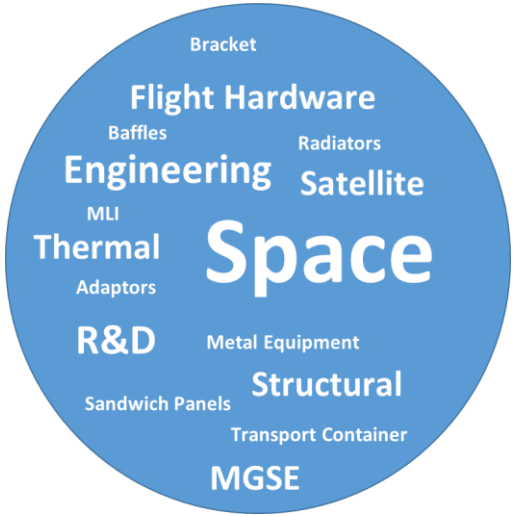
Navigation Markers Development



Admatis
Advanced Materials In Space

2026.07.01.

ESA, ESTEC

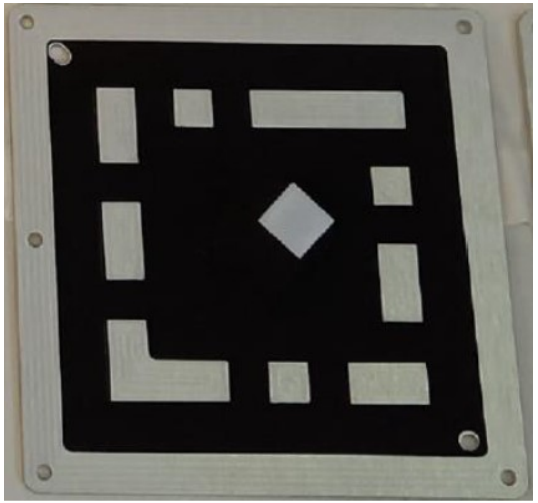
CONTENT

1. INTRODUCTION
2. TECHNICAL DESCRIPTION
    a) 3D Marker
    b) 2D Marker
    c) Phosphorescent marker
3. SUMMARY

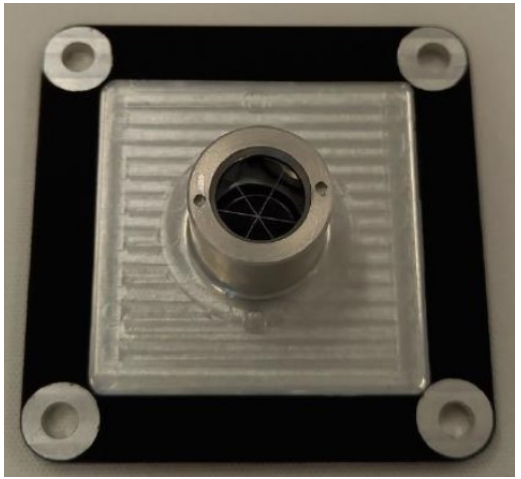
INTRODUCTION

Active debris removal, in-orbit servicing operations can be supported using reflective solutions, such as rendezvous markers, installed on the target spacecraft, as a passive and cheap solution to improve the target attitude and pose estimation.

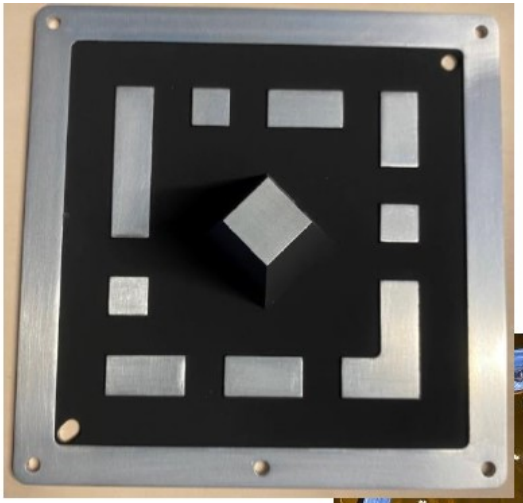
For the last moments of the rendezvous, up to capture (below 5 m), a single ***„3D”*** marker is required to perform pose estimation.

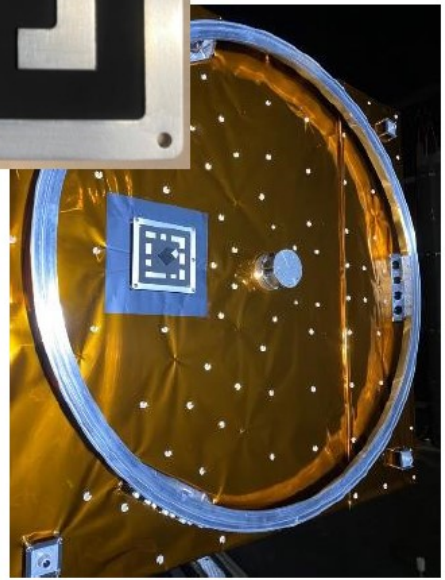


From far to close rendezvous (~50-5 m), and for ground-based SLR detection, planar distributed ***„2D”*** markers can be used for attitude and pose estimation



3D MARKER

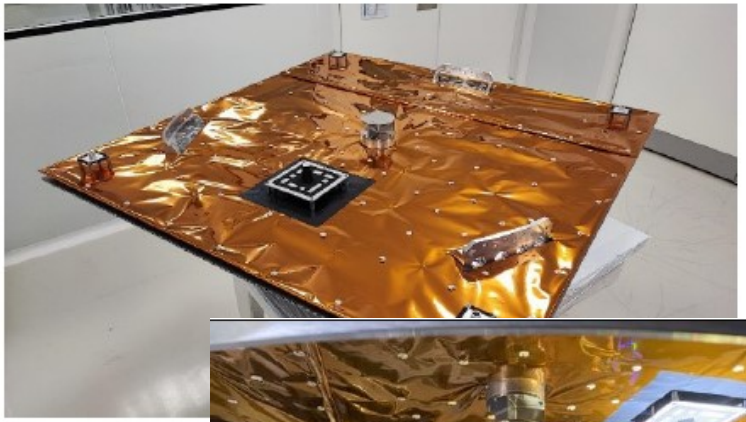


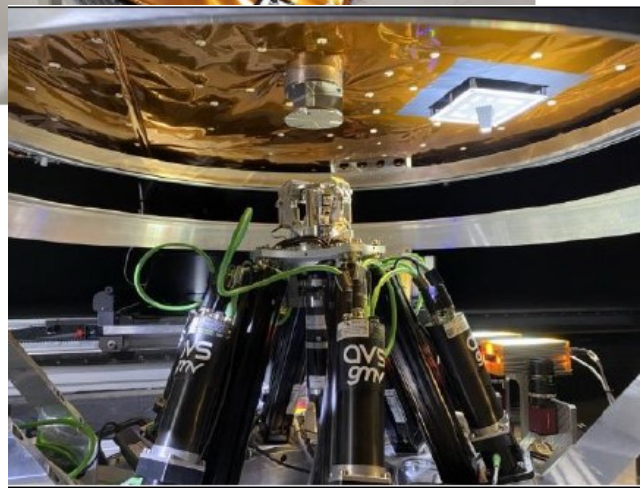


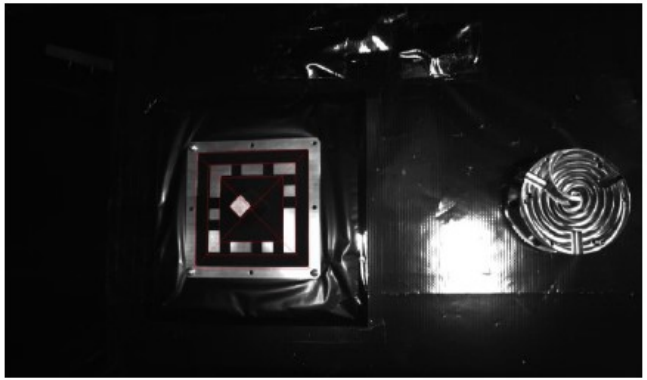
- 150×150×40 mm
- EN AW6082 aluminium
- bore and slot for adjustment with Ø5mm dowel pins
- Mass: 0.21 kg; using 20% mass margin for screws and washers : 0.25kg
- Grounding is implemented by the interface screws.
- coatings are TCCC + black paint giving contrast in the VNIR and TIR spectra for detection
- TCCC used mainly for corrosion protection and provides homogenous grey surface
- Black area is a matte, conductive silicone coating. Provides very high resistance to ATOX and UV irradiation. Provides a very good thermal stability at very low temperature at (-170°C), a very low level of specular reflectance
- Attachment to SC: 5pcs of M4 screws + M4 washers + 5pcs of thermal washers as an option

3D MARKER

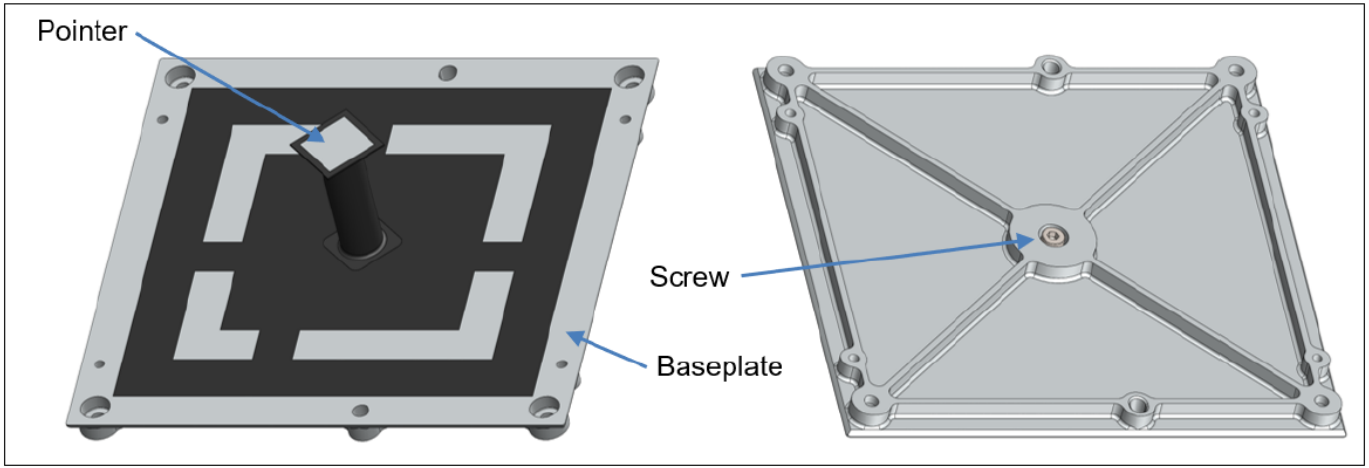
3D marker has been used for on-orbit detection demonstration in CAT project.



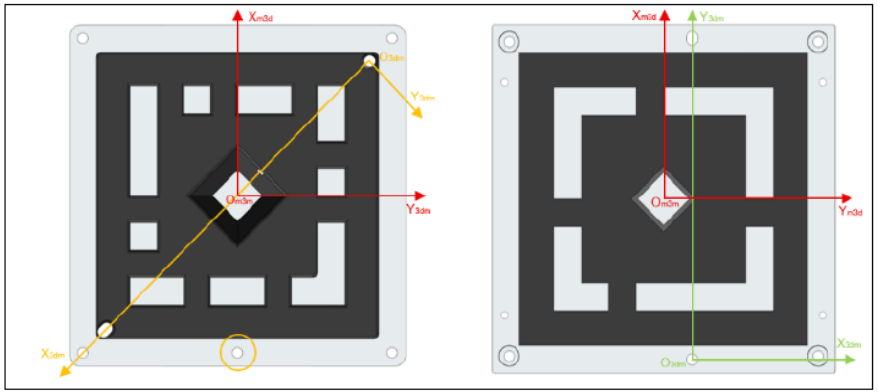


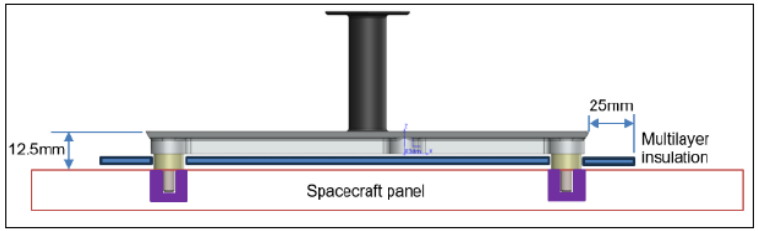


3D MARKER

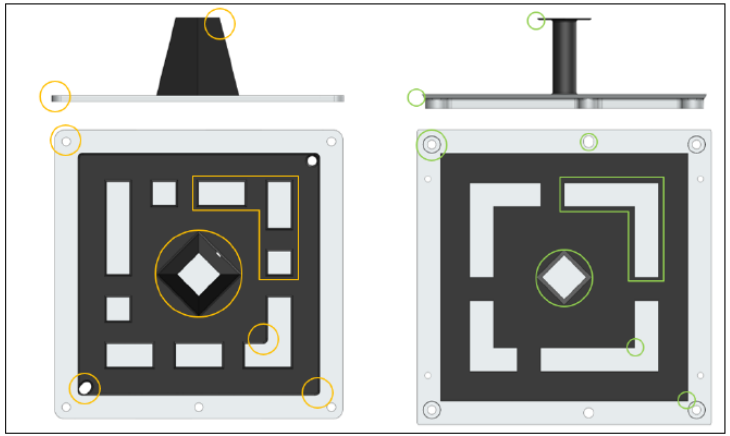


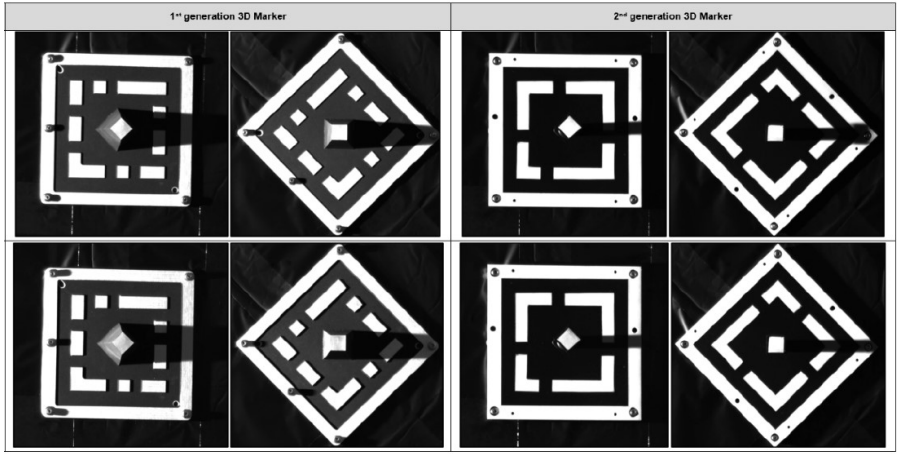
- 2nd gen is under development; the design is fixed
- Reduced mass (207 g → 172 g)
- Better detection performance





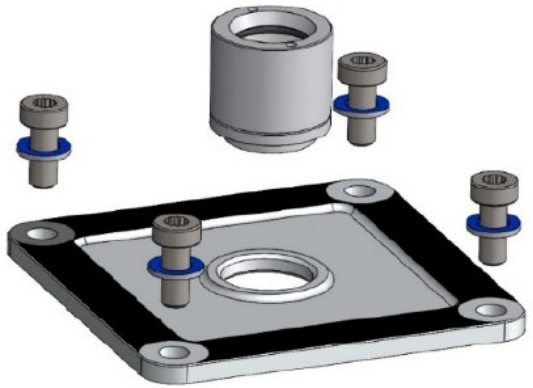
3D MARKER

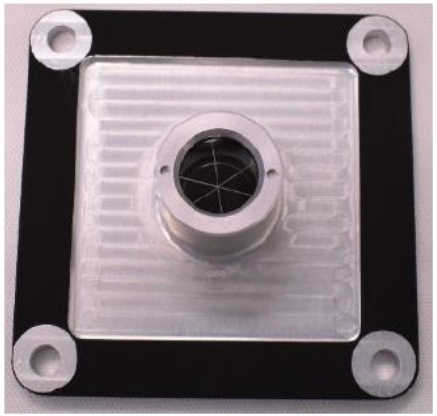




- sinking screw heads preventing shadows and occlusion
- Alignment holes have been moved to prevent interference with the pattern
- Baseplate is completely flat to reduce optical artifacts
- Corners in the pattern and baseplate are sharp with no rounding to improve detectability
- Internal lines have increased length while retaining assymmetry for clocking angle determination, to improve detection accuracy
- the out-of-plane feature has been changed to a narrow cylinder to reduce optical perturbations
- 2 mm black border has been added around the out-of-plane white tip to ensure robust contrast

2D MARKER

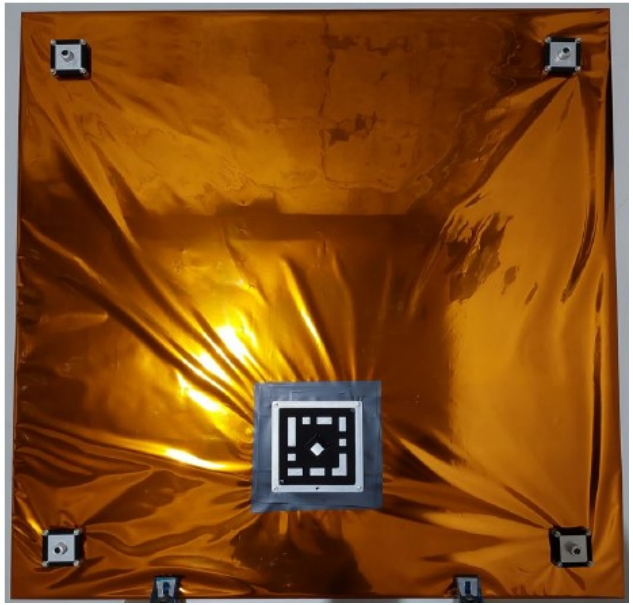


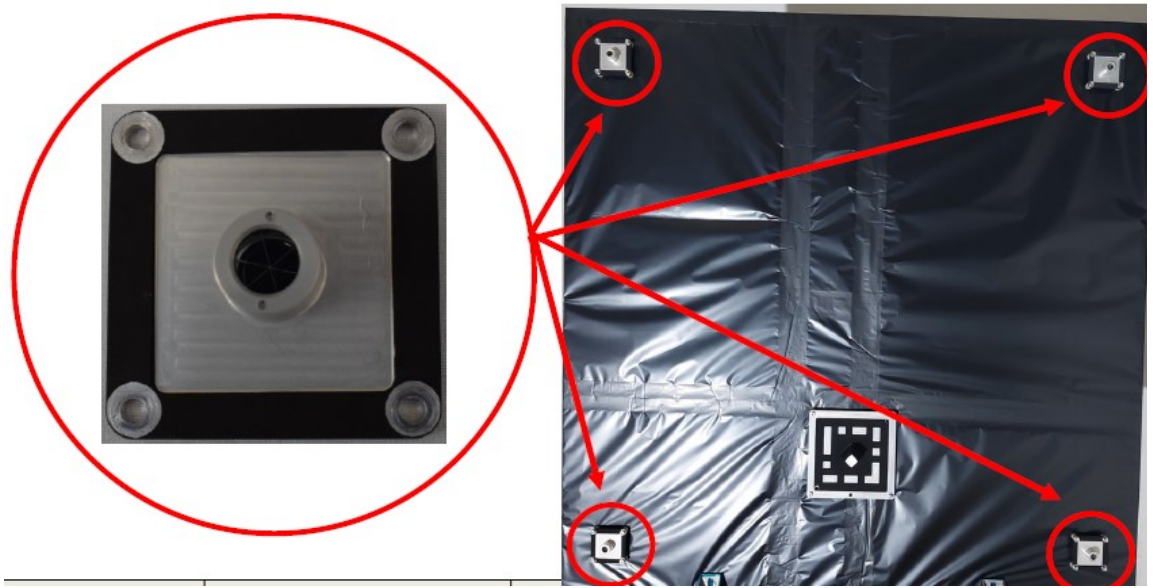


- 60 × 60 ×18 mm
- EN AW6082 aluminium
- an LRR unit screwed to the base plate
- Fused Silica Corner Cube Retroreflector
- LRR FOV ±35°; It can be adjusted to specific mission needs
- Coating TCCC + black paint
- Visible in the VNIR and TIR spectrum
- Attachment to SC: 4pcs of screws M4 washers.
- Mass:0.035kg; using 20% mass margin for screws and washers
- Grounding is implemented by the interface screws.
- 20 pcs of 2D Markers are installed per SC, 4 per side, one side without markers
- ***2nd gen is under development; the 2nd gen design is not fixed yet***

2D MARKER

Visibility of the 2D Markers in laboratory conditions

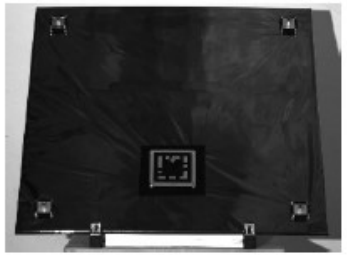
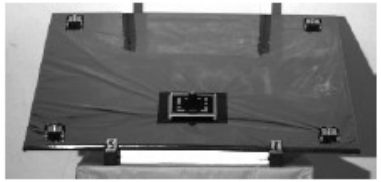




- Contrast: difference of the white levels of pixels on the image
- Contrast can be maximized selecting optimal camera settings and with image processing

2D MARKER

VNIR visibility

	0°	20°	40°	60°
5m				

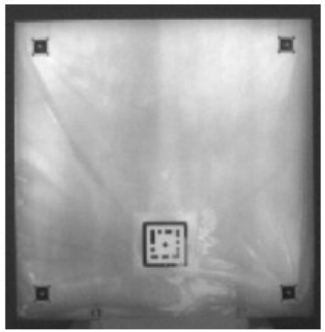
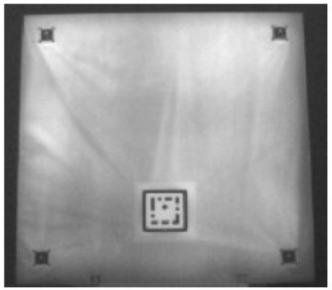
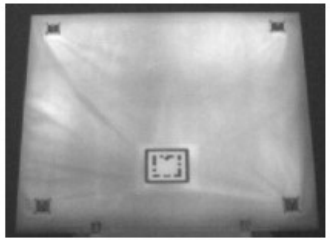
KAPTON background-VNIR

	0°	20°	40°	60°
5m				

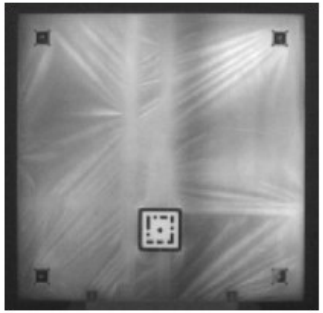
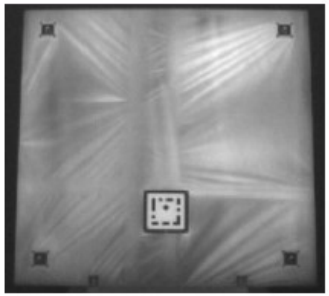
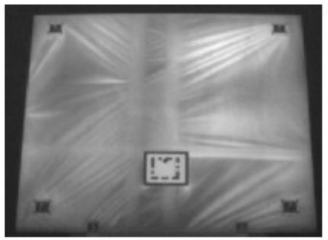
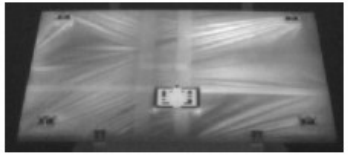
Black KAPTON background-VNIR

2D MARKER

TIR visibility

	0°	20°	40°	60°
5m				

KAPTON background-TIR

	0°	20°	40°	60°
5m				

Black KAPTON background-TIR

Detectability with visual camera

- Analysis of the optical detectability of the 2D markers in a range between 5 and 50 m distance between servicer and client
- Assumptions:
  - the servicer is pointing towards the client center
  - visibility of at least three markers is guaranteed in the whole range
  - markers are located on the client spacecraft side forming a square of 1m side
  - the required minimum contrast for the detection assumed is the 75% white level difference between the marker black and white areas

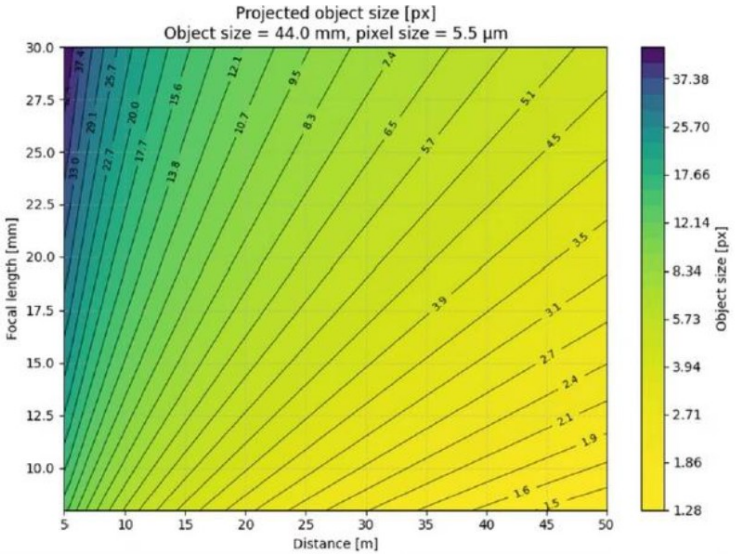


Figure 4-3. Projected marker size in image plane [px] with respect to distance.

Detectability with visual camera-Conclusions

- a resolution of at least 5 pixels may be sufficient for centroid-based detection algorithms to calculate marker positions systematically, when provided with adequate prior knowledge
- a suitable focal length can be chosen for the specific mission needs
- If a tumbling spacecraft is approached, an angle of ***55 deg*** is safe to use, as the rotating spacecraft will always have a face with its corresponding markers pointing to the camera with that angle or lower
- achieving a size of 5 pixels at 50m requires a large focal length above 30mm
- If the spacecraft is not cooperative, achieving an effective size of 5 pixels in all rotations requires a very large focal length >50mm
- The CAT long-range camera could be used for detection. The „reliable” distance is up to 20-25m. It can be extended up to 50m, but more and more extra devices, analyses, algorythm development is needed.

2D MARKER

Example for centroid-based algorithm detection

1. Binarize image-image processing, proper camera settings for high contrast
2. Detect and analyze contours
3. Calculate and sort centroids – assign coordinates to the markers
4. PnP problem solving – pose is solved based on assigned image centroid coordinates
5. Use extrinsic guess for next frame - using prior knowledge from previous frame

2D MARKER

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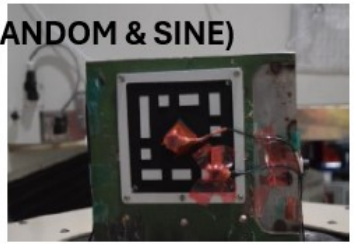
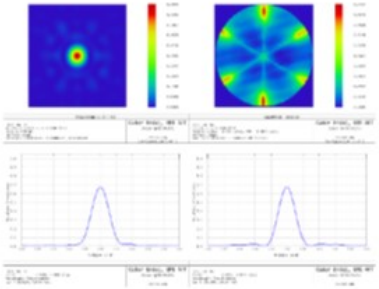
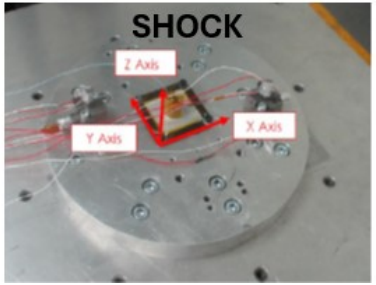
Both marker types are qualified for HPCM environment



OPTICAL MEASUREMENTS

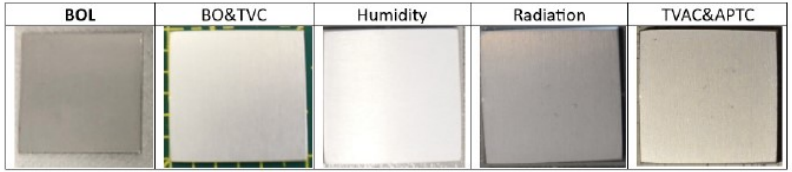


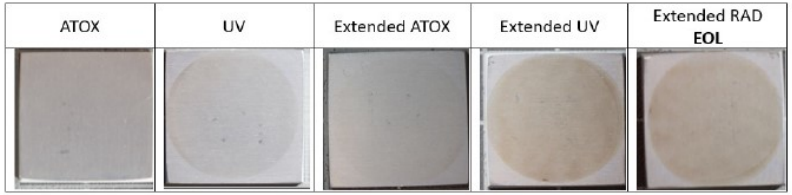


LEO, 600-820km, SSO, incl. 98 deg, 12.5 years

2D MARKER

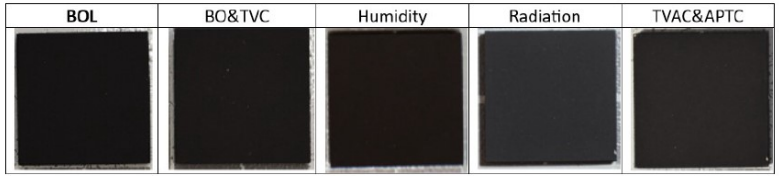
Coatings ageing properties

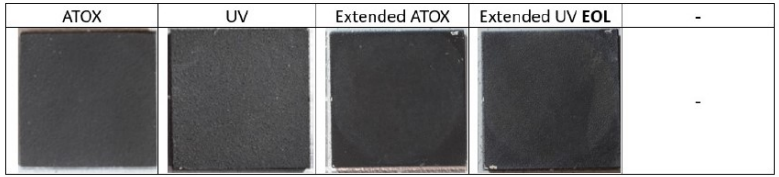




- slight darkening
- All samples passed the visual inspection and the adhesion tests after each ageing tests.

TO property	BOL	After TVAC	After ATOX	After UV	After Ext. ATOX	After Ext.UV	After Ext. Rad. EOL	Δ
Solar absorptance	0.29	0.33	0.32	0.32	0.31	0.42	0.44	+0.15
Thermal emittance	0.03	0.05	0.04	0.04	0.02	0.02	0.04	+0.01





- Visual change due to aging negligible
- All samples passed the adhesion test after each ageing tests

TO property	BOL	After TVAC	After ATOX	After UV	After Ext. ATOX	After Ext.UV EOL	Δ
Solar absorptance	0.97	0.97	0.97	0.97	0.97	0.97	0.00
Thermal emittance	0.93	0.90	0.92	0.95	0.96	0.96	+0.03

2D MARKER

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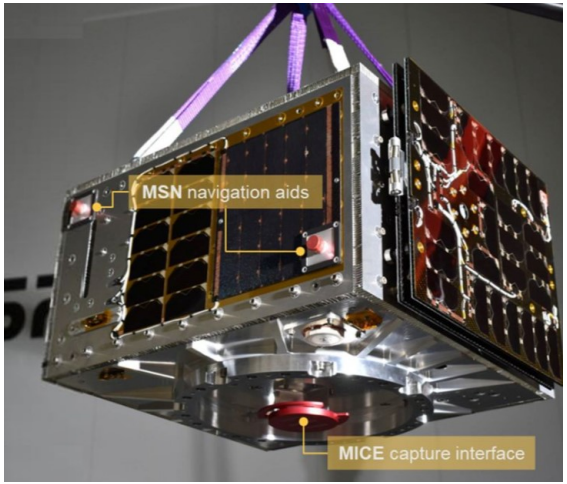
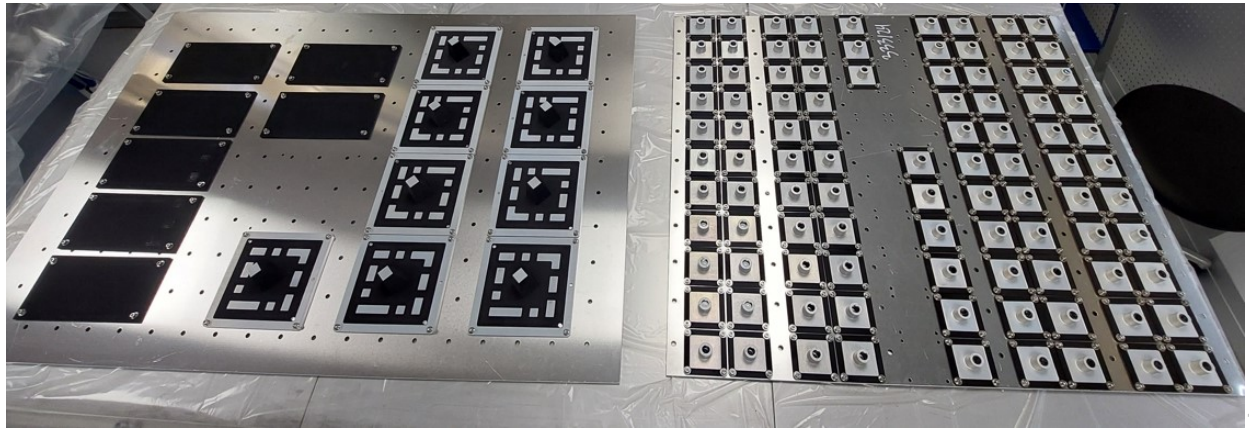
As a first step of the MSN industrialization 6 pcs of 2D Marker have been manufactured for the AVS LUR-1 CAT In Orbit Demonstration satelit, which was launched on August 16, 2024.

Industrialization

Mission	Prime	Delivered QTY	Delivery date
CRISTAL	AIRBUS	47 units	2025
LSTM	AIRBUS	47 units	2025
CO2M	OHB	66 units	2025
CHIME	TAS	42 units	Manufacturing in progress
HARMONY	OHB	45 units	Manufacturing in progress

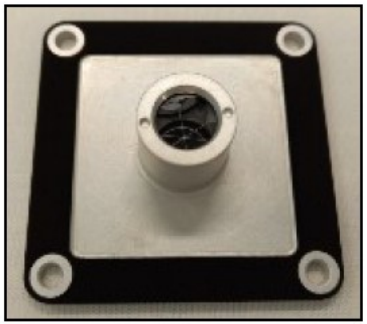
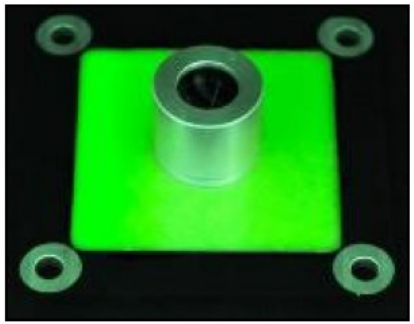
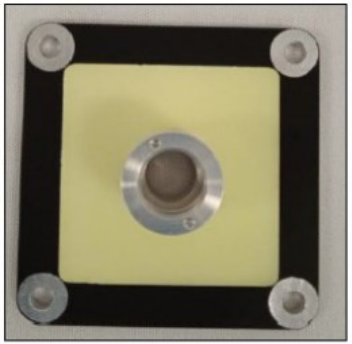
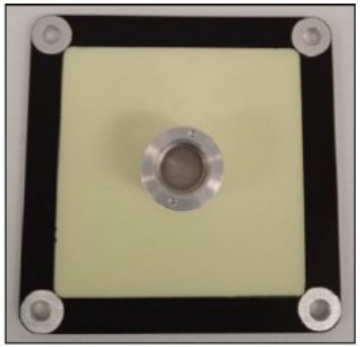




PHOSPHORESCENT MARKER

Phosphorescent Markers Supporting Navigation

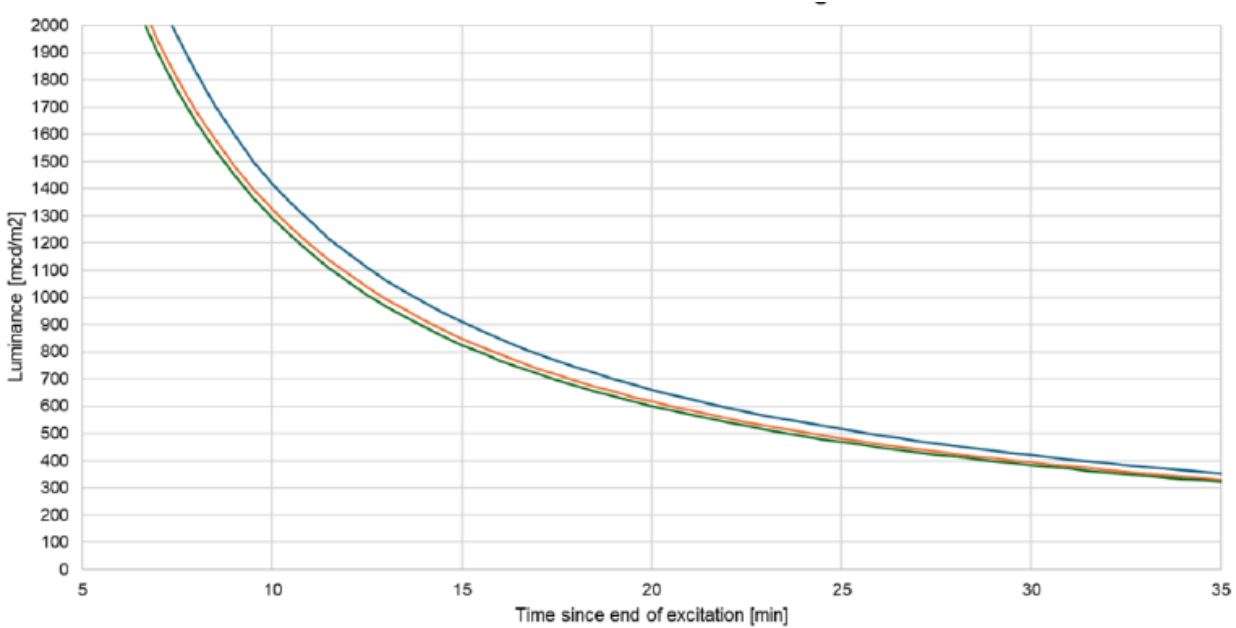
- an ESA R&D activity focusing on further development of the MSN (Markers Supporting Navigation) 2D Markers, which have previously reached TRL 8

- Mounted on the target satellite, MSN 2D Markers support vision-based navigation of a chaser satellite during active debris removal and in-orbit servicing missions by containing high-contrast aging-resistant binary navigation patterns
- Navigation in the visible spectrum ***during eclipse*** in LEO is not possible with the current 2D Marker design, which issue could be solved by using phosphorescent coatings

PHOSPHORESCENT MARKER

Phosphorescent paint afterglow properties



- Charged by Sun light / artificial illumination
- Intensity of afterglow decreases wrt. time

PHOSPHORESCENT MARKER

2 kind of paint systems, 2 different sizes of markers (60×60mm; 75×75mm) have been manufactured and tested to reach TRL5

PHOSPHORESCENT MARKER

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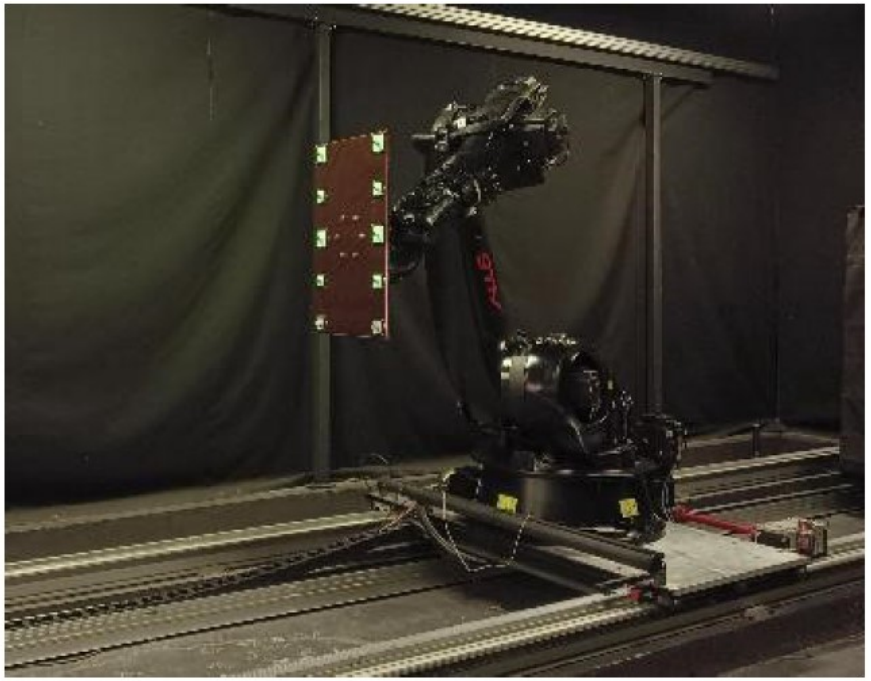
Navigation performance testing at GMV



- Camera sensor CMV4000
- 2048x2048 pixel(4.2 Megapixel) resolution
- 25mm focal length

PHOSPHORESCENT MARKER

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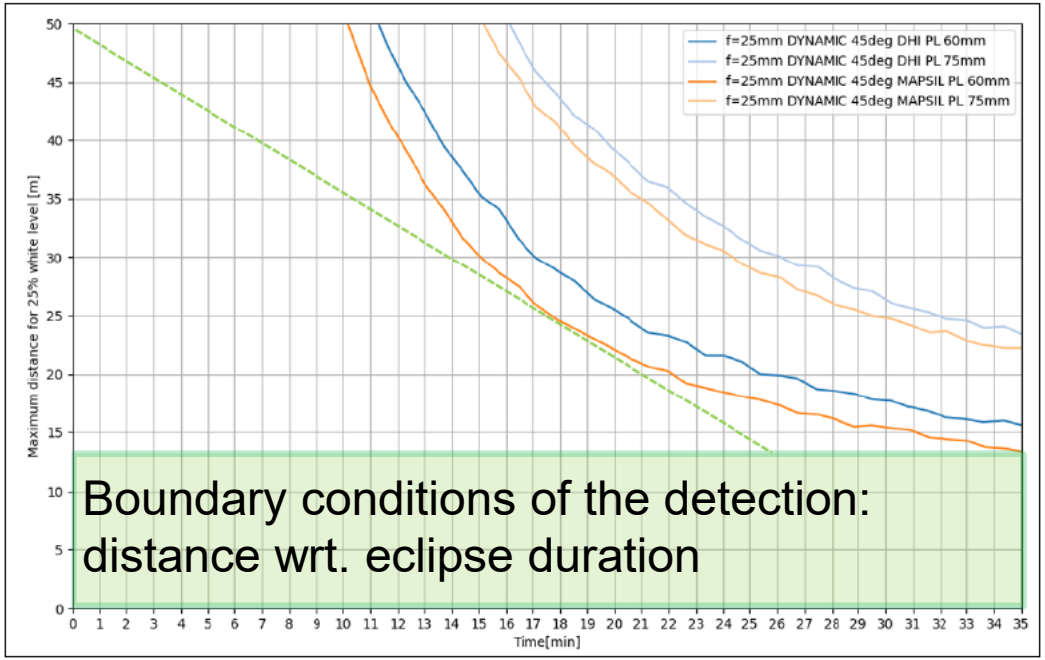
Static and dynamic navigation performance tests have been performed, which showed that with careful selection of CONOPS, it could be possible to utilize the phosphorescent Markers for navigation as-is.



For example, starting the approach at the beginning of the eclipse period from 50 m and steadily approaching with at least 25 mm / sec velocity would make all ofthe tested markers just sufficient for navigation. Below 12 m distance is predicted to be a „safe zone" where all of the markers have enough white level for the full 35-minute eclipse duration. Careful design of the marker size and mission CONOPS is necessary, but ***the technology has a very promising usability for space navigation in the 50m to 5m range.***

SUMMARY

- 2 kind of markers have been developed at ADM, „3D” for close-range, „2D” for mid-range operations
- Provide contrast in the VNIR and TIR spectral ranges
- LIDAR compatibility will be charachterized
- Currently 20 pcs of 2D markers are installed on the target SC, 4 per face, forming different configurations
- Centroid-based algorythm is proposed for pose estimation
- Qualified for HPCM mechanical and thermal environment, reaching TRL8
- High resistancy against ATOX, UV, radiation environment
- These markers are standardized by ESA, public ICD is available at ESA or ADM
  - Design for Removal - Interface Requirements Document for LEO and GEO missions
- Industrialized for CRISTAL, LSTM, CO2M, CHIME missions
- Phosphorescent marker developed is also a promising solution (TRL5)

- **ADM is open for improvement of the 2D Markers based on the feedbacks**

SUMMARY

Thank You for attention!

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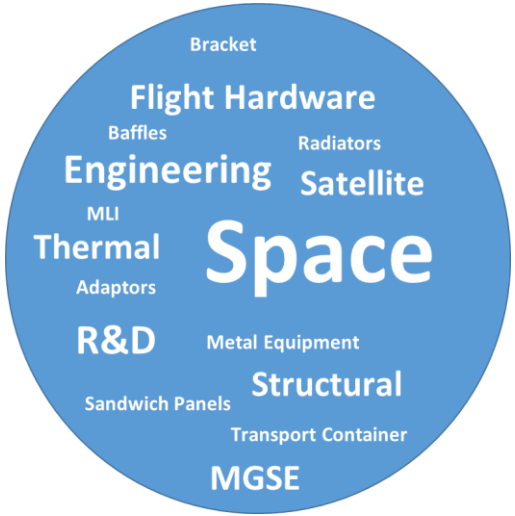

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