2023 Clean Space Industry Days

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

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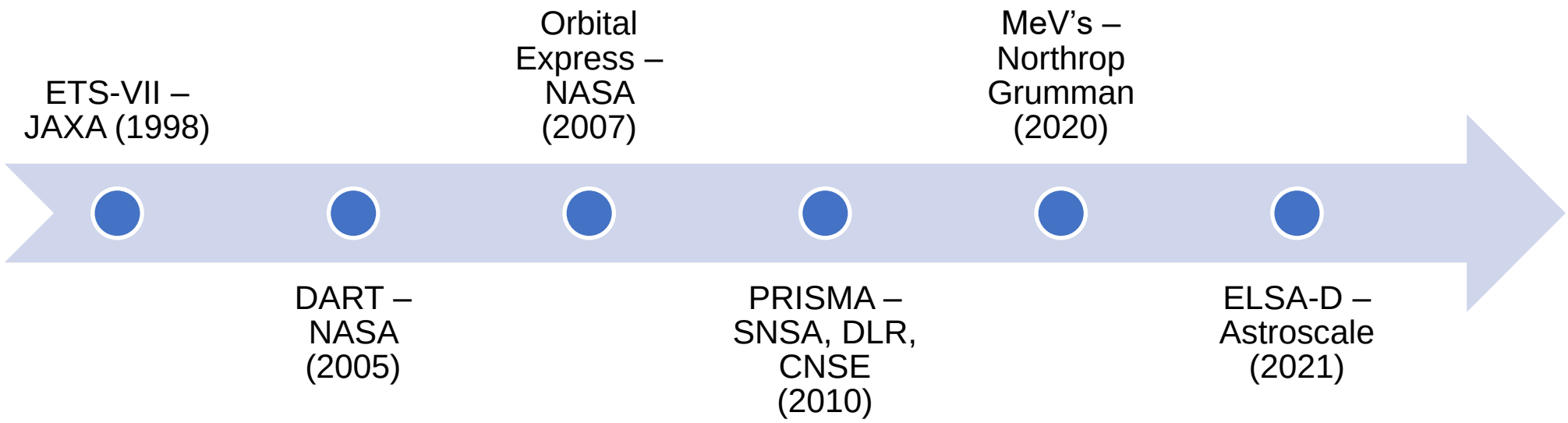
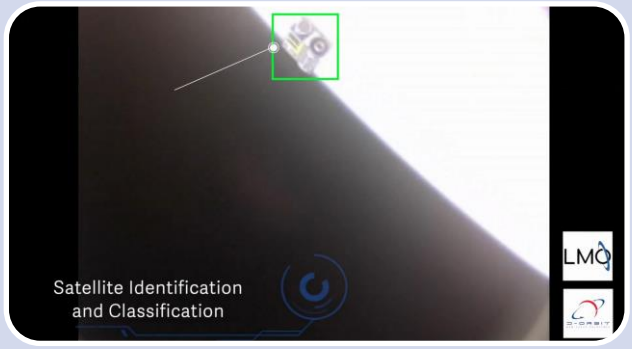
Starting point



- 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

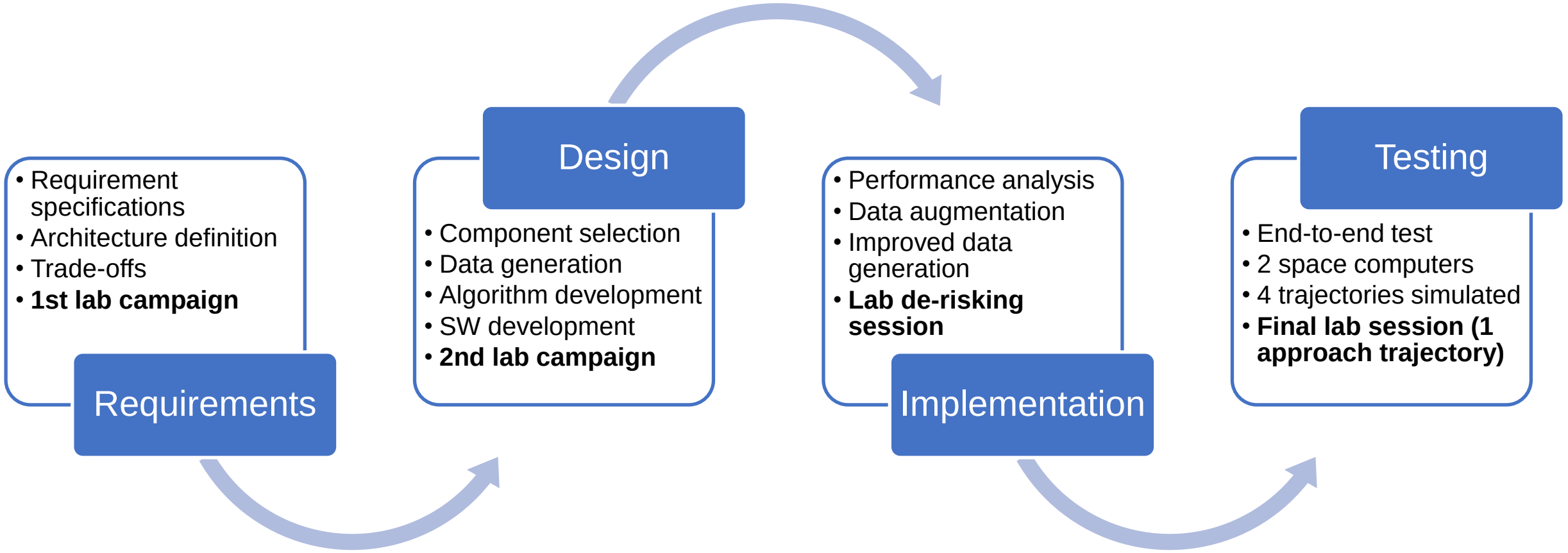
Phase 0/A completed

In-orbit demonstration

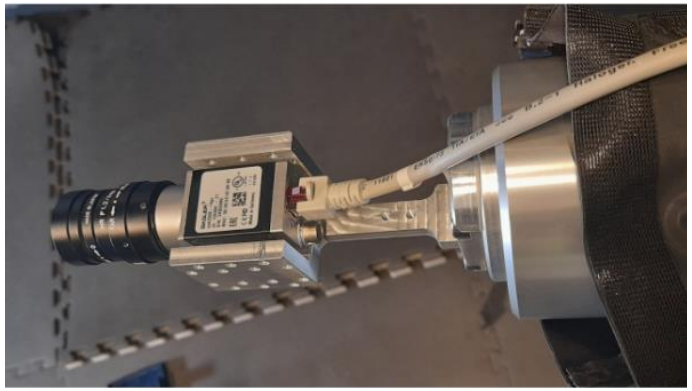
Audacity

Object detection demo SW

DIOSSA – Development steps

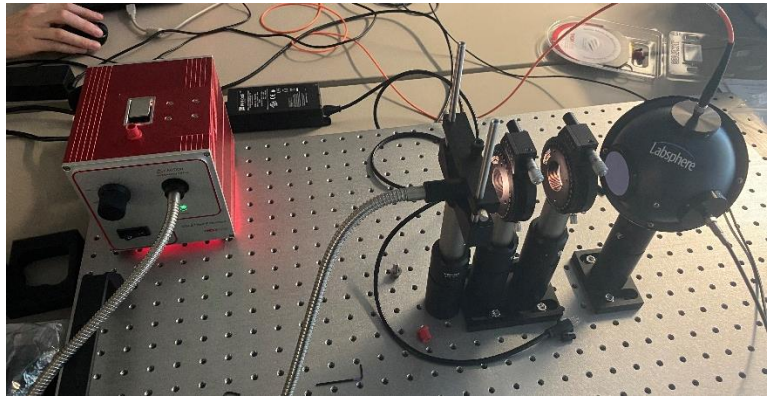


DIOSSA – Space segment: camera and mock-ups

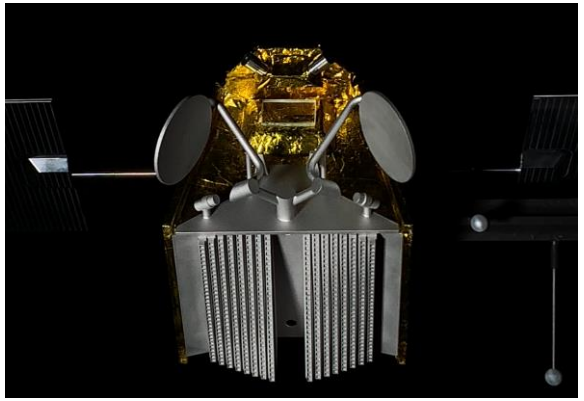


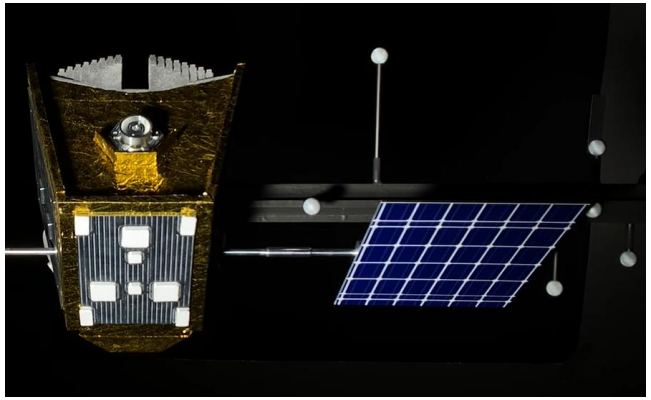
Camera with representative sensor mounted on custom made bracket

First OneWeb mock-up



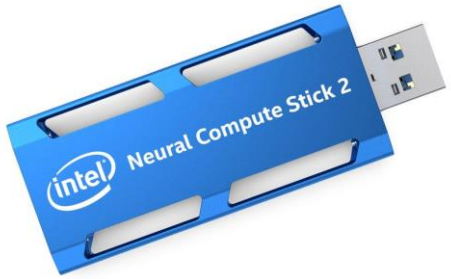
Sensor characterization



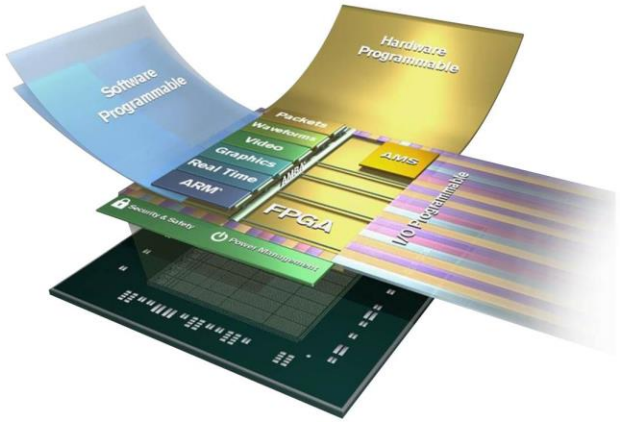


Final OneWeb mock-up

DIOSSA – Space segment: flight computer



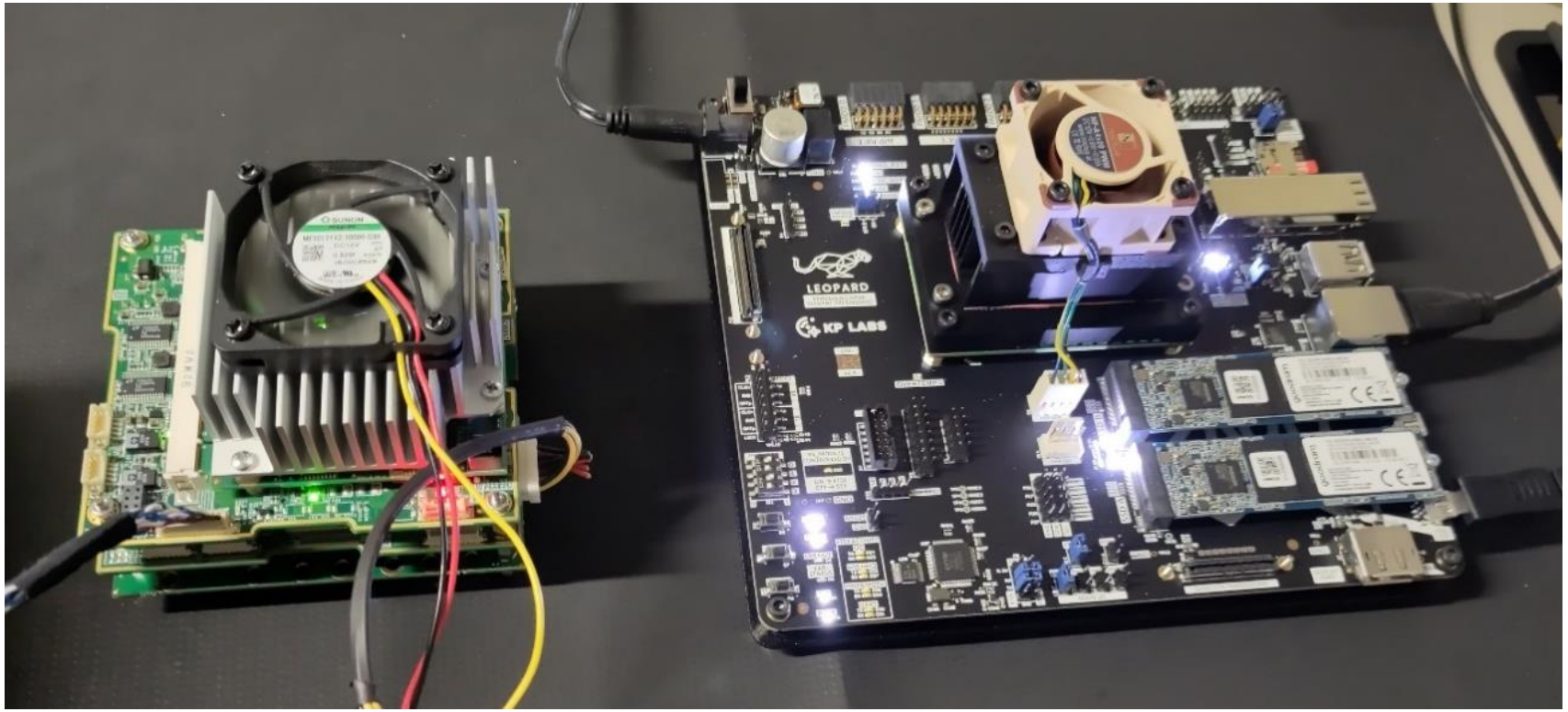
Intel Myriad X



Xilinx MPSoC

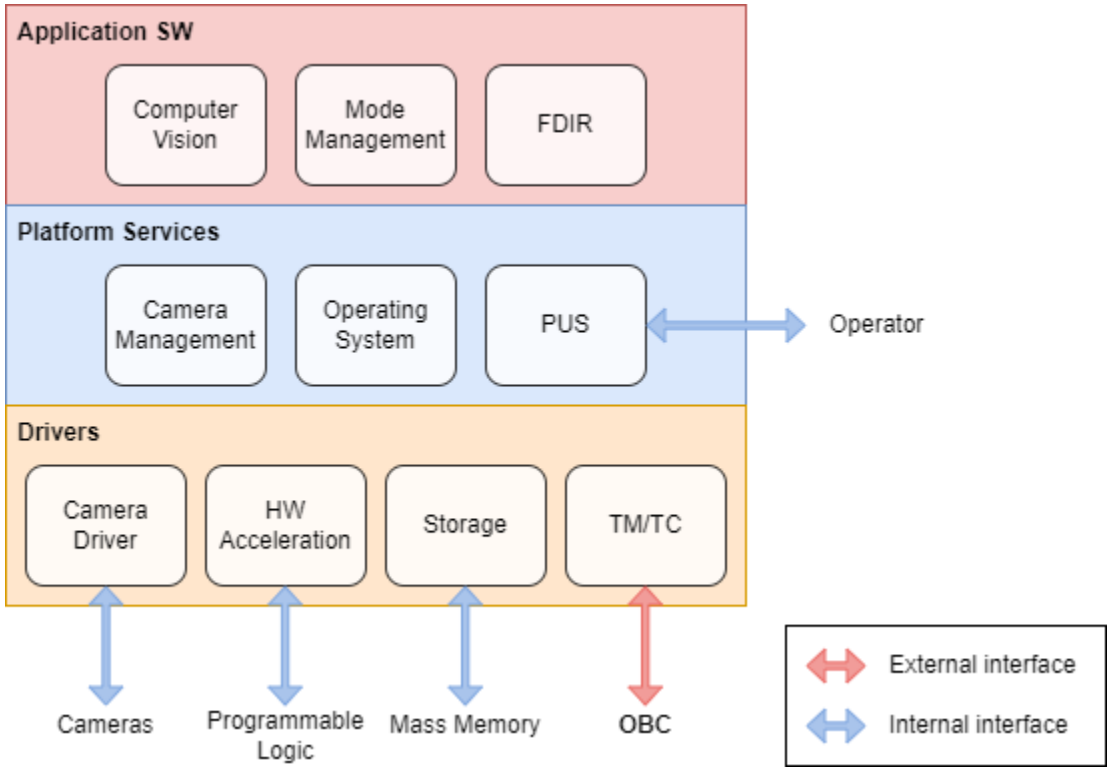
Unibap iX5

KP Labs Leopard EBB

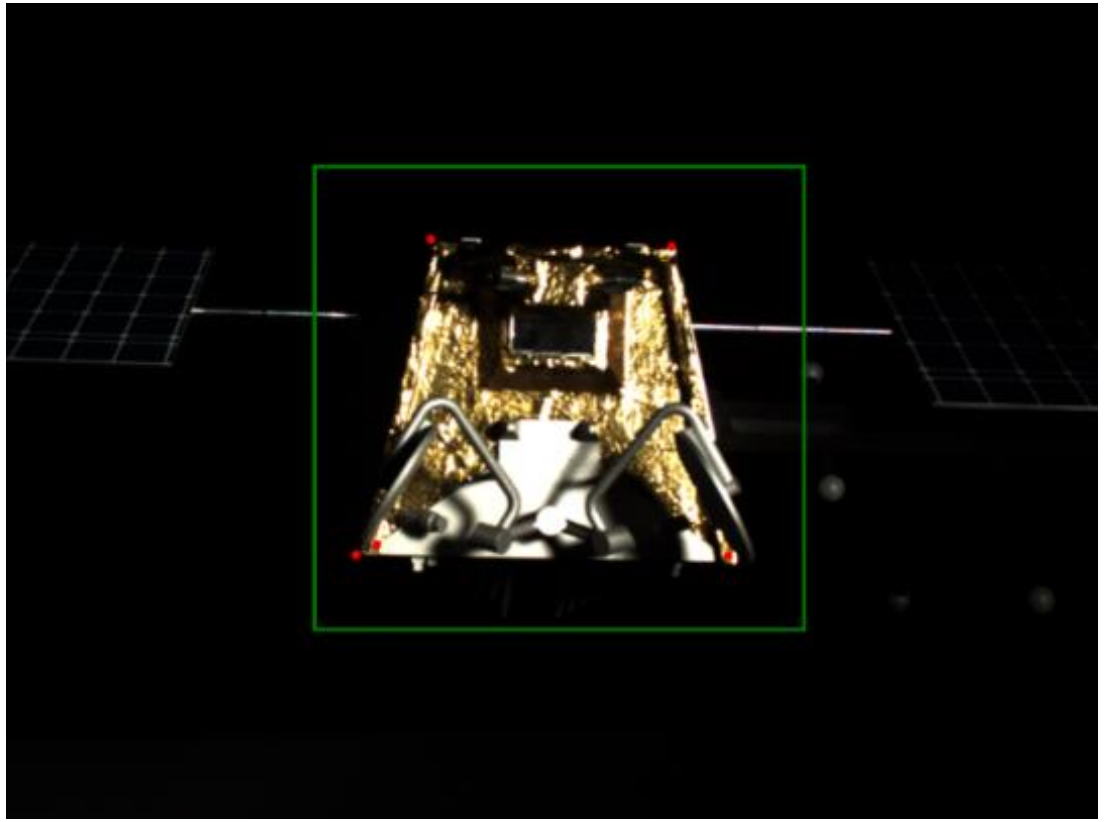


DIOSSA – Space segment: software

SW architecture

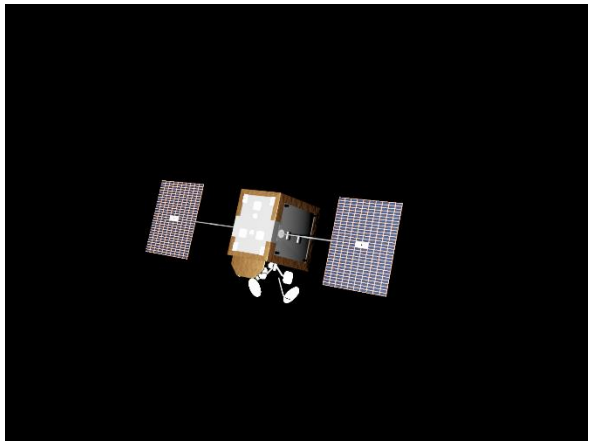
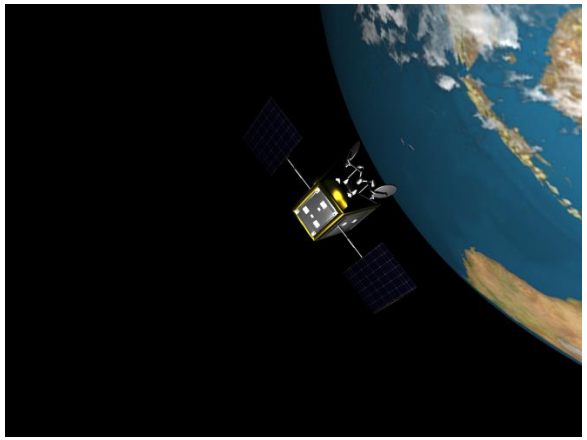
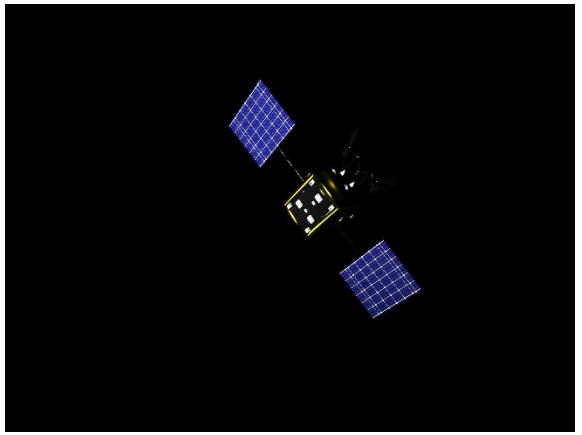
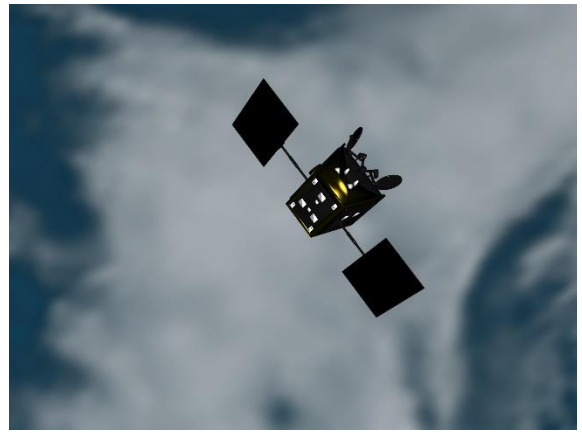
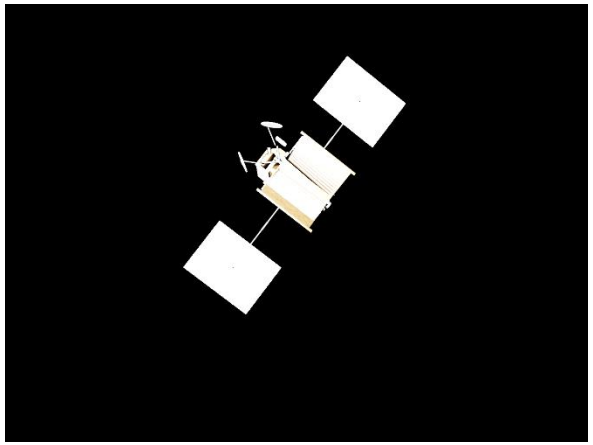
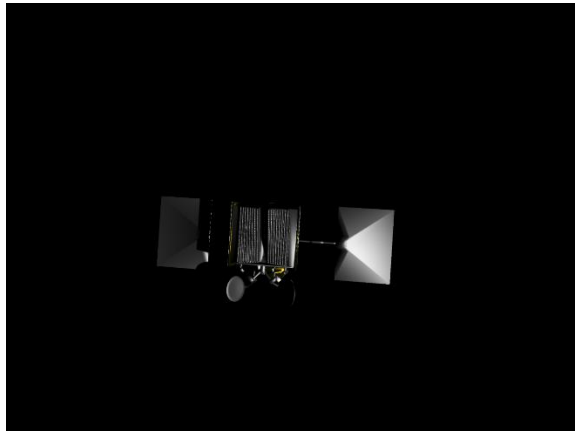
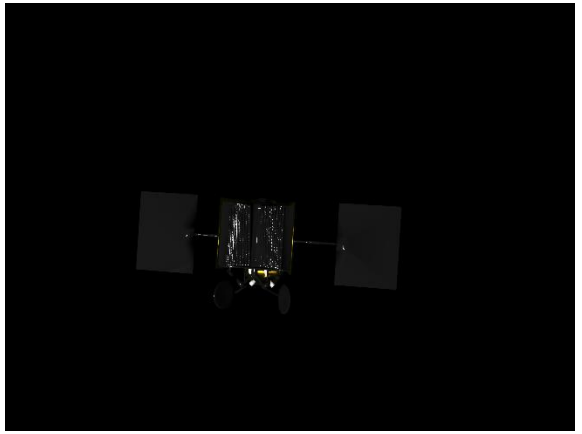
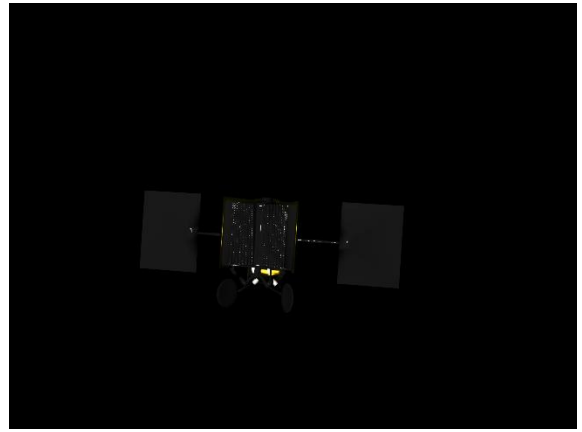


SW output



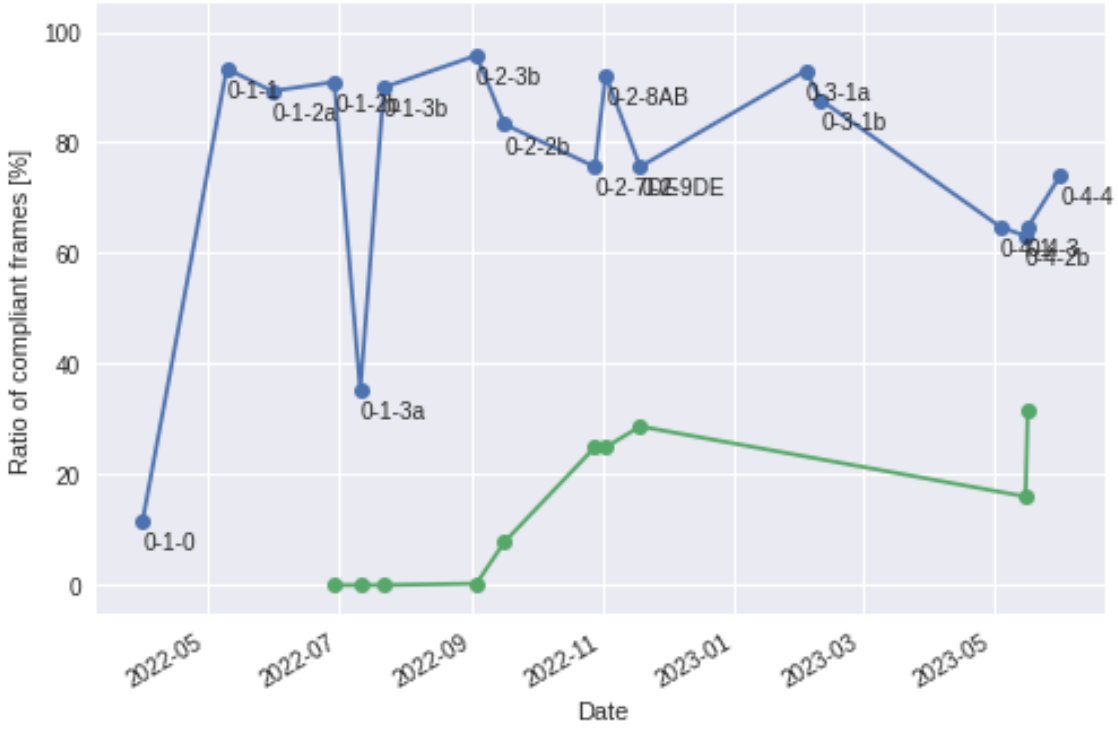
DIOSSA – Ground segment: machine learning training data

Blender | Pangu v1 | Pangu v2 | Pangu v3

DIOSSA – DNN models: performance tracking

Position error



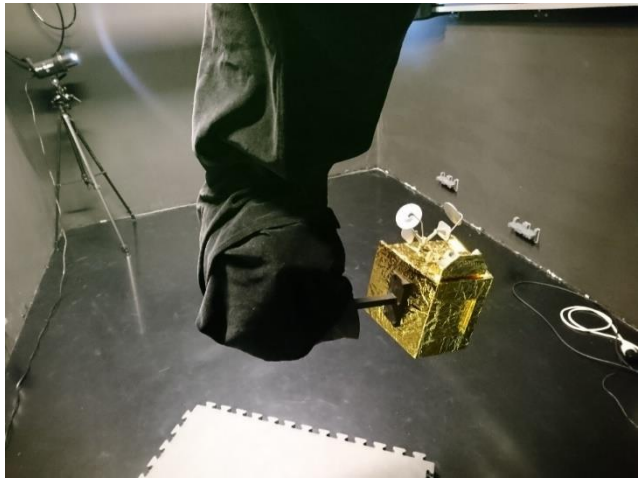
Orientation error

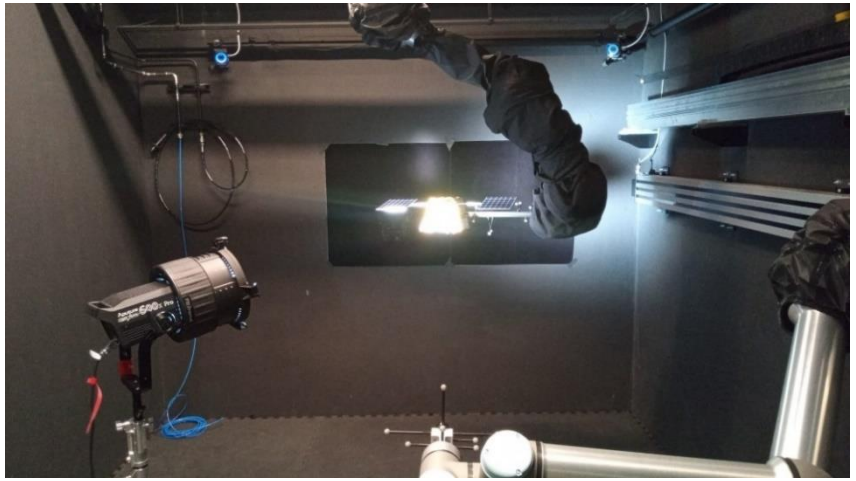
DIOSSA – Lab campaigns: Zero-G lab at Uni of Luxembourg

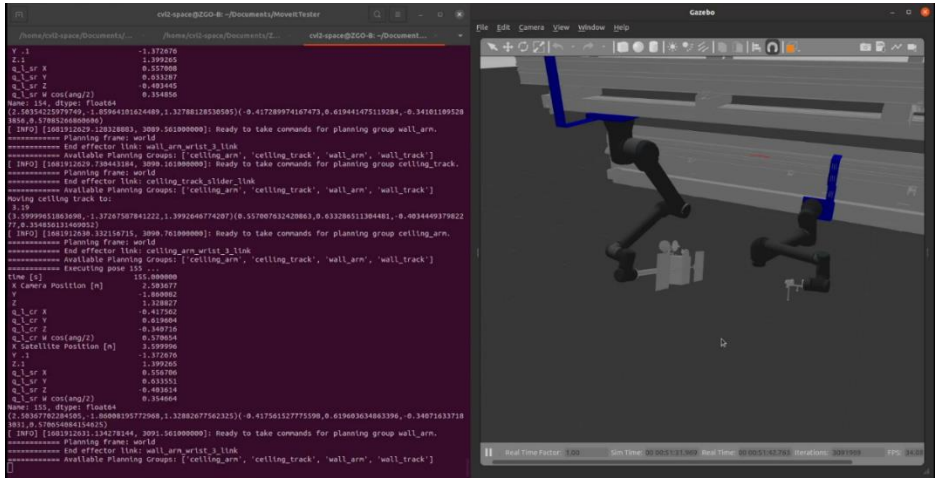
Spring 22
Knowledge gathering

Summer 22
Data collection

Spring 23
End-to-end validation



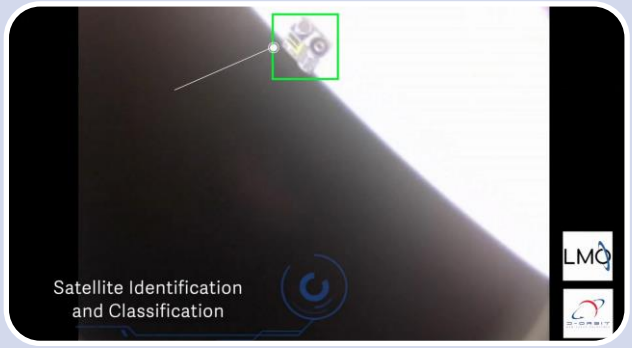




DIOSSA – DNN models: Best performance

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



Technology maturation

DIOSSA

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16 months

Industry partnerships

Proof-of-Concept 1

ESA IOD mission

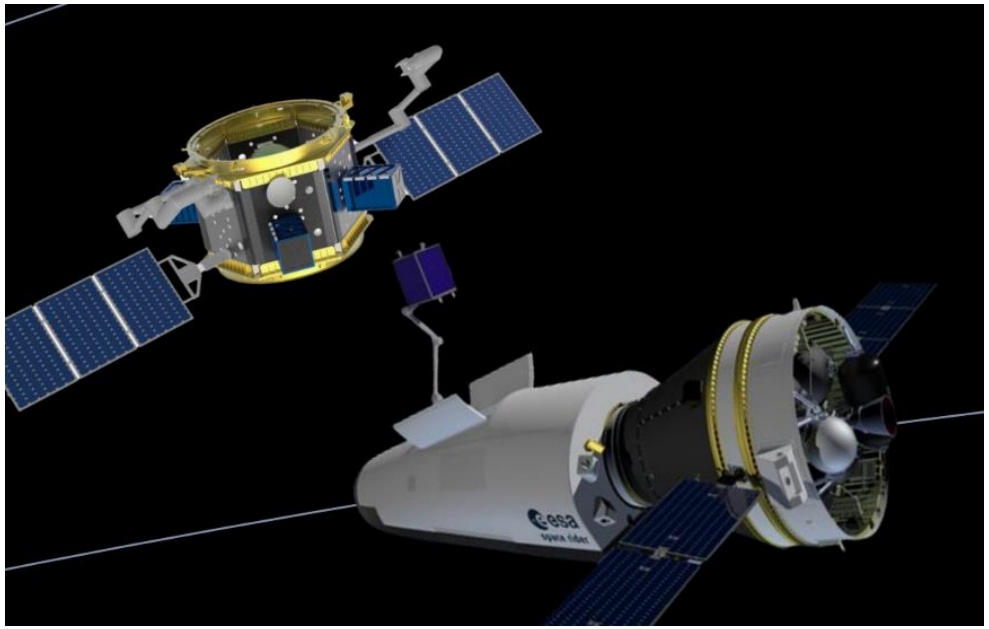
Phase 0/A completed

In-orbit demonstration

Audacity

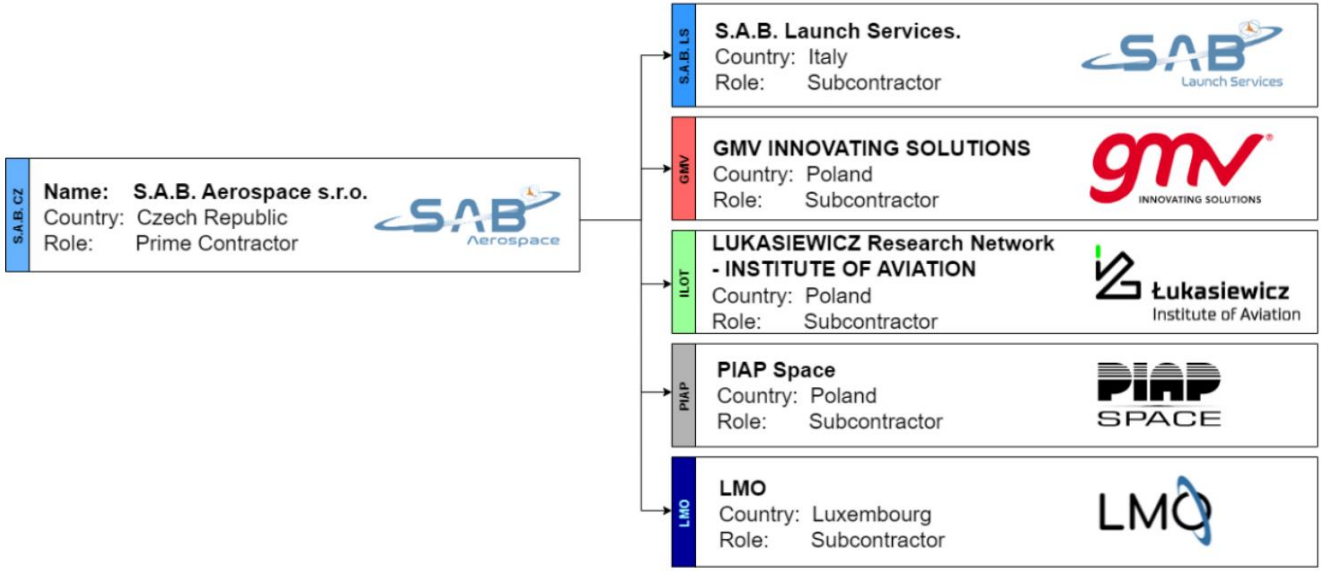
Object detection demo SW

PoC-1 – Mission objectives



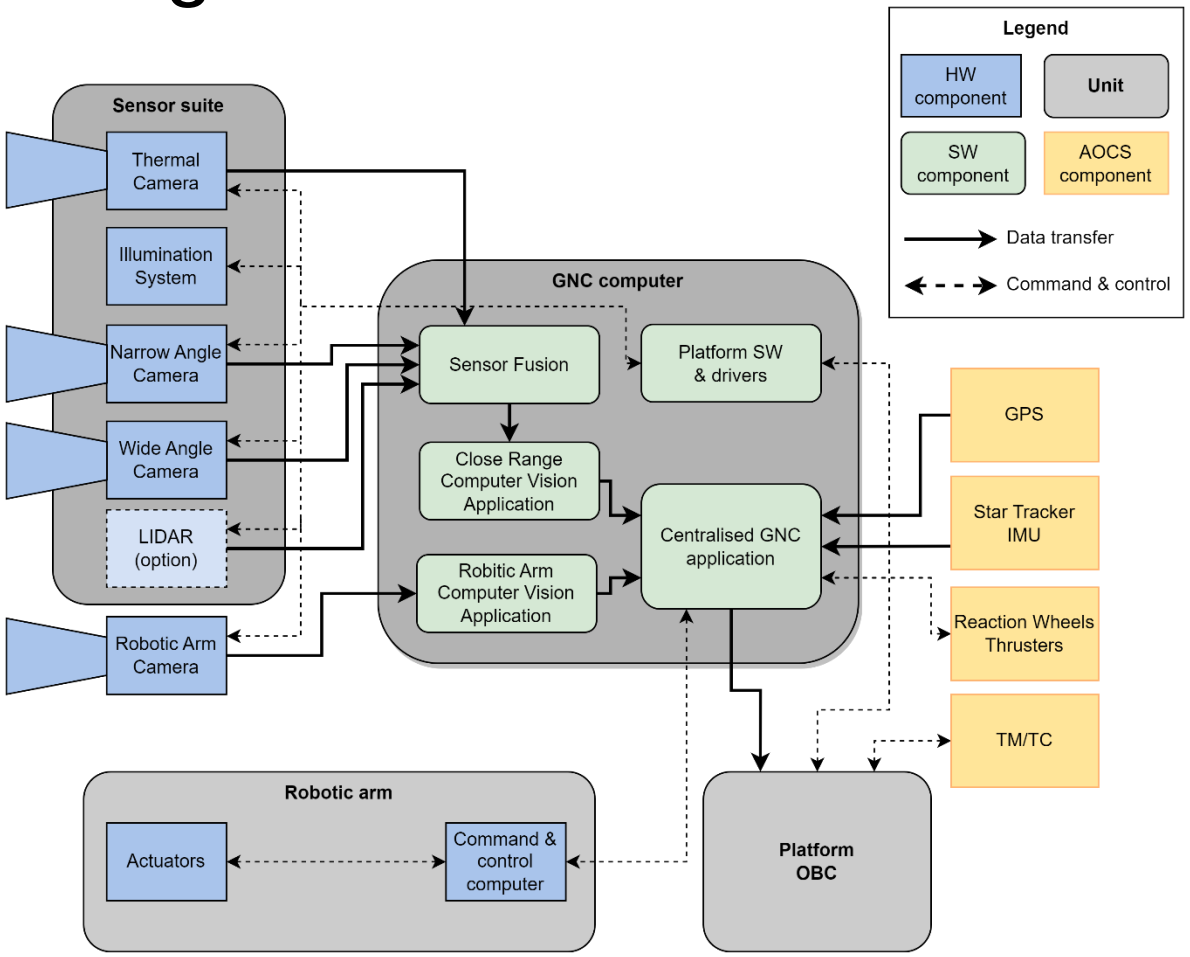
Demonstration of the key enabling transport capability of in-orbit automatic rendezvous and docking between two orbital systems

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



Proximity System preliminary design

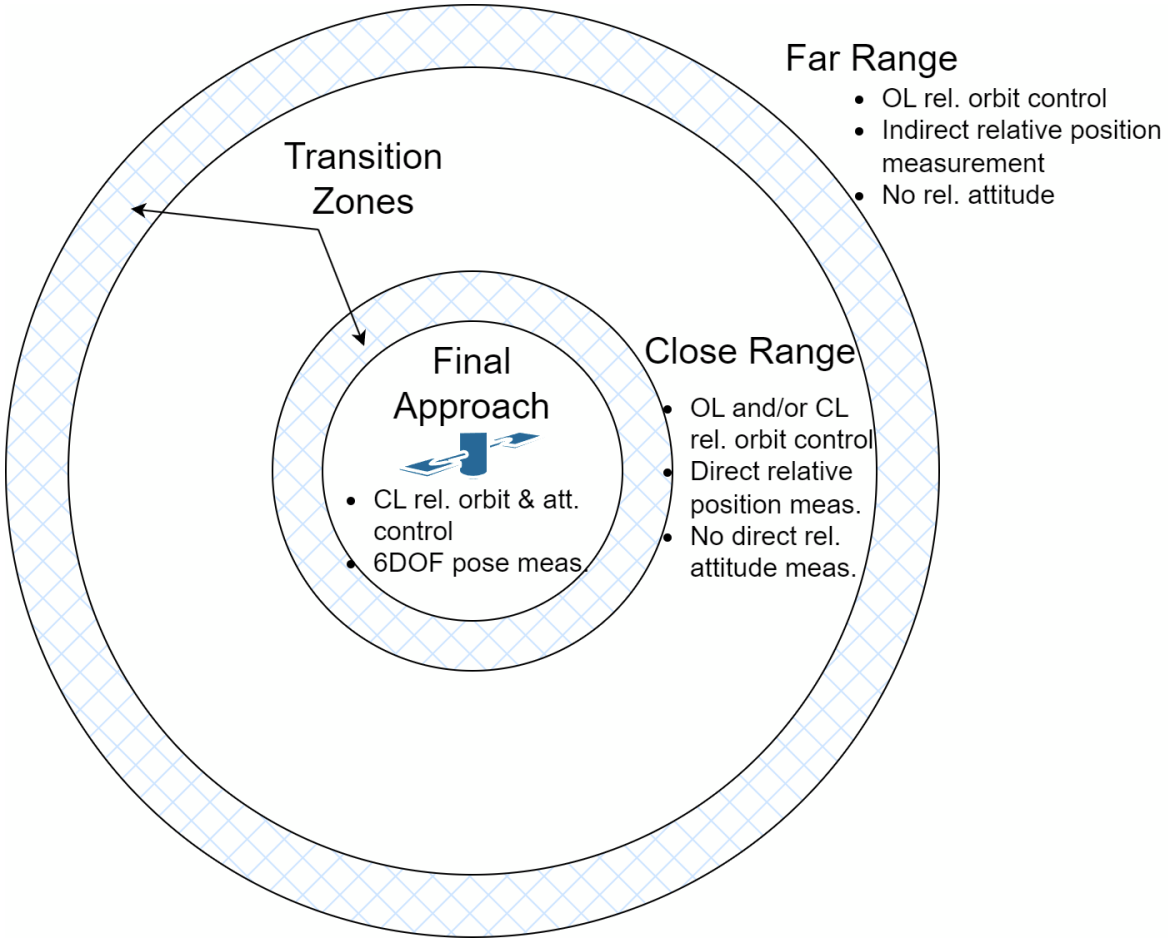
- Centralized architecture with the GNC application collecting the data from the Computer Vision application and AOCS sensors
- Use of monocular cameras only (visible and thermal)
- Lidar as option (for reliability or redundancy, with impact on technical budgets)



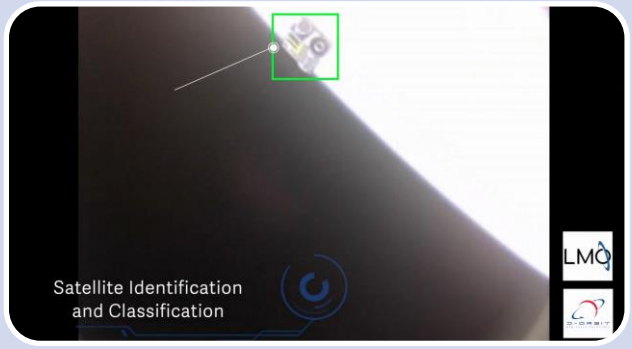
Proximity operations concept

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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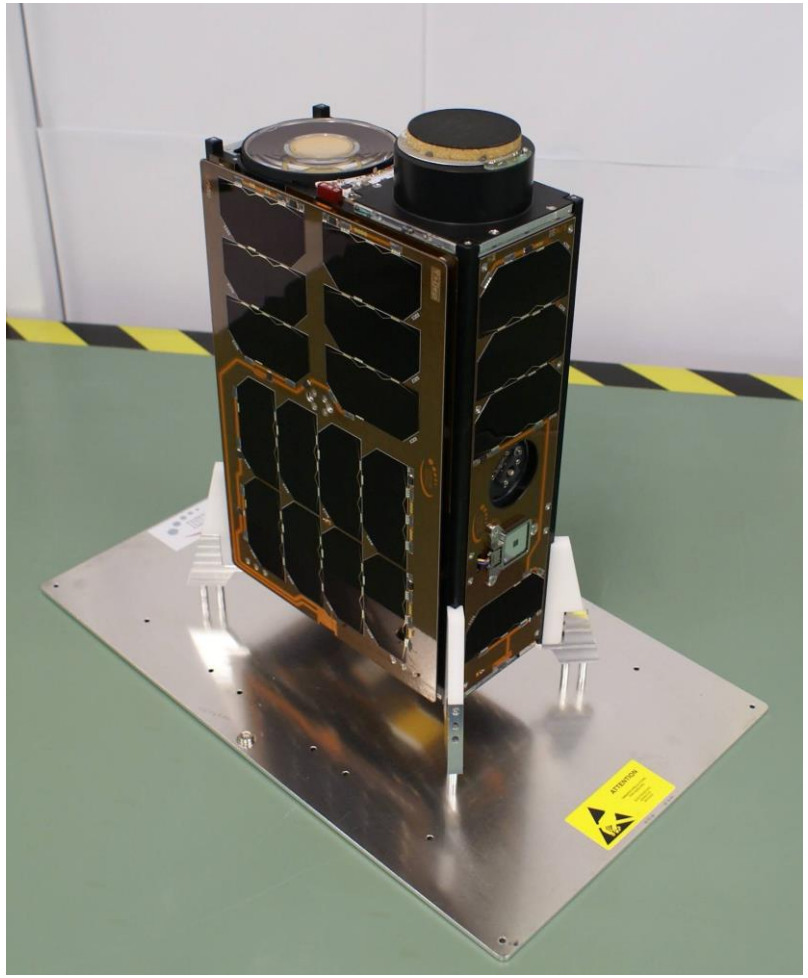
Object detection demo SW

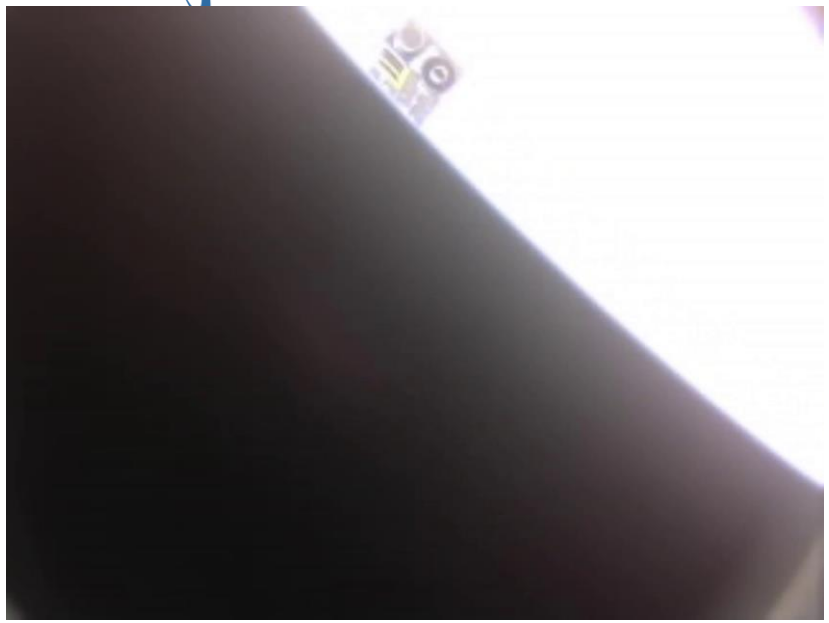
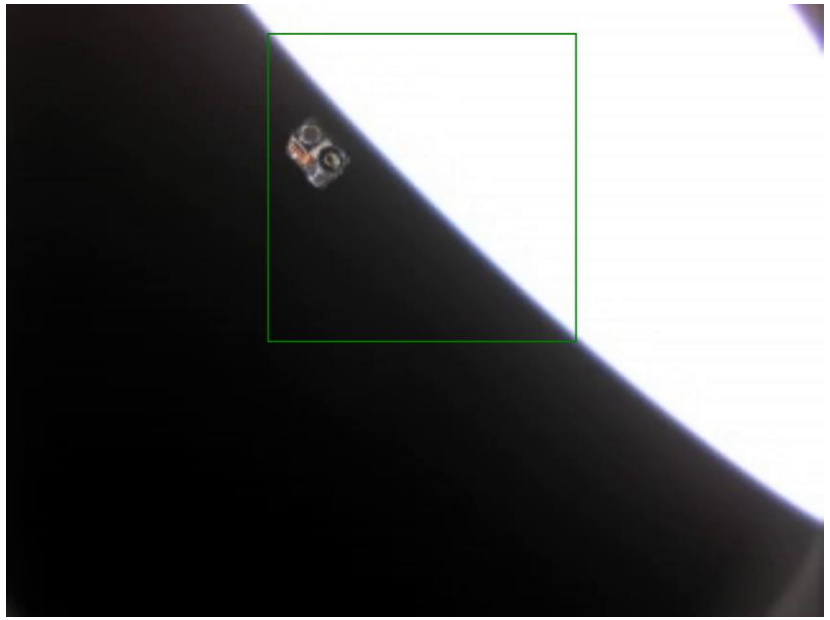
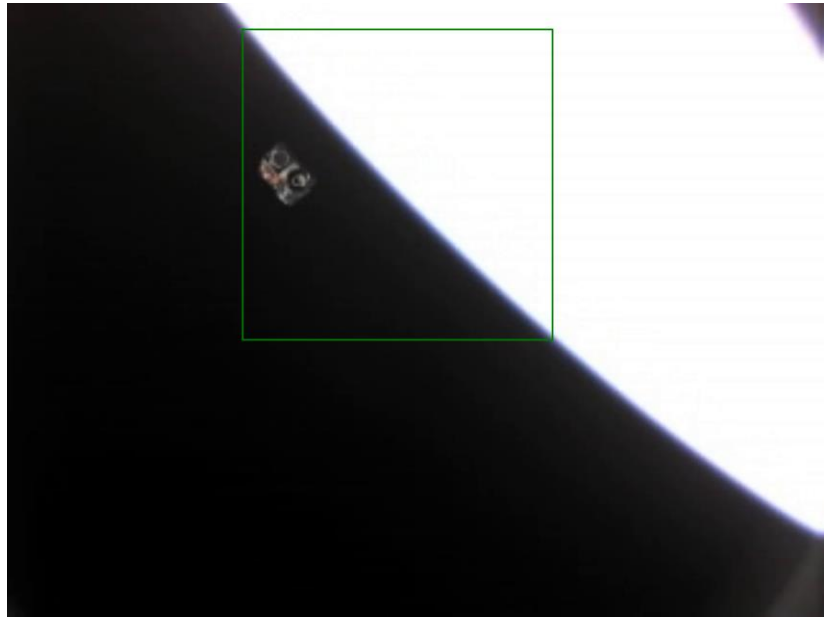
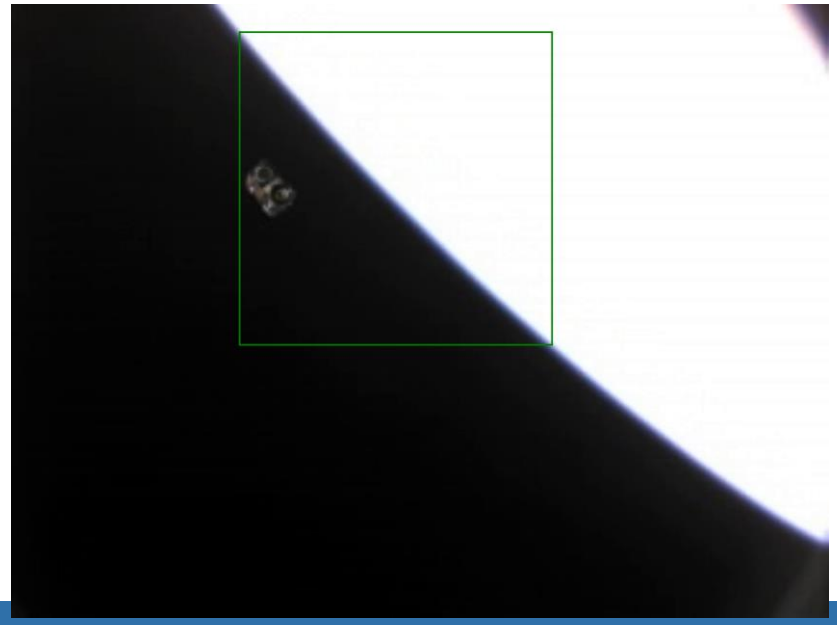
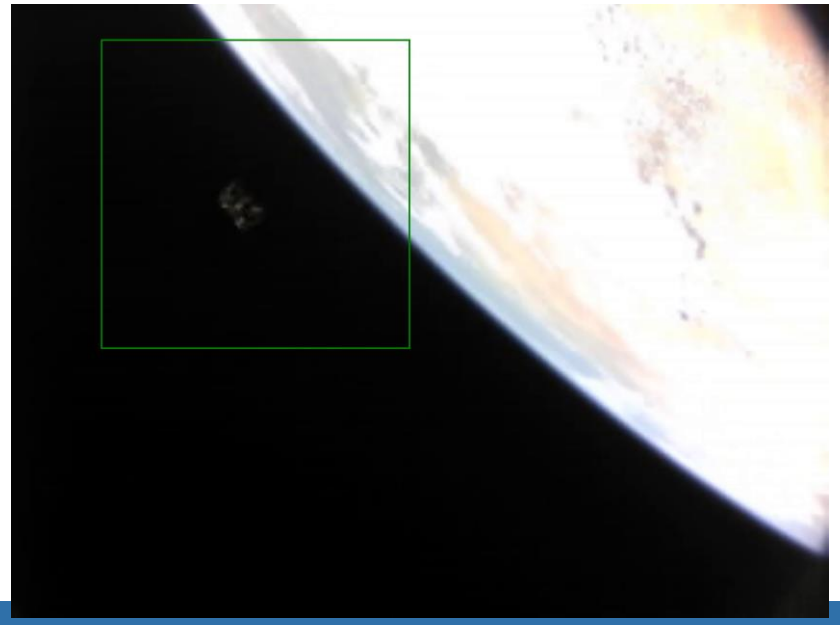
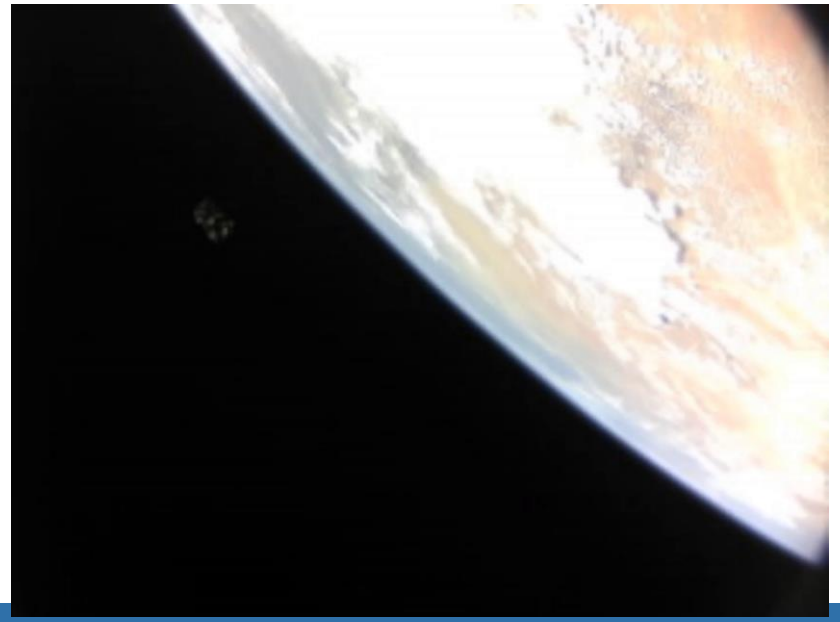
UNIBAP

UNIVERSITÉ DU LUXEMBOURG

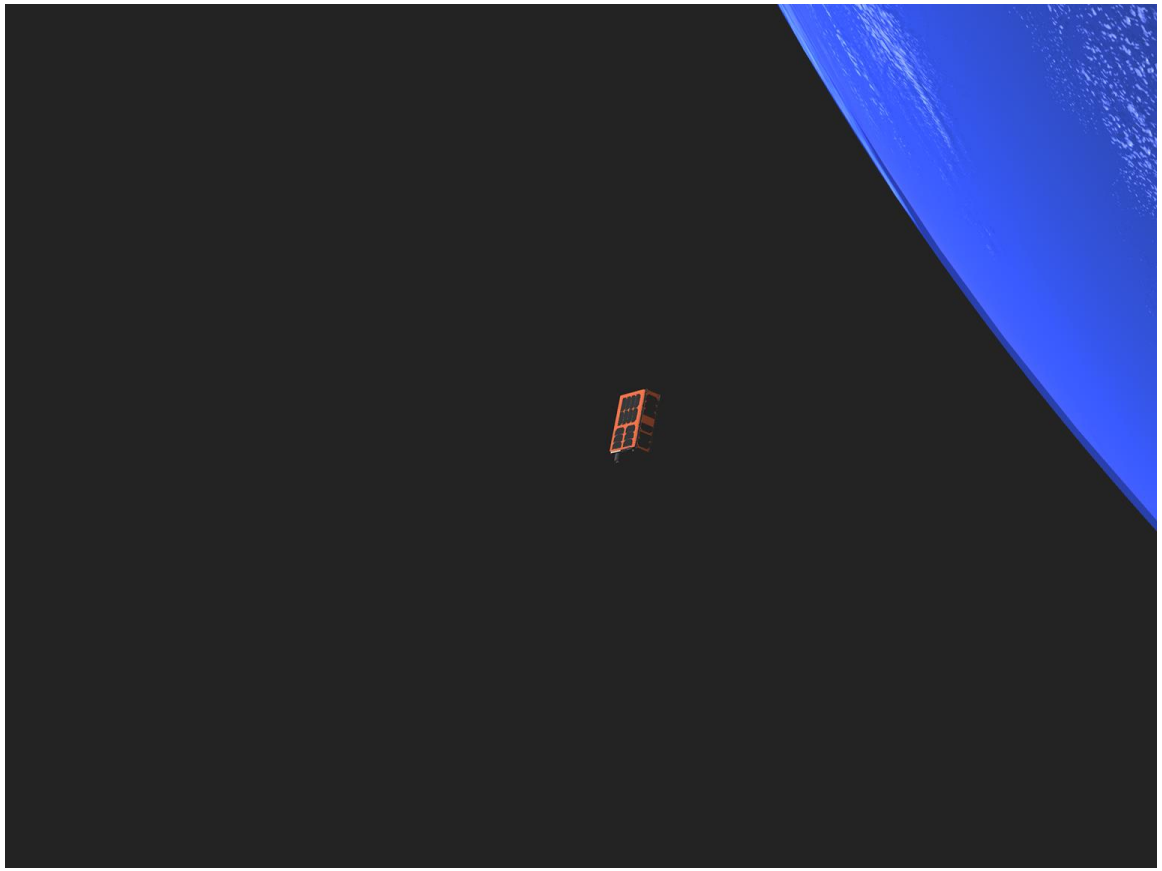
Audacity: In-Orbit Demonstration of Object Detection

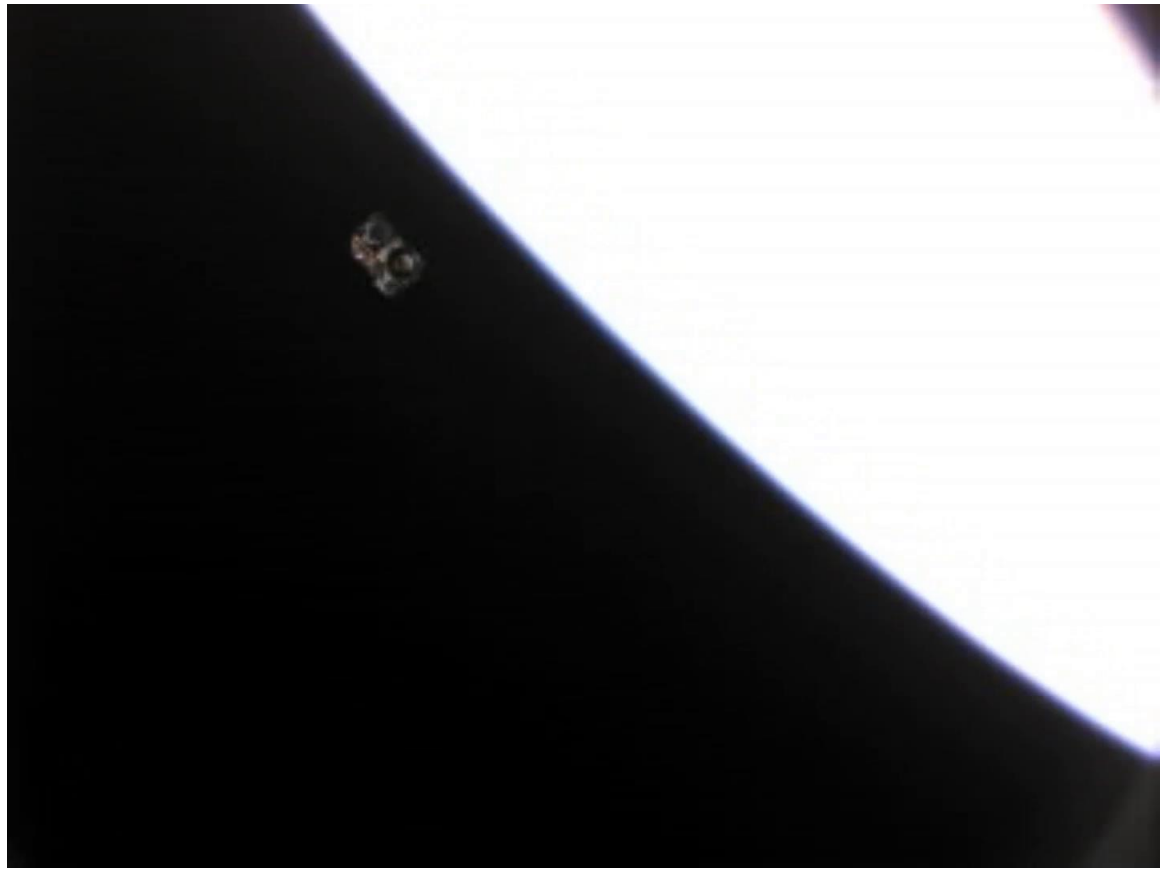


- Using pre-recorded video of the NAPA-2
- In-house CAD design and synthetic images
- Running application on-board
- SW optimized to cope with limited uplink and processing power

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

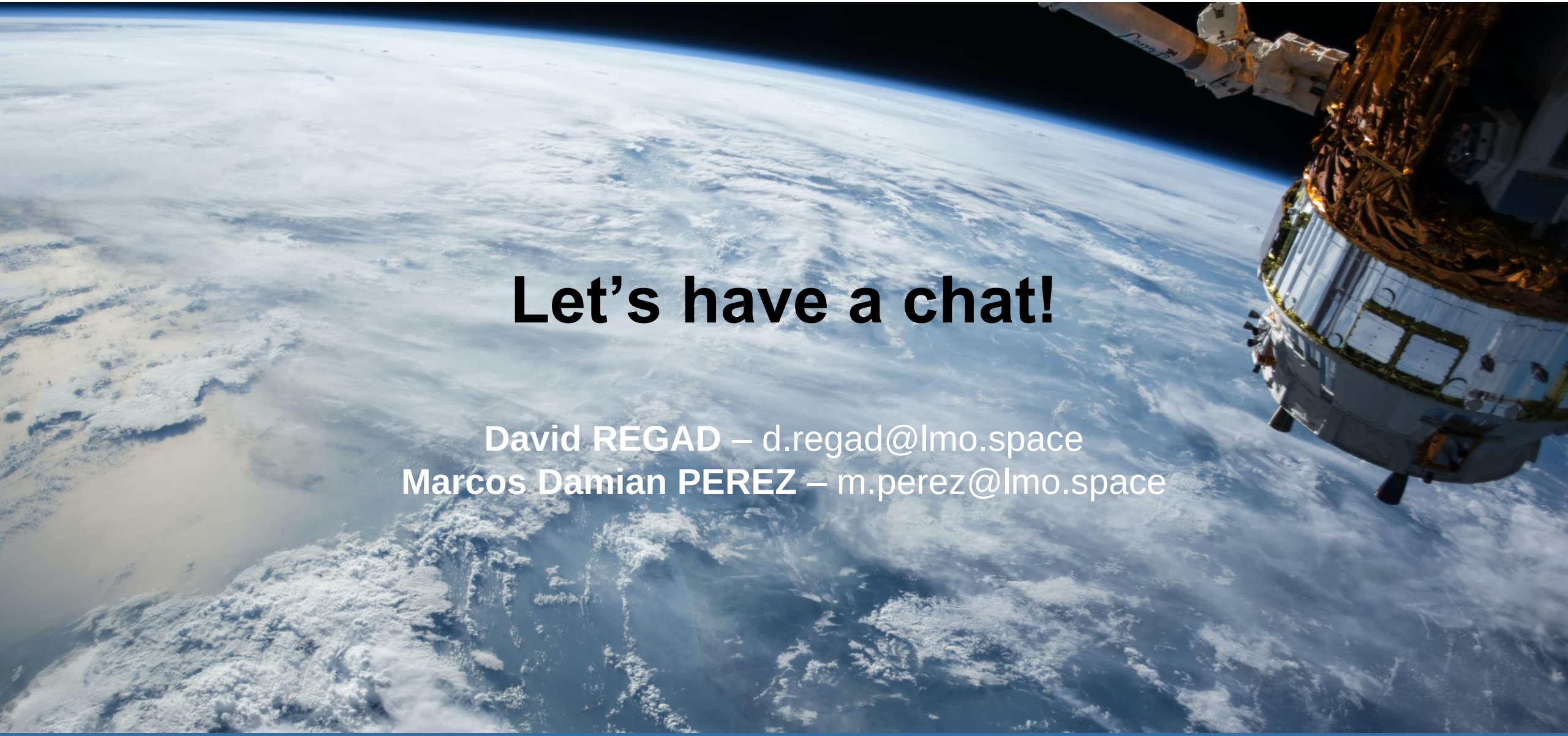
3. The concept of operation used for current and past missions cannot be generalized
   - There is a consensus on the use of zones and transitions, but they are too dependent on the characteristics of the mission (size of the serviced vehicle, sensing capability of the servicer, etc.)

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

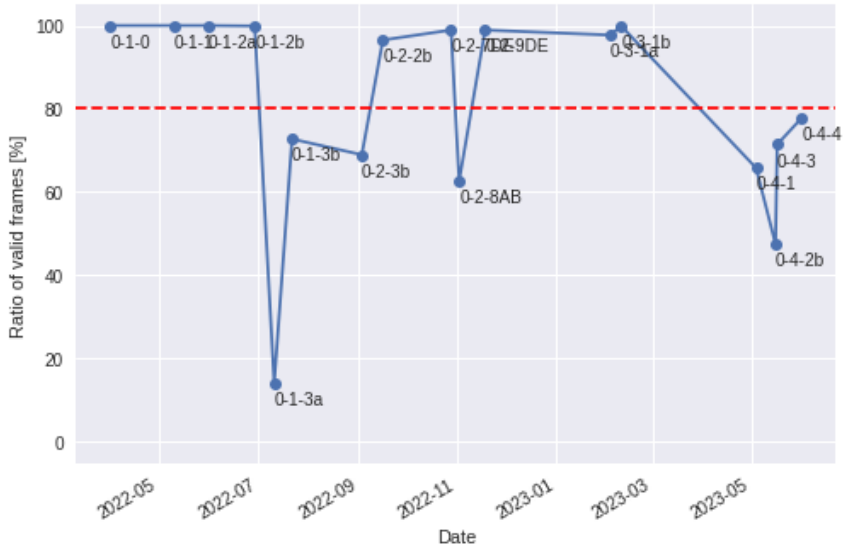


Let’s have a chat!

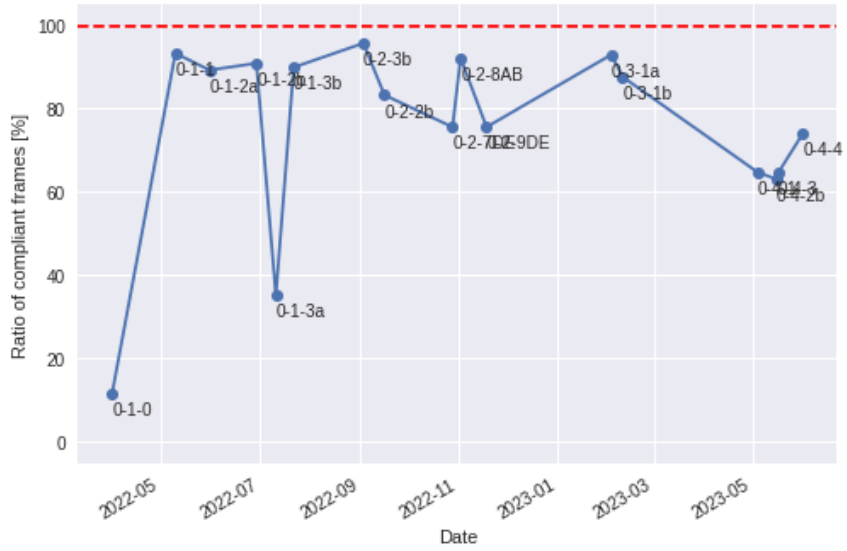
David REGAD – d.regad@lmo.space
Marcos Damian PEREZ – m.perez@lmo.space

DIOSSA – DNN models: Evolution

Validity ratio



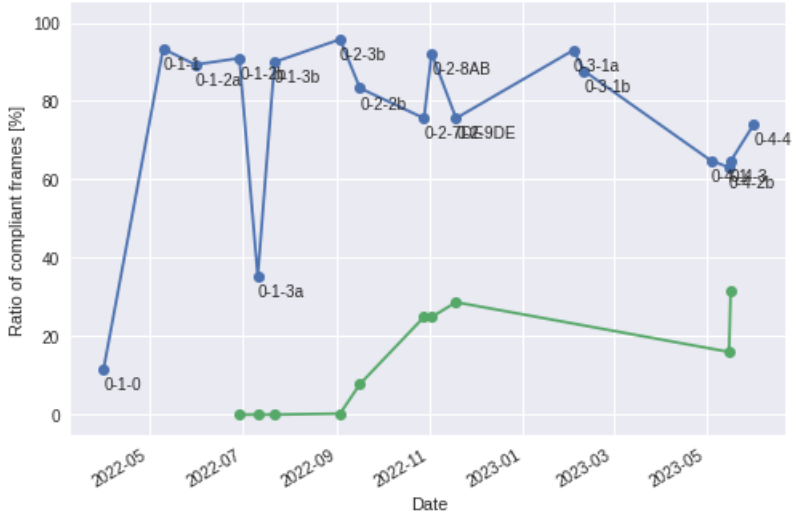
Position error



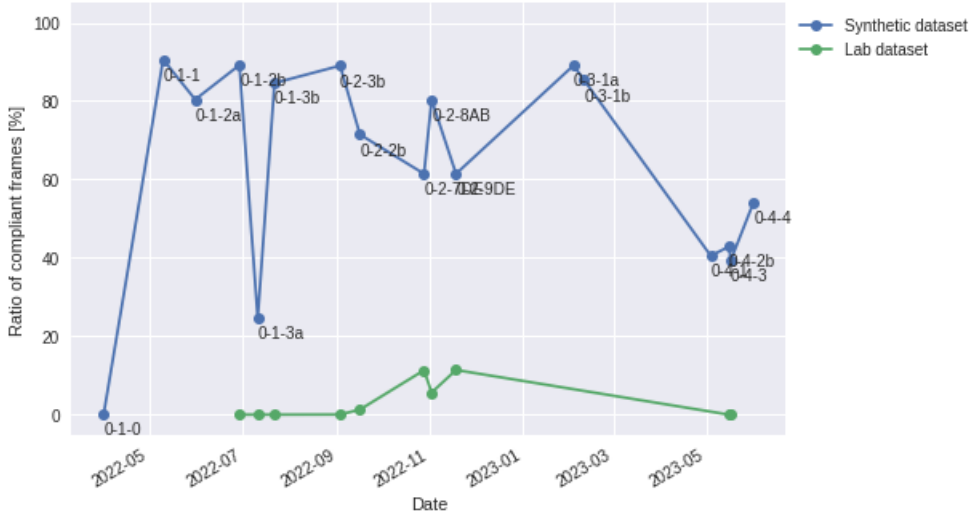
Orientation error

Validity ratio

Position error

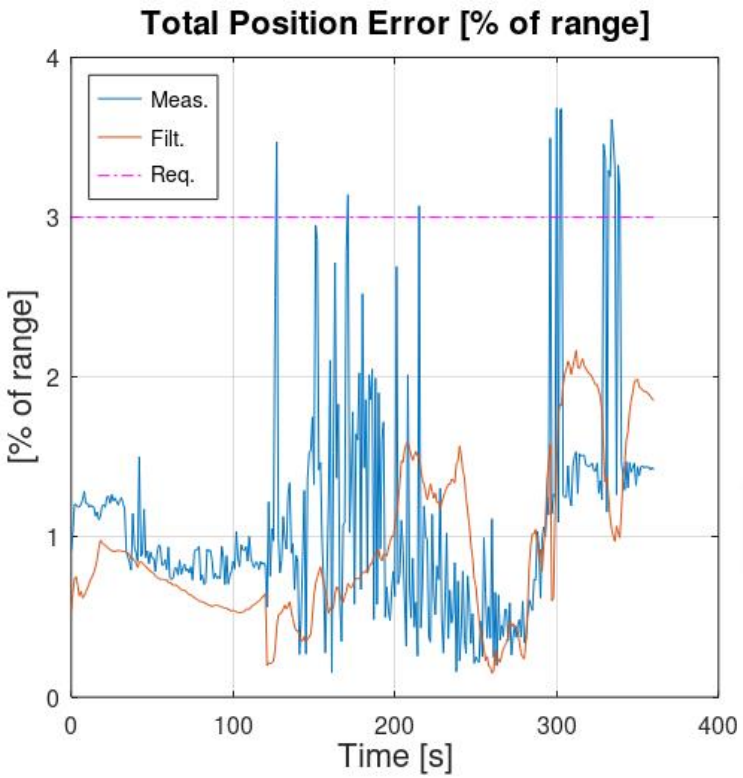


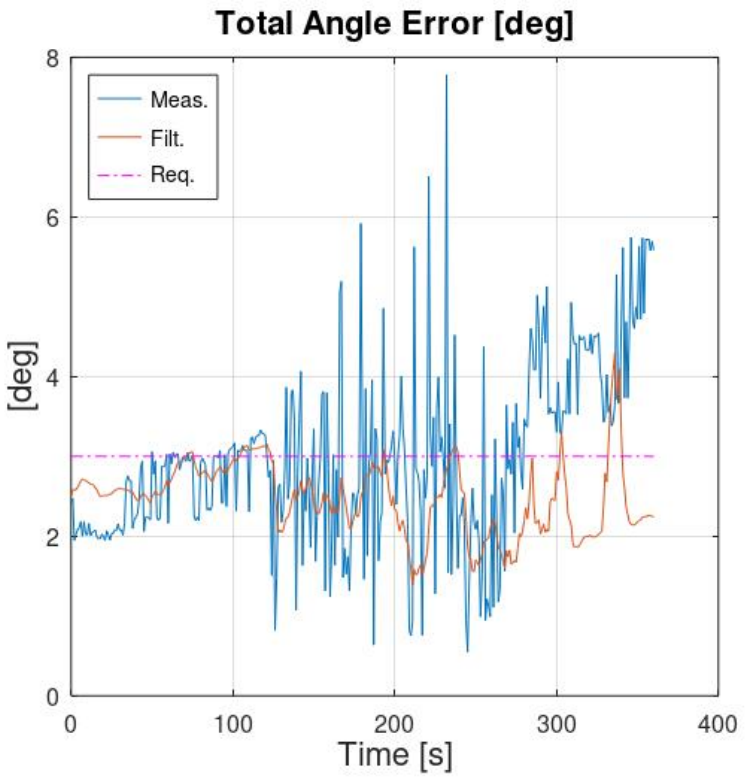
Orientation error



DIOSSA – Output Filtering

Synthetic trajectory





Lab trajectory