A CubeSat mission to asteroid Apophis based on M-ARGO?

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What is M-ARGO

- M-ARGO = Miniaturized Asteroid Remote Geophysical Observer
- 2017: ESA-internal study for a 12-unit CubeSat mission for planetary science
- Final focus: Asteroids
- Exploring small asteroid below spin barrier to see whether there is no regolith
- 2019: Phase-A study will start end of May, continue to 2020
- Studies to increase the technology readiness have or are starting: high-gain antenna, solar array drive mechanism, cold gas reaction control system...
M-ARGO from the ESA-internal study

<table>
<thead>
<tr>
<th>M-ARGO Spacecraft</th>
<th>PHY7</th>
<th>PHY9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry Mass incl. margin (kg)</td>
<td>18.75</td>
<td>19.48</td>
</tr>
<tr>
<td>Wet Mass incl. margin (kg)</td>
<td>21.61</td>
<td>22.33</td>
</tr>
<tr>
<td>Power available to Electric Propulsion System at 1 AU, SSA 0 deg (W)</td>
<td>93.1</td>
<td>120</td>
</tr>
<tr>
<td>Thrust level at 1 AU (mN)</td>
<td>1.7</td>
<td>2.4</td>
</tr>
<tr>
<td>Specific Impulse at 1 AU (s)</td>
<td>3050</td>
<td>3179</td>
</tr>
</tbody>
</table>
| Payload                                                                                           
| PHY: ASPECT MSI with Laser Rangefinder. Pixel scale at least 0.15 m/pxl in VIS range, 0.36 m/pxl in NIR. 154 Mbit/week expected data return. |

PHY7 = Physical characterization of asteroids with 7 solar cells
PHY9 = with 9 solar panels
ASPECT MSI = Asteroid Spectral Mult—Spectral Imager, Kestilä et al. 2016, Kohout et al. – VTT Technical Research Centre of Finland, Univ. Helsinki - flown on Aalto-1

VIS = visible wavelength range  
NIR = near-infrared
## ASPECT – Asteroid Spectral Imager

<table>
<thead>
<tr>
<th>ASPECT</th>
<th>VIS 500 – 900 nm</th>
<th>NIR 900 – 1600 nm</th>
<th>SWIR 1600 – 2500 nm</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field of View [deg]</strong></td>
<td>6° × 6°</td>
<td>5.3° × 5.3°</td>
<td>5° circular</td>
</tr>
<tr>
<td><strong>Spectral res. [nm]</strong></td>
<td>&lt; 20 nm</td>
<td>&lt; 50 nm</td>
<td>&lt; 25 nm</td>
</tr>
<tr>
<td><strong>Spectral bands (tunable in flight)</strong></td>
<td>~ 14</td>
<td>~ 24</td>
<td>~ 30</td>
</tr>
<tr>
<td><strong>Image size [pixels]</strong></td>
<td>614 × 614</td>
<td>256 × 256</td>
<td>1 pixel</td>
</tr>
<tr>
<td><strong>Pixel size [um]</strong></td>
<td>5.5</td>
<td>30</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Focal length [mm]</strong></td>
<td>32.3</td>
<td>81.5</td>
<td>11.7</td>
</tr>
<tr>
<td><strong>F/#</strong></td>
<td>3.3</td>
<td>5.04</td>
<td>0.9</td>
</tr>
<tr>
<td><strong>GSD at 500 m</strong></td>
<td>9 cm</td>
<td>18 cm</td>
<td>44 m</td>
</tr>
<tr>
<td><strong>SNR at phase angle &lt;20°</strong></td>
<td>&gt;40 (t &lt;sub&gt;int&lt;/sub&gt; = 50 ms) at 500-800nm</td>
<td>&gt;40 (t &lt;sub&gt;int&lt;/sub&gt; = 15 ms) at 900-1500nm</td>
<td>&gt;100 (t &lt;sub&gt;int&lt;/sub&gt; = 10 ms) at 1600-2500nm</td>
</tr>
<tr>
<td><strong>Mass incl. laser rangefinder and DMM</strong></td>
<td></td>
<td></td>
<td>1.08 kg</td>
</tr>
</tbody>
</table>

Image credit: VTT Technical Research Centre of Finland, Univ. Helsinki
Additional payload

- **DLEM 20 laser range finder**
  - From Jenoptik Germany
  - Mass 33 g
  - 50 mm x 22 mm x 34 mm
  - < 1.8 W
  - 0.5 .. 1 m measurement accuracy
  - Commercial – needs to be space-qualified

- **Magnetometer**

- **Radio science**
How to get there

- Delta-v ~ 5 km/s – comparable to Venus or Mars missions
- CubeSat carrier as co-passenger to GTO (possibly LEO)
- Or: ride share to L2, then return, near Earth, lunar swingby – dv ~ 1.5 km/s. Add 2 to 2.5 km/s by SEP, or Earth swingby one year later
- Kick stage to leave Earth gravity well
- Launch Apr 2028
- Arrival Feb 2029
- Break maneuver, CubeSat deployment
What to do?

Can we see particles moving due to tidal forces?

- $d_{\text{Apophis}} = 375$ m
- $d_{\text{Apophis-Earth}} = 38300$ km
- $v_{\text{Apophis}} = 5.87$ km/s
- $\rho_{\text{Apophis}} = 2500$ kg/m$^3$
- $\omega_{\text{Apophis}} = 30.6$ h

Then:

- $F_{\text{tidal}} = 2.7 \times 10^{-6}$ N
- $F_{\text{grav}} = 1.3 \times 10^{-4}$ N (Apophis gravity)
- $F_{\text{cent_rot}} = 6.1 \times 10^{-7}$ N

Shear strength $67P \sigma = 3..15$ Pa

$\Rightarrow F_{\text{tidal}} > \sigma$ for $A = 0.3 \times 0.3$ mm$^2$
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What to do?

- Constrain surface strength
- Bulk object properties (rubble pile, compact; mass; size; density tbd)
- Surface topography (regolith; size distribution)
- Mineralogical properties
And: Great outreach opportunity!
Conclusions

- Only 9.9 years to go - An Apophis mission should be started now
- Science - Outreach
- One proposal within an ESA framework: F-class mission – as just heard: Deller et al. – others: APEX (Plesco et al.) - or Apophis explorer (Prado et al. 2015)...
- The Apophis Y-Price?
- Minimalist scenario for picture only: High eccentric orbit around Earth with proper phasing