WORKSHOP ASI

"L'impegno italiano nel settore dei CubeSat: tecnologie e missioni future" – 2° EDIZIONE

HYPSOS-Earth Observation

(HYPSOS PROJECT - Strumento 4D stereo-iperspettrale per CubeSat)

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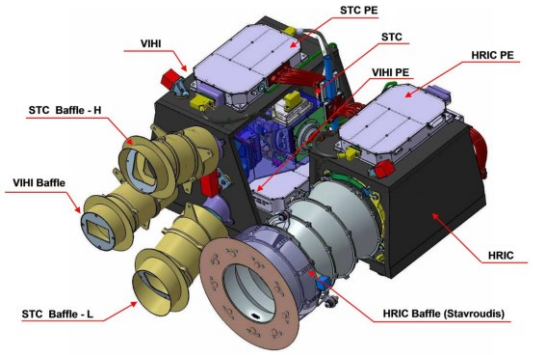
1. INTRODUCTION. HYPSOS-Earth Observation

The Hyperspectral-Stereo Camera for CubeSat (HSSC) of the HYPSOS-EO System is a novel instrument for CubeSat remote sensing able to simultaneously extract 4D information, spatial and spectral, using two channels of a pushbroom stereo camera coupled to a spectrometer. The HYPSOS-EO System represents a precursor in the panorama of Italian Space Activities, being unique in its kind and could be able to generate a great know-how in terms of return on data for the territory. The aim is to obtain an innovative instrument, with a notable scientific/industrial and strategic potential as it is placed in a technologically cutting-edge sector such as the development of optical instrumentation for satellites.

The optical design of HYPSOS-EO is the result of a transfer of knowledge and experience in the realization of SIMBIOSYS, the imaging system of the ESA BepiColombo Mission

High-Resolution Imaging Channel (HRIC)

Visible and near Infrared Hyperspectral Imaging channel (VIHI)



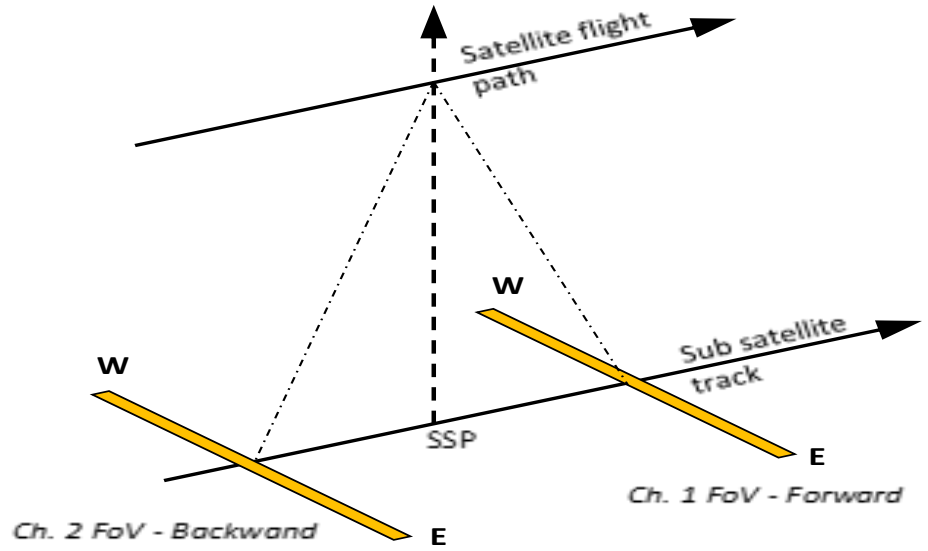
Credits: https://www.cosmos.esa.int/web/bepicolombo/simbio-sys

STereo imaging Channel (STC) HYPSOS

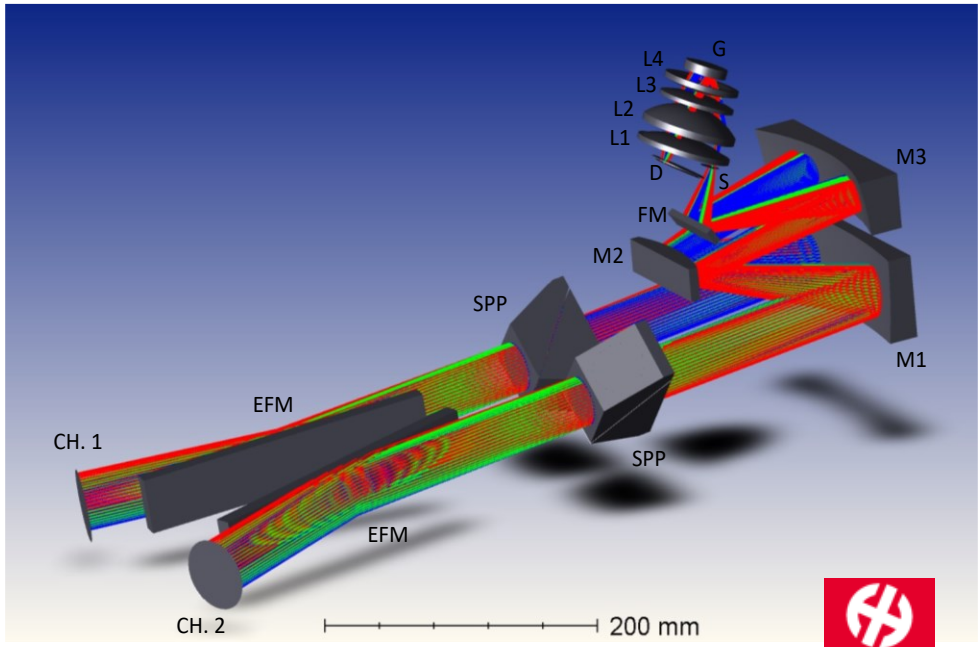
Starting point for designing HYPSOS-EO System

1. INTRODUCTION. From HYPSOS to HYPSOS-Earth Observation

- **The possibility of collecting spatial and spectral information with a single observation coupled to stereoscopic capabilities makes HYPSOS (HYPerspectral Stereo Observing System) an innovative new-concept instrument that can be housed on satellites for planetary/lunar remote sensing**

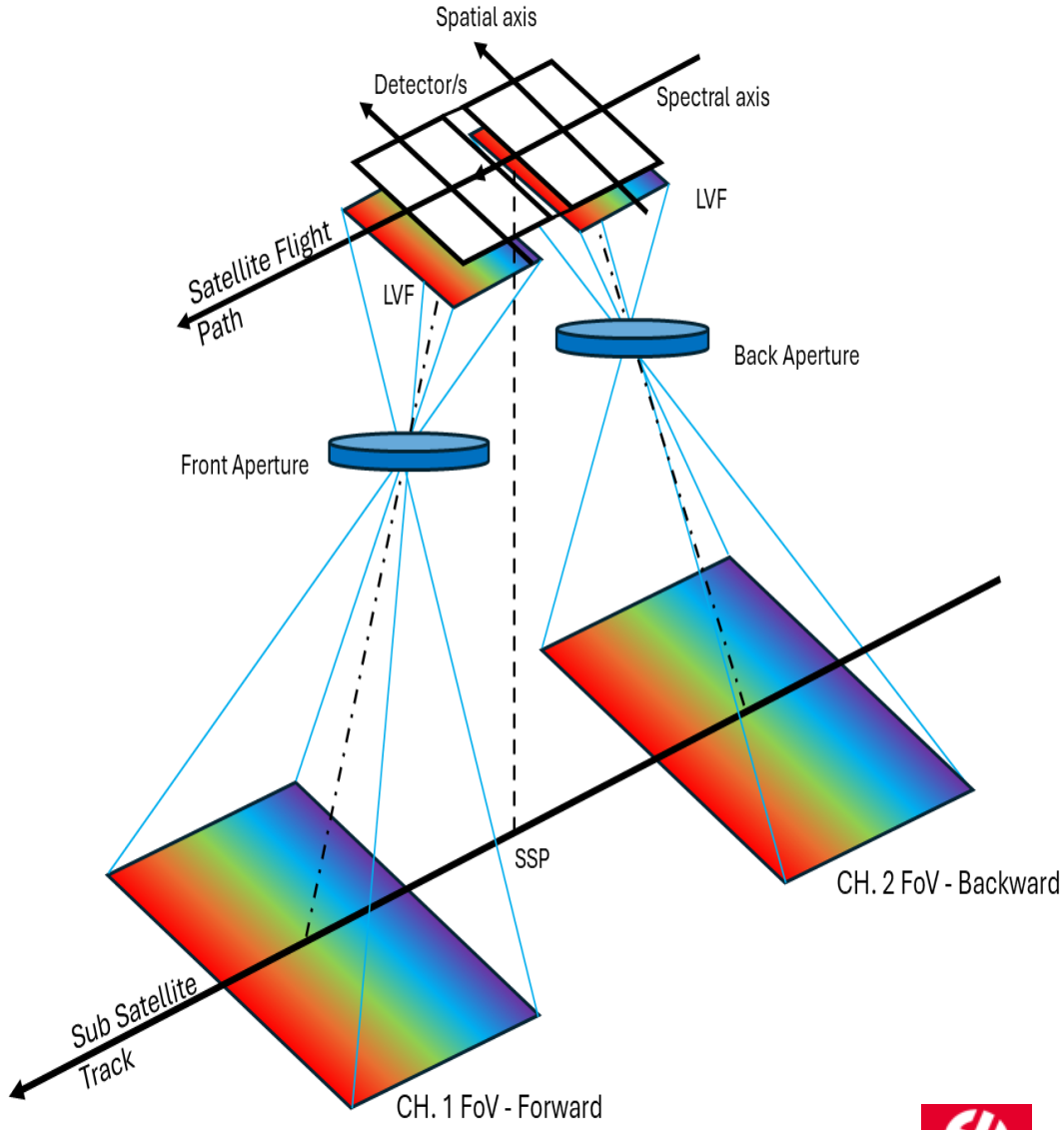


- **It was decided to develop an apparatus capable of providing a hyperspectral digital terrain model (HDTM) as final product. To achieve this, the design evaluations considered a mission scenario in polar orbit, with a fixed two-channel system (Channel 1 & Channel 2) working in pushbroom mode, where one looks forward and one looks backwards with respect to nadir along the flight direction.**



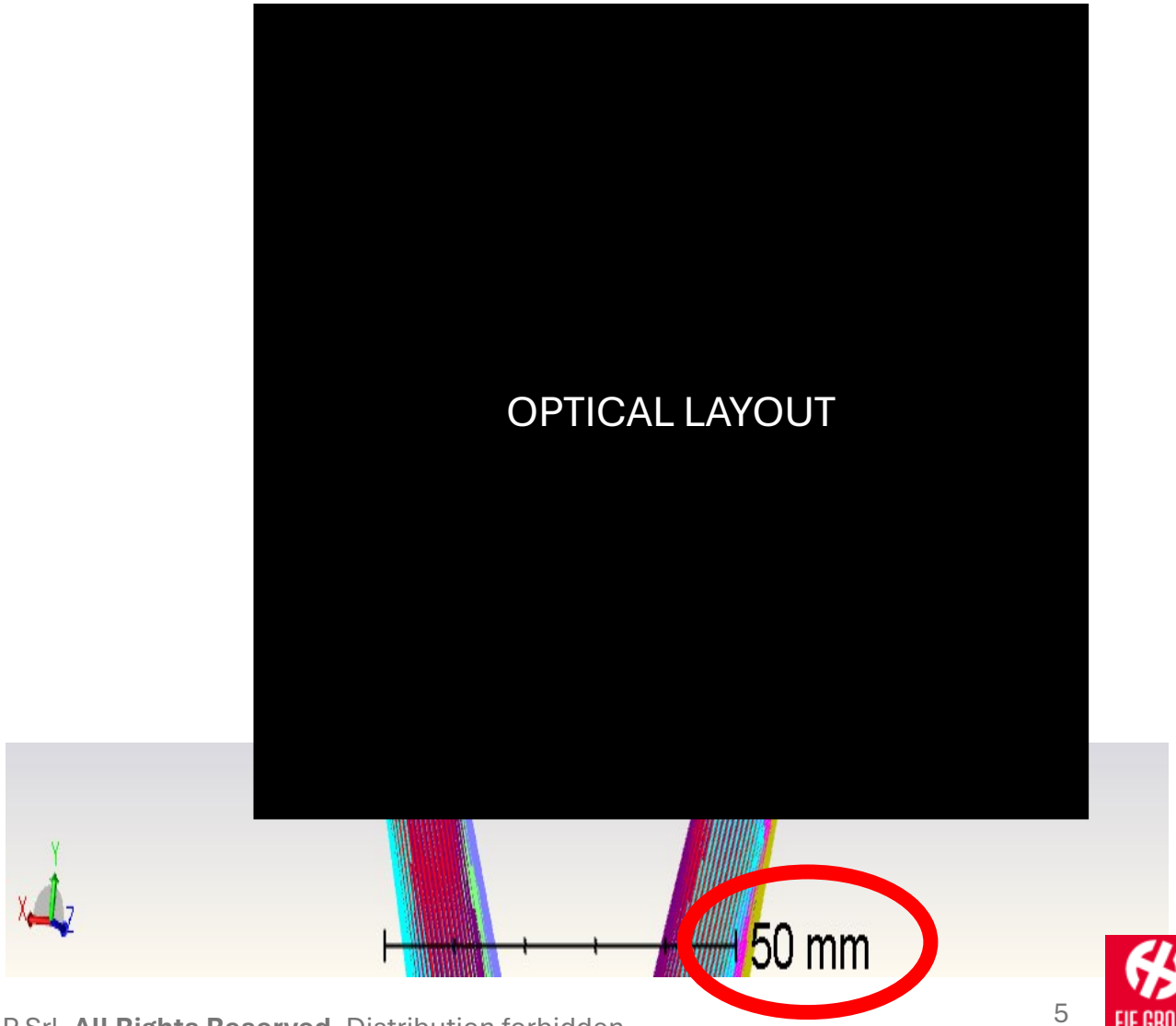
1. INTRODUCTION. HYPSOS-Earth Observation (HYPSOS-EO)

Instrument Environment	LEO-Orbit (400 km)*
System structures	Aluminium panel concept with internal shear frame. Turned and milled elements. Metal Additive Manufacturing
System size	Payload compartment: ~1U. *Scalable for different resolutions.
Thermal Control Subsystem	Passive cooling of electronics
Spectral Range	400 - 800 nm (Extendable for IR)
Telescope	Three-Mirror Anastigmat / TMA with two symmetric entrance pupils Focal Length: ~ 100 mm Aperture (Pupil Diameter-D): < 30 mm F-number: ~ 10 - 6.7
Spectrometer	Linear Variable Filter (LVF) Resolving spectral element (double sampling): < 10 nm
Spatial Resolution	< 30 m
FoV	~ 11deg x 9 deg Two Channels folded by ±15° with respect to nadir pointing



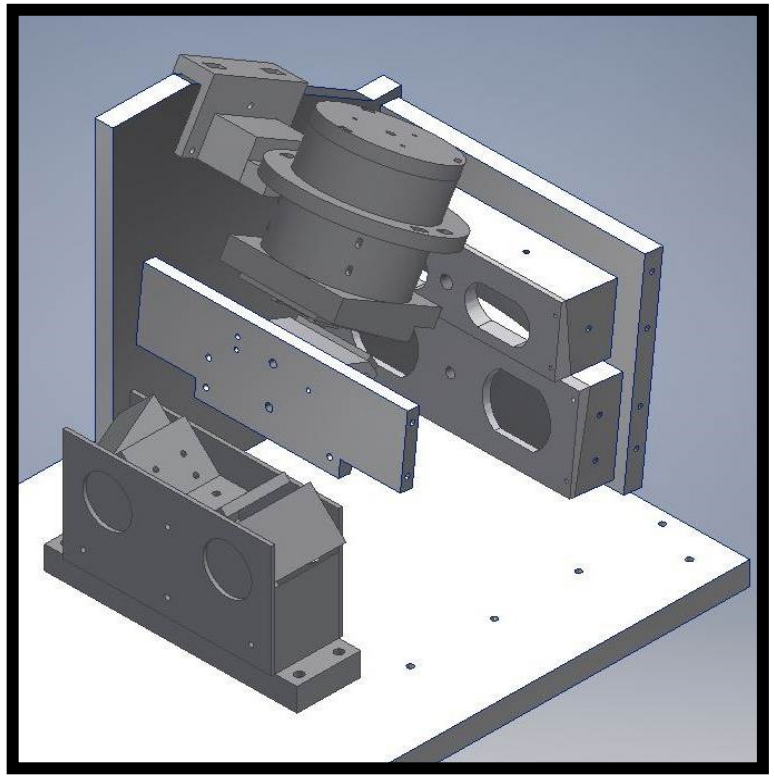
2. HYPSOS-EO. HSSC OPTICAL DESIGN FOR CUBESAT

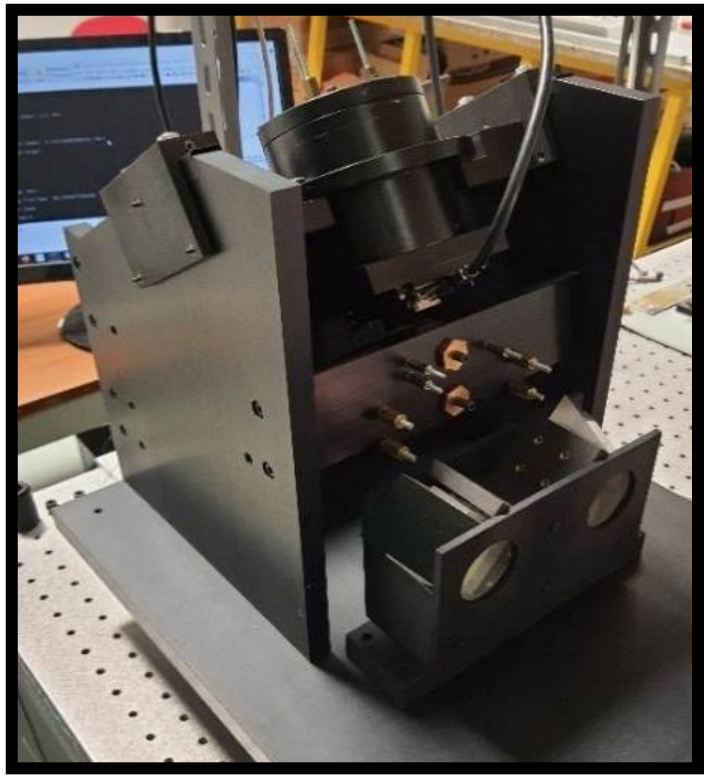
Telescope	
Three-Mirror Anastigmat / TMA with two symmetric entrance pupils	
M1	Concave surface
M2	Convex surface
M3	Concave oblate surface
Spectrometer	
LVF	Linear Variable Filter (LVF)
Sensor: VIS (Possible extension into IR)	
CMOS	1 or 2 units BI



3. FROM HYPSOS LAB PROTOTYPE TO HYPSOS-EO (CubeSat)

A peculiar feature of HYPSOS is that it has a Three Anastigmatic Mirrors (TMA) telescope configuration whose focal plane corresponds to the spectrometer entrance slit plane. To obtain a single-input slit spectrograph starting from the two separate linear fields of view provided by the pushbroom acquisition mode of the two channels, a 90° field rotation is provided by two 45° inclined Schmidt-Pechan (SPP) prisms, positioned in front of the TMA apertures.



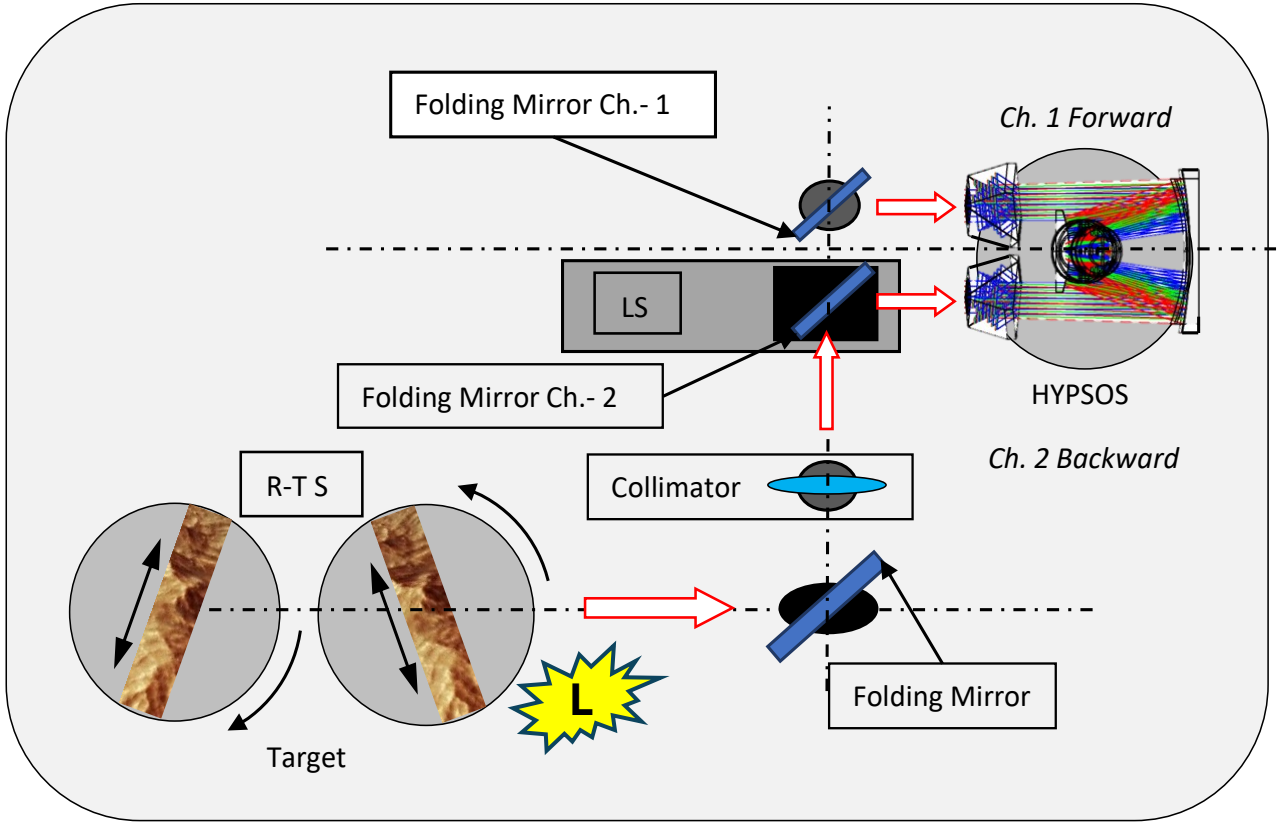


Pubblications:

- ❑ **In-lab Characterization of HYPSOS, a Novel Stereo Hyperspectral Observing System: Latest Results**
- ❑ **In-lab characterization of HYPSOS, a novel stereo hyperspectral observing system: first results**

4. HYPSOS ACQUISITION CONFIGURATION SCHEME (adaptable for HYPSOS-EO)

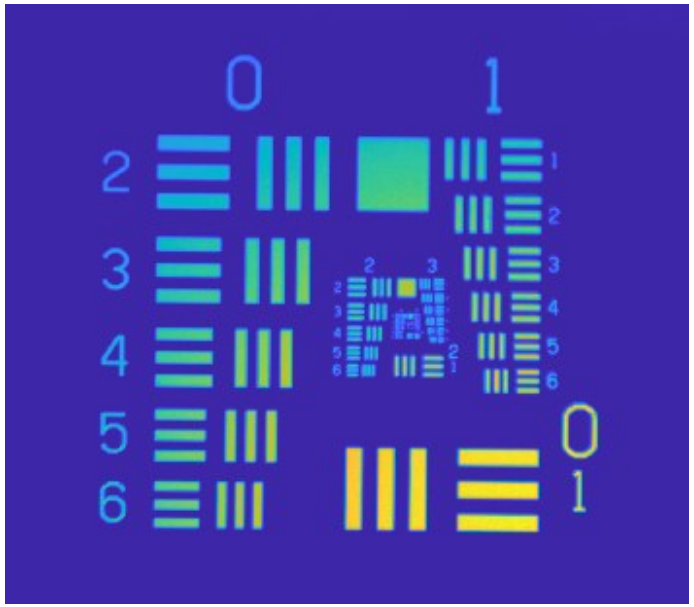
- Targets like rocks of different compositions
- A halogen lamp light source
- A rotational stage capable of reproducing the stereo angle of HYPSOS similar to the flight model
- A translational stage capable of reproducing the push-broom modality
- A 1010 mm focal length collimator
- A linear stage that selects one of the two acquisition channels.

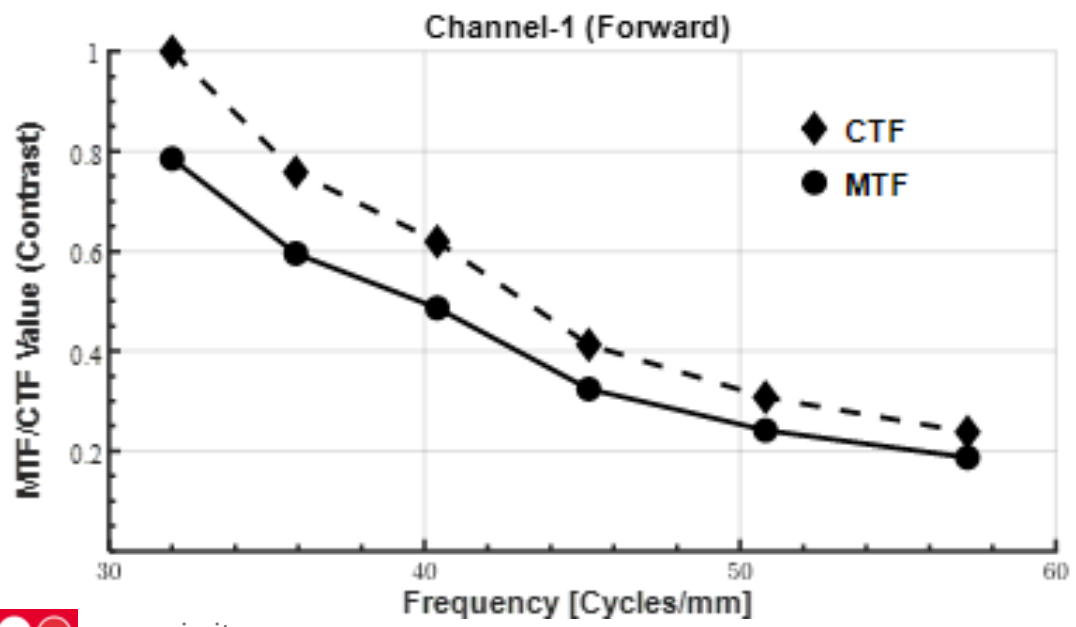


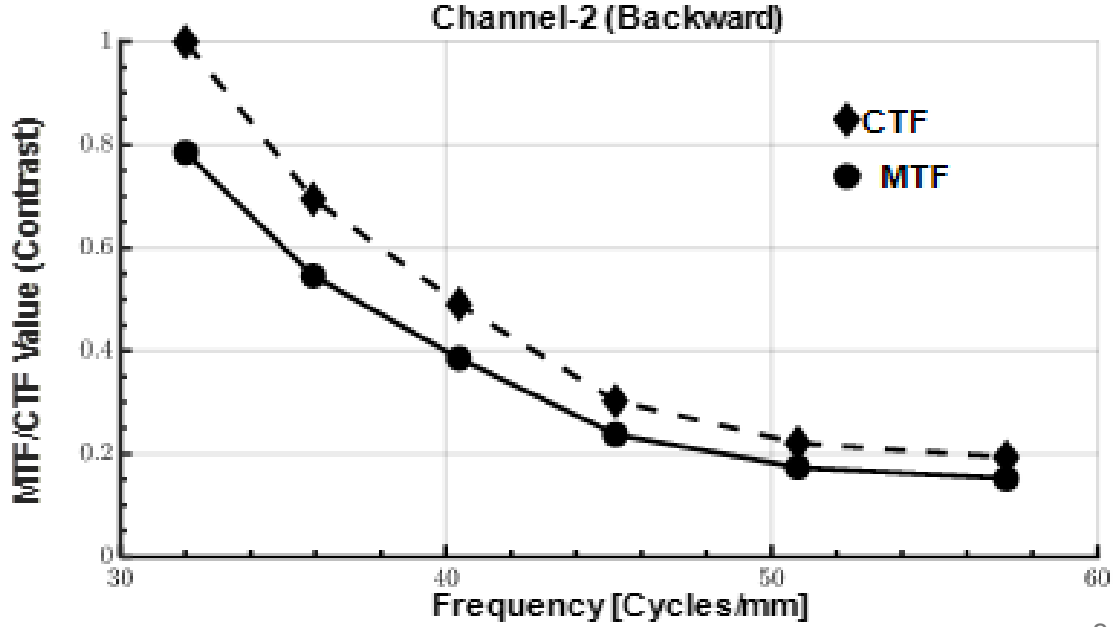
The acquisition system is automatically controlled and synchronizes the speed of the translation stage simulating the pushbroom scan with the acquisition frame rate of the sensor.

5. HYPSOS TELESCOPE OPTICAL PERFORMANCE

To estimate the telescope performance, the contrast transfer function (CTF) has been measured using a USAF target, and the modulation transfer function (MTF) was then derived



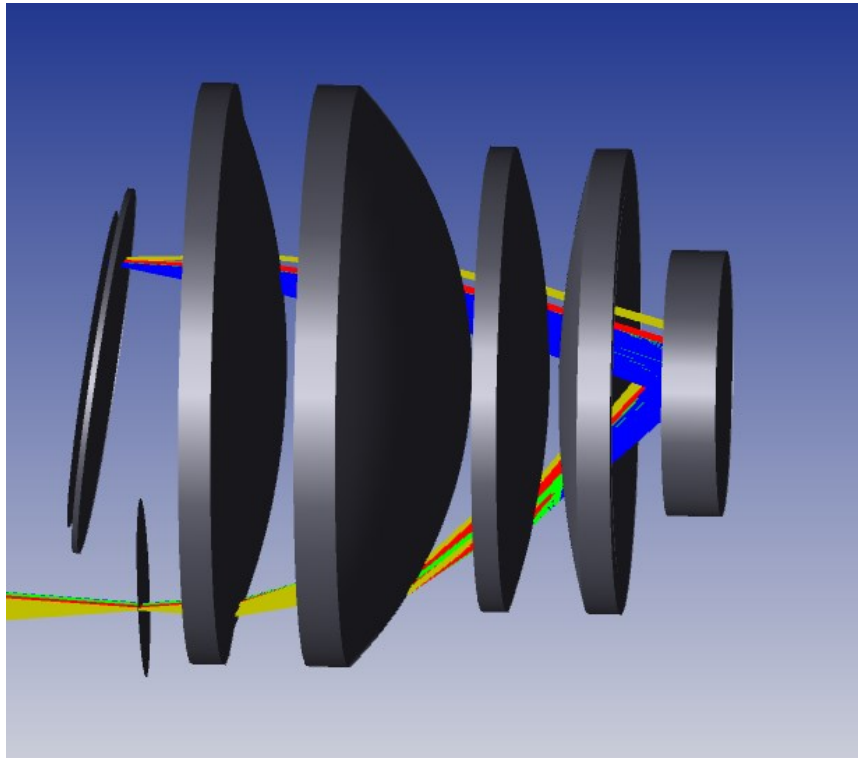


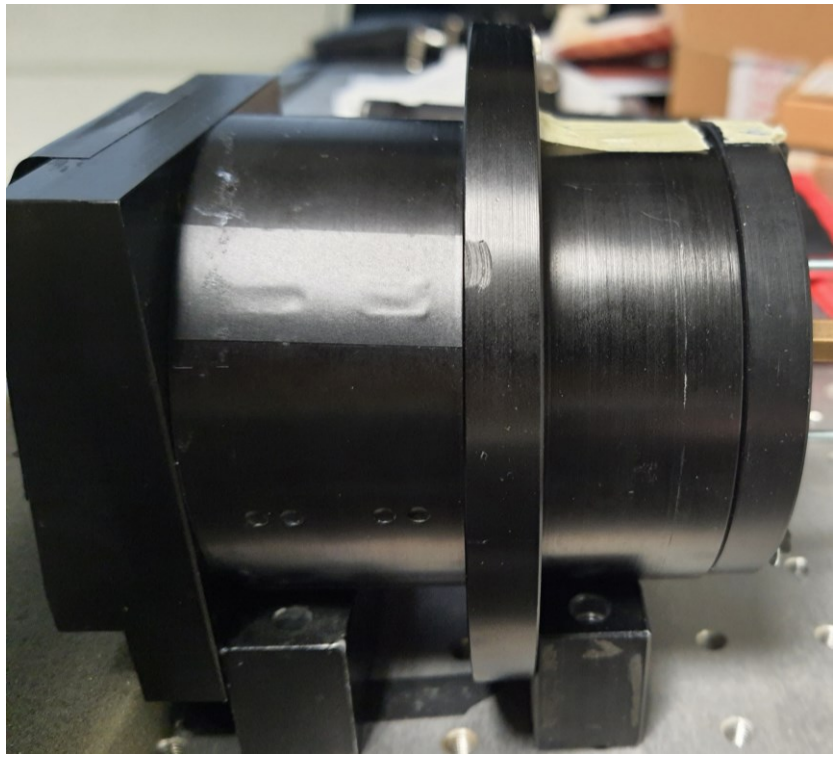


6. HYPSOS SPECTROMETER

Spectrometer Assembling and Integration on HYPSOS

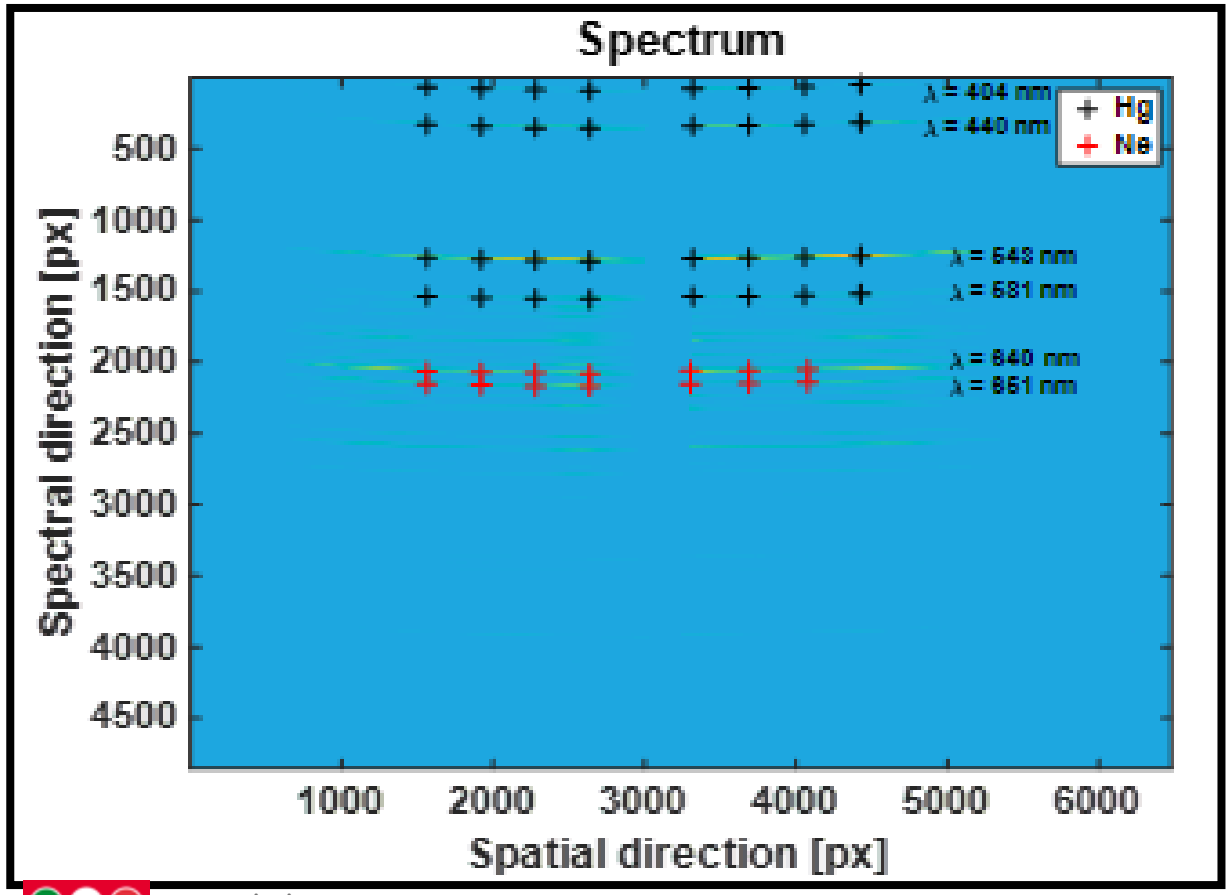
The spectrometer optics have axial symmetry and have been assembled with known mechanical tolerances



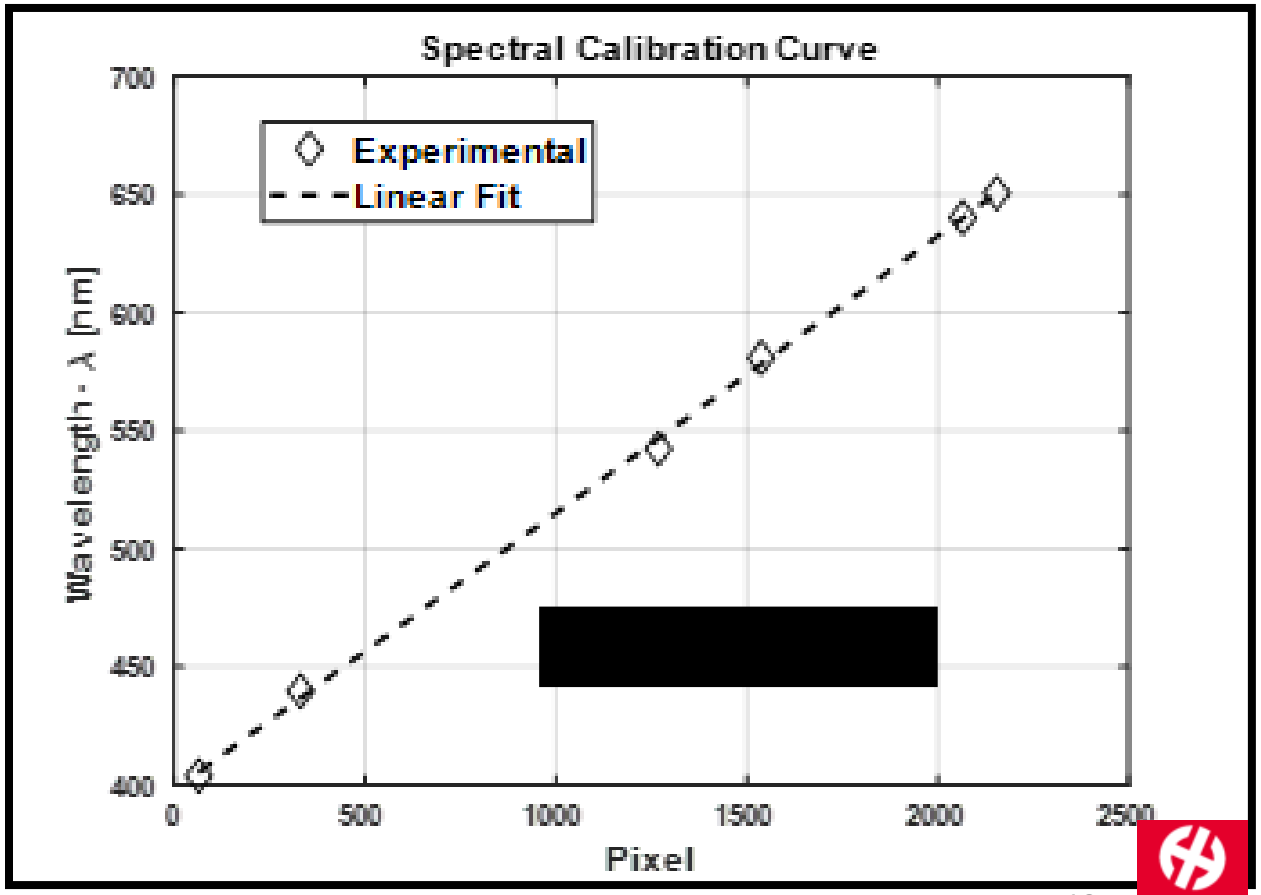


HYPSOS full configuration response

Spectral Lamp Calibration – Hg & Ne



Fitted Curve

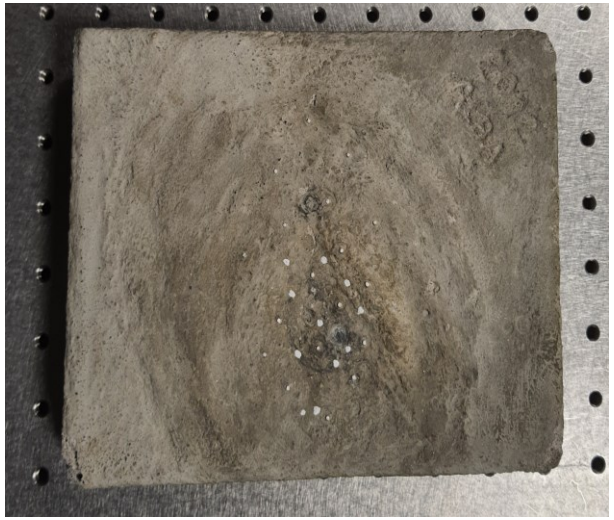


8. OBSERVED TARGETS

❖ **Rocks of different nature and spectral variegations (Anorthosite, Basalt, Cement, ...) are used as 3D targets; their 3D surface has been completely characterized with an accuracy of 20 µm. The halogen lamp illuminates the stones, their diffused light is collected by the collimator and enters HYPSOS apertures for being spatially and spectrally analysed.**

➢ **Anorthosite**

➢ **Gabbro**

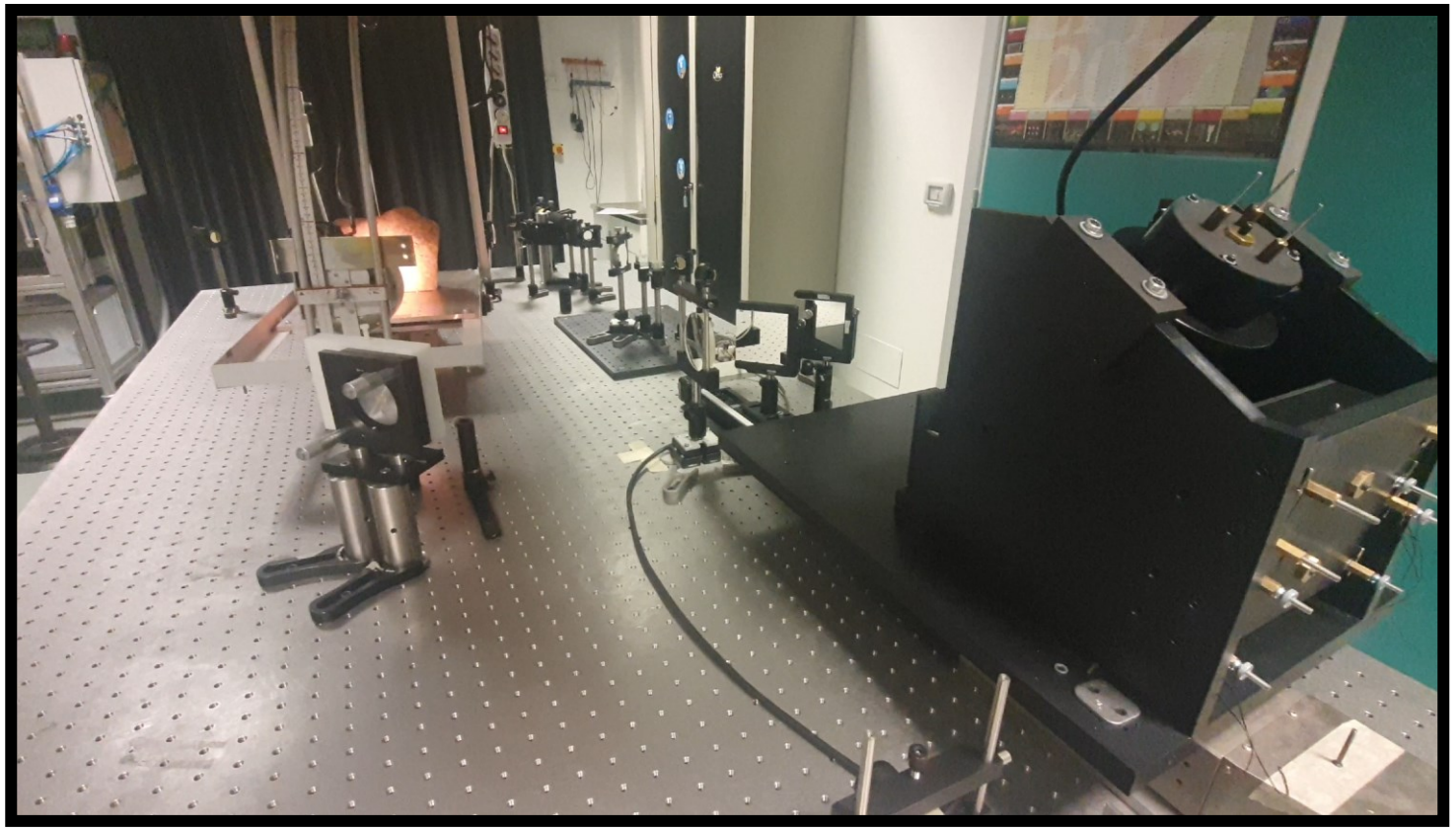


➢ **Cement**

➢ **Monzonithe**

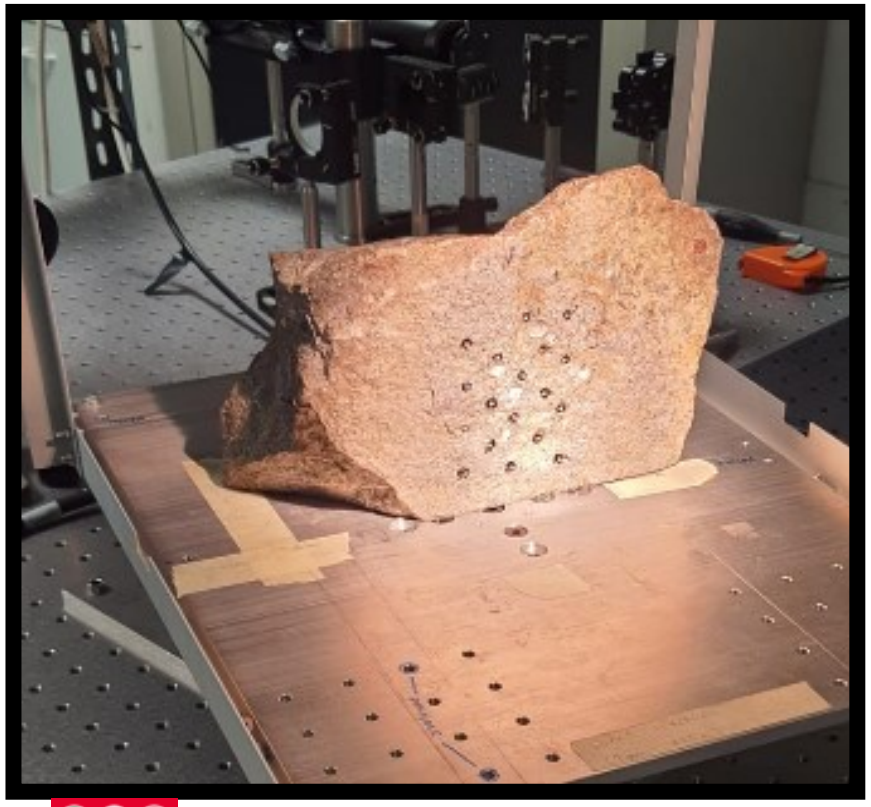
9. LABORATORY MEASUREMENTS SETUP

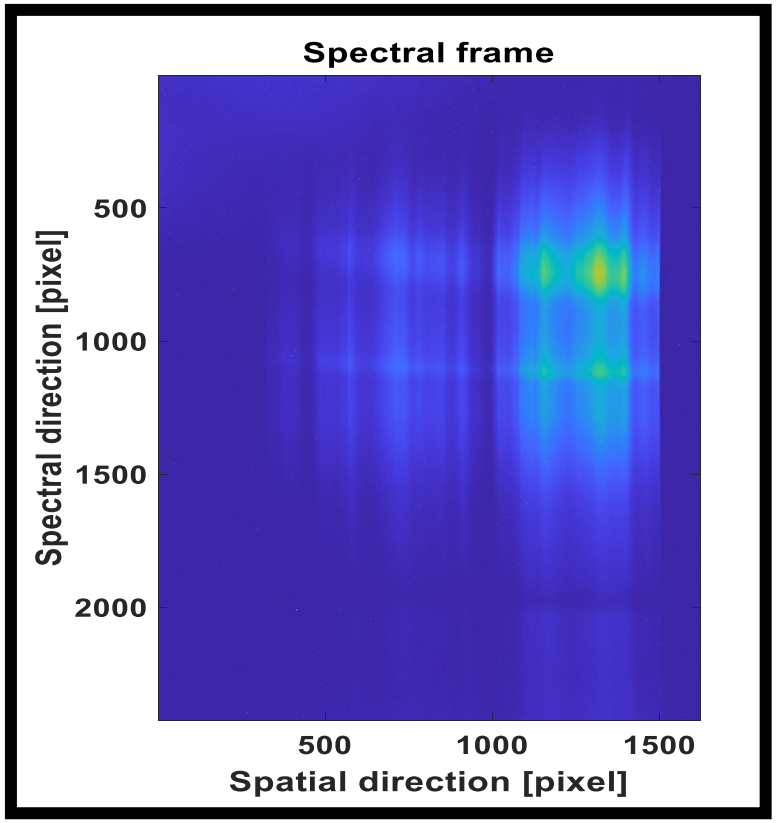
STEREO & PUSHBROOM SETUP SIMULATION

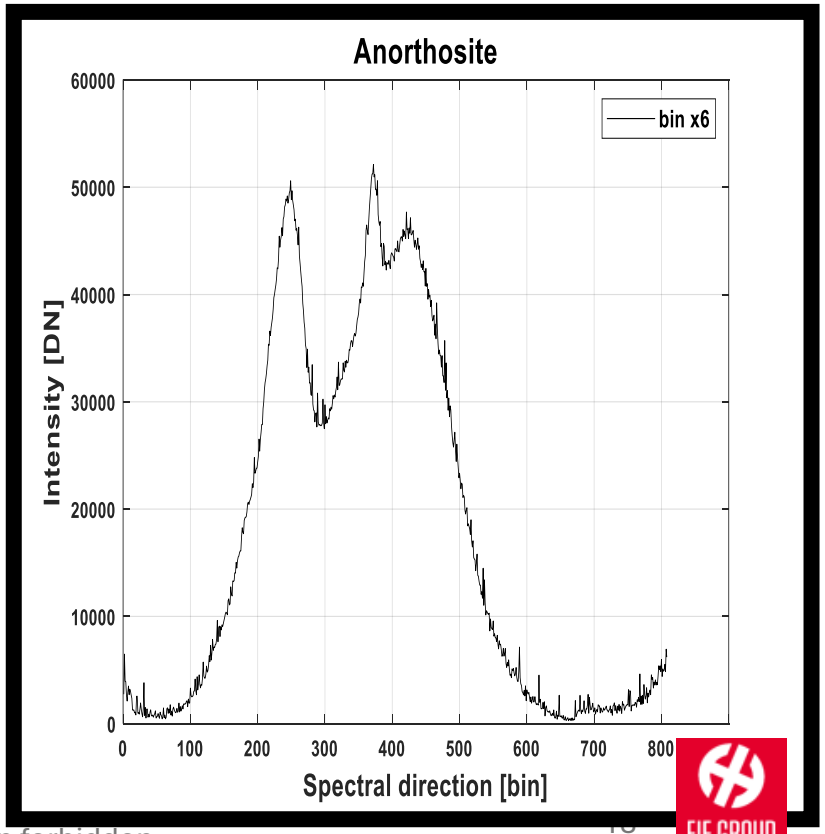


10. SPECTRA ACQUISITION

After the integration of the whole instrument, we started to acquire the target spectra simulating the pushbroom acquisition modes

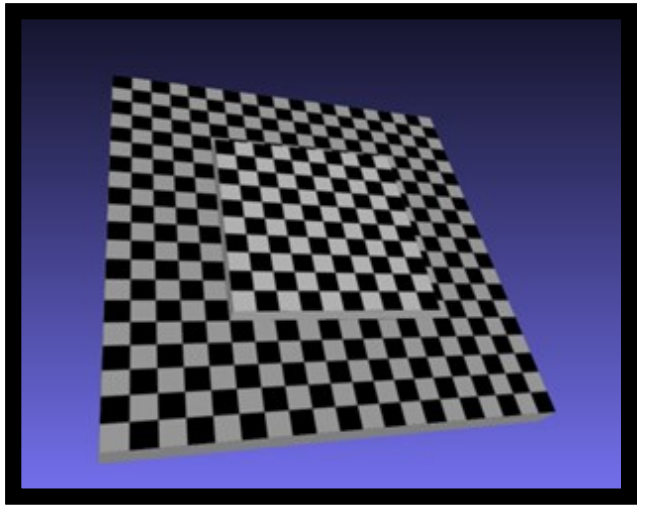


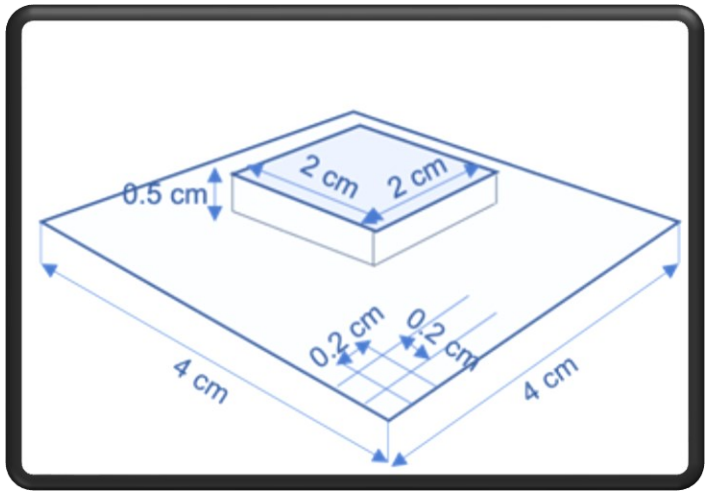




11. HYPSOS PHOTOGRAMMETRIC CALIBRATION

❖ **Gauge Reference - This gauge has a large number of three-dimensional reference points, and thanks to them it has been possible to estimate the components of the instrument projection matrix *M***



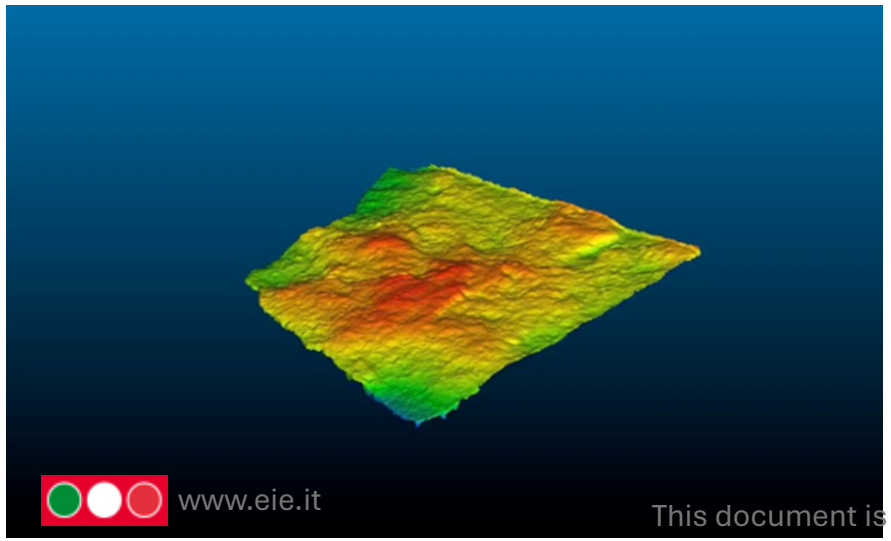


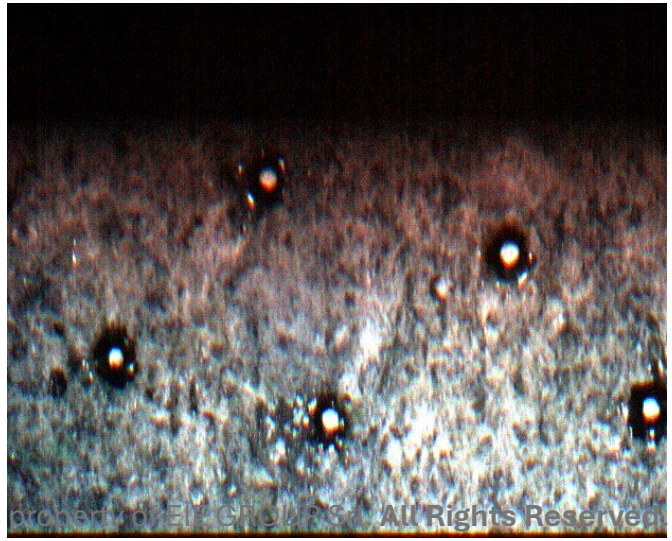
❖ **The obtained projection matrix is the compact representation of the internal and external parameters of the camera.**

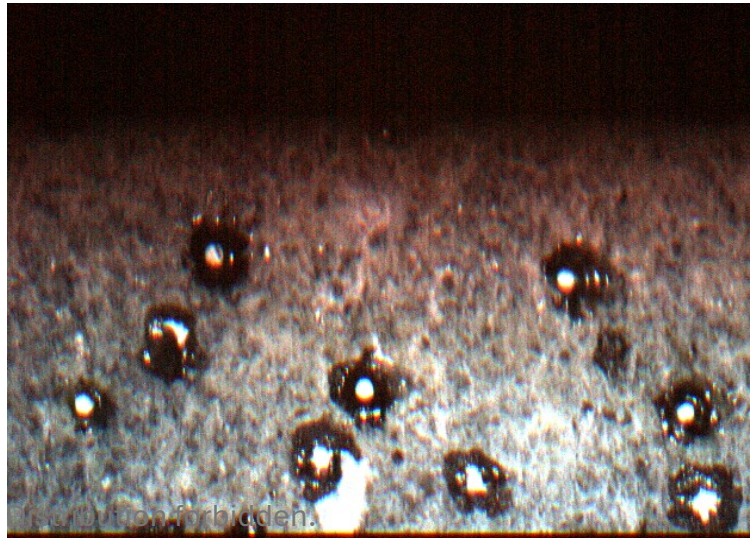
12. HYPSOS PROJECT DATA PROCESS REDUCTION

HYPSOS 3D final product data to validate the system performance

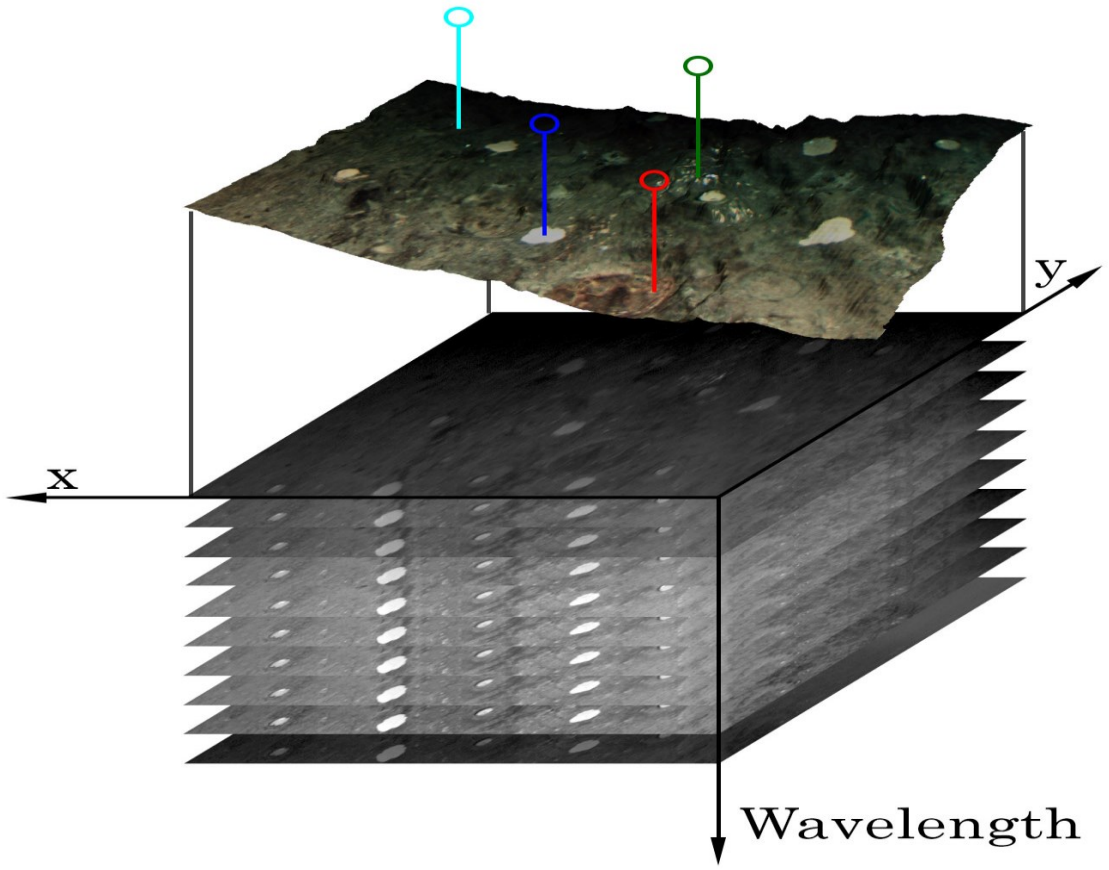
- The extraction of 3D information from the spectral pairs of stereo images acquired with HYPSOS is performed following a specific photogrammetric pipeline
- With the information about the two channels obtained by the calibration process it is possible to analyse the disparity and derive the coordinates 3D in the form of a sparse point cloud or grid DTM
- Comparison methodology will be used: all the targets under measurement by HYPSOS are rock samples whose surface has been previously measured by means of a high precision laser scan system (20 µm resolution) and with known spectral characteristics

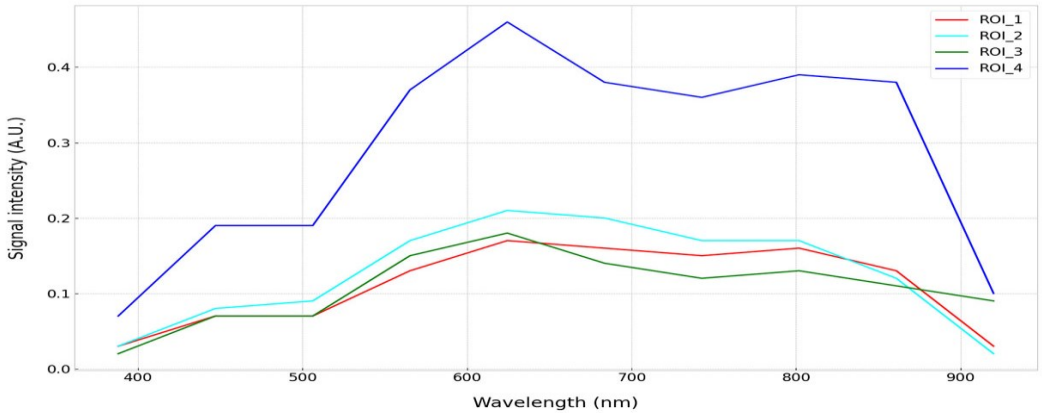






13. HYPSOS HYPERSPECTRAL PRODUCTS



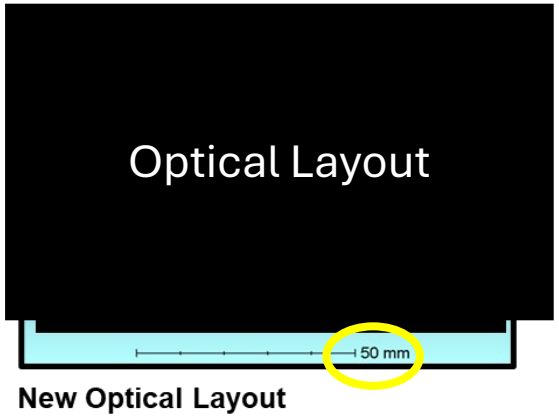


14. FUTURE WORK ON HYPSOS-EO & CONCLUSION

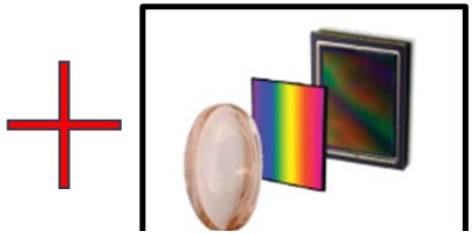
New optimization opportunities have been identified for HYPSOS: → HYPSOS-EO System

- **HYPSOS-EO for CUBESAT Application**
- **Adaptations for Freeform Optics , IR extension, …**
- **AI Algorithms, …**

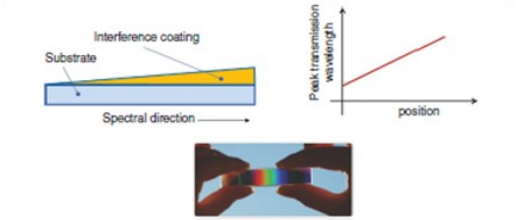
STERO-Hyperspectral
Space Optics Instrumentation

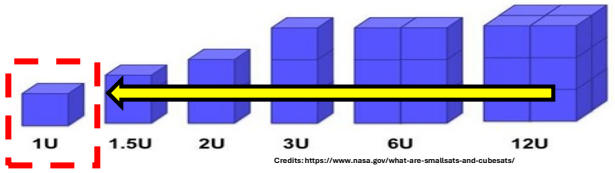


New Optical Layout



Credits: https://ebrary.net/205102/engineering/spectral_filters_based_approach





Credits: https://www.nasa.gov/what-are-smallsats-and-cubesats/

Identify New Opportunities

We have identified some In Orbit Mission to be able to install an IOD HYPSOS-EO or HYPSOS System in the future and test the apparatus.

PAYLOAD - 3D CAD MODEL
Topological Optimization Concept

Join us…

Pubblications:

- In-lab Characterization of HYPSOS, a Novel Stereo Hyperspectral Observing System: Latest Results
- In-lab characterization of HYPSOS, a novel stereo hyperspectral observing system: first results

ACKNOWLEDGEMENTS

Thanks to all the people of the Project Team who participated in the activities

HYPSOS-EO. Opportunity for new agreement...