Electro-Optical Payloads & AI-powered Data Processing Computer for Nanosatellites

L’impegno Italiano nel Settore dei CubeSat
Tecnologie e Missioni Future

Who We Are

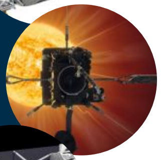
Techno System Developments S.r.l (**TSD-Space**) is a leading Italian private company established in 1977, specialized in designing, developing, and manufacturing of **cutting-edge on-board and ground electronic equipment for aerospace applications.**

FIRST FLIGHT ON 1993

MORE THAN 300.000 HOURS

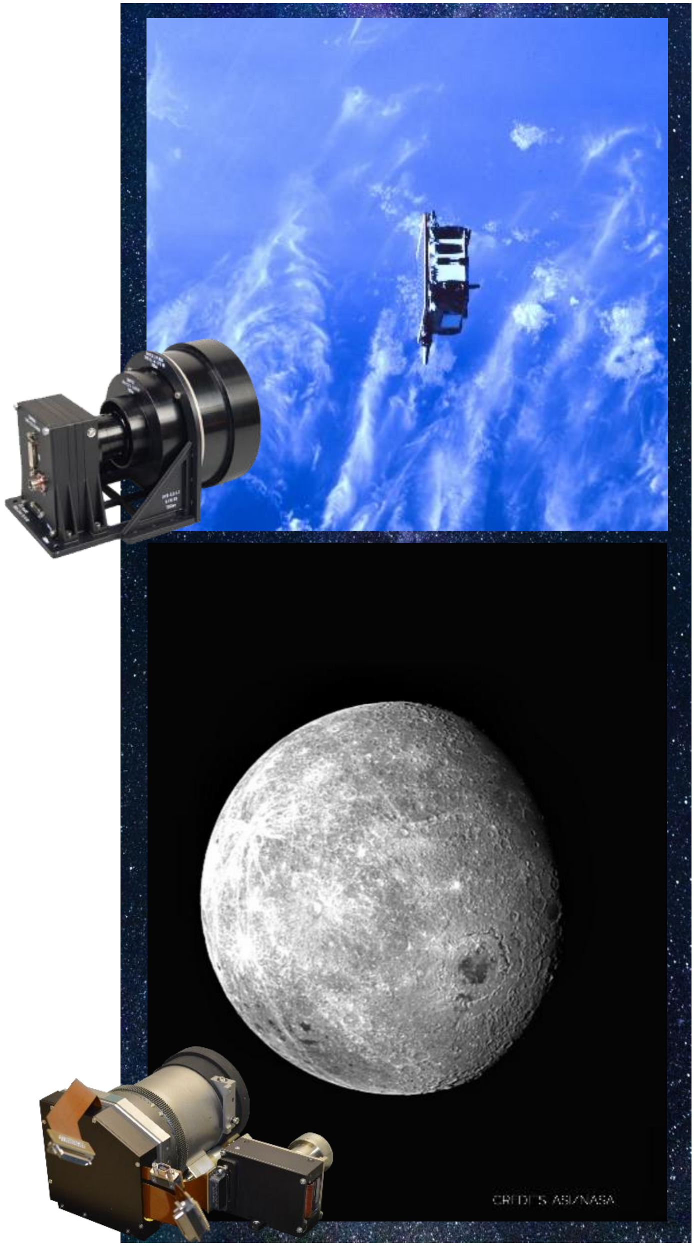
27 Space Missions

FIVE System in Space NOW



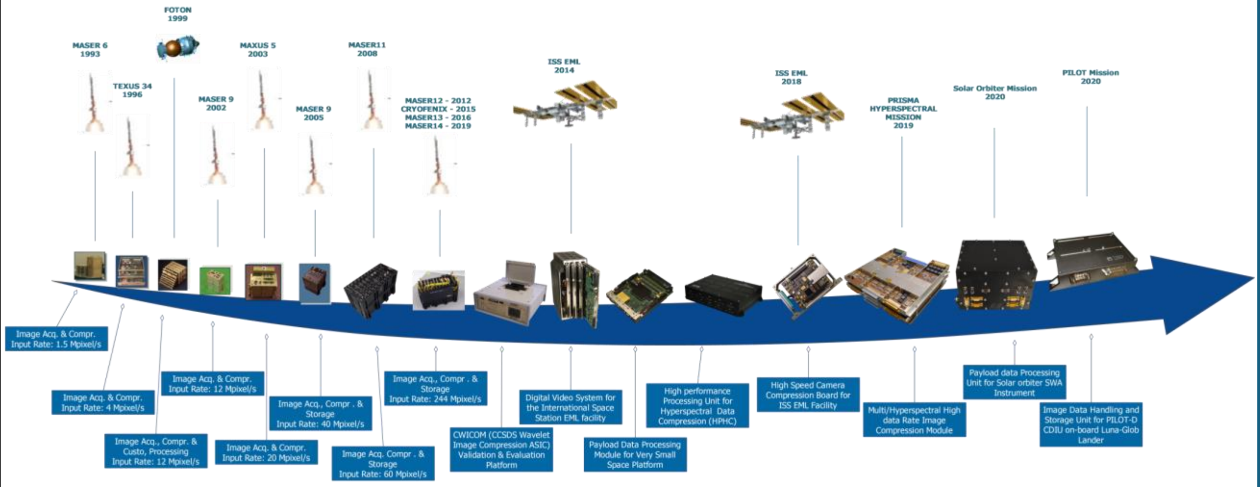
Since the 90s, TSD-Space has been focused on the development of space electronics, paying particular attention to **reducing size**, **mass,** and **power consumption** to make them **suitable for small platforms**, such as **micro** and **nanosatellites**.

In the last decade, technological advancements in the microelectronics, mechatronics, and micromechanics sectors, along with the availability of high-density FPGAs and memories, multi-Gigabit transceivers, and reliable micro and nano-connectors, have facilitated the **development of high-performance and reliable electronics equipment for nanosatellites**.

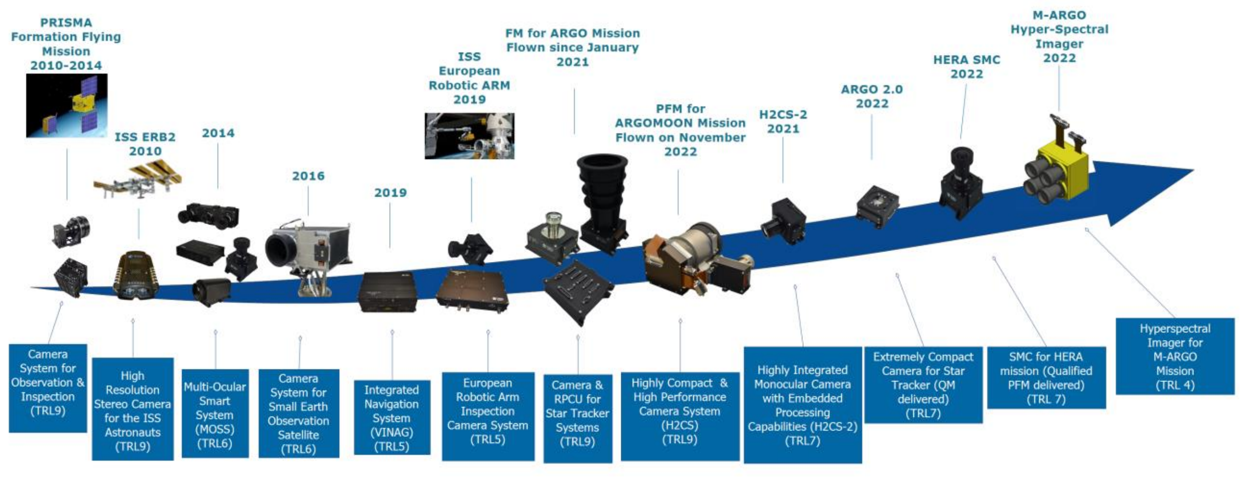


Products Road Map

Throughout its initial 15 years, TSD dedicated its efforts to the development of high-performance, compact **data handling units**, with a primary focus on tasks such as **image acquisition**, **compression**, **onboard storage**, **CCSDS encoding**, and other related functionalities.



Data Handling & Processing Road Map



Camera Road Map

In the last decade, TSD has expanded its expertise to the development of **advanced Camera Systems** for **navigation**, **inspection** and **Earth observation**. The **Newer -main products under development for CubeSats:**

- ❑ **PAN & Multi-Spectral Cameras** for HR and VHR *Earth Observation (EO) imagers*
- ❑ **AI-powered Data Handling & Processing Units** for both **navigation** and **EO applications**

EarthNext Mission

EarthNext is a **16U CubeSat mission**, in the framework of **ASI ALCOR program**, developed by Officina Stellare as prime contractor, that aims at the in-orbit demonstration of **Very Low Earth Orbit (VLEO) operations for multispectral imaging of the Earth**, for land and marine applications.

It has successfully passed the Preliminary Design Review (PDR), thus marking the conclusion of the preliminary design phase.

TSD-Space is responsible for developing:

- **Data Handling & Processing** for **Platform & Payload**
- **FPA & Camera Electronics** of a multispectral payload
- **Cloud Camera (**Wide FOV & Low Res)
- **Electrical Power System**
- **Data Communications**

EarthNext – FPA & Camera Electronics

The multispectral camera is characterized by a very innovative design solution, ensuring an **extremely compact architecture**. The camera is composed of two thermo-structurally decoupled assemblies.

- The **Focal Plane Assembly** (FPA): hosting CMV20k, a COTS CMOS image sensor by CMOSIS with a resolution of 5120x3840 pixels (detector size = 6.4 μm)

- **Main Camera Electronics** (CE): the mechanical configuration is based on a fully stand-alone stack solution. The PCB sections are located in a number of independent mechanical/structural frames that then are piled up in a stack.

The FPA and the CE **are interconnected** by means of **flexible PCB-based link**. It allows a very accurate positioning of the focal plane with respect to the overall telescope assembly and reduces the thermal noise contribution to the FPA.

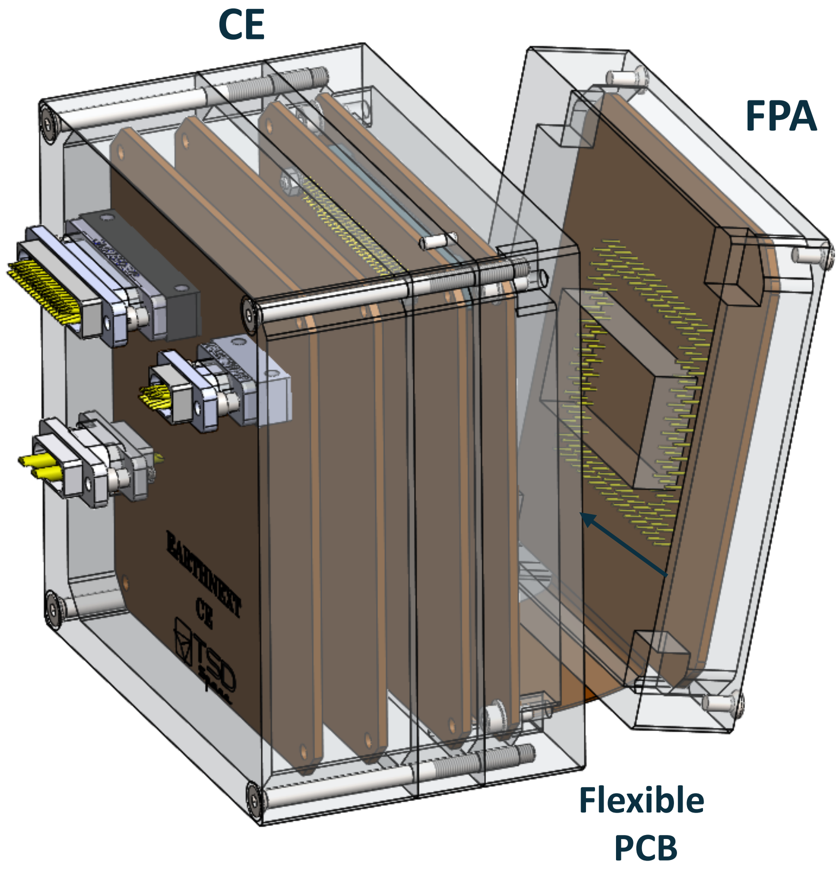
Item	Mass [g] (Electronis + Mechanical)
CE + FPA	798.5
FPA	208.5

Status	Power Consumption [W]
Acquisition	14.6
Idle	1.1

SpaceWire:
- Configuration
- Control
- Monitoring
- Time syn
- In-flight program

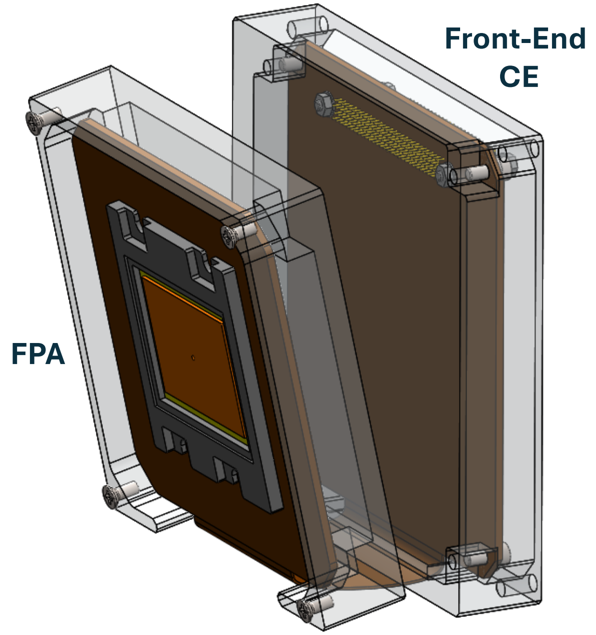
2x ChannelLink
- Image Data Output
- Request & Grant HS

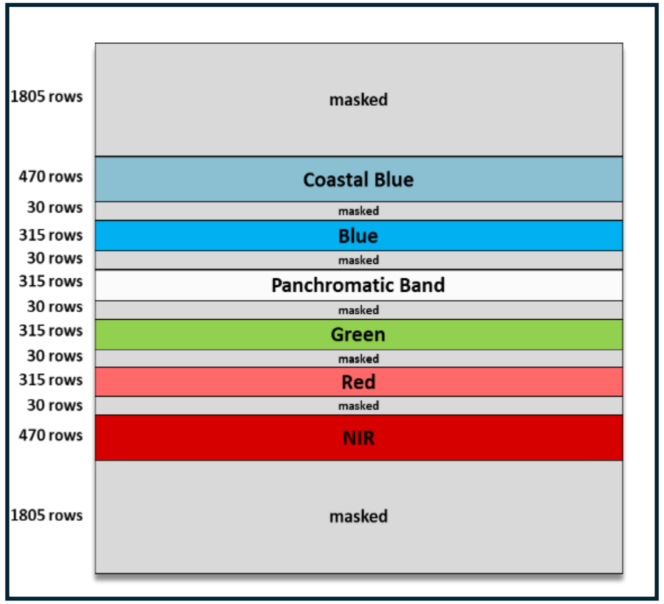
Power Input
Power Enable
Status
Trigger input
Heaters & Thermistor

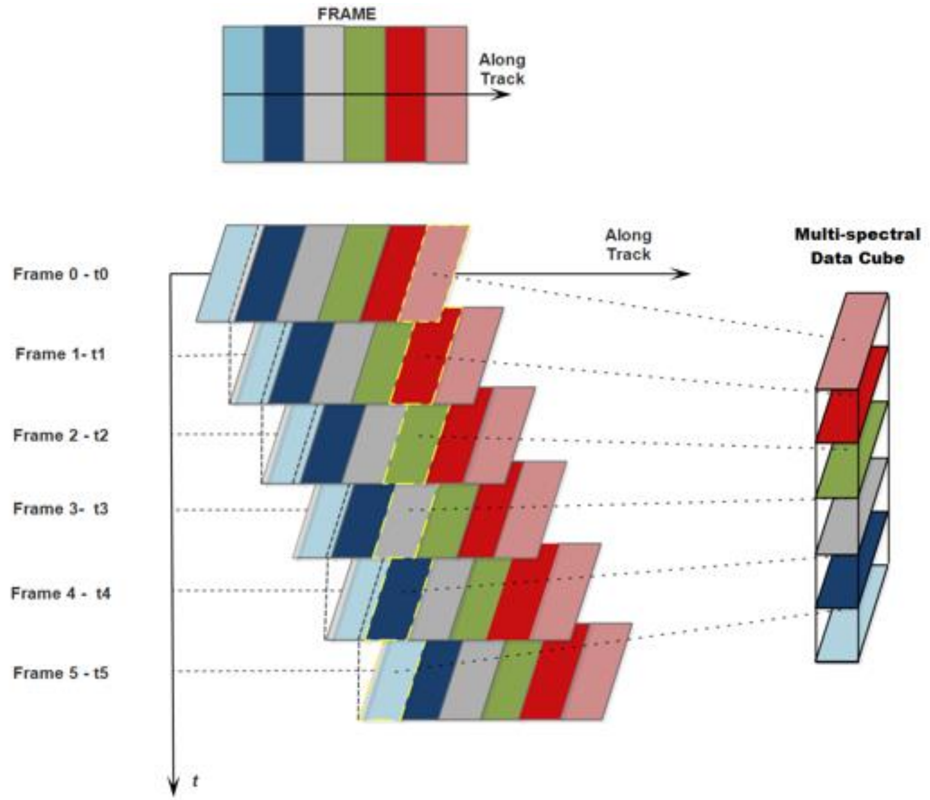


EarthNext – FPA Details

The Explorative Payload adopts the ***stairing mode*** (or ***area mode***) for the imaging operation. The imaging can be carried out *frame by frame*: a snapshot is taken at one instant covering a certain area on the surface . A stairing sensor works by collecting image data across the orbital swat and utilizes the forward motion of the spacecraft along the path of the orbit to provide successive frame with a certain overlap.



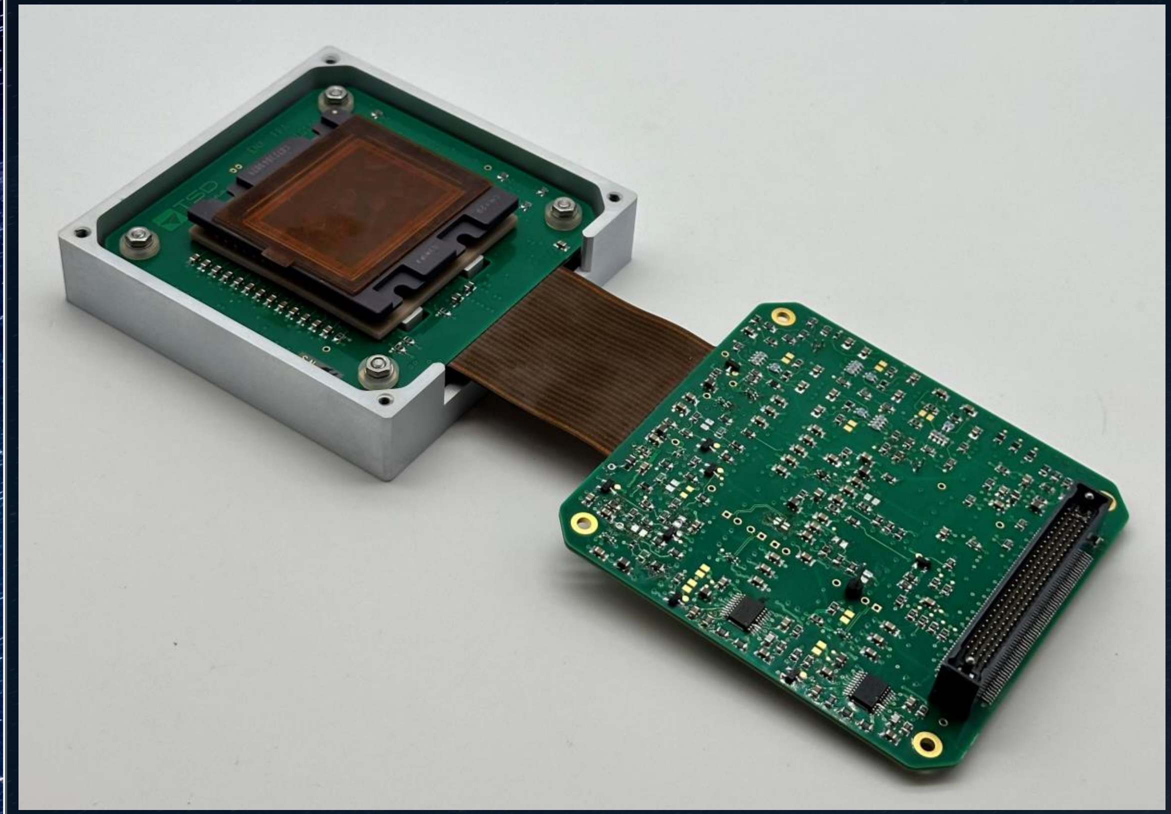


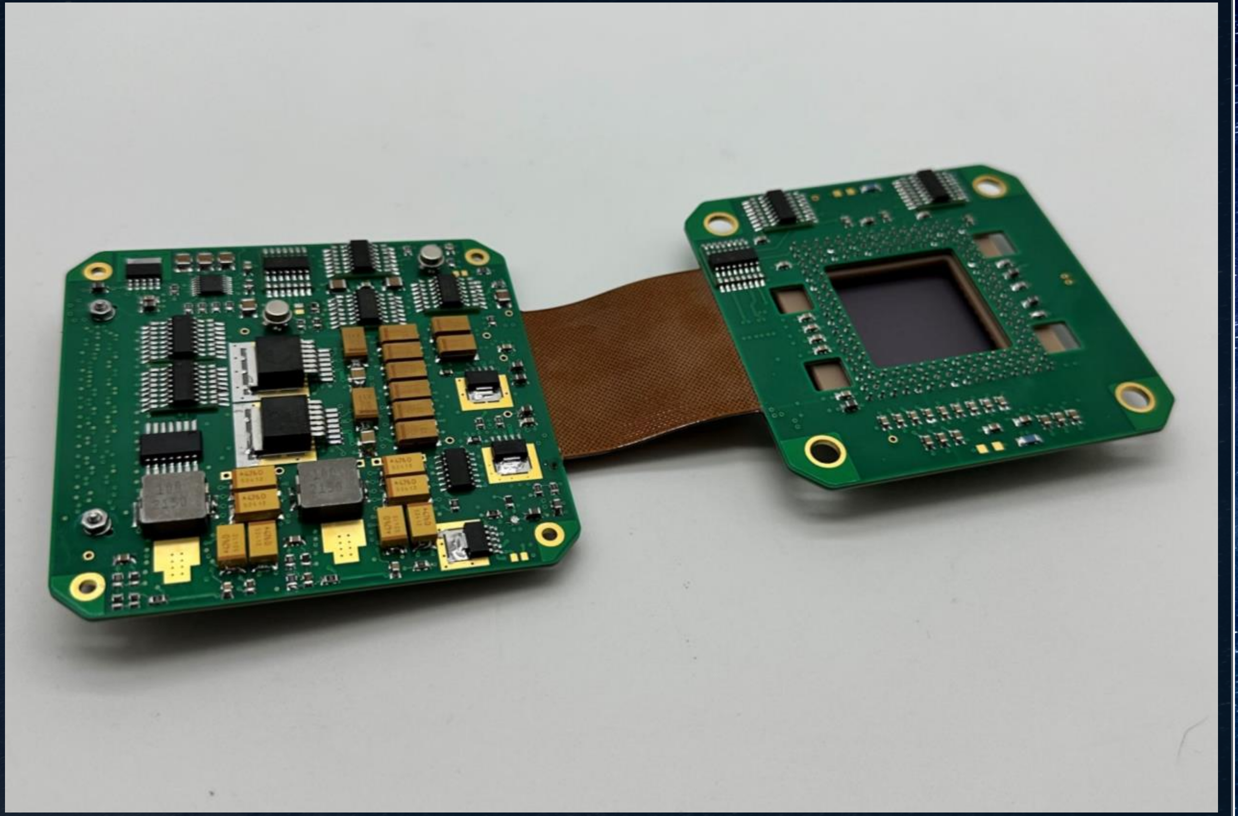


The multispectral filter array applied to the 2D image sensor, allows to implement the "**Spatio-Spectral Scanning**". It is based on the adoption of a filter array that transfers the selected spectral wavelengths of the optical signal to different regions (sub-stripes) of the 2D image sensor

EarthNext – FPA & Front-End CE BreadBoard

The **FPA B/B** has been developed as an **engineering model**, to solve any possible criticality in Phase B and reduce significantly any risks in Phase C/D.



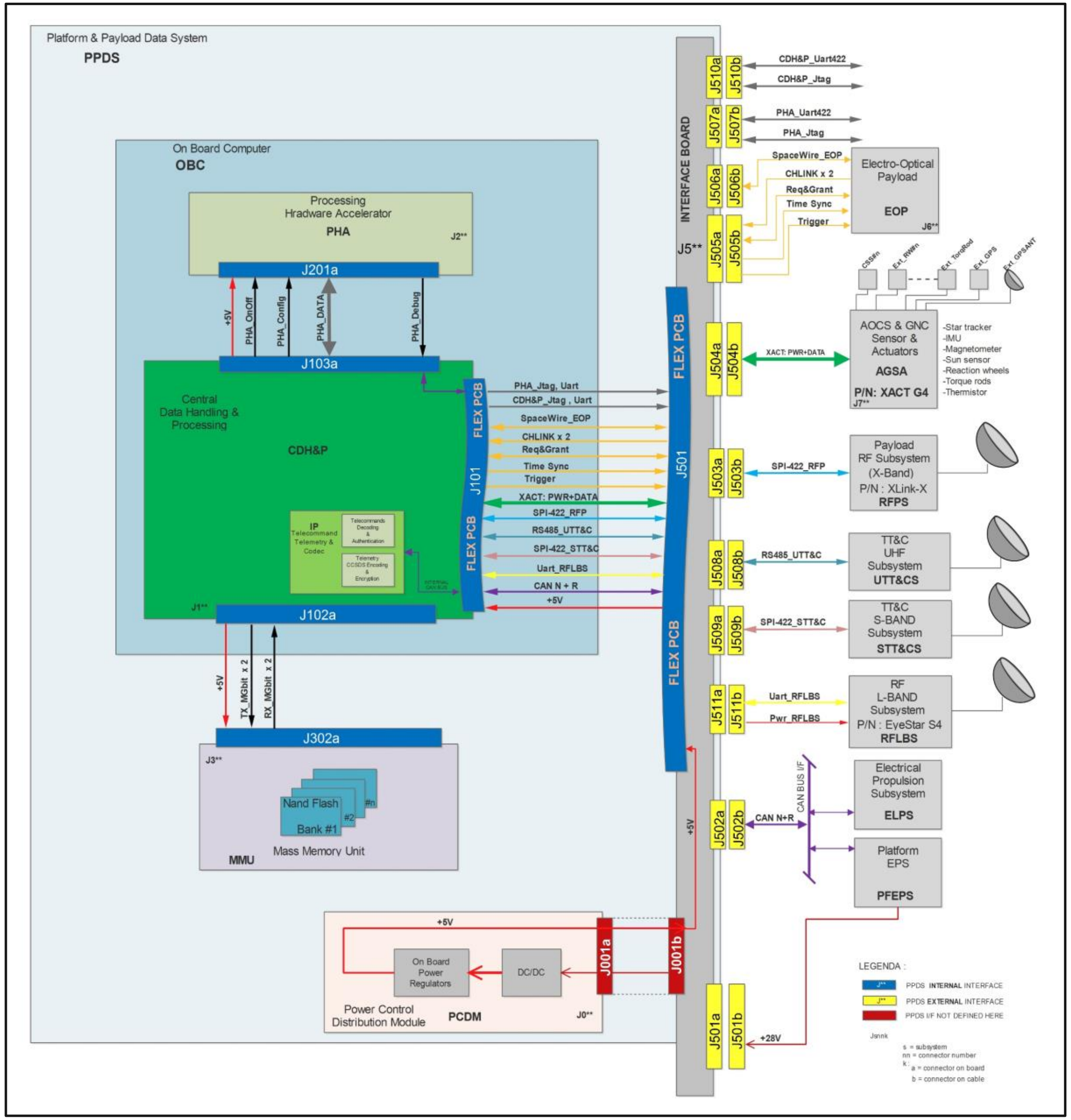


EarthNext – PPDS

The EarthNext avionics architecture is based on an integrated data system, named “**Platform & Payload Data System**” (PPDS), able to support both **the platform and the payload data handling and processing**. Thanks to the very high integration level of the PPDS, it became possible to provide a complete set of functionalities, typically available onboard larger satellite platforms than a 16U CubeSat. The PPDS includes:

- The On-Board Computer (**OBC**)
- The Mass Memory Unit (**MMU**)
- The Power Control & Distribution Module (**PCDM**)
- I/F Board

The OBC performs the control and management of all the avionics and electro-optical payload subsystems. The OBC is characterized by a distributed hardware and software design, based on two subsystems.

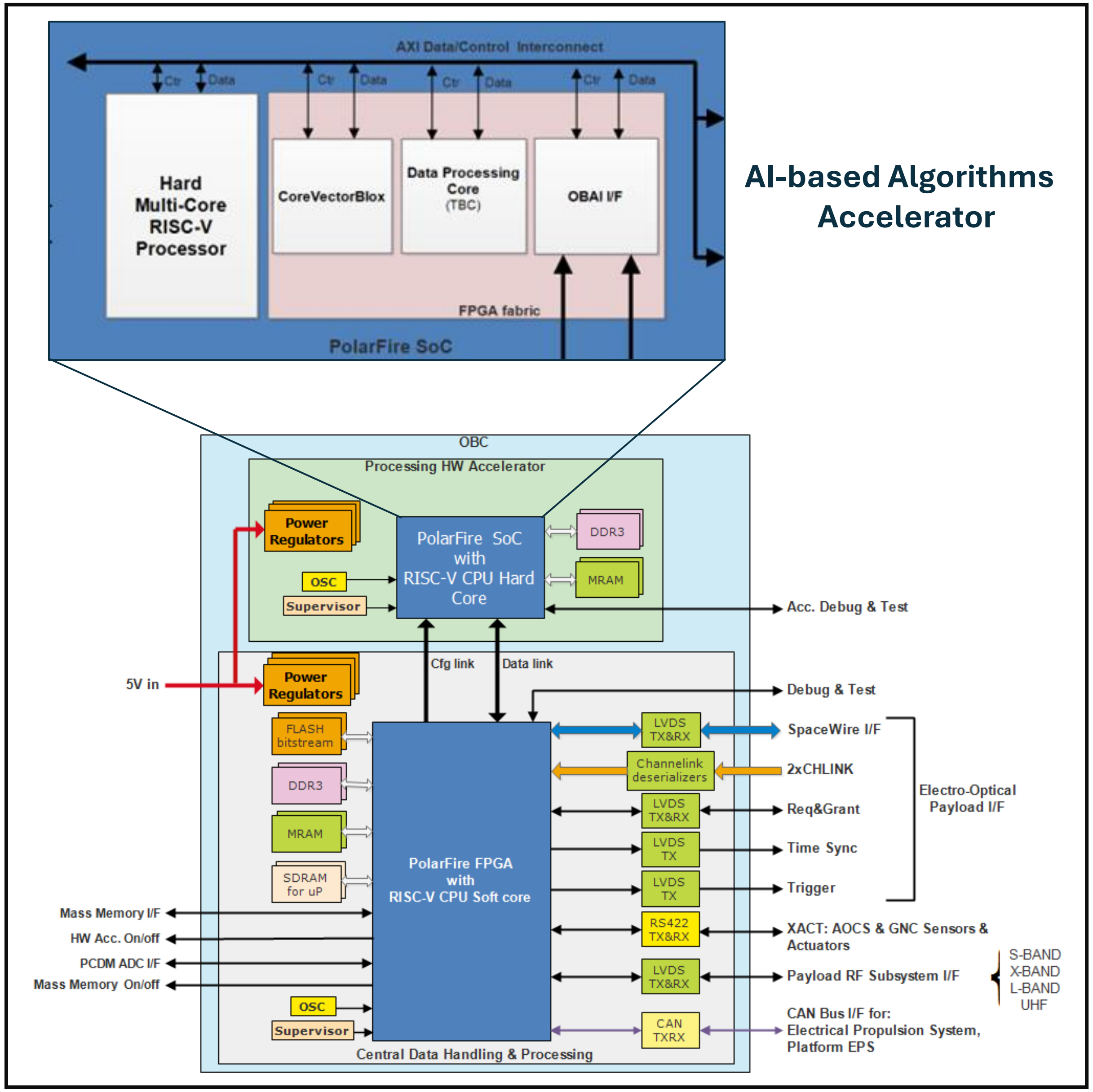


EarthNext – OBC

The OBC is characterized by a distributed hardware and software design, based on two subsystems:

- ❑ The hardware and software architecture for the **Central Data Handling & Processing** (**CDH&P**) is based on Rad-Tolerant PolarFire FPGA to ensure **high reliability** and **robustness** in the **space radiation environment**. The FPGA integrates the RISC-V architecture as soft-core CPU, for the execution of the Application Flight Software, and other VHDL modules for **real-time payload data processing** such as **compression**, **data handling** and **storage**.

- ❑ The **Processing Hardware Accelerator** (**PHA**) leverages the advanced capabilities of Microchip's PolarFire System on Chip (SoC) that combines a powerful hard multicore RISC-V microprocessor, with the FPGA fabric in a single device. The PHA is designed to **enable the deployment of AI-based algorithms onboard spacecraft**. The programmable logic is configured to accelerate challenging computational workflows such as those required by **Deep Learning-based inference processes**.

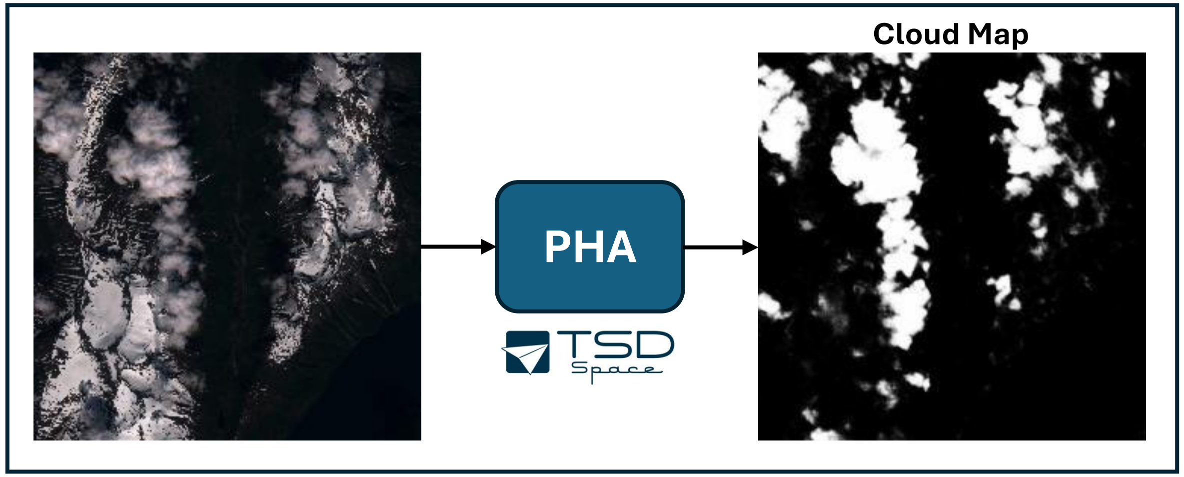


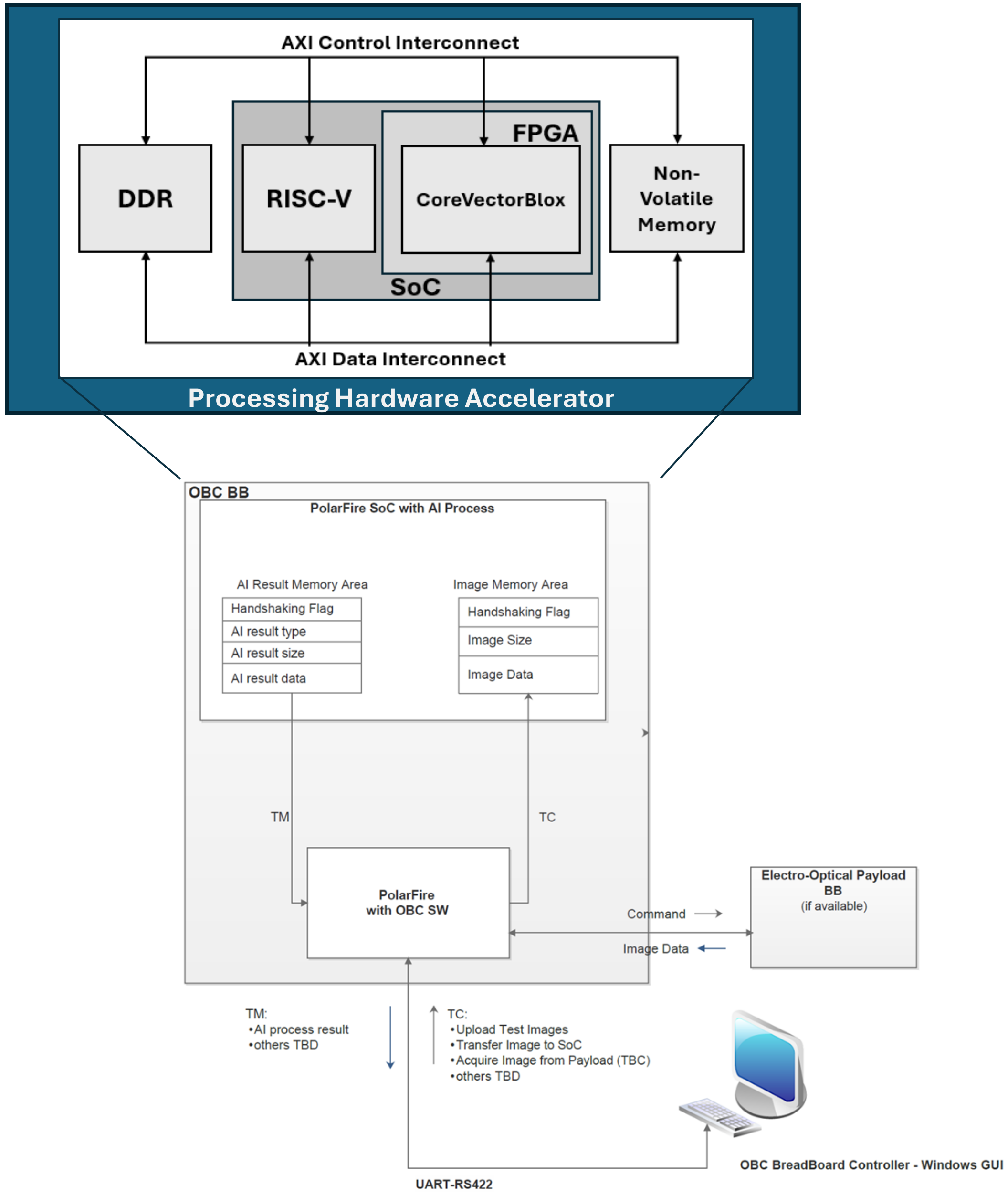
EarthNext – PHA for Onboard AI

In the framework of EarthNext, **AIKO** are developing Deep Learning models for onboard image processing:

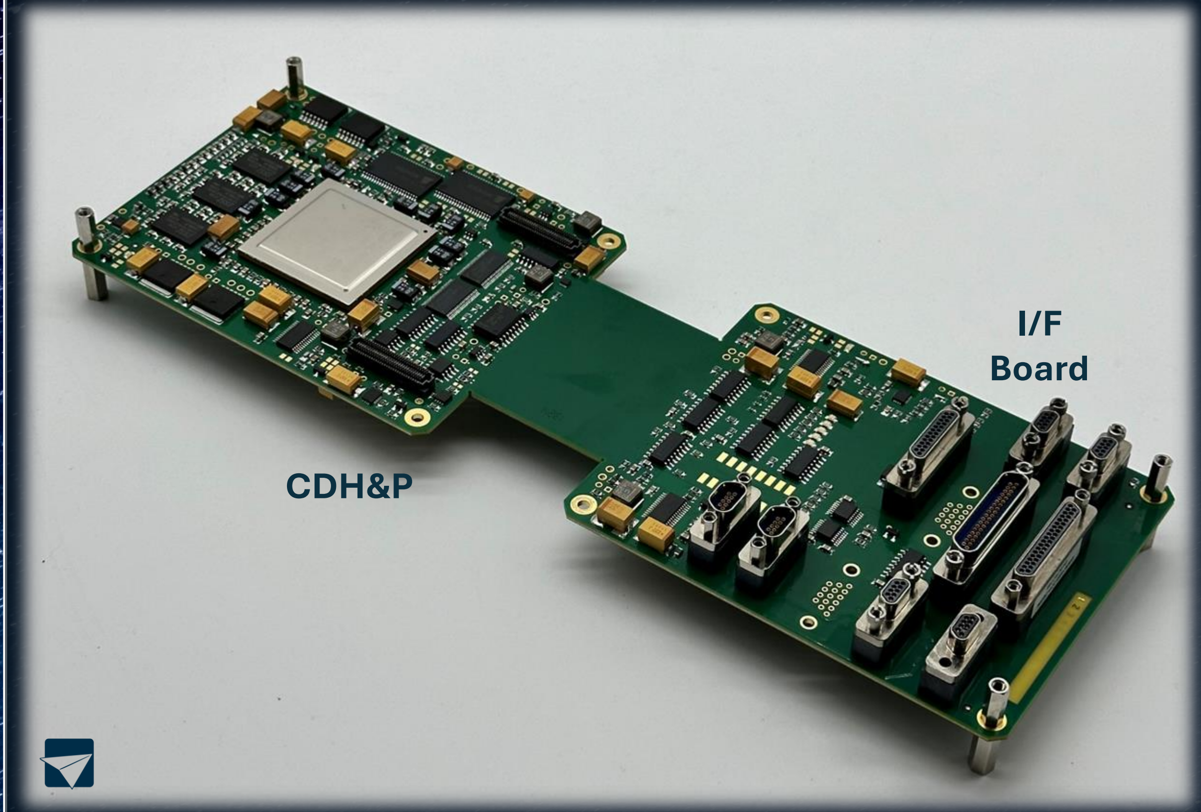
- Cloud Detection task
- Change Detection (Image Segmentation)
- Change Detection (Change Map)
- Precise Agriculture

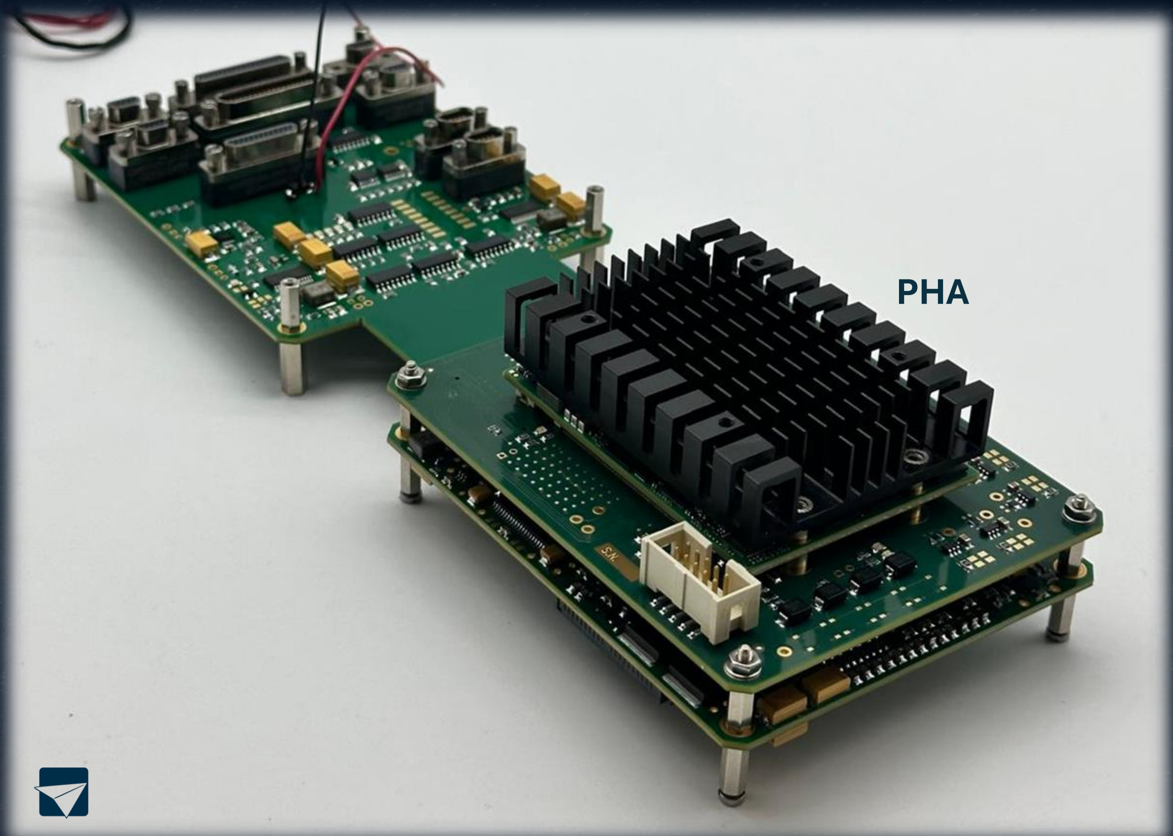
The PHA is tailored to speed up heavy computational algorithms such as Deep Learning models for onboard image processing. The design is based on the Microchip FPGA HW accelerator **CoreVectorBlox**





EarthNext – OBC BreadBoard



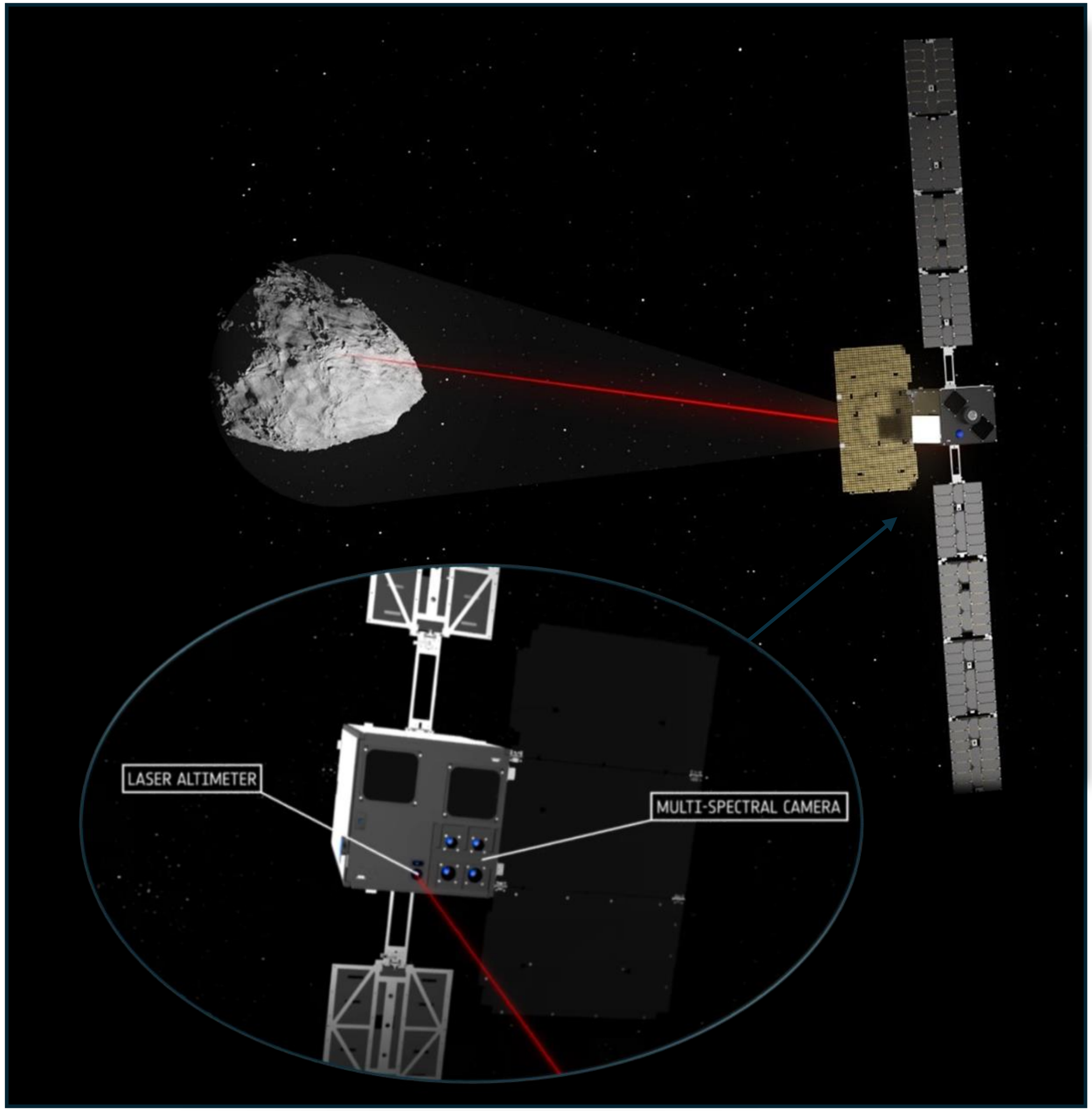


M-ARGO Mission

The **M**iniaturised **A**steroid **R**emote **G**eophysical **O**bserver (**M-ARGO**) mission is designed to be **ESA**'s **first stand-alone CubeSat to independently travel in deep space** with its own electric propulsion and direct-to-Earth communication systems in order to **rendezvous with a near-Earth asteroid (NEO) and perform its physical characterization**.

- TSD-Space are developing the Hyperspectral Camera. The **imager is dedicated to the identification of silicates and hydrated minerals on NEO target**, to be down-selected from a long list of 119 accessible NEO targets, within mission & system design constraints.

- This mission is ambitious, targeting an asteroid located 150 million kilometers from Earth, chosen from over 700,000 potential candidates through a rigorous selection process. The core mission objective is to analyze the asteroid's physical properties, including its shape, mass, and composition, providing invaluable insights into the potential for in-situ resource utilization on such celestial bodies.

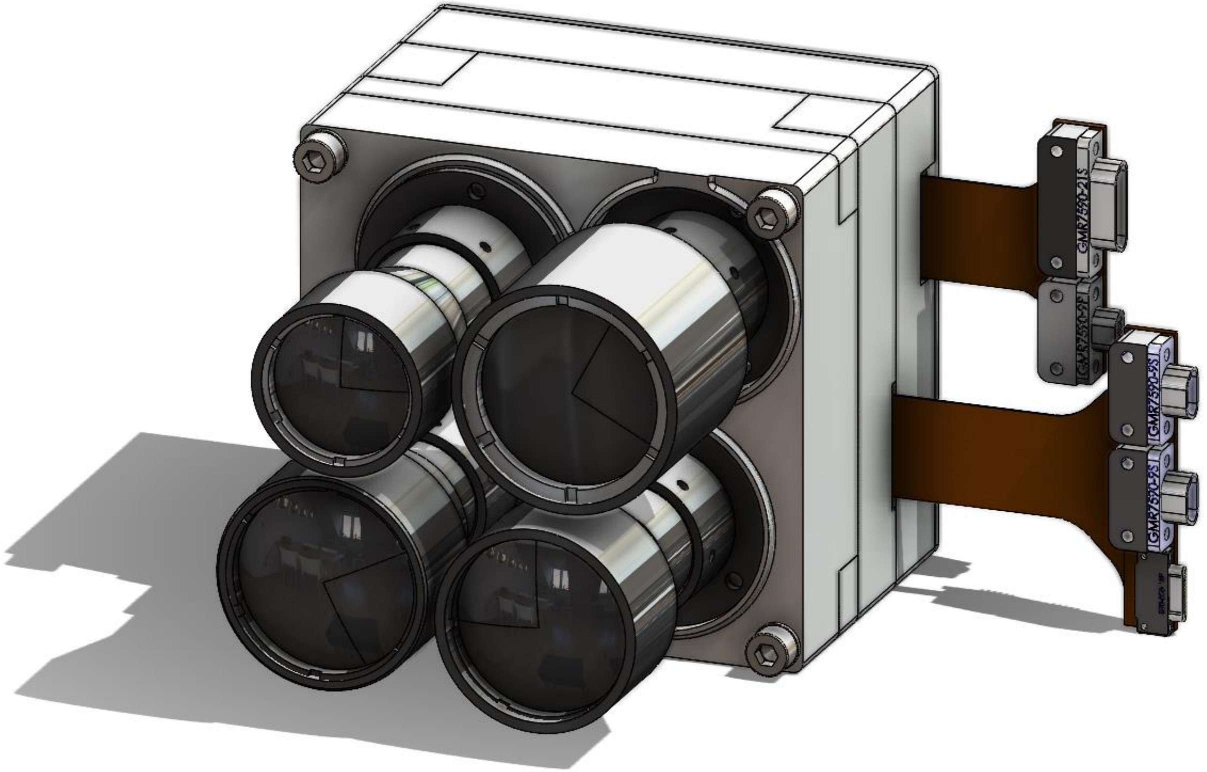


M-ARGO: CHEIDES

The M-ARGO imager is named **"CHEIDES" (C**ompact and **H**igh p**E**rfomance **I**mager for **De**ep **S**pace**).** It features 4 channels:

- VIS
- NIR1
- NIR2
- SWIR

- ❑ CHEIDES is capable to detect and observe the target, acquiring more than **forty spectral bands** to provide a global color map of the asteroid, allowing its physically characterization.
- ❑ CHEIDES offers a **very high reliability** to face a deep space mission, and at the same time it fulfils **demanding performance requirements**, including **AI-based processing capability**
- ❑ CHIEDES is extremely compact, occupying **a volume of only 1.25U**, so to burden as little as possible on the 12U XXL CubeSat platform selected for M-ARGO



Mass [g]	< 1.25 Kg
Power Consumption	**< 10.6 W**

Credit ESA

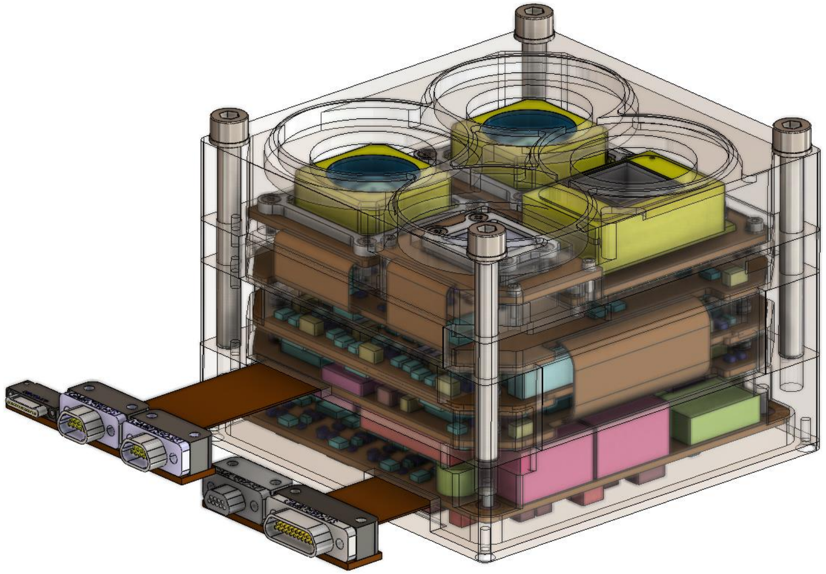
M-ARGO: CHEIDES

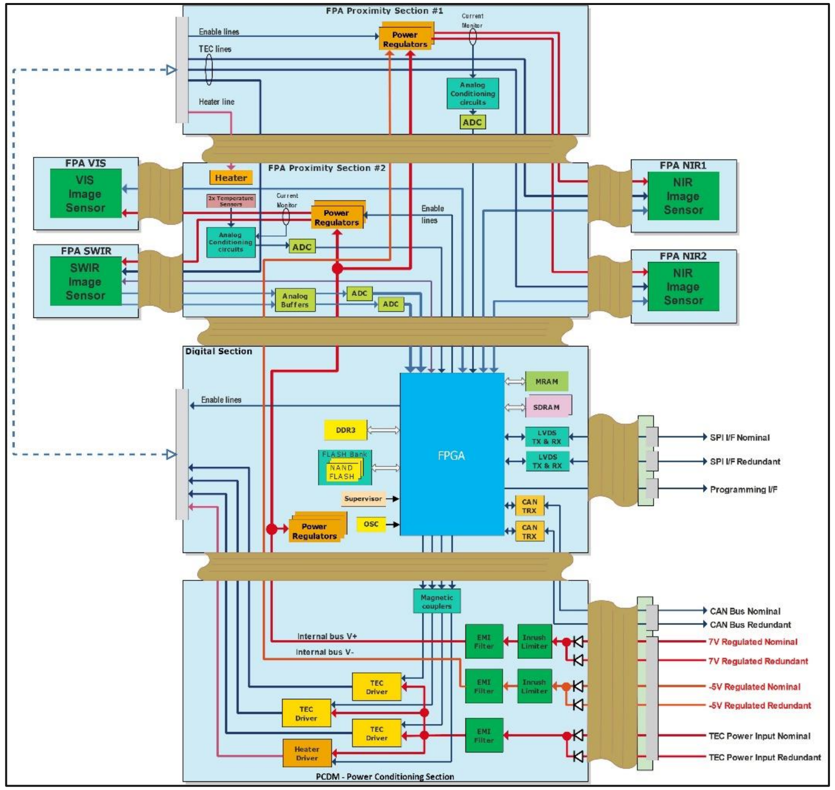
The CHEIDES Hyperspectral Imager is characterized by a very high degree of integration, having to include several sections, each of them, with a significant complexity grade:

- FPA hosting 4 detectors each provided with a specific snapshot spectral mosaic filter
- FPA proximity electronics for 4 detectors
- Digital Section for a large number of functionalities like image acquisition, processing, storage, communications, etc.
- Power Section including also circuitries for Thermo Electric Cooler (TEC) of 3 image sensors

The **CHEIDES is an AI-powered imager**. Its FPGA is designed to **accelerate deep learning models** for image data processing directly **within the camera.**

The CE architecture comprises an optical frontend and an FPGA-based Data Processing Unit (DPU) for image capture and preprocessing. The DPU's advanced processing capabilities enable onboard **machine learning algorithms**, allowing for **accurate determination of asteroid compositions** and **detection of potential in-situ resources**.





Credit ESA

ANHEO PROJECT

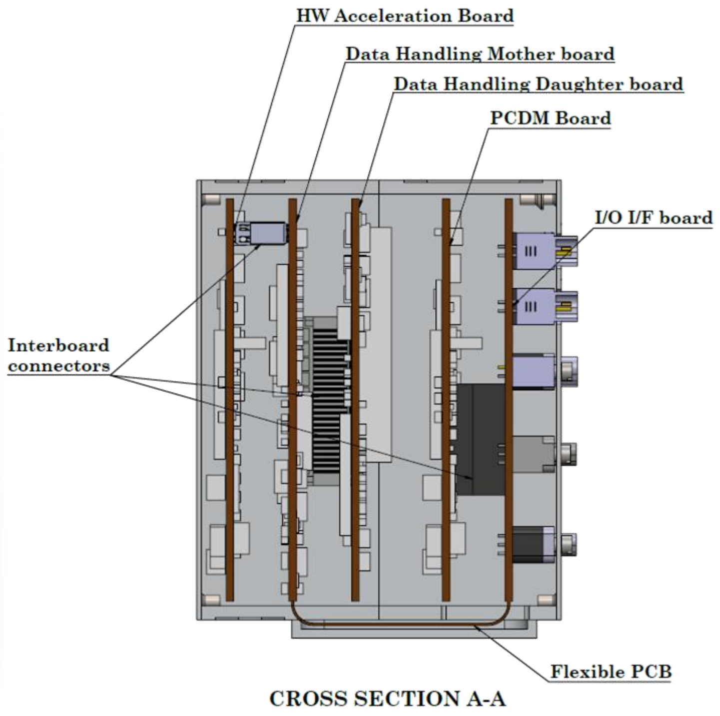
- The ANHEO project was proposed by TSD-Space and selected by the Italian Space Agency (ASI), under the “New satellite navigation techniques/systems for small satellites on other planets” call, with the University of Naples Federico II as a sub-contractor.

- The ANHEO system is **a highly integrated unit for autonomous absolute and relative navigation of nano- and microsatellites, from low Earth orbit and high Earth orbits, up to lunar altitude.**

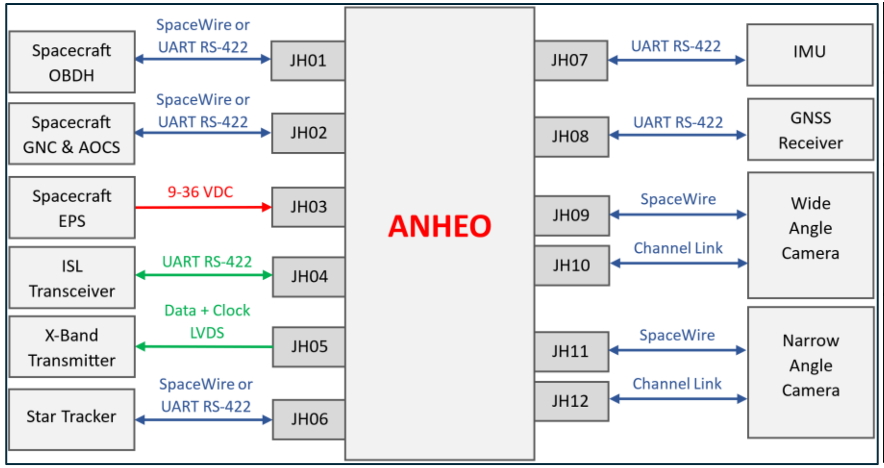
- It is **specifically designed** for use on board **6U-12U CubeSats**, in terms of **form factor**, **interfaces**, **mass vs. power consumption**.

- The system relies on the **processing of available GNSS observations**, as well **as IMU** and **Star Sensor observations**, to navigate within the Space Service Volume extended to the Moon, and on the **acquisition and processing of monocular images** to support **relative navigation** with respect to another vehicle in orbit.

- Whitin the ANHEO project, TSD-Space are developing an Elegant B/B. Most of the configuration is representative of the Flight Model design.



ANHEO I/F



Volume	< 1U
Mass	600 [g]
Power Consumption	3 – 4 [W]
Power Consumption (Including Hardarware Accelerator)	7 – 9 [W]

ANHEO HW Design Overview

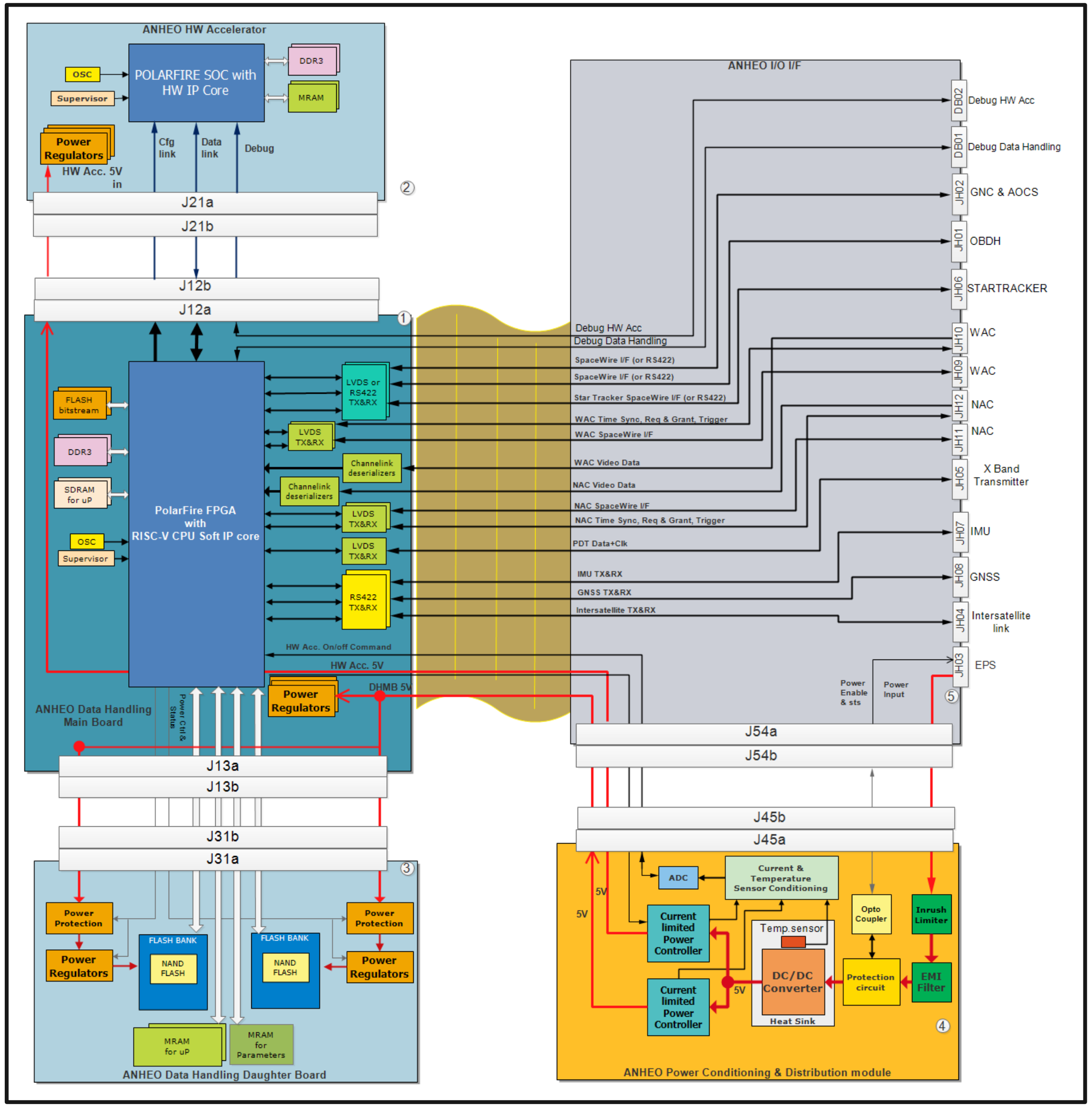
The **Data Handling Main Board** (DHMB) is the main subsystem of the ANHEO platform. The EB/B unit is equipped with the **Microchip PolarFire FPGA.** The same chip is also available in a radiation-tolerant version and can be adopted to ensure high reliability and robustness under the adverse effects of radiation, guaranteeing its operational effectiveness.

The ANHEO Application Software running on the soft processor, with the other VHDL modules implemented in the programmable logic, ensures the management of all the ANHEO units, the communication with the external subsystems, the **data processing** (e.g. ***inline compression module***), **storage** and **payload data handling & transmission**.

The DHMB activates the *HW accelerator* to execute complex algorithms and transfer the resulting data from the execution of absolute and relative navigation algorithms to the OBC.

The ANHEO HW Accelerator leverages the advanced capabilities of Microchip's **PolarFire SoC** that combines a powerful **64-bit 5x core RISC-V Microprocessor Sub-System** (MSS), with the **PolarFire FPGA fabric** in a single device.

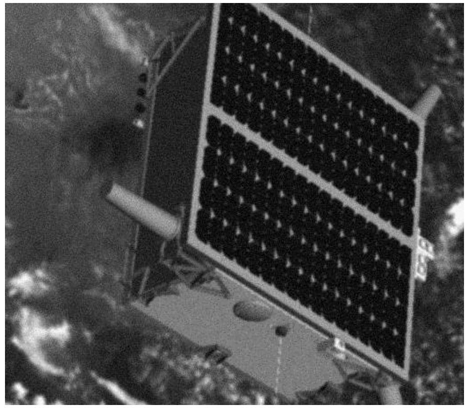
The FPGA design is tailored to **accelerate deep-learning algorithms** for **relative vision-based navigation** by including the CoreVectorBlox coprocessor that serves as a **flexible neural network accelerator.**



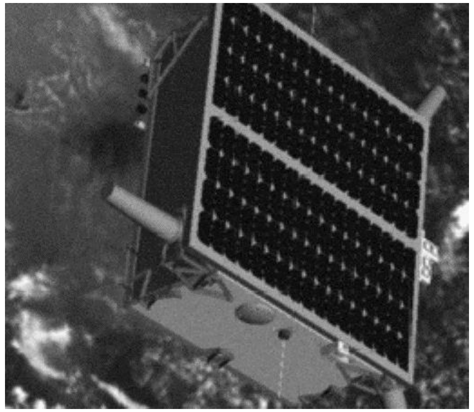
ANHEO Compressor

The **visual lossless** compression module developed by TSD-Space is based on the *2D Wavelet Transform* and requires a limited number of logical resources (~1,1%), allowing multiple VHDL modules to be instantiated in parallel in the PolarFire FPGA, to increase the compression bit rate. This enables **inline compression processes** for the **real-time downlink** of imaging data.

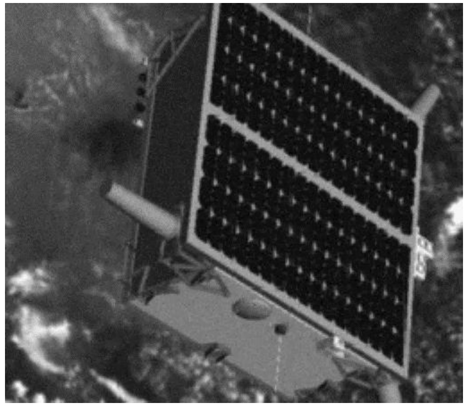
Raw Data



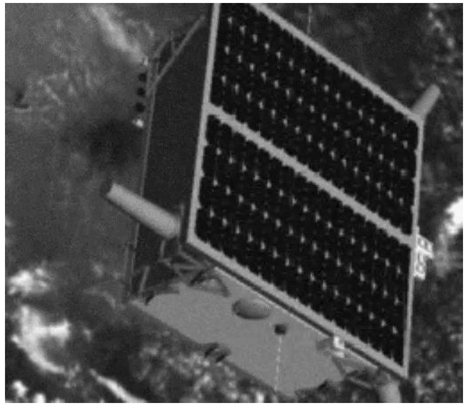
Cf 4 – 78.88 Mbit/s



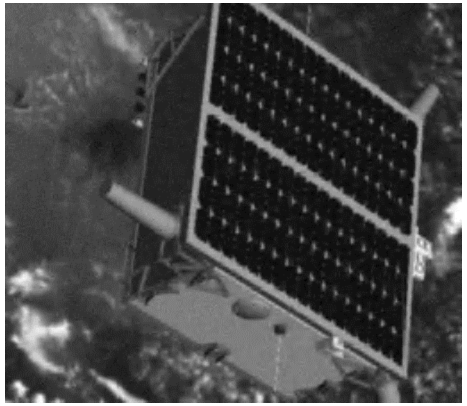
Cf 10 – 82.16 Mbit/s



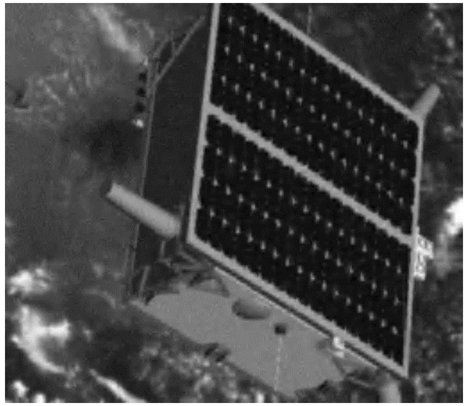
Cf 15 – 230.64 Mbit/s



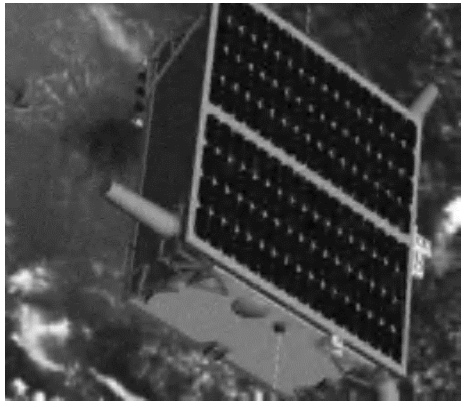
Cf 20 – 279.52 Mbit/s



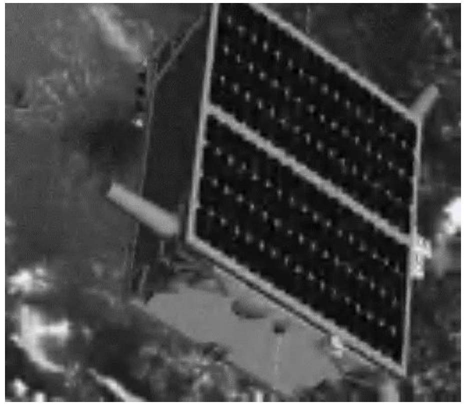
Cf 25 – 305.04 Mbit/s



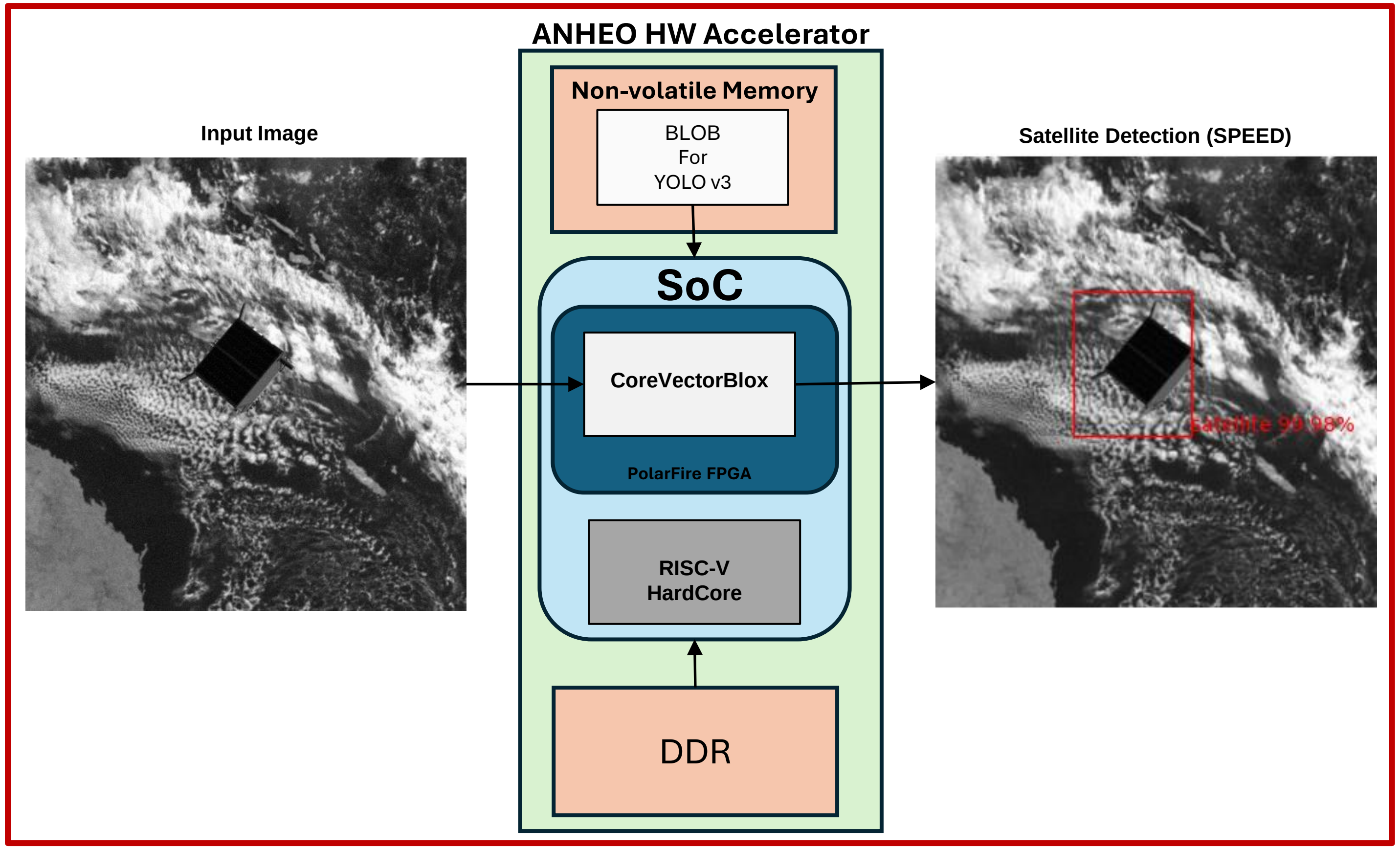
Cf 30 – 328.80 Mbit/s



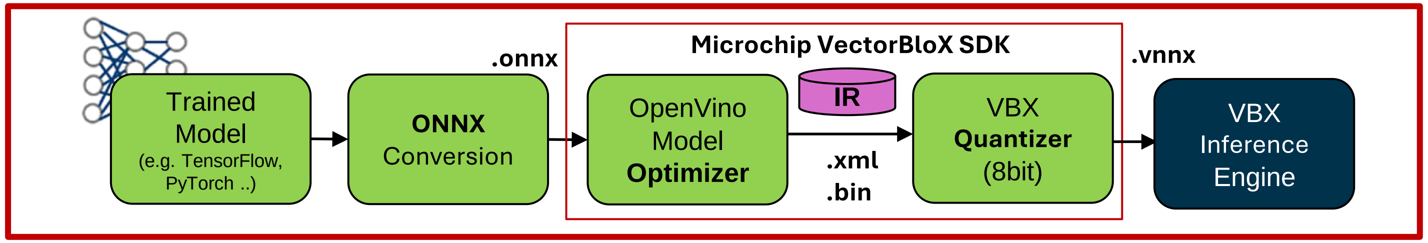
Cf 50 – 410.40 Mbit/s



ANHEO HW Accelerator for Onboard AI



Deployment Flow



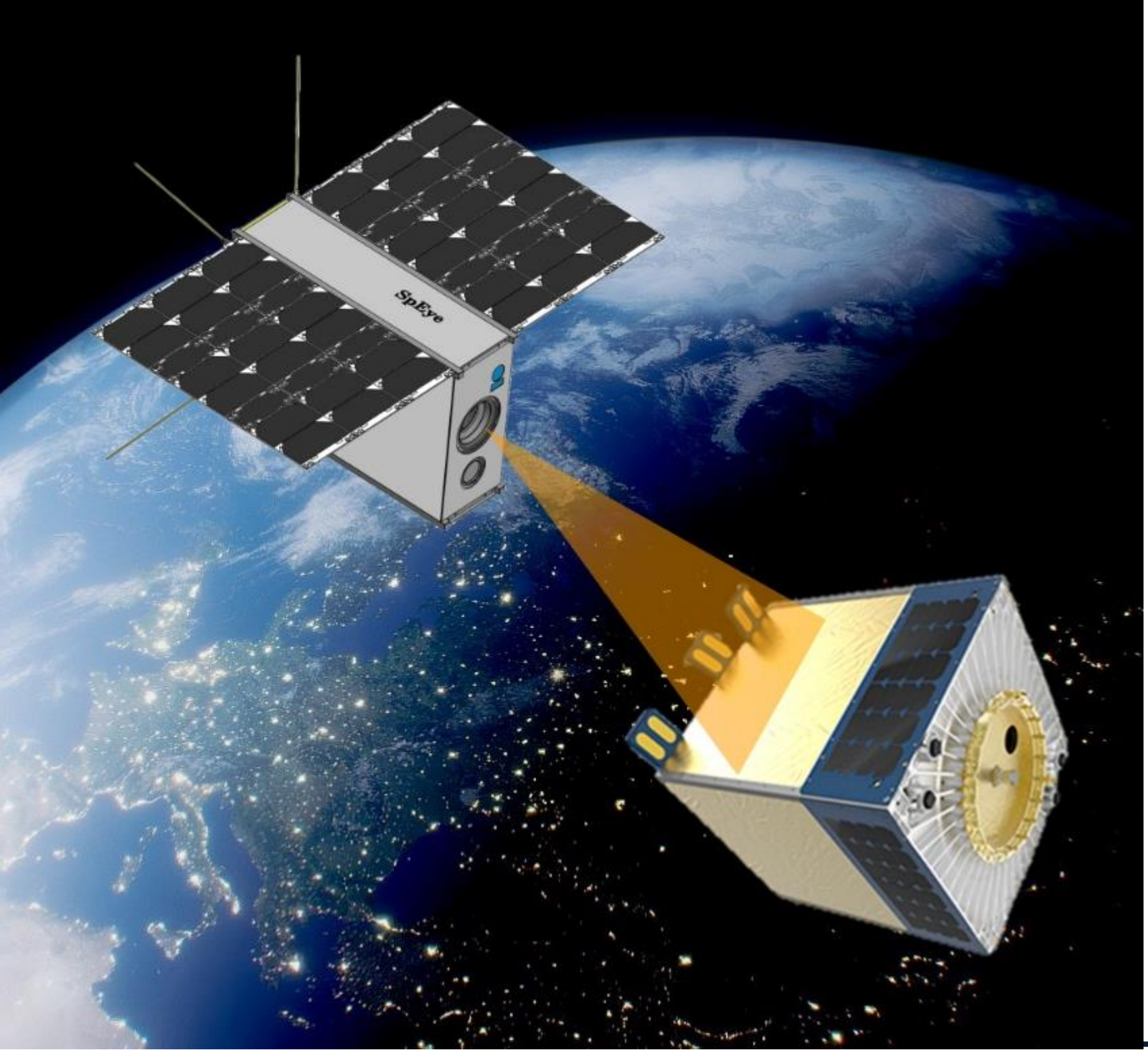
- The ANHEO HW Accelerator is designed with an **overlay architecture** that allows the **deployment** of **different neural networks** onboard without the need to reconfigure the programmable logic resources.
- Techniques such as **pruning** and **quantization** enable the efficient running of very deep NNs with high power efficiency and no loss of accuracy.
- In addition, the BLOB can be updated even in-flight, providing satellite operators with the ability to change processing algorithms after a satellite has been launched.

Table 6: VectorBlox IP Power Consumption Breakout

CoreVectorBlox Configuration	Peak GOPs	Dynamic Power (mW)	Static Power (mW)	Total Power (mW)	Total Power (mW/GOP)
V250	79	387	65	452	7.1
V500	146	698	127	825	6.4
V1000	279	1094	206	1300	5.1

USING THE VECTORBLOX™ ACCELERATOR SOFTWARE DEVELOPMENT KIT TO CREATE PROGRAMMABLE AI/ML APPLICATIONS IN RADIATION TOLERANT (RT) POLARFIRE® FPGAs
Aaron Severance (1) , Diptesh Nandi (1) , Ken O'Neill (1)

SPACE EYE (SPEYE) Mission



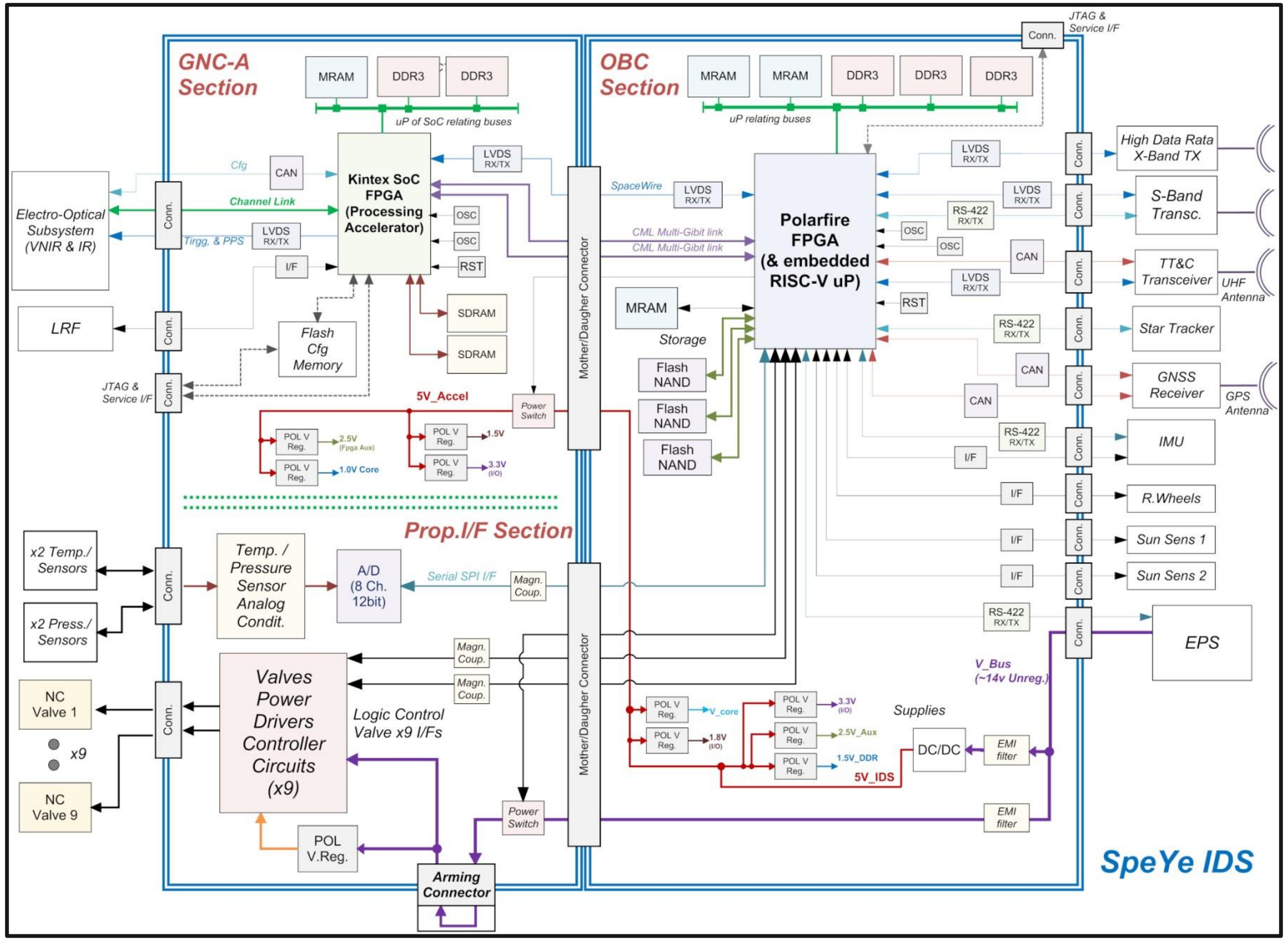
SpEye a **two-satellite technology demonstration mission** for the in-flight validation of critical technologies and techniques related to advanced **on-orbit inspection** and **formation-flying**, applicable to future operational **nano-satellite** capabilities and operations.

SpEye aims to demonstrate **safe** and **cost effective in-orbit inspection** and **rendezvous** under **cooperative** and **non-cooperative** conditions using a nanosatellite.

A **6U CubeSat Free Flyer** will be developed, equipped with a six-degrees-of-freedom propulsion system and a multipurpose electro-optical system for **autonomous navigation** and **inspection**

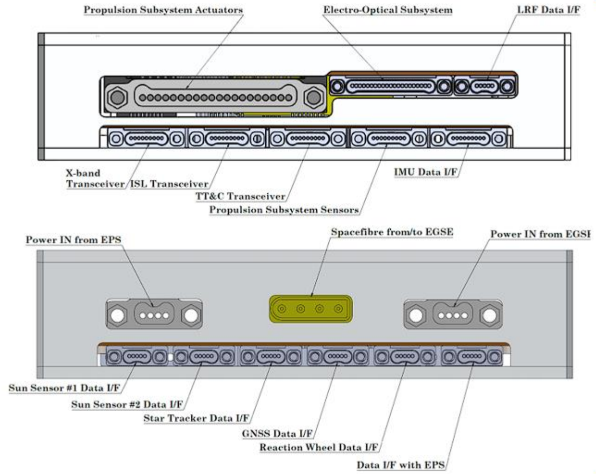
Led by TSD-Space (Prime Contractor), the SpEye mission brings together a consortium of **all-Italian partners**, including D-Orbit, T4i Technology for Propulsion and Innovation, Planetek Italia, Politecnico di Milano, and Università degli Studi di Napoli Federico II

SPACE EYE – Integrated Data System (IDS)



The architecture of the Free Flyer data system has been conceived by <u>merging the OBC C&DH and GNC Accelerator in a single unit</u> called **Integrated Data System** (IDS), so to optimize volume, mass, harness.

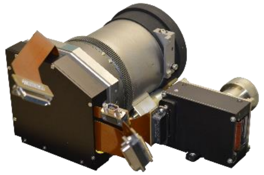
Additionally, in the IDS, the <u>I/F electronics</u> needed for the control and driving of the propulsion subsystem have also been embedded.



SPACE EYE – Electro-Optical System

The Electro-Optical System is based on the design of the **Argomoon camera**, which includes:

- **2 Optical Heads including FPAs (NFOV and WFOV)**
- **Common Electronics**
- **Motorized optics for NFOV**

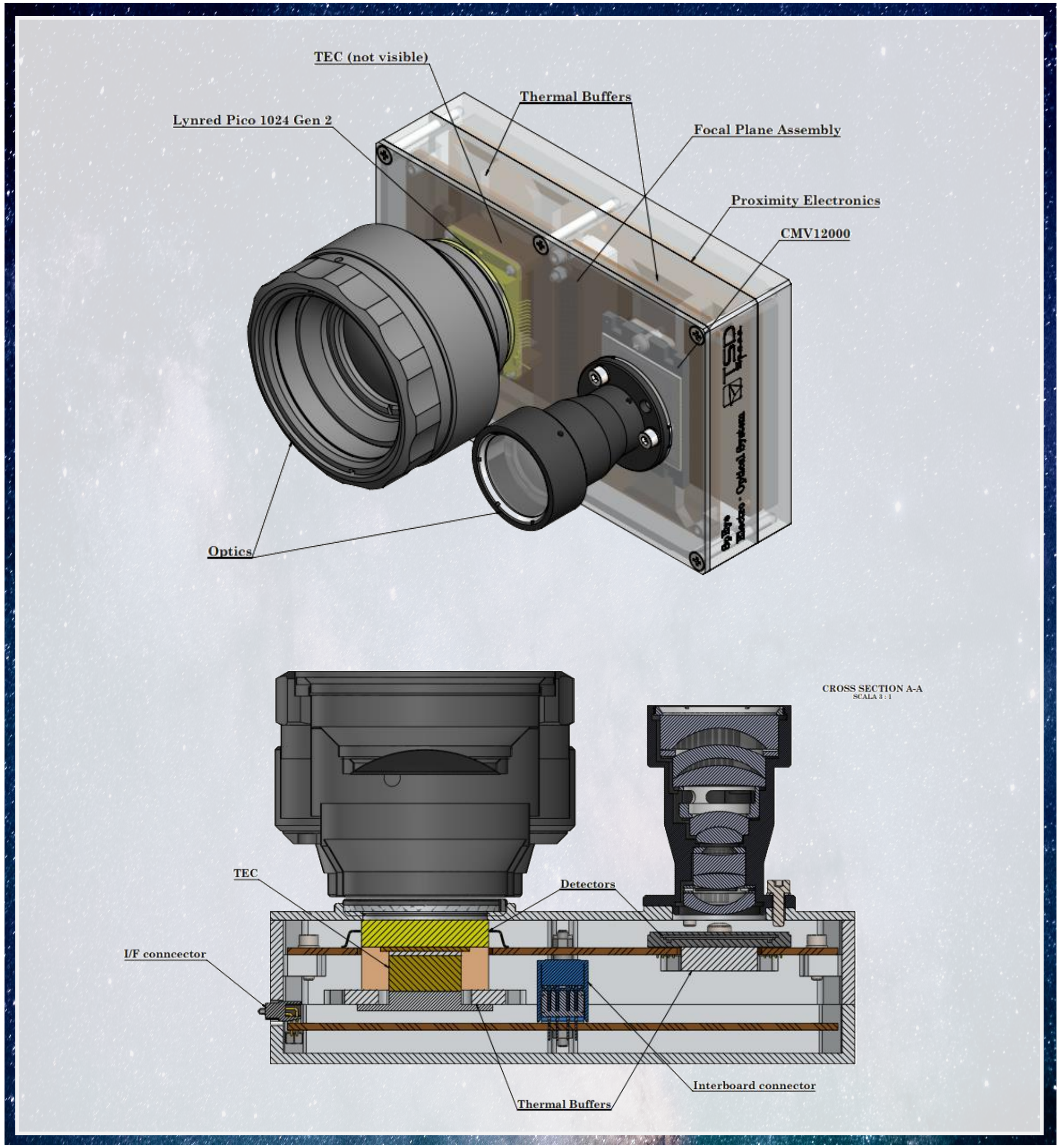


ArgoMoon Camera

It will be modified so to fulfill the requirements of the SpEye Electro-Optical System:

- **2 Optical Heads (multispectral VNIR and thermal infrared)**
- **Common Electronics**

The thermal infrared FPA will require a specific detector and proximity electronics. The Main electronics will provide additional functionalities to drive the TEC located on FPA and to interface the thermal infrared proximity electronics



TSD Space

Thank you
for your attention

Giovanni Maria Capuano

gmcapuano@tsd-space.it

info@tsd-space.it

www.tsd-space.it