold gas RCS
  o deep space transponder & HGA
  o “high power” deployable steerable solar array
  o highly integrated rad-hardened avionics
• Potential missions:
  o NEO rendezvous for physical characterisation (science, resources)
  o Sun-Earth L5 for space weather (storm advance warning)
• Technology Reference Study performed in ESA Concurrent Design Facility to assess feasibility, tech developments, cost/schedule
Conclusions

• Stand-alone Deep Space CubeSats are technically feasible in the near-term
• Delta-V capability (3.75 km/s) encompasses at least 4 NEO targets for rendezvous (up to 30 as of time of study), and transfer to Sun-Earth L5 for space weather mission
• Technologies are either high TRL for CubeSat COTS products or TRL 3/4 to be developed to TRL 6 within the frame of the ESA Technology Programme (SADM, EPROP subsystem, X-band transponder & HGA)
• Radiation hardness assurance of COTS electronics components wrt destructive latch-ups needed in the project, and some delta-qualification of equipment
• Schedule to flight readiness in early 2021, launch July 2021 assuming technology developments start soon
• ROM cost is considered to be marginally feasible within 25 MEuro budget
• Major cost driver is the Flight Dynamics support cost (50% of the overall ROM cost estimate) -> lower cost approaches to be investigated
• Next steps: kick-off tech dev activities & identify piggyback launch, then start Phase A/B
## Acknowledgements to ESA CDF Study Team

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<th>CUSTOMER</th>
<th>I. Carnelli (General Studies Programme)</th>
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<td>TARGET SCREENING</td>
<td>D. Izzo A. Merata</td>
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THANK YOU

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