

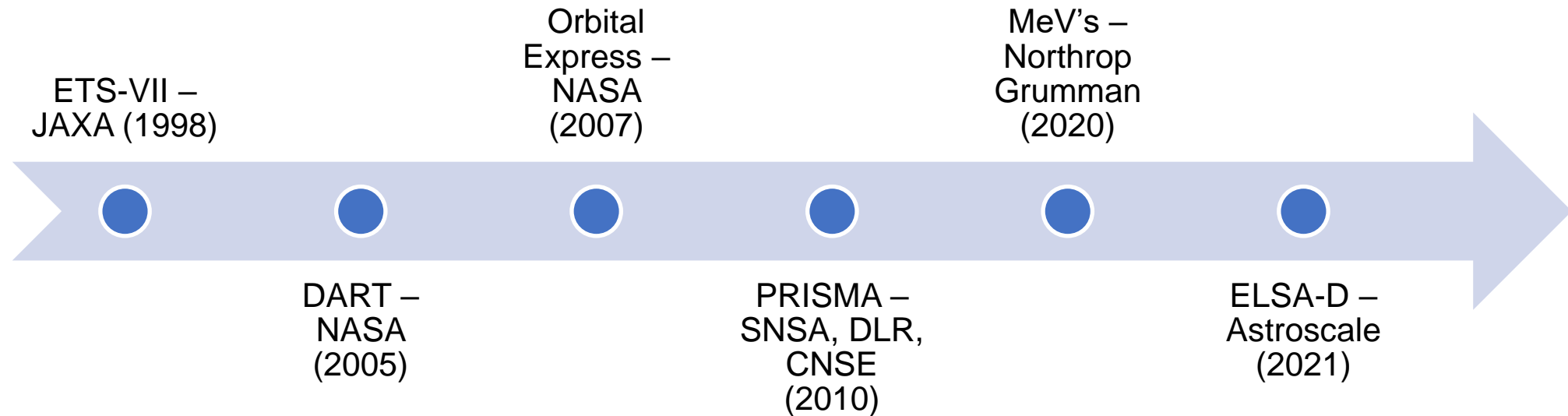
A photograph of a space station or satellite in orbit above Earth. The station's complex structure, including a large gold-colored thermal blanket and various modules, is visible on the right side. The Earth's surface below shows a mix of blue oceans, white clouds, and brownish landmasses. The horizon of the planet is clearly visible against the blackness of space.

2023 Clean Space Industry Days

Progress in vision-based navigation technologies for non-cooperative close proximity operations

David REGAD – Lead System Engineer, LMO
Marcos Damian PEREZ – Chief Technology Officer, LMO

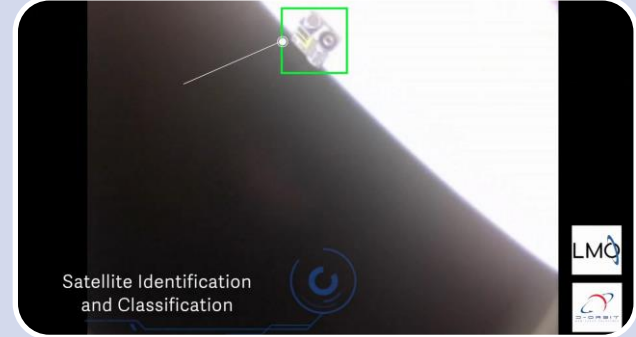
Starting point



- Previous demonstration missions have been using a combination of sensors
- All but one used markers on the target satellite

Vision: recent progress in machine learning will be an enabler for autonomous rendezvous and proximity operations with uncooperative targets

Technology development strategy



Technology maturation

DIOSSA
TRL 2 => 4
16 months



Industry partnerships

Proof-of-Concept 1
ESA IOD mission
Phase 0/A completed

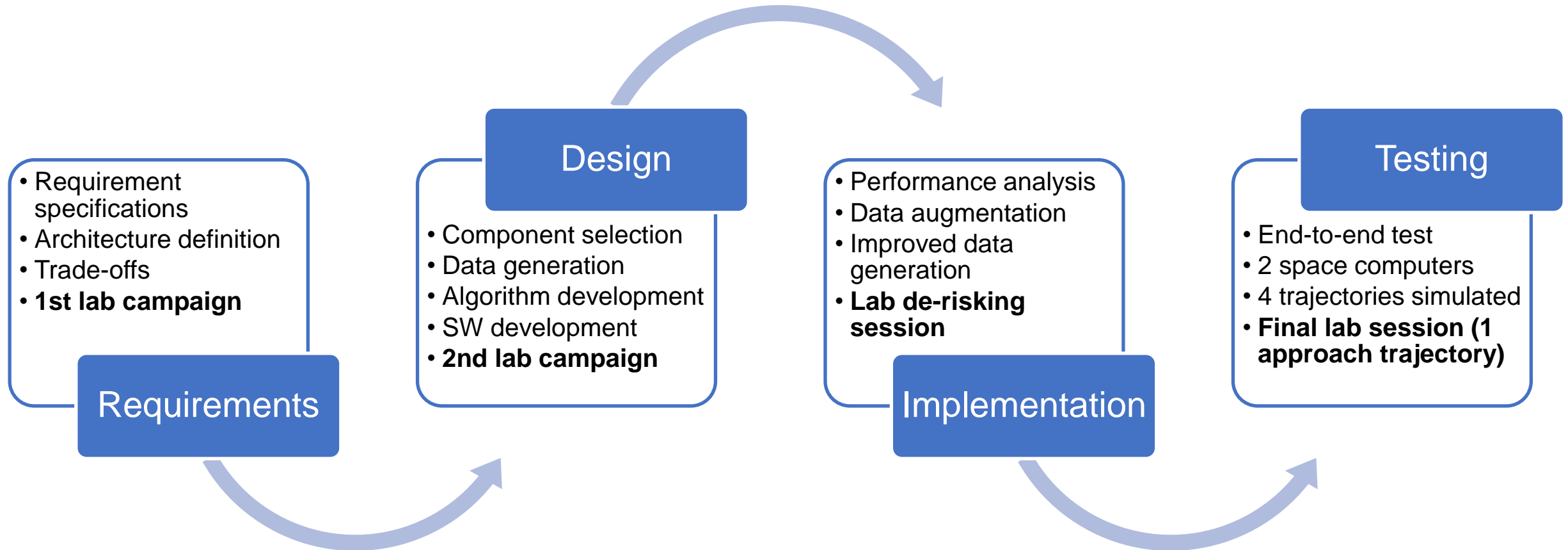


In-orbit demonstration

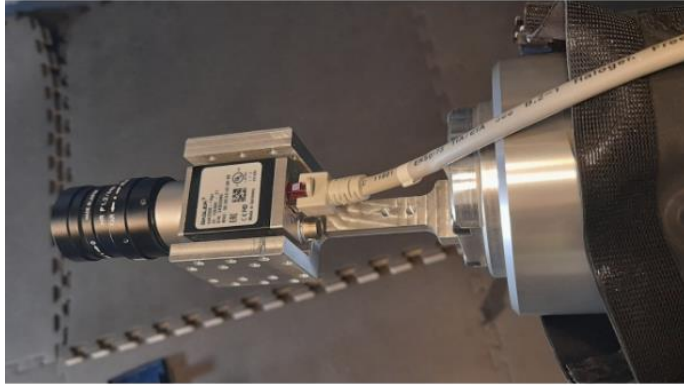
Audacity
Object detection
demo SW



DIOSSA – Development steps



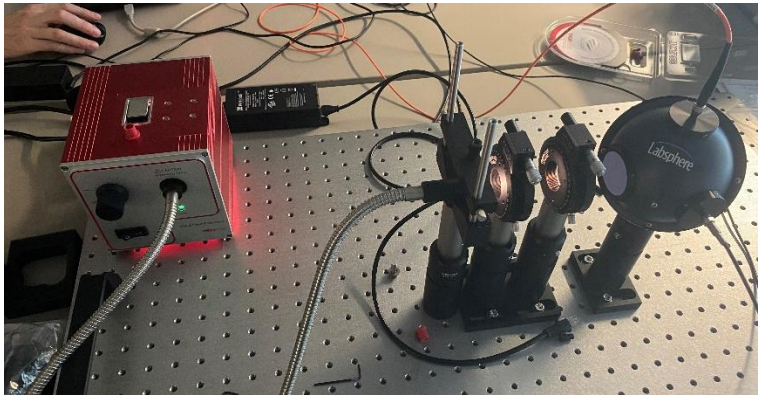
DIOSSA – Space segment: camera and mock-ups



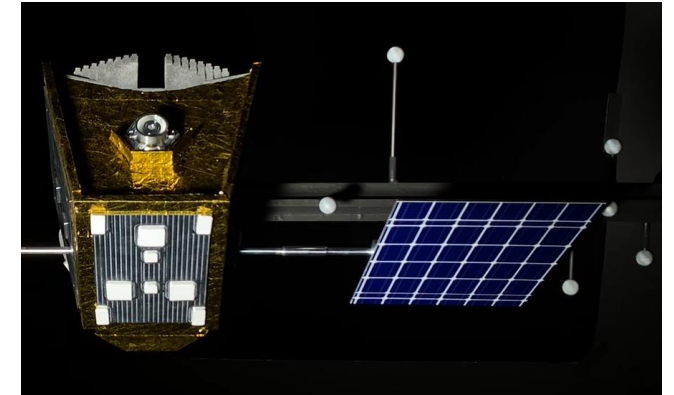
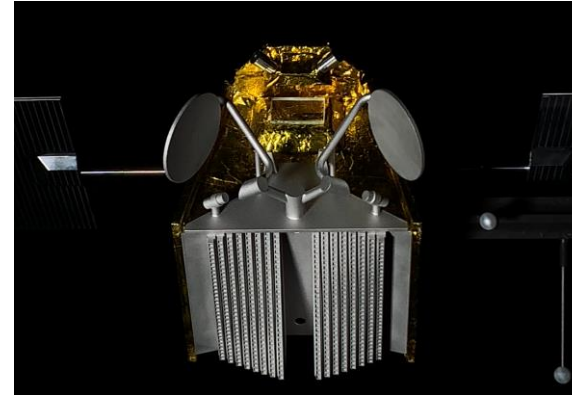
Camera with representative sensor mounted on custom made bracket



First OneWeb mock-up

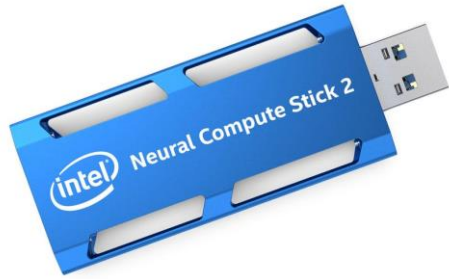


Sensor characterization

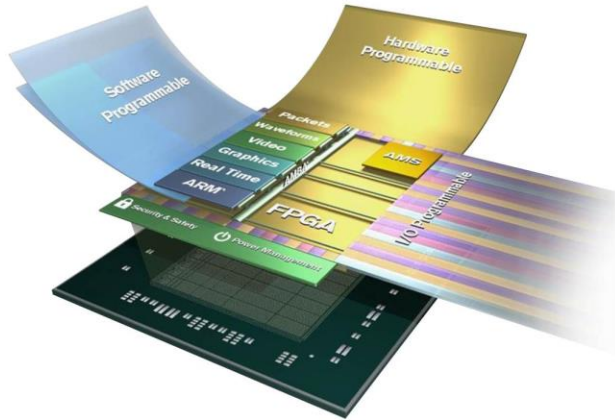


Final OneWeb mock-up

DIOSSA – Space segment: flight computer

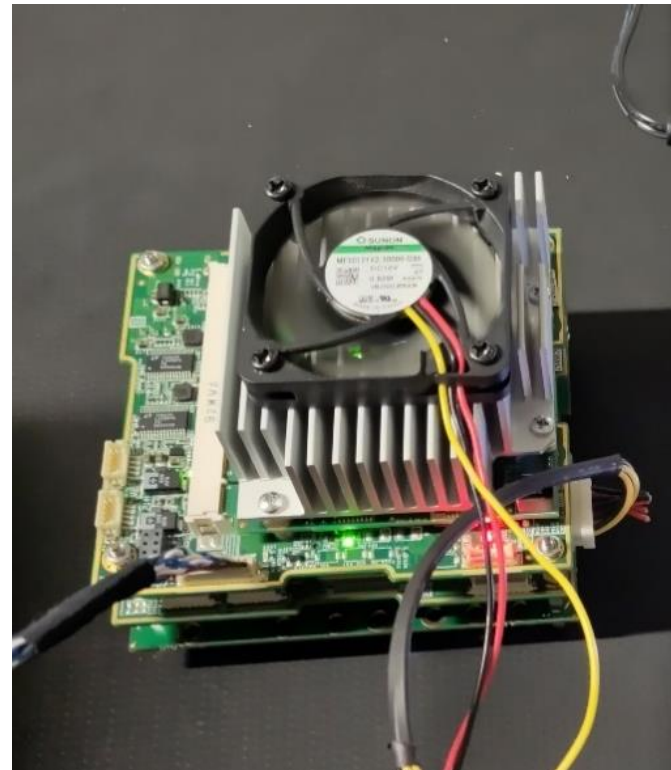


Intel Myriad X

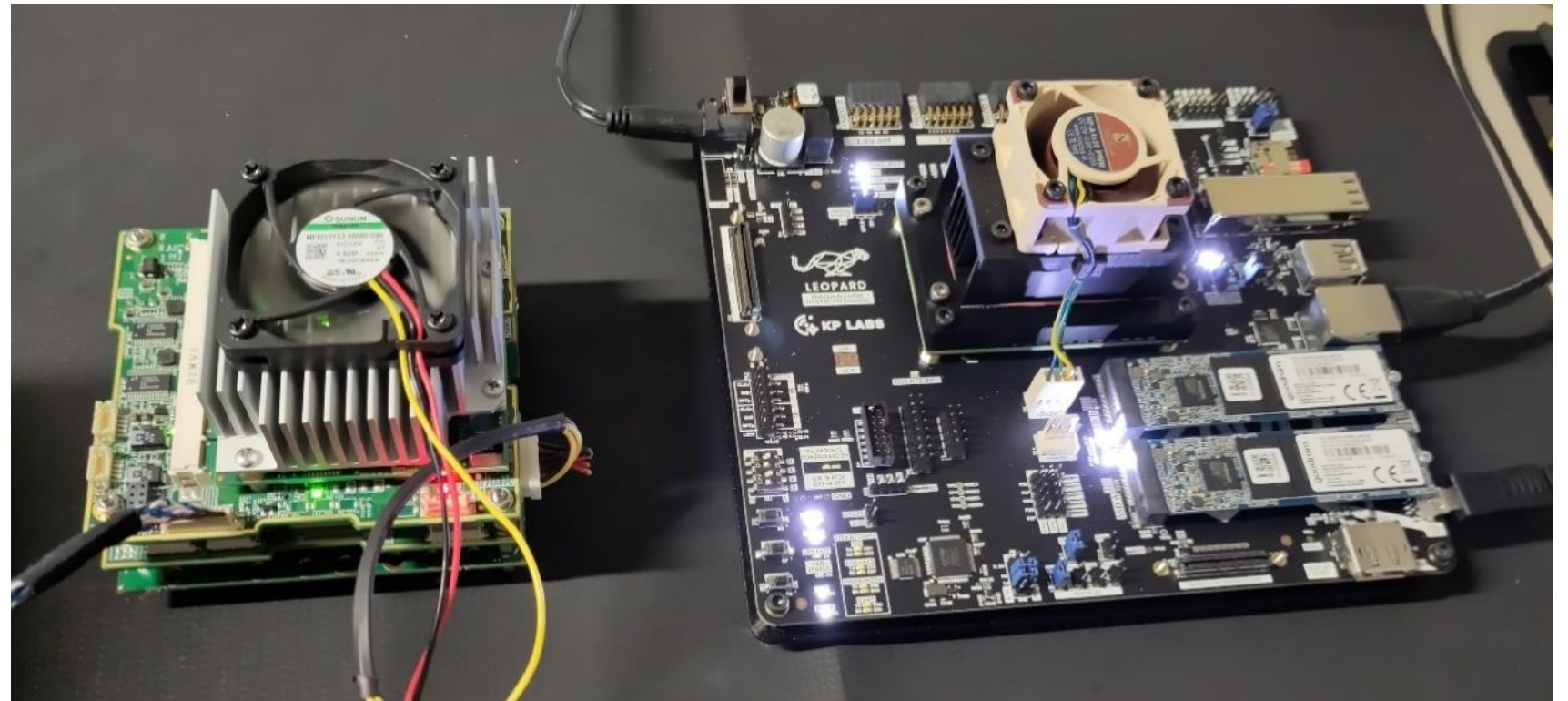


Xilinx MPSoC

Unibap iX5

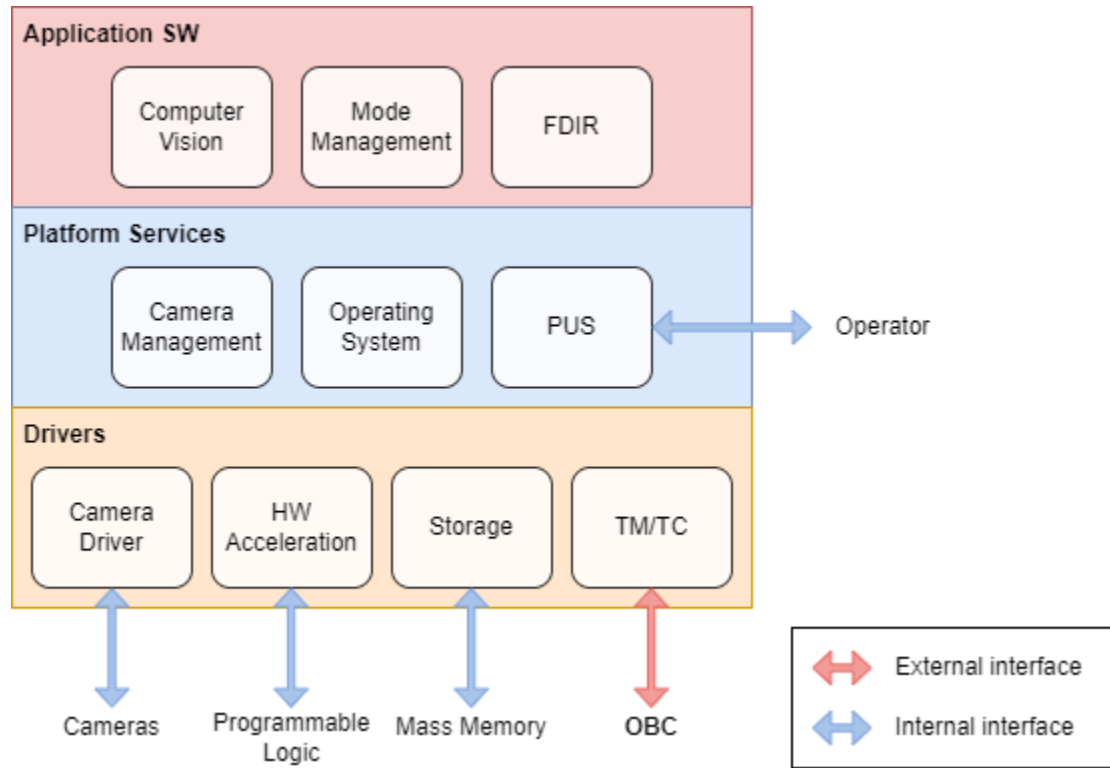


KP Labs Leopard EBB

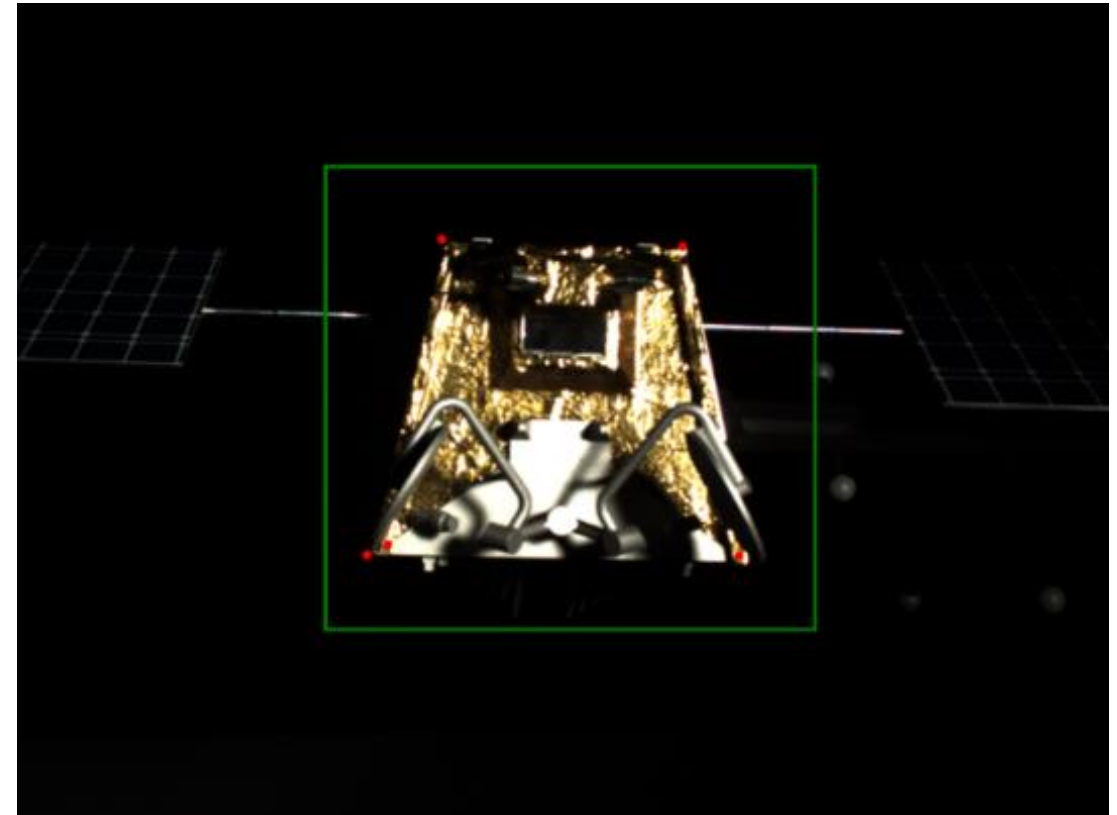


DIOSSA – Space segment: software

SW architecture

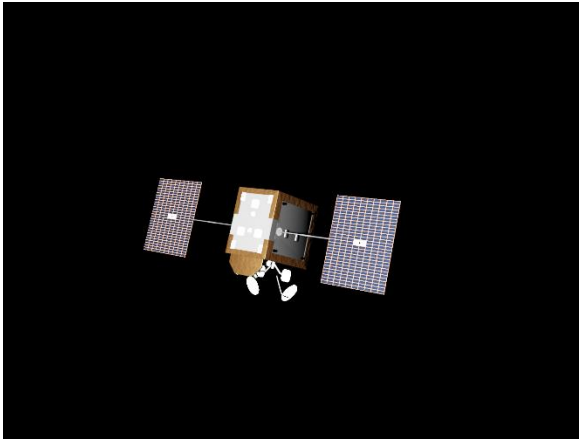


SW output

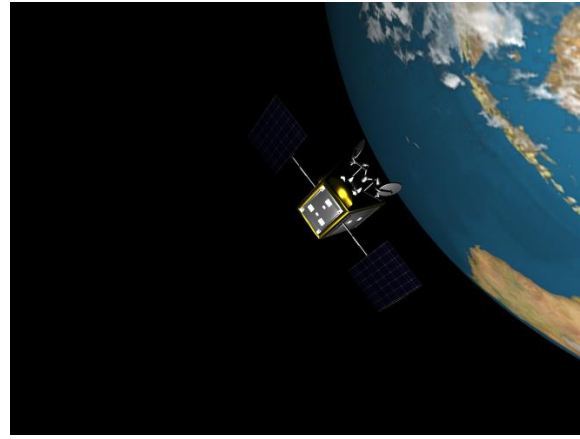


DIOSSA – Ground segment: machine learning training data

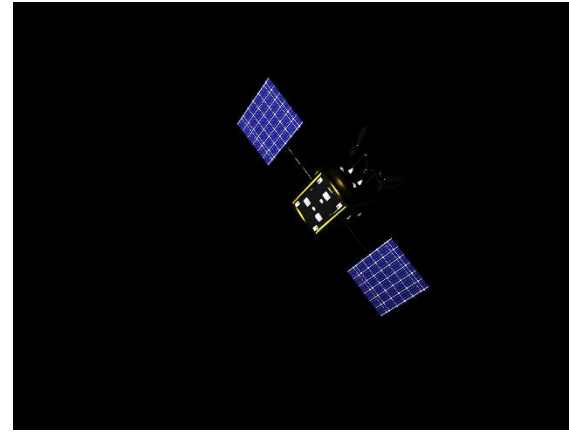
Blender



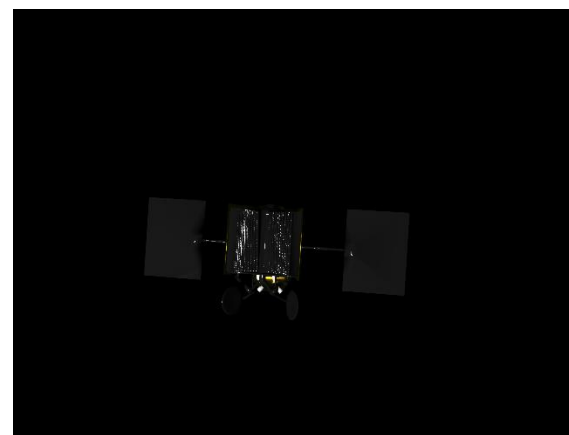
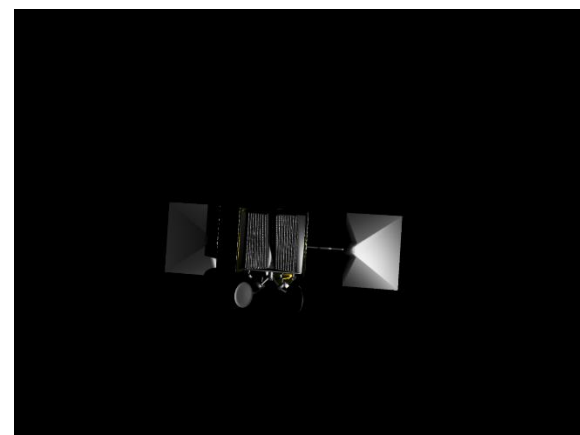
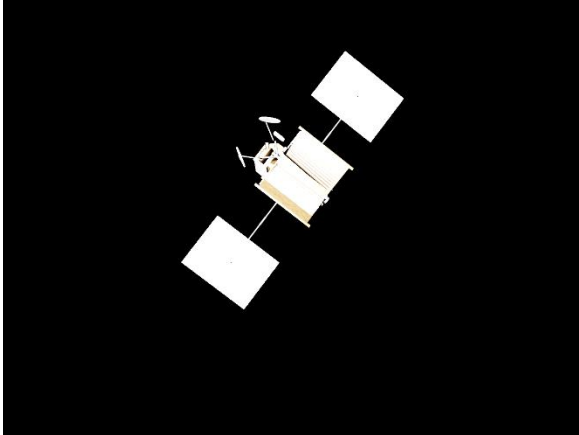
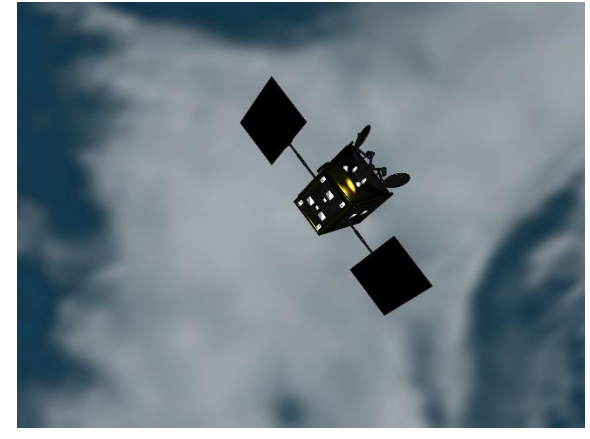
Pangu v1



Pangu v2

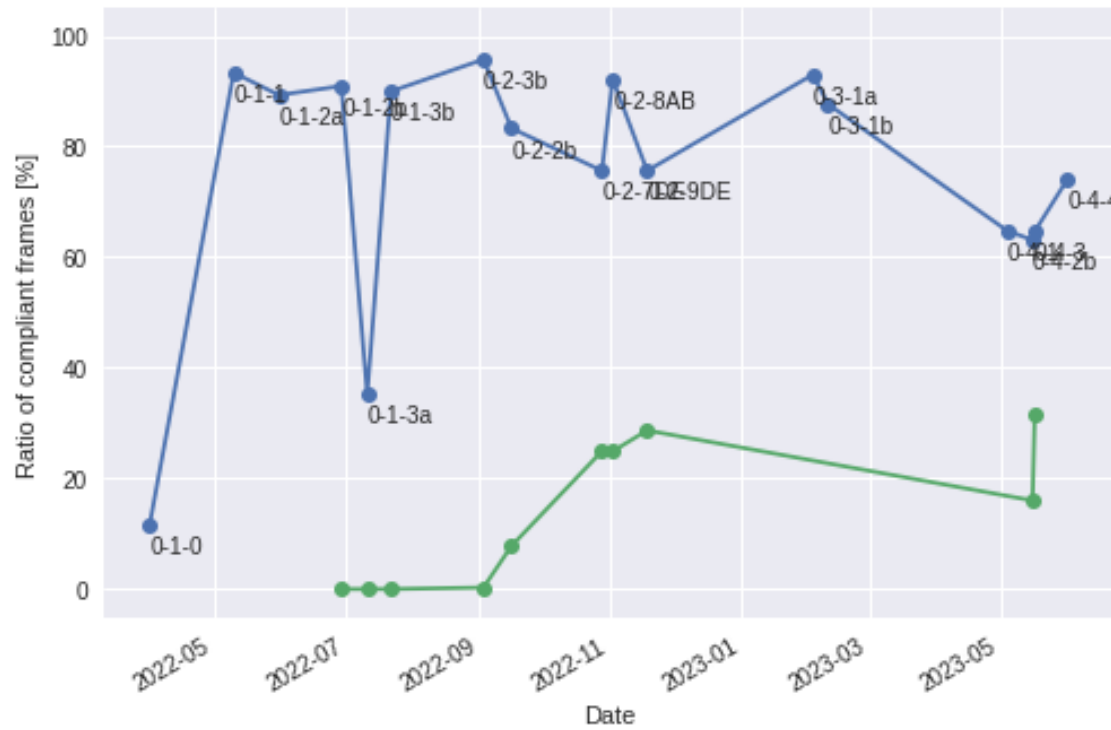


Pangu v3

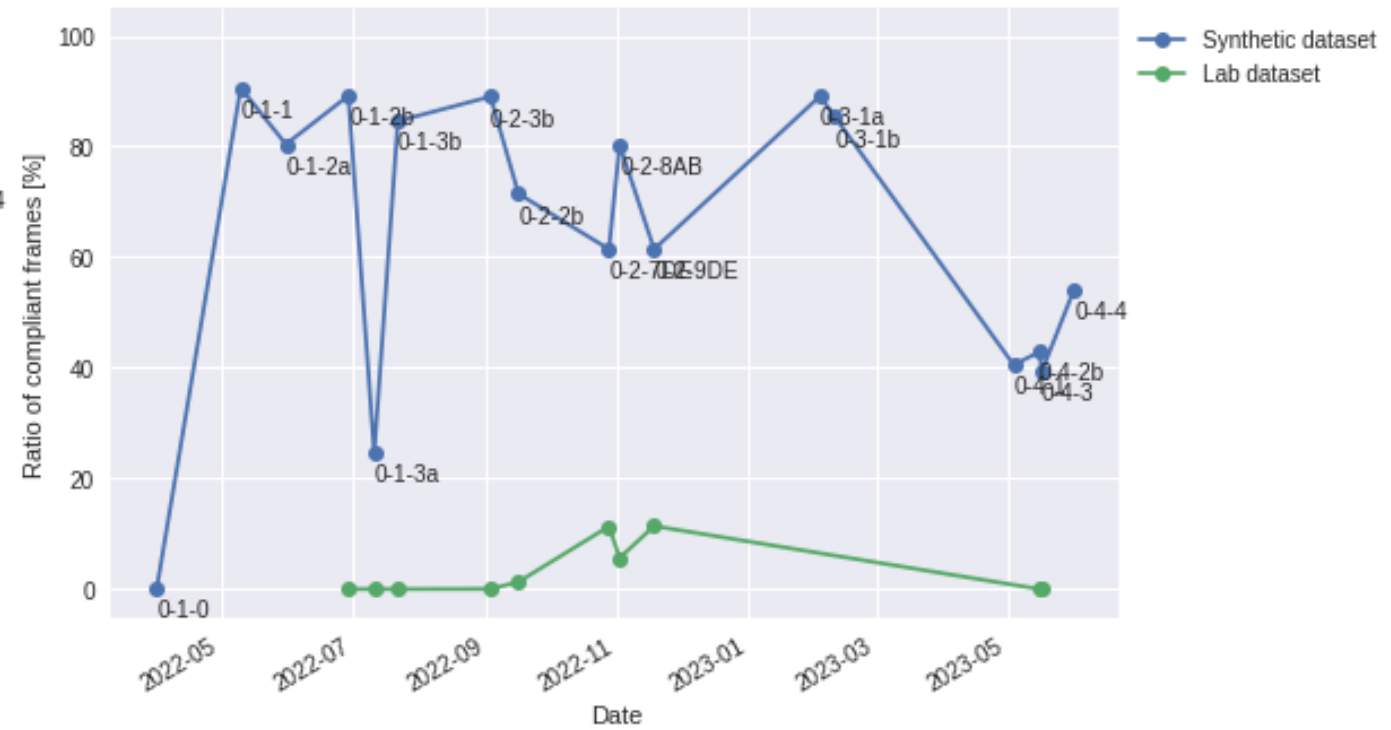


DIOSSA – DNN models: performance tracking

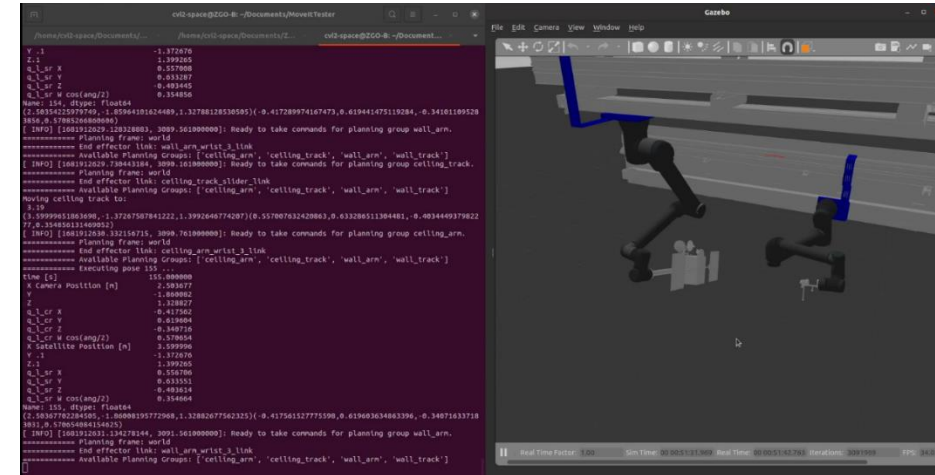
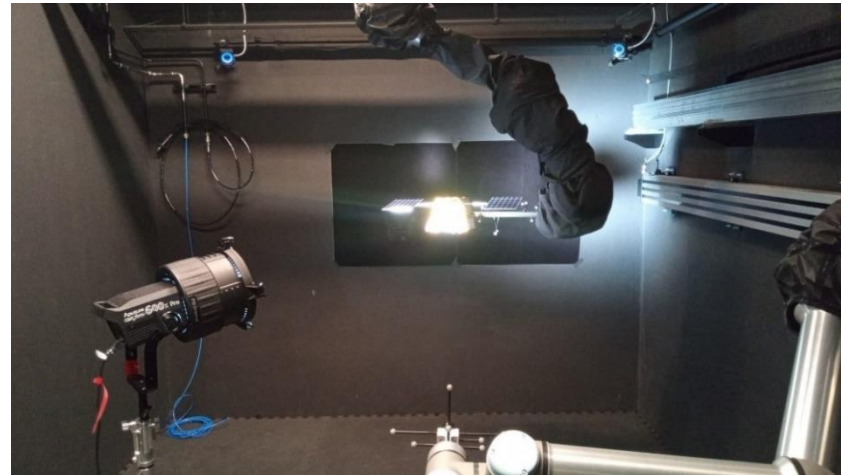
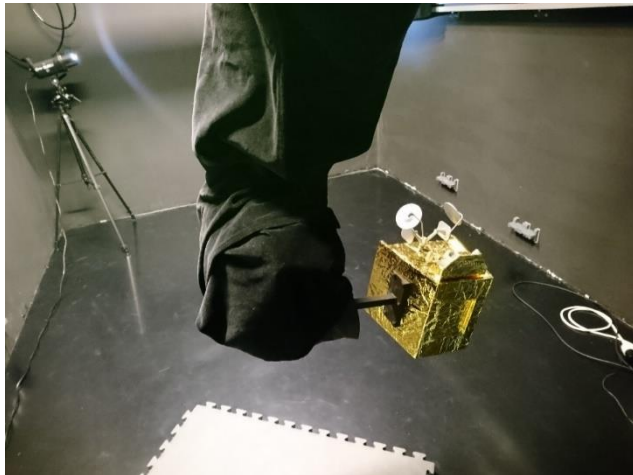
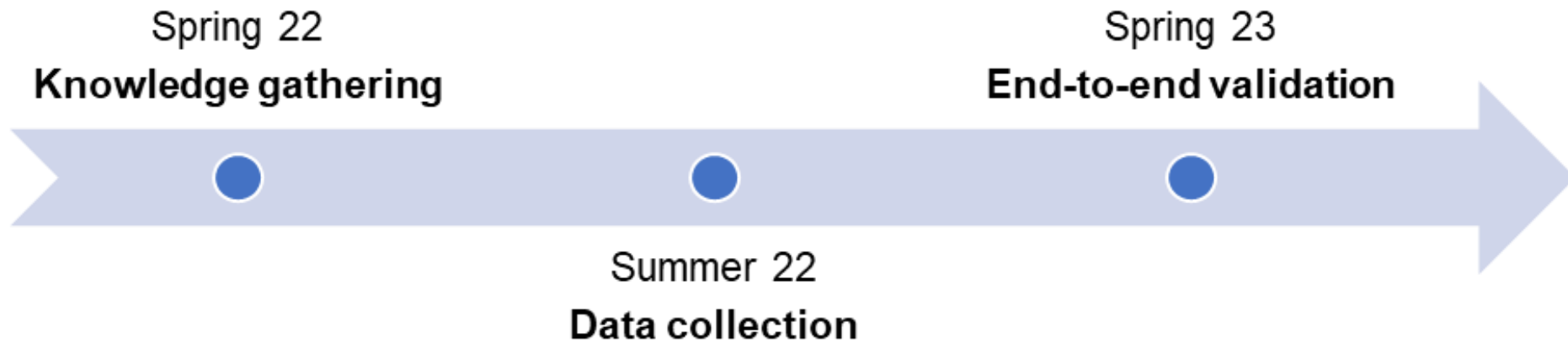
Position error



Orientation error



DIOSSA – Lab campaigns: Zero-G lab at Uni of Luxembourg

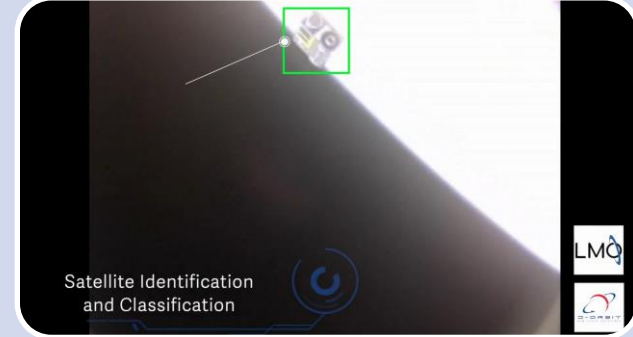




DIOSSA – DNN models: Best performance

Domain	Synthetic			Lab		
Algorithm version	0.3.1a			0.2.7DE		
Metrics	Target	Measured	Filtered	Target	Measured	Filtered
Validity ratio	80%	97.7% valid frames	–	(none)	68.9% valid frames	–
Position error	3% of range (99.73% probability)	7.6% of range	2.14% of range	10% of range (mean value)	5.7% of range	3.8% of range
Orientation error	3 degrees (99.73% probability)	7.6 deg	4.20 deg	10 degrees (mean value)	12.4 deg	7.2 deg

Technology development strategy



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Industry partnerships

Proof-of-Concept 1
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Phase 0/A completed



In-orbit demonstration

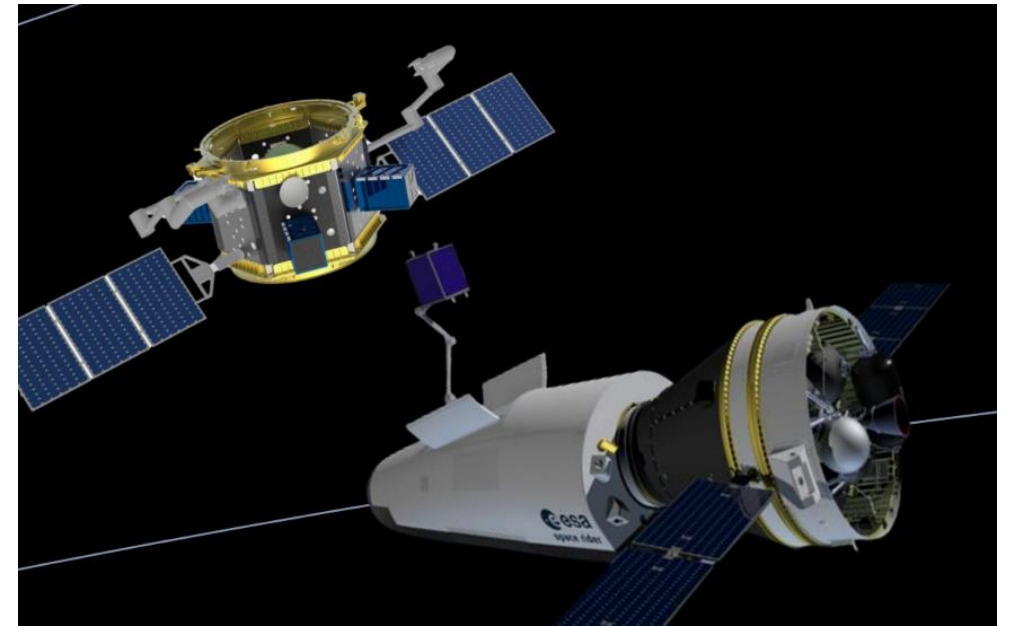
Audacity
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demo SW








PoC-1 – Mission objectives

Demonstration of the key enabling transport capability of in-orbit automatic rendezvous and docking between two orbital systems

- Consortium of 5 companies
- Phase 0/A (6 months)
- LMO was responsible for proximity operations

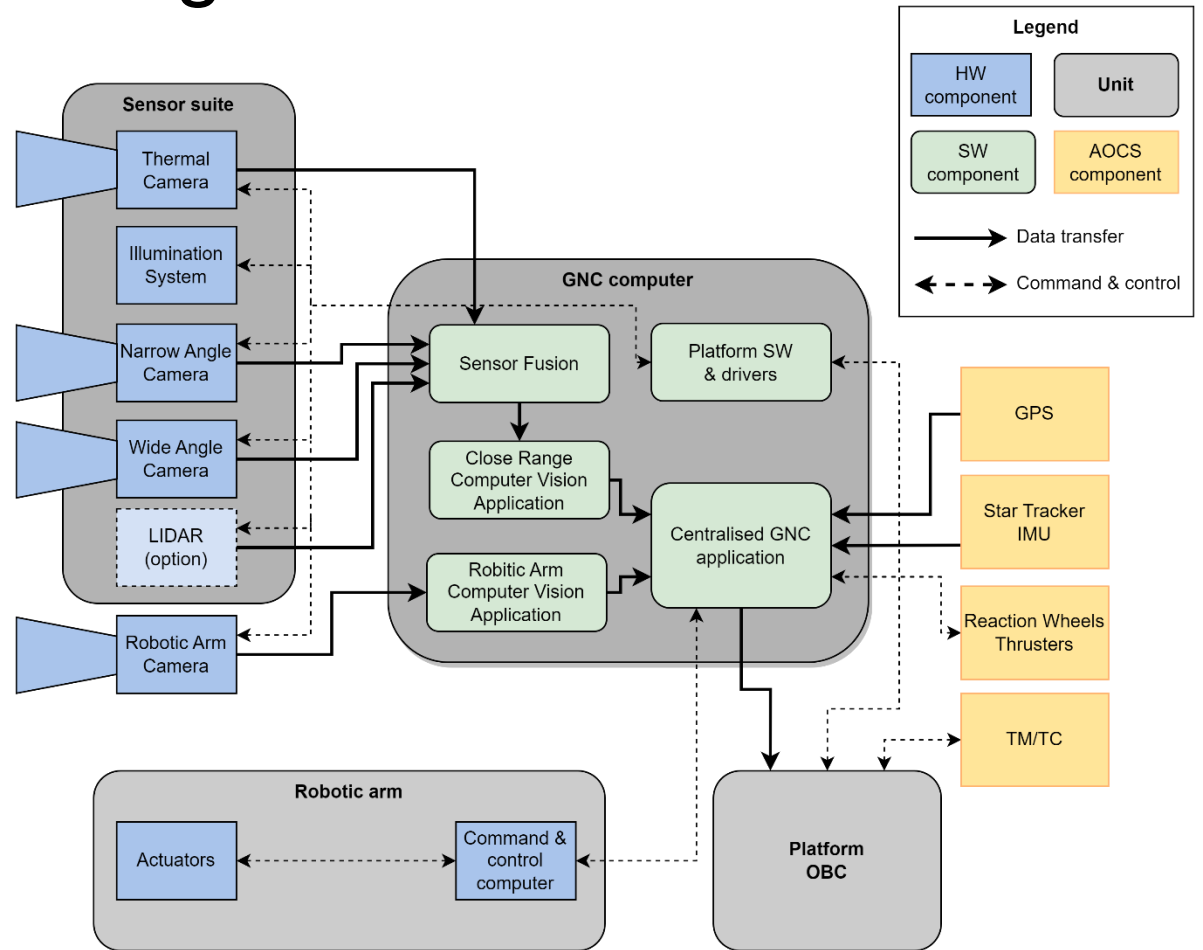


S.A.B. CZ	Name: S.A.B. Aerospace s.r.o. Country: Czech Republic Role: Prime Contractor	
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S.A.B. LS	S.A.B. Launch Services. Country: Italy Role: Subcontractor	
GMV	GMV INNOVATING SOLUTIONS Country: Poland Role: Subcontractor	
ILOT	LUKASIEWICZ Research Network - INSTITUTE OF AVIATION Country: Poland Role: Subcontractor	
PIAP	PIAP Space Country: Poland Role: Subcontractor	
LMO	LMO Country: Luxembourg Role: Subcontractor	

Proximity System preliminary design

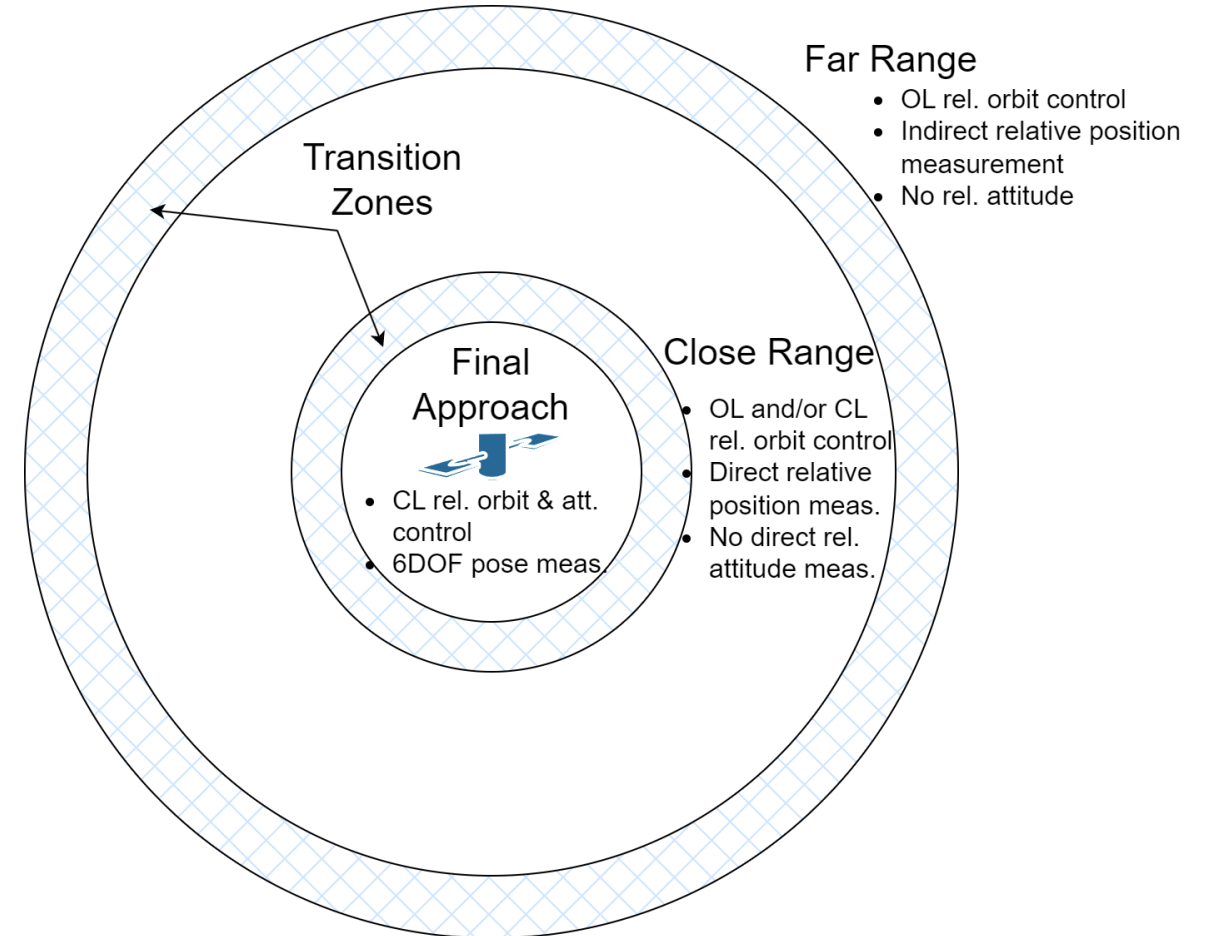
- Centralized architecture with the GNC application collecting the data from the Computer Vision application and AOCS sensors
- Use of monocular cameras only (visible and thermal)
- Lidar as option (for reliability or redundancy, with impact on technical budgets)



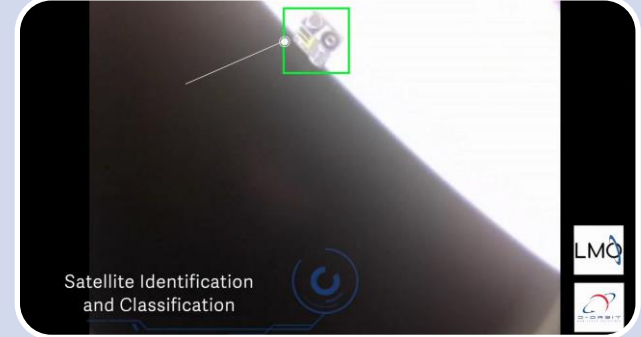
Proximity operations concept

Definition of zones and transitions

- In close range, use of visible and thermal monocular cameras for relative position estimation
- In final approach, 6-DoF pose estimation with visible cameras and a light source



Technology development strategy



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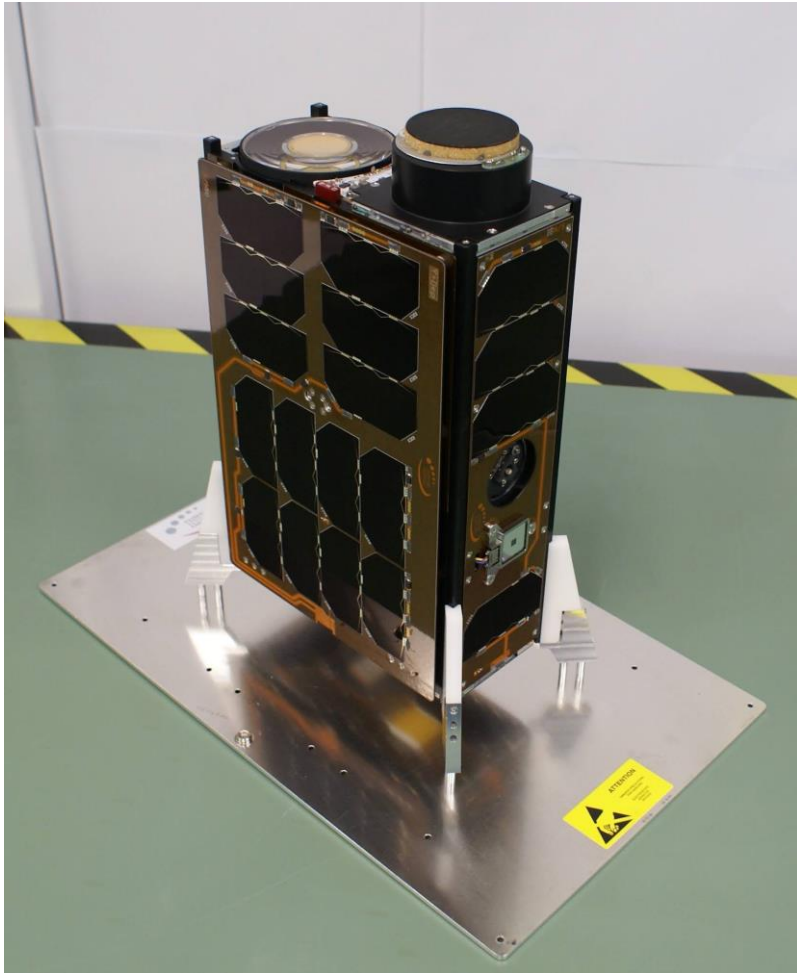


In-orbit demonstration

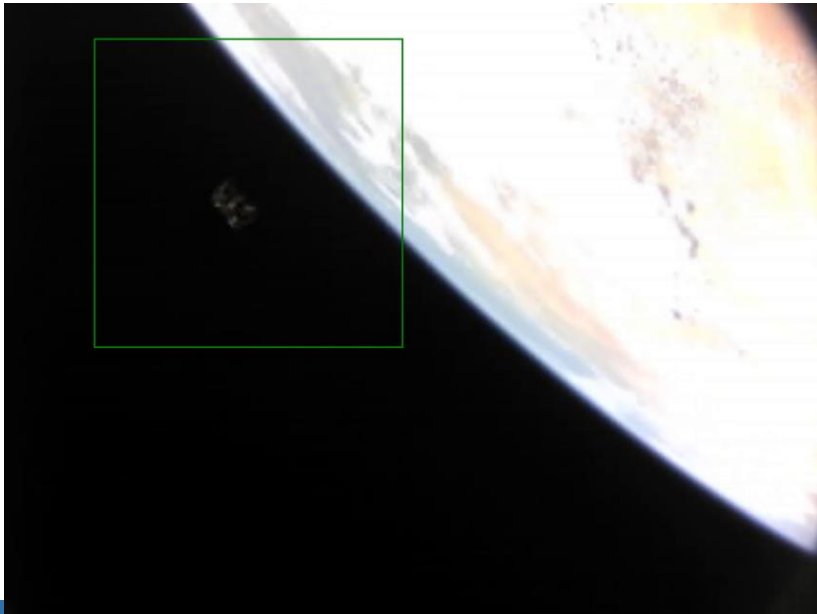
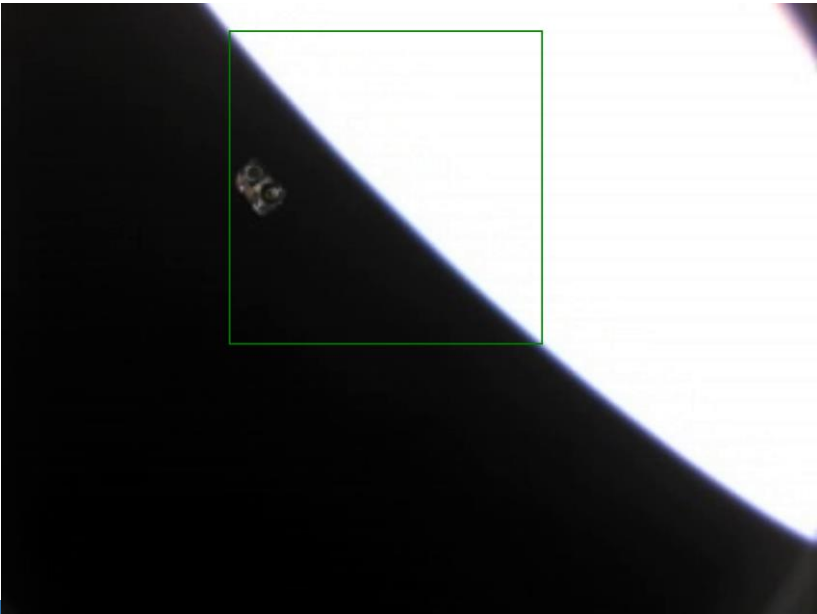
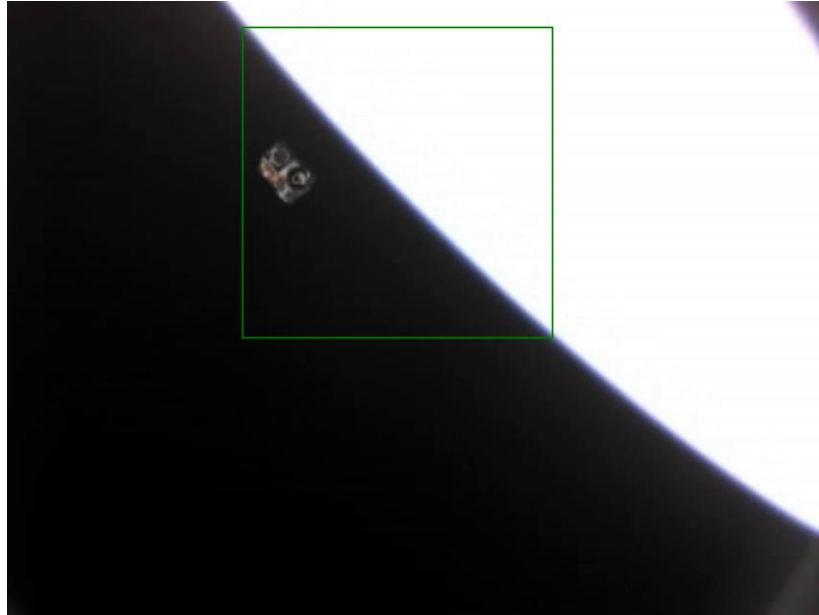
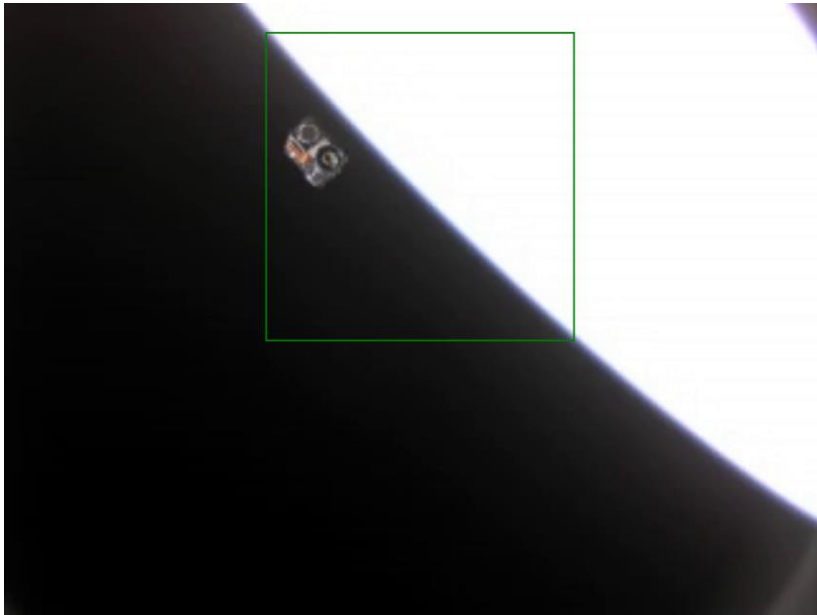
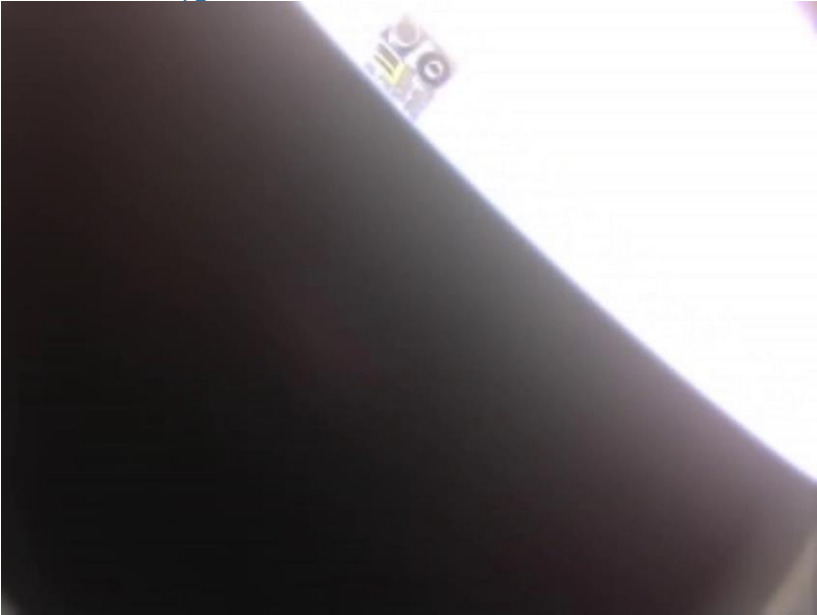
Audacity
Object detection
demo SW



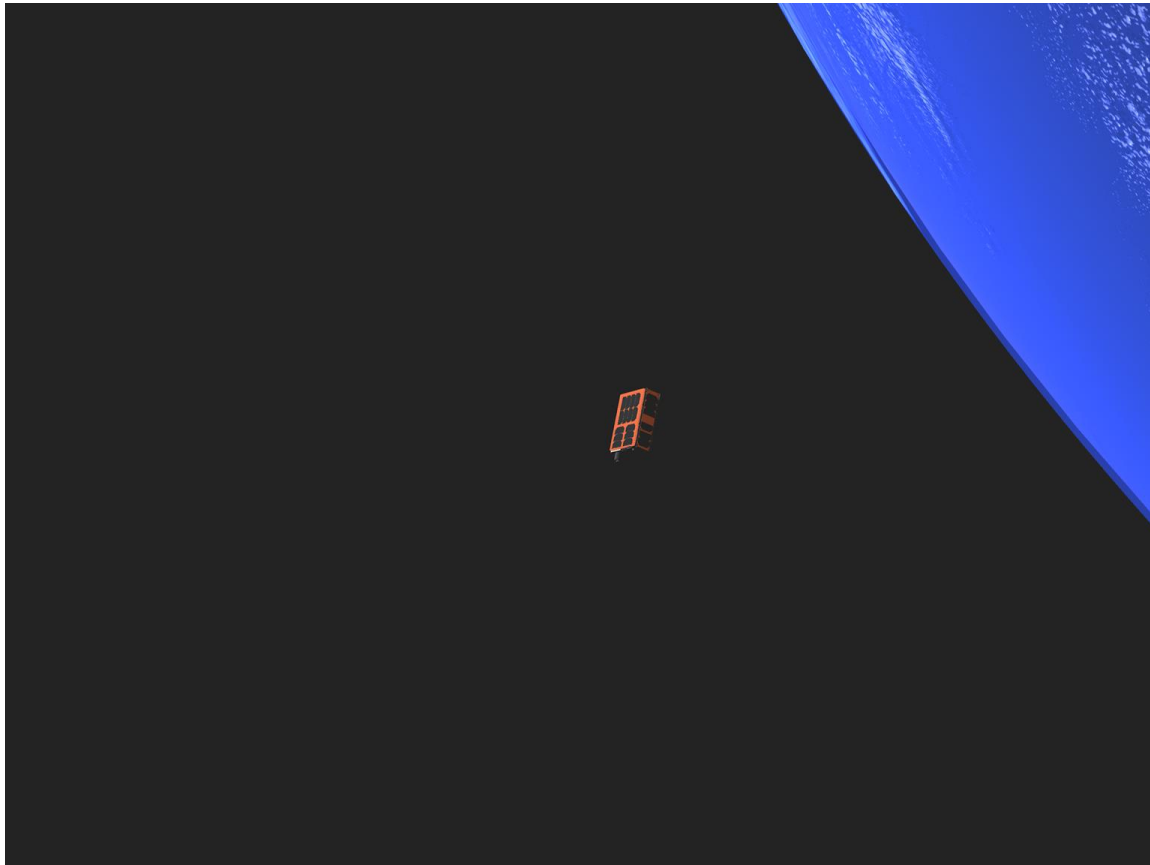
Audacity: In-Orbit Demonstration of Object Detection



- Using pre-recorded video of the NAPA-2
- In-house CAD design and synthetic images
- Running application on-board
- SW optimized to cope with limited uplink and processing power



Domain gap



Lessons learned

1. Off-the-shelf DNN models are not directly adaptable for flight computers
 - Custom DNN models need to be developed for the selected HW platform
2. Addressing the domain gap requires specific methods
 - Parameters tuning and data augmentation are not enough to generalize to different domains
3. The concept of operation used for current and past missions cannot be generalized
 - There is a consensus on the use of zones and transitions, but they are too dependent on the characteristics of the mission (size of the serviced vehicle, sensing capability of the servicer, etc.)

Next steps

1. In-house development of DNN models and training process
2. Simulation and analysis of defined scenarios to adapt and validate the modes and associated performance requirements
3. Development of a Safety Assurance approach to guarantee safe proximity operation under any circumstances

A wide-angle photograph taken from the International Space Station (ISS) looking out over the Earth. The planet's surface is covered in a dense layer of white clouds, with the blue of the oceans and the brownish-green of the continents visible through the gaps. The curvature of the Earth is clearly visible against the blackness of space. On the right side of the frame, the golden thermal blankets and white structural elements of the ISS are visible, along with a robotic arm extending towards the center.

Let's have a chat!

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Marcos Damian PEREZ – m.perez@lmo.space

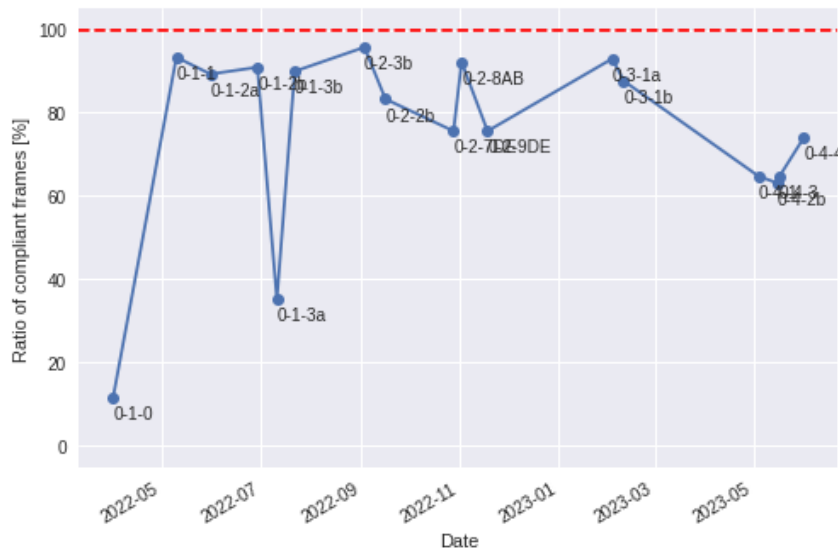


DIOSSA – DNN models: Evolution

Validity ratio



Position error



Orientation error



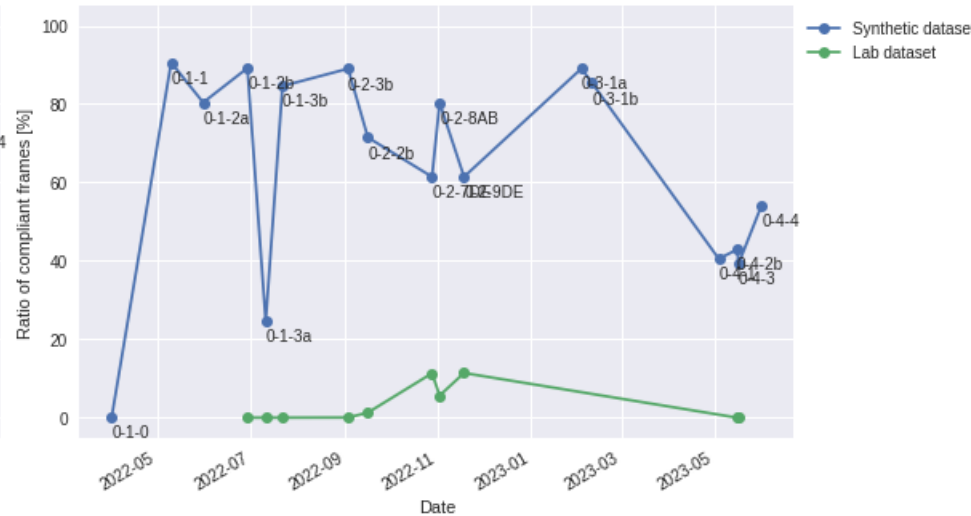
Validity ratio



Position error



Orientation error



DIOSSA – Output Filtering

Synthetic trajectory

Lab trajectory

