The ESA Φsat-2 Mission: an A.I Enhanced Multispectral CubeSat for Earth Observation

Small Satellite Conference – Logan - Utah

Nicola Melega, Valentina Marchese, Agnė Paškevičiūtė-Kidron, Bernardo Carnicero Dominguez, Nicolas Longepe, Oriol Aragon Casaled, Irina Babkina, Alessandro Marin, Hano Steyn, Léonie Buckley, Jakub Nalepa, Sofia Oliveira, Giorgia Guerrisi

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Outline

- Background
- Objectives
- Consortium
- Status-Plan
- Phisat-2
    - Mission Description/Architecture
    - Platform
    - Payload
        - Payload Data Processing
    - AI Implementation
        - Sat2Map
        - Cloud Detection
        - Vessel Detection
        - Compression
    - Applications Challenge

Background – Why NewSpace

- Follow the miniaturization trend (COTS)
- Increased capabilities (performances and reliability) of the small, micro and nano satellites
- Capitalize on other directorates activities (IOD/IOV, ARTES)

Advantages
- Relaxed requirements due to short lifetime
- Components standardization
- Rideshare launches

Effects
- Reduced development time
- Overall cost reduction
- Fly more frequently
- Fly in constellations

Enables
- To perform in-orbit verification of new EO Techniques
- New approaches to established EO techniques like AI

Background – ESA EOP Small Missions

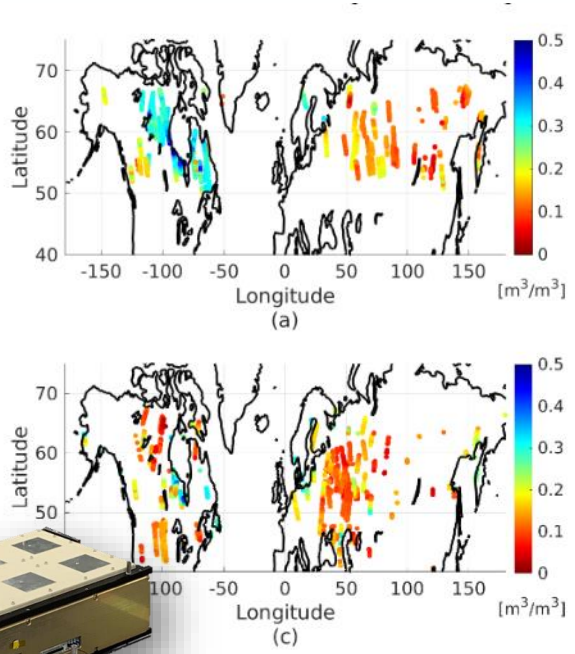
Within Earth Explorer and Earth Watch broad component lines the European Space Agency (ESA) has specifically designed and put in place missions to support the use of small and nano-satellites for specific Earth Observation mission.

1. **Scout missions:** As part of Research missions, to demonstrate novel Earth Observation techniques in Earth science and related non-commercial applications;
2. **InCubed missions**: As part of Earth Watch, to invest in industrial innovation, including the development of end-to-end mission aimed to support and increase the European companies' competitiveness;
3. **Φ-sat missions**: to develop missions for fast demonstration of EO new technique and enable capability of innovative/disruptive technologies such as AI.

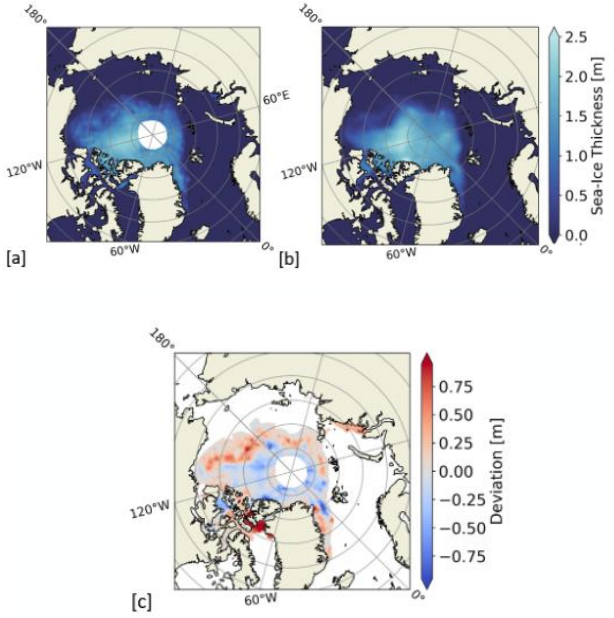
Background – Φsat-1 Experiment

UPC (ES), winner of **Copernicus Master Challenge (2017)**

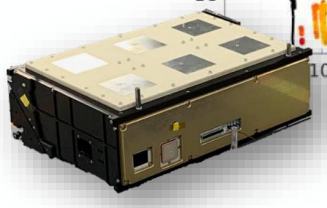
- 2 **Tyvak (IT)** Endevour 6U Cubesats were integrated as follow:
  - Sat-A equipped with Flexible Microwave Payload FMPL-2 (GNSS-R + L-band radiometer)
  - Sat-B equipped with HyperScout-2 + Φ-sat-1 experiment
- FSSCAT Satellites launched on 03-Sep-2020 onboard Vega PoC SSMS



Combined MWR and GNSS-R SM estimations



SIT measurements

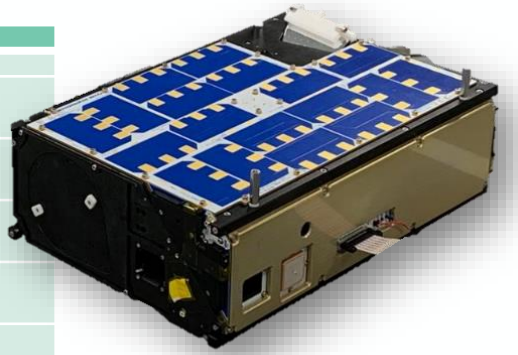


Φ-sat-1 Experiment

Goal: Demonstrate Onboard Cloud Detection using AI

- Hyperscout-2 Payload – ***Cosine (NL)***
- Use of Myriad2 VPU (COTS, low power, small size, radiation tested) – ***Ubotica (IL)***
- Training dataset from Sentinel-2 – ***Sinergise (SL)***
- Inference Engine (based on a ML algorithm) design and training – ***University of Pisa (IT)***

Parameter	Hyperscout-2
Orbit	540 km
FoV (ACT c ALT)	CH1: 31° x 16° CH2: 31° x 16°
GSD	CH1: 75 m CH2: 390 m
Swath	CH1: ~ 310 km x 150 km CH2: ~ 310 km x 150 km
Active pixels	CH1: 4000 x 1850 px CH2: 1024 x 768 px
Spectral range	CH1: 400 nm – 1000 nm CH2: 8 µm – 14 µm
Spectral bands	CH1: 45 CH2: 4
Spectral resolution	CH1: 16 nm CH2: B1: 1.1 µm B2: 1.1 µm B3: 1.1 µm B4: 6 µm
SNR (NeDT@300K)	CH1: 50 – 100 CH2: (0.5 – 3 K) * NeDT improvement with temporal and spatial averaging will be experimented



Objectives

Mission Objectives

- Demonstrate the enabling capabilities of running onboard Artificial Intelligence applications
- Demonstrate relevance for applicative scenarios and operational missions
- Demonstrate the ability of running multiple applications on board (either segregated or combined in a sequential way) and to update and upload them in different moment throughout the entire mission lifetime

The Phisat-2 mission will represent a game-changing Earth Observation CubeSat platform in space capable of running Artificial Intelligence applications onboard

- **Phase 1** - 4 months feasibility study (ended Dec 2021)
- **Phase 2** - 12 months of development/implementation + 12 months of operations (started Jan 2022, currently targeting launch in H2 2023)

To proper fulfil the Phisat-2 objectives the proposed solution will

- Provide a space segment capable of
  - acquiring multispectral images in 7 different bands (VNIR) satisfying the different application requirements in terms of image quality
  - Provide the required level of pre-processing (calibration, registration, geolocation) before AI inference, apply the AI algorithm onboard and store the data
  - Provide the necessary link for the satellite tasking and for the download of the acquired data
- Provide a ground segment capable of
  - Allow the control of the spacecraft (tasking, maintenance) as prescribed by the mission requirement
  - Provide a solution to collect application provider requests and translate them into inputs for the mission analysis and scheduling of the mission
  - Store and disseminate the collect data
- Provide a suitable launch

Consortium

OPEN COSMOS

Mission Prime contractor

- Platform and launch provider
- System Integration
- Ground Segment
- Operations
- Data Dissemination

CGI

- Phisat-2 Phase 1 coordinator
- Payload Control Center
- NanosatMo Framework developer
- AI App providers coordination

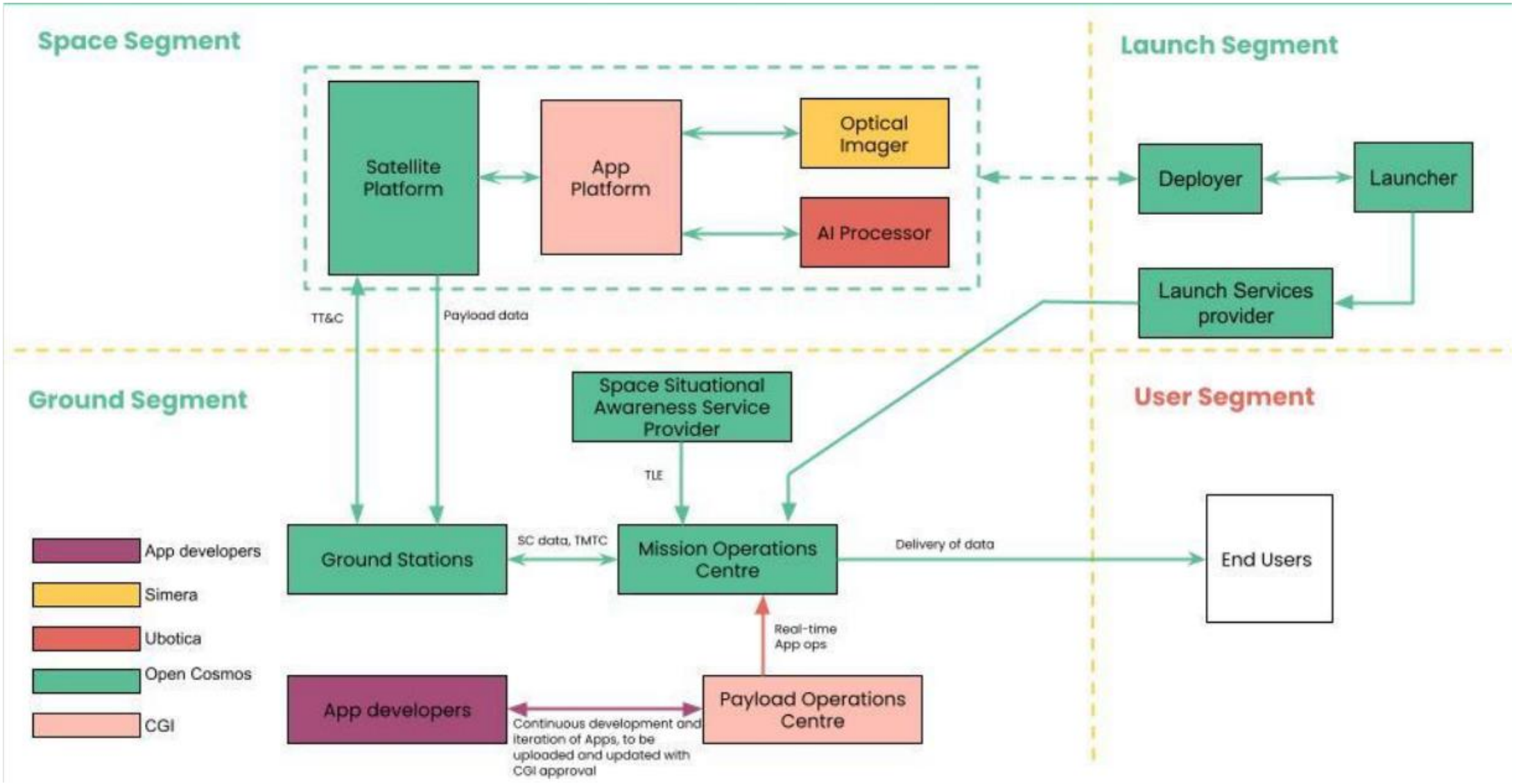
ubotica SIMERA GROUP

- Multispectral Camera – Multiscape 100 (Simera Group)
- AI Inference system (Ubotica)
- Support to data processing (Ubotica)
- Support to payload system integration (Ubotica + Simera Group)

CEIIA GEO-K KP LABS CGI

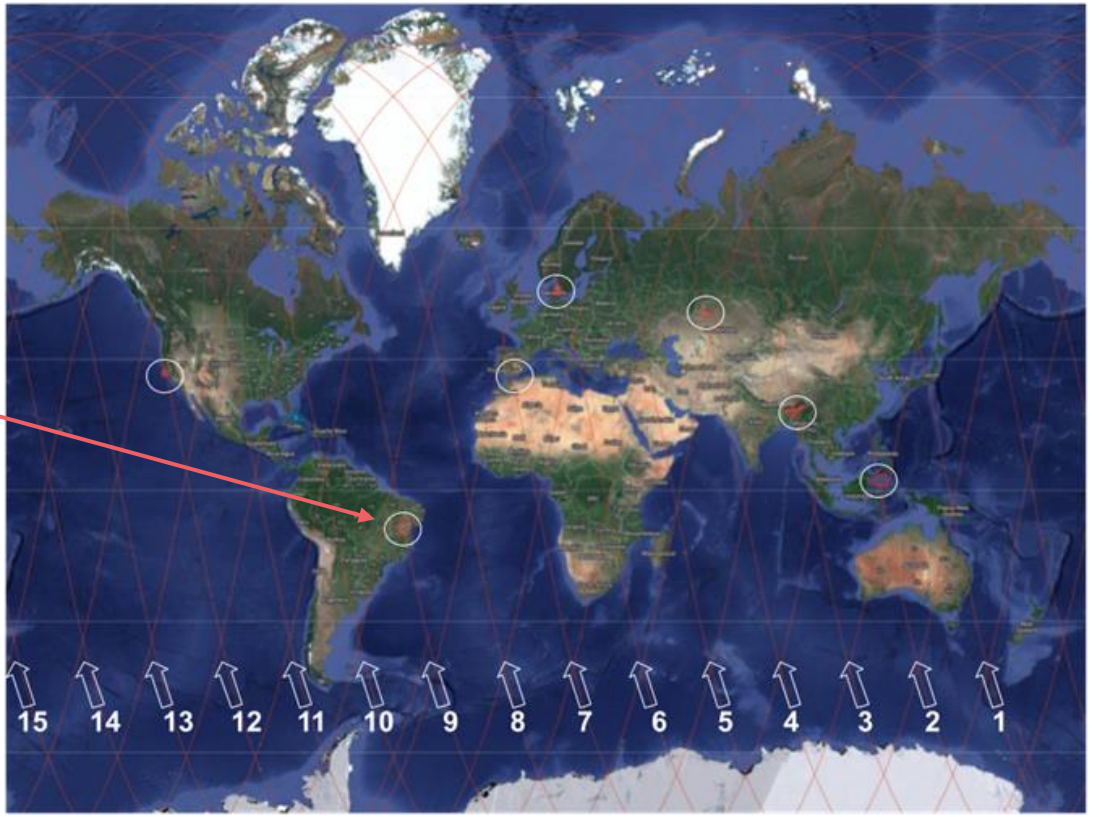
- Sat2Map Application (CGI)
- Autonomous Vessel Detection (CEIIA)
- Cloud Detection (KP Labs)
- Deep Compression (GEO-K)

Mission Architecture



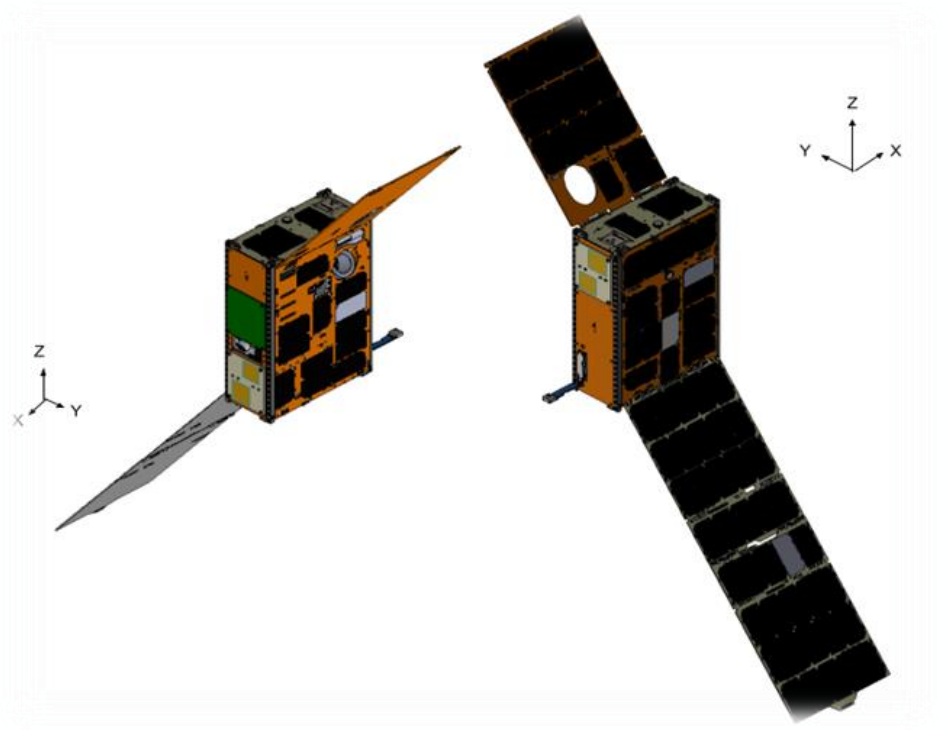
Mission Description

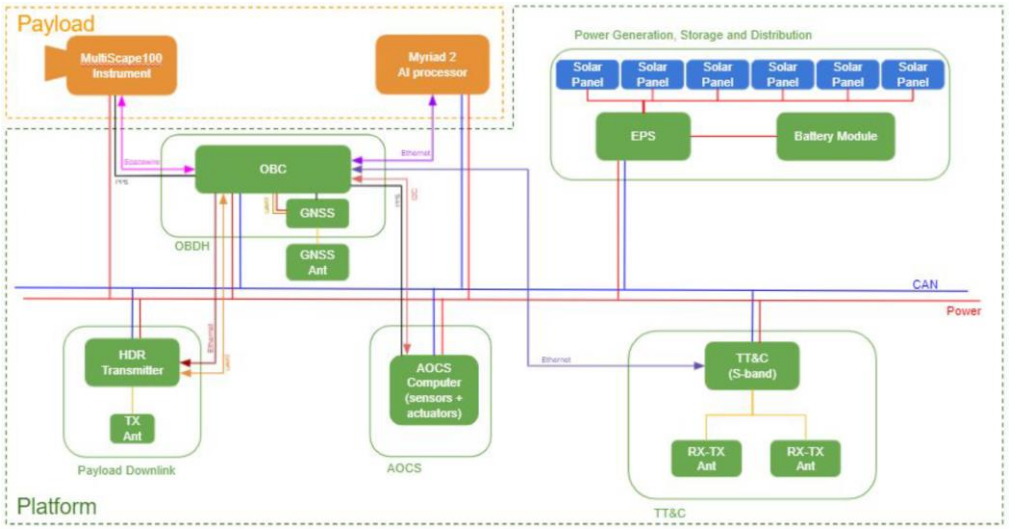
- Orbital Parameters:
  - Altitude range 500-530 km (rideshare launch)
  - SSO
  - LTAN 10:00-11:00 AM
- 4 pre-selected applications (+2 to be selected before mission launch) that are the main driver for the mission design, ROIs
- Application provider can select the number of bands to be acquired during the passage (up to 7)
- CONOPS foresee a baseline activity that will alternate the acquisitions for the various apps throughout the day (minimal platform off-pointing capability required to provide required coverage)
- Specific request from Application Providers will be managed during the mission operative phase via the payload control center
- Data is acquired, stored and transmitted to ground 4 times a day (K-SAT Lite, Svalbard GS)

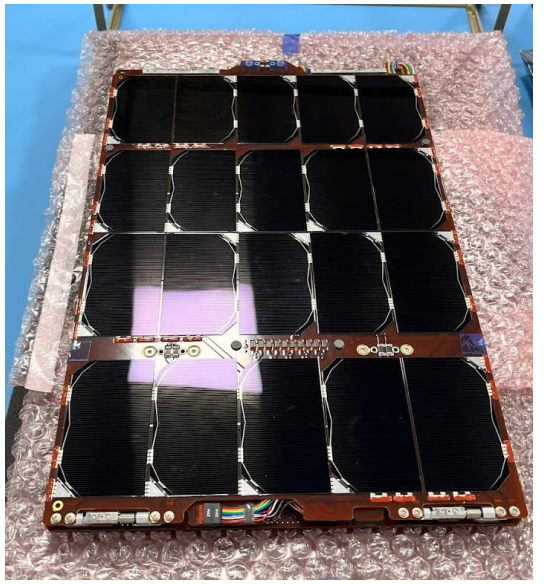


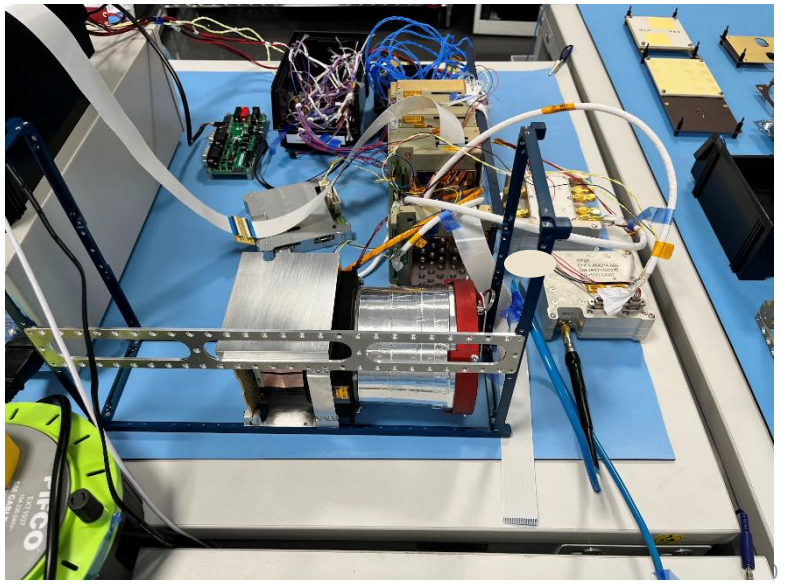
Platform

- Standard 6U Open Cosmos Platform with deployable SA
- High Performance Cubesat AOCS system with RWs dampening system
- S-band link for TT&C and X-Band link for data download (>250 Mbps, use of acknowledged type protocol)



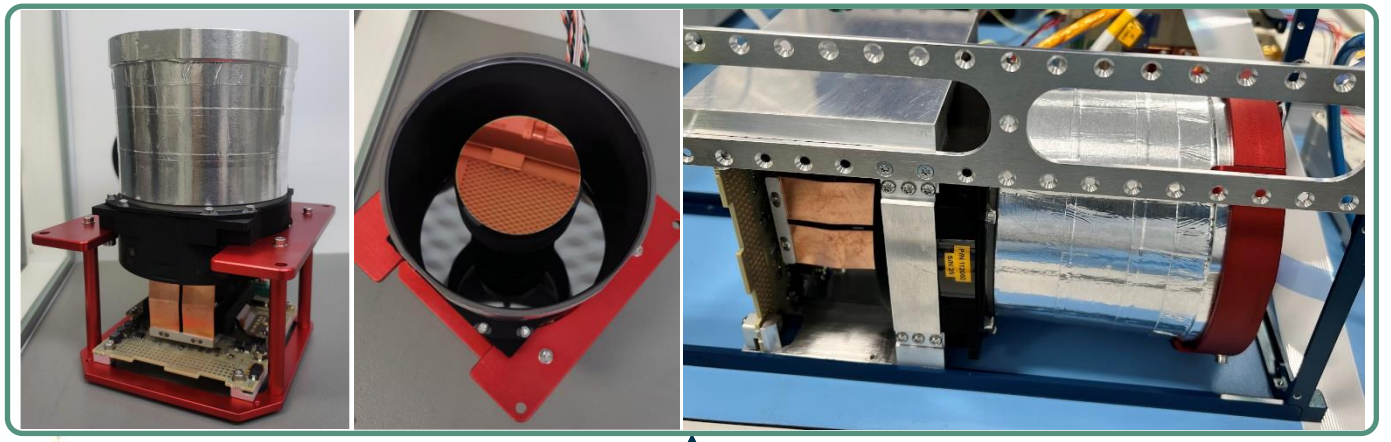


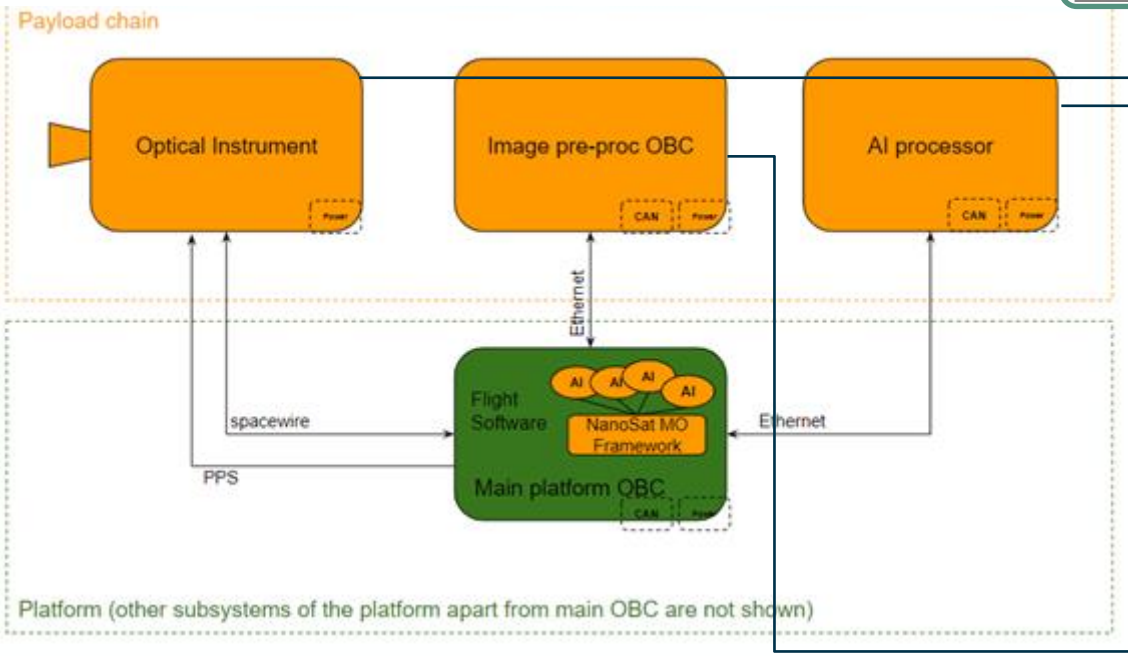


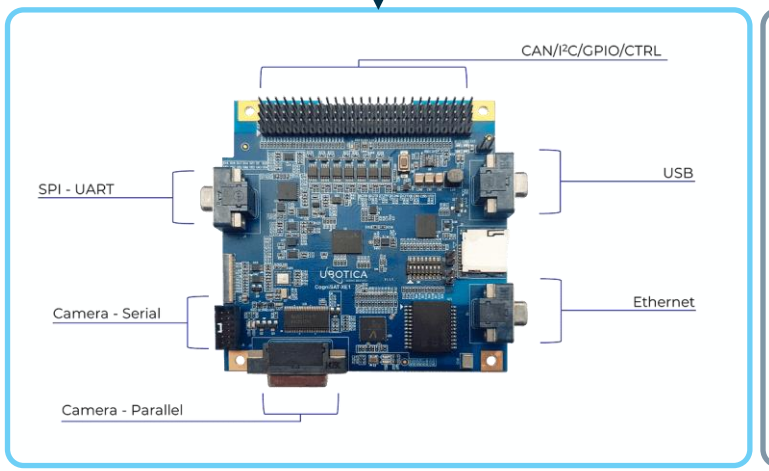


Payload System Architecture

- SIMERA Sense Multiscape 100
  - 5 m GSD @ 500 km
  - FOV 2.22 deg ACT, 1.67 ALT
  - 1 PAN + 7 MS
  - 4096x4096 CMOS Detector (5.5 um pitch)
  - 8 dTDI stages selected (up to 32)



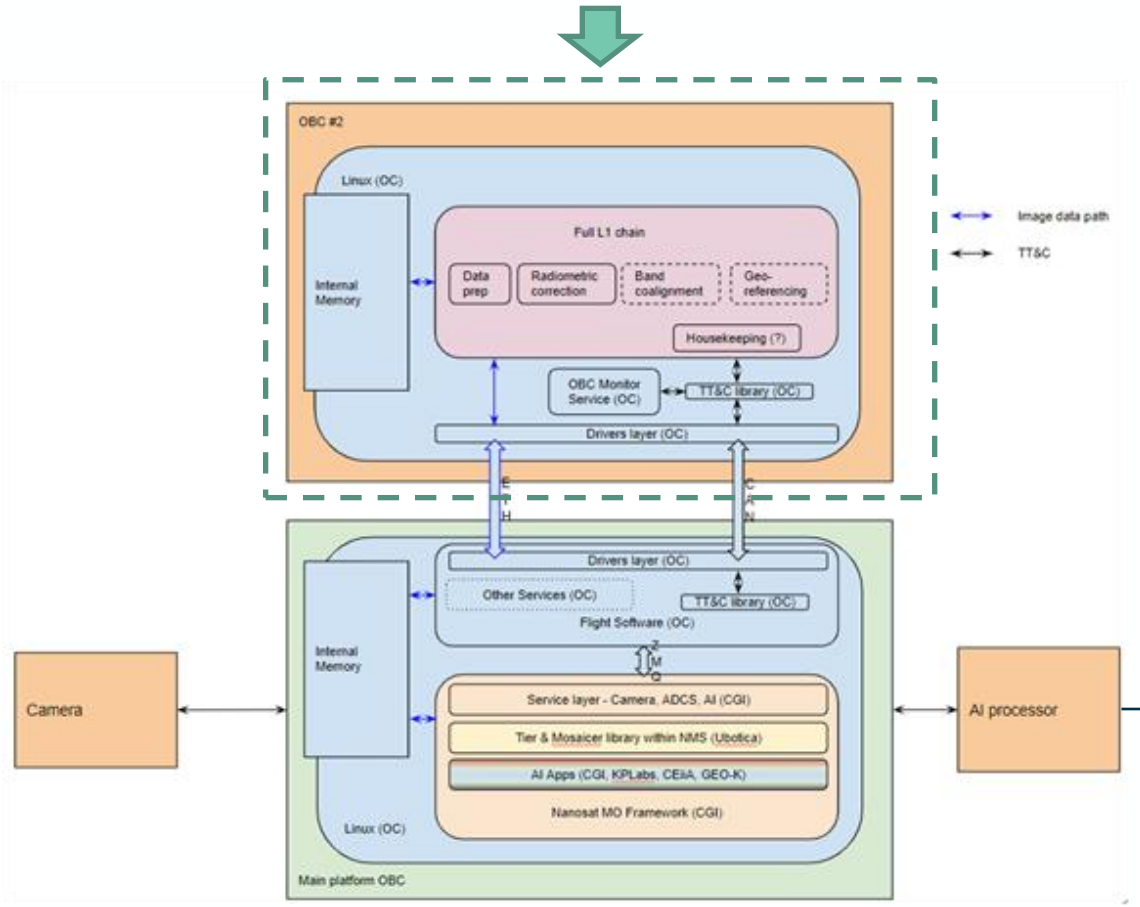


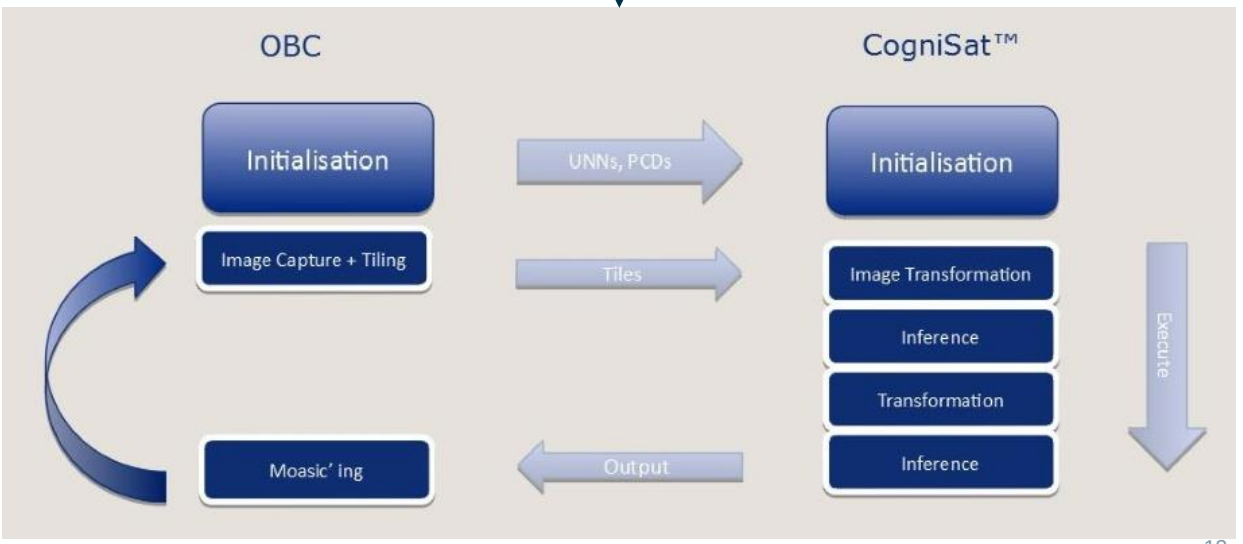


Payload Data Processing - Overview

- Outcome of Phase-1 was the need to:
  - Improve band to band registration accuracy
  - Improve onboard data geolocation capabilities

Name	Data-Products description
Level 1A	Top of Atmosphere Radiance in sensor geometry, no geo-referenced, no band-to-band alignment
Level 1B	Top of Atmosphere Radiance in sensor geometry, fine geo-referenced, fine band-to-band alignment (<10 m RMSE).
Level 1C	Top of Atmosphere Reflectance in sensor geometry, fine geo-referenced, fine band-to-band alignment (<10 m RMSE). This product level is not orthorectified.





Payload Data Processing - Implementation

- The Level 1B/C pre-processing library is currently implemented on the Φsat-2 flatsat on its representative unit:
  - All processing steps have been measured in terms of processing time and resource utilization
  - Verification campaign is currently being performed with representative images from a different mission (moving from synthetic to actual data)
  - SW is currently being optimized in parallel to verification campaign to minimize the resource usage
  - Further optimizations will be provided during the commissioning phase of the mission

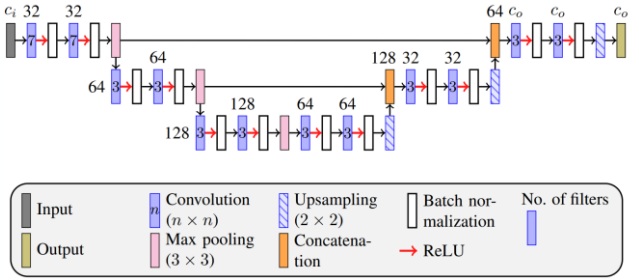
Algorithm	Execution Time [s]
Data Preparation	0.8306
Relative Calibration	0.5859
Cosmetic Filling	0.0189
Denoising	11.0114
Absolute Calibration	0.2993
Bands Co-Registration (per band)	9.617
Radiance to TOA Reflectance (per band)	10.0912
Geolocation	8.9405
Data formatting/saving (per band)	7.6781

Application	Execution Time [s]
Cloud Detection (standalone application)	79.4930
Cloud Detection (Service)	79.0614
Street Mapping	78.8457
Vessel Detection	67.5177
Deep Compression	78.8457
All bands	297.2039

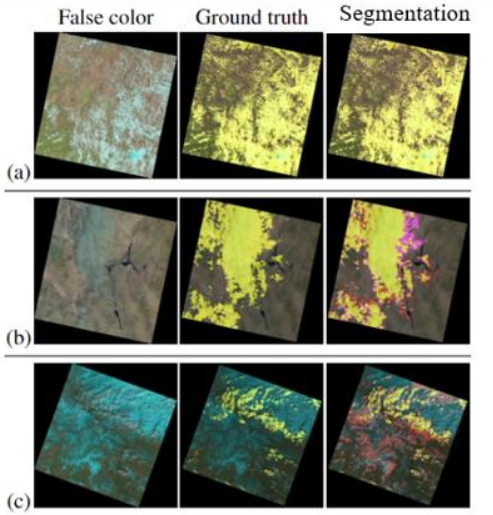
AI Implementation: Cloud detection

Objectives:

- Enable prioritization of data to be downlinked to Ground Segment based on standard cloud coverage and new concentration measure (homogeneous or heterogeneous cloud masks e.g. clouds scattered around the entire scene…)
- Act as an onboard service for other applications to offload them from the tasks of a cloud assessment
- AI techniques:
    - U-Net
- Training database:
    - Phi-Sat-2 representative simulated patches (e.g. MTF, band-to-band mis-alignement, spatial sampling, noise) from Sentinel-2 L1C images (Sentinel-2 KappaZeta dataset).
- Region of interest:
    - Global



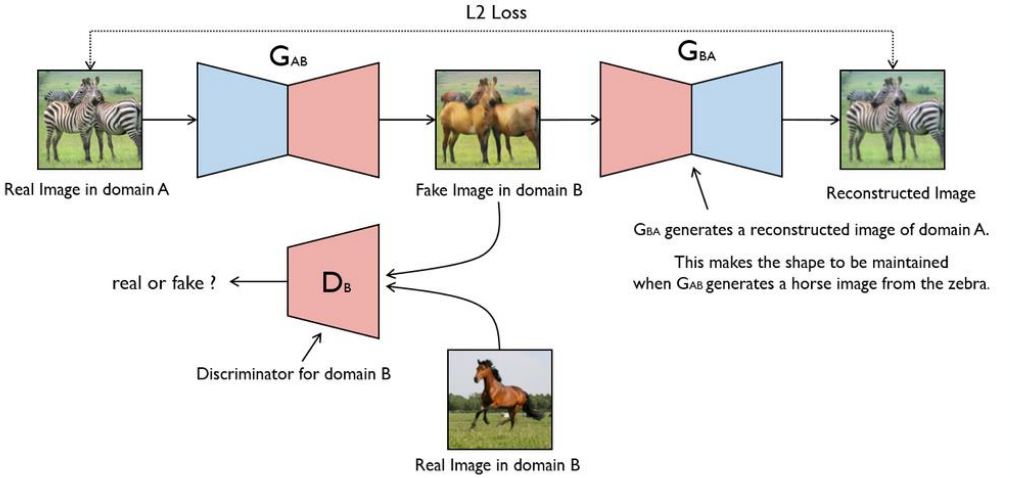
Metric	38-Cloud	L8CCA
Jaccard	73.26	66.67
Precision	85.78	72.82
Recall	83.23	87.91
Specificity	96.27	87.37
Accuracy	94.03	87.82

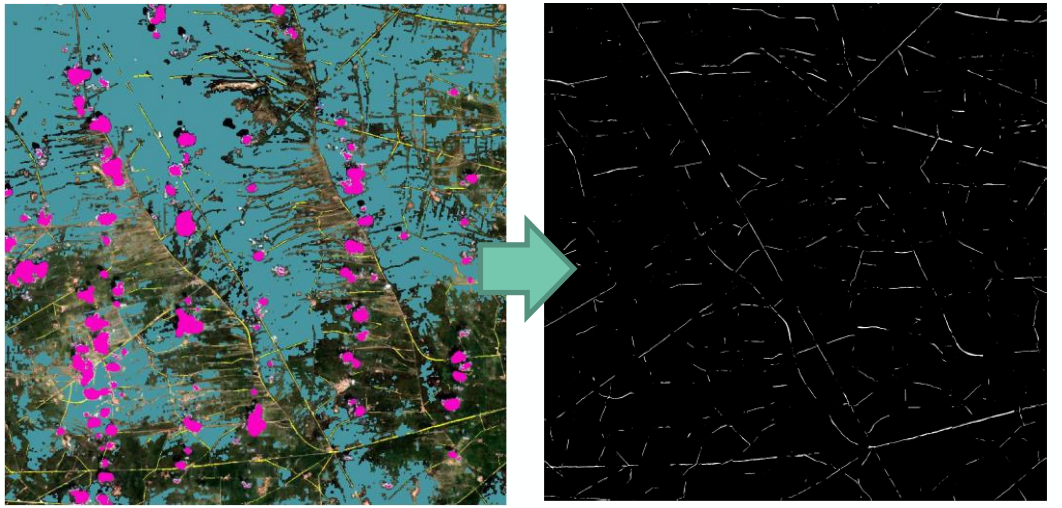


AI Implementation: *Sat2Map*

Objectives:

- automatically obtain street map information from MSI images using AI.
- enable rescue teams, for example, to use standard satellite images to identifying which roads are accessible after an earthquake or flood.
- AI techniques:
    - CycleGAN architecture
- Training database:
    - Open Street Map
    - Phisat-2 simulated images (e.g. MTF, spatial sampling, noise) from Planetscope L1A and Sentinel-2 L1C products
- Region of interest for first demonstration:
    - South East Asia

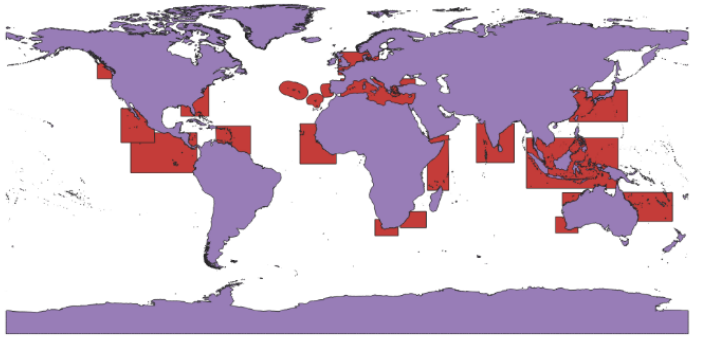




AI Implementation: *Autonomous Vessel Awareness*

Objectives:

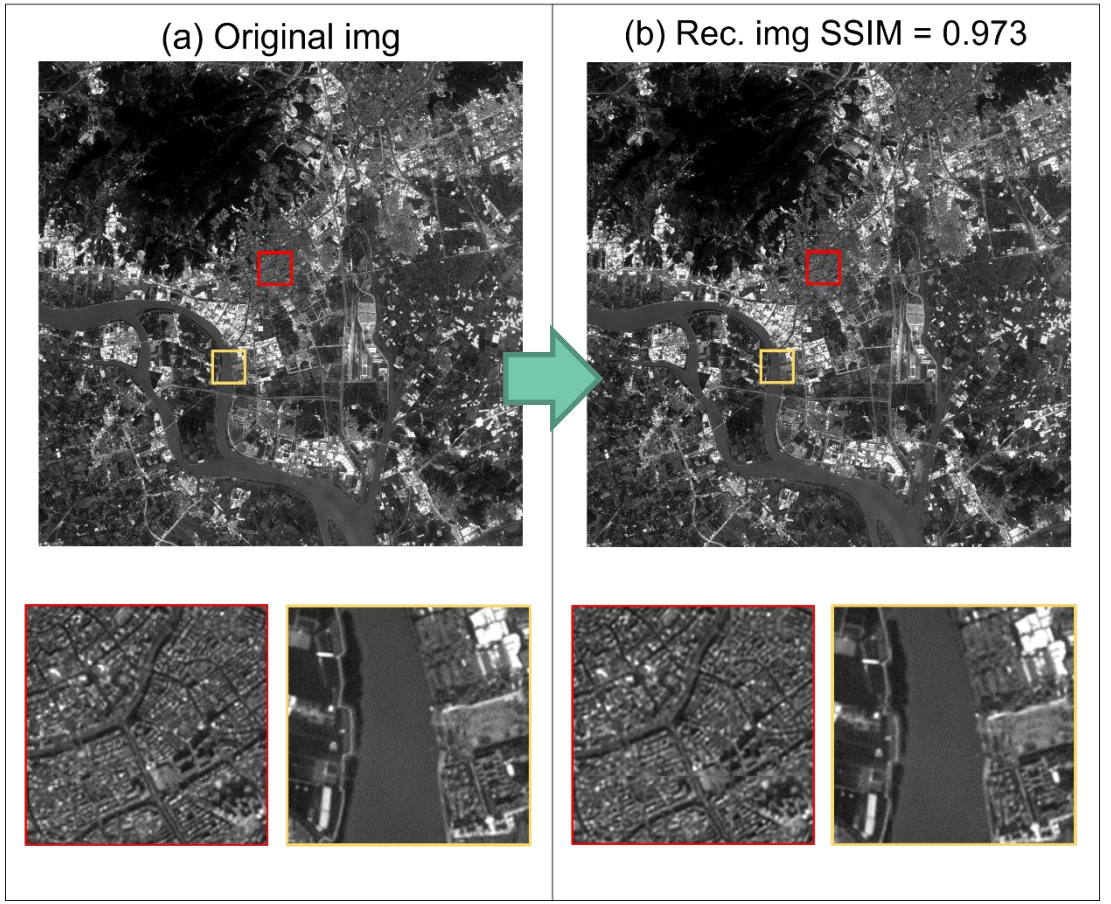
- autonomously develop awareness about vessels (detect and classify various vessel types) in the maritime domain using AI
- enable reduction of downlinked data volume (only downlink of vessel patches), reduce image processing on ground enabling faster responses for final end-users (e.g. maritime authorities..)
- AI techniques:
    - Single Image Super resolution (SRCNN) + CNN Yolo-based network
- Training database:
    - 36 000 Phisat-2 simulated patches (e.g. MTF, band-to-band mis-alignement, spatial sampling, noise) from Sentinel-2 L1C images, with corresponding AIS information
- Region of interest:
    - Global focusing on protected areas and areas prone to illegal activities



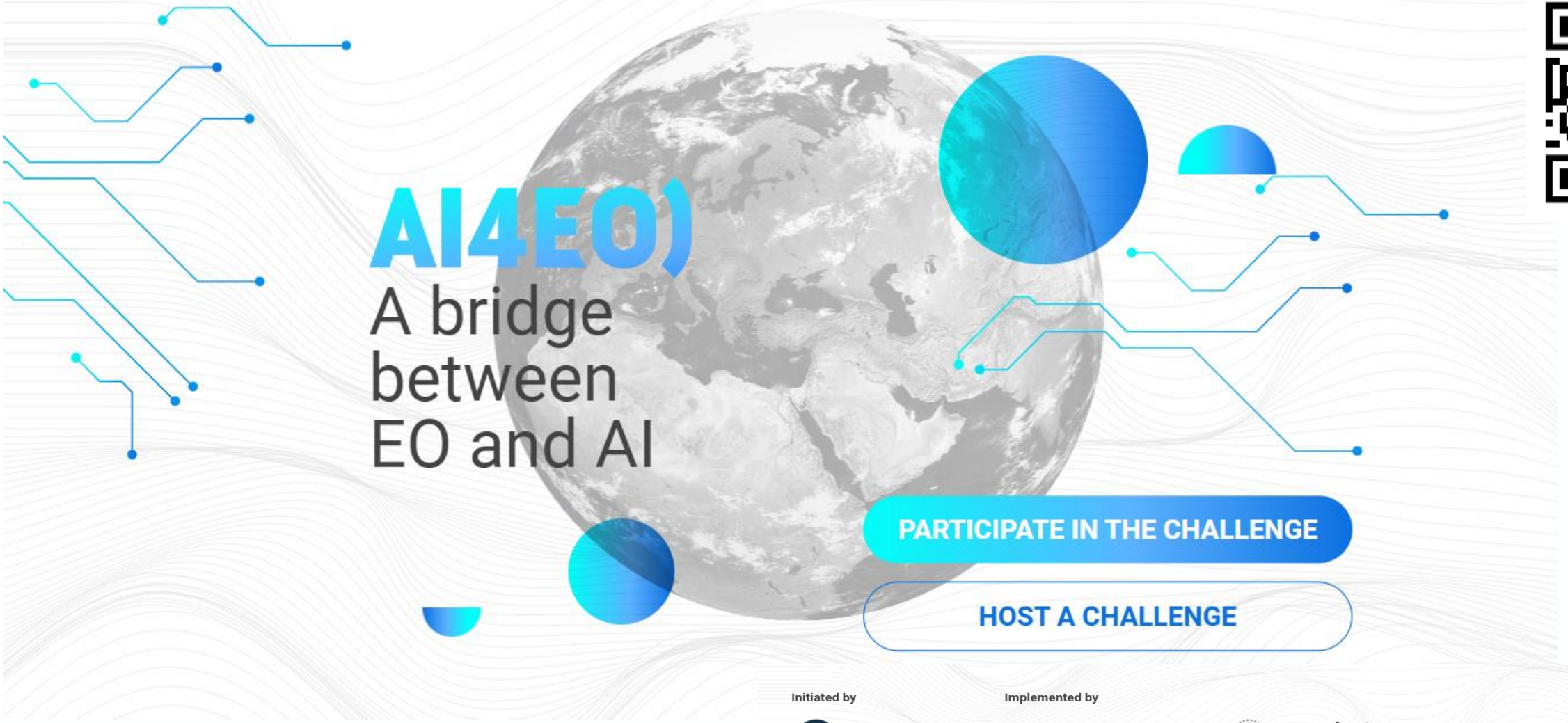
AI Implementation: Deep Compression

Objectives:

- Reduce the amount of data to be sent to the ground with a limited information loss.
- Compression of the image is performed on-board, Reconstruction on the ground by means of the decoder.
- AI techniques:
  - Convolutional AutoEncoder (CAE) -> currently compression rate of ~7 for a single band
  - Currently investigating band-to-band mutual information
- Training database:
  - Phi-Sat-2 representative simulated patches (e.g. MTF, spatial sampling, noise) from S-2
- Region of interest:
  - First demonstration in Europe, focusing on building detection



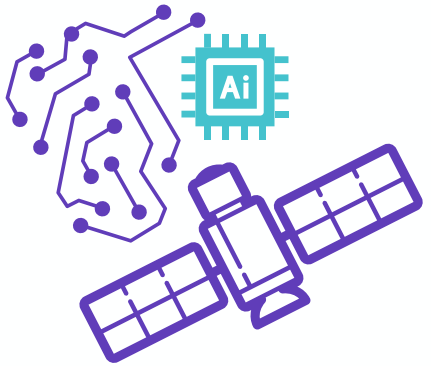
AI Implementation: *Application Challenge*



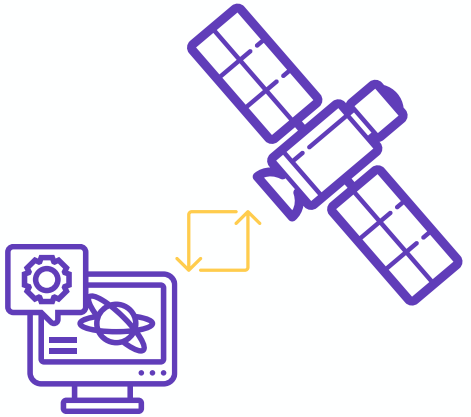
Initiated by

Implemented by

Launch your idea into space!



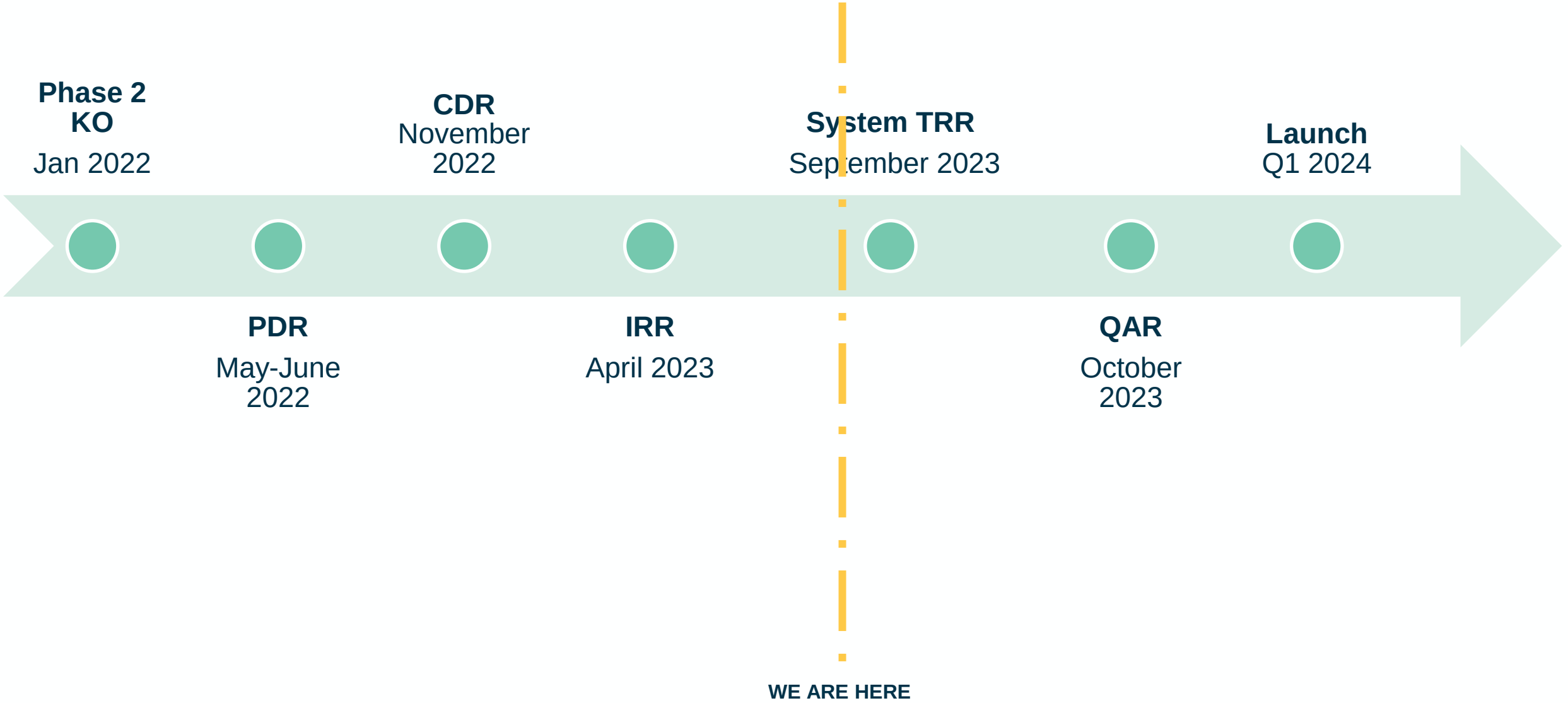
Innovative ways to combine **Artificial Intelligence** and **Earth Observation** using **onboard data processing**



Easily deployed on the spacecraft, **updated during flight**, and operated from the ground using a **simple user interface**

Demonstrate how **satellite data**, coupled with advanced **onboard digital technologies**, can bring **benefits** to **business, industry, and science**

Plan


Phase 2
KO
Jan 2022
CDR
November
2022
System TRR
September 2023
Launch
Q1 2024
PDR
May-June
2022
IRR
April 2023
QAR
October
2023
WE ARE HERE