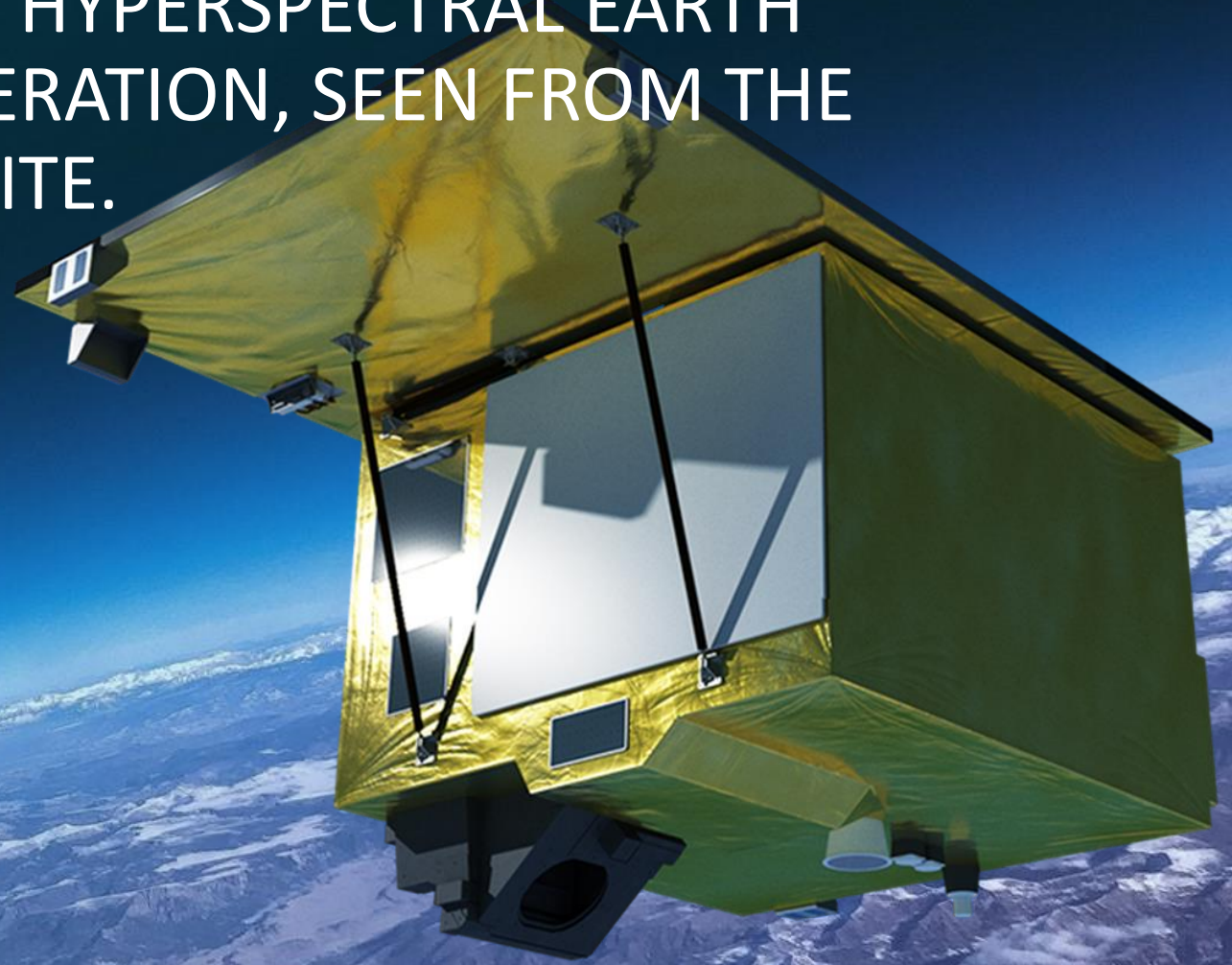
ENMAP: A BREAKTHROUGH FOR HYPERSPECTRAL EARTH OBSERVATION. ONE YEAR IN OPERATION, SEEN FROM THE MANUFACTURER OF THE SATELLITE.



ENMAP USER WORKSHOP, DLR/GFZ, 10-11 OCTOBER 2023

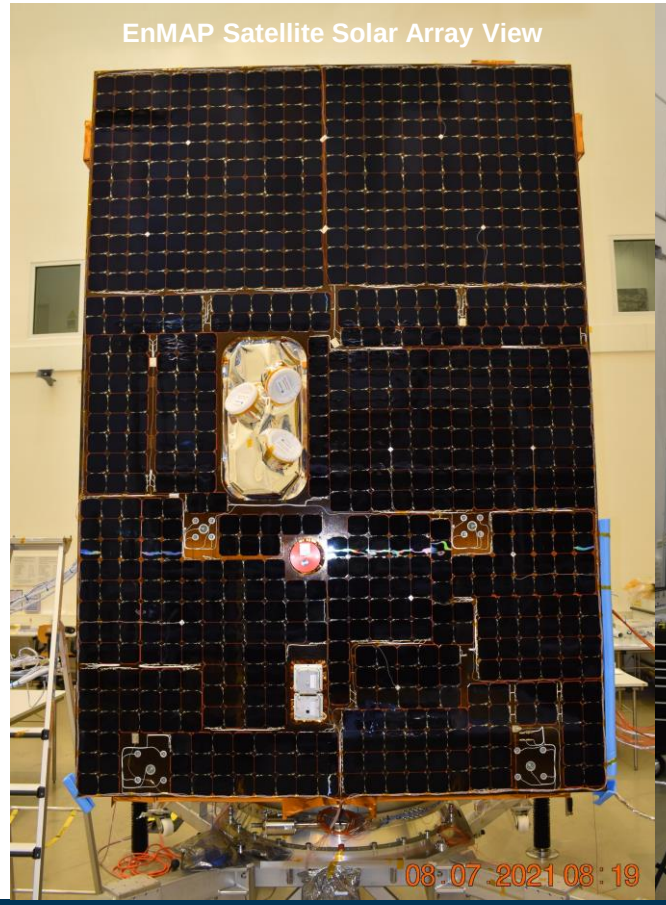
PREPARED BY THE OHB ENMAP TEAM
OHB-SYSTEM AG, OCTOBER 2023

ENMAP – A HYPER-SPECTRAL MISSION

OHB'S ENTRY INTO THE WORLD OF HYPER-SPECTRAL SPACEBORN INSTRUMENTS

- Germany's first satellite carrying a hyper-spectral imager instrument
- Major step for OHB into building spaceborne hyper-spectral instruments as both, instrument prime and satellite prime
- Demanding users' needs required components with very high performance made of new technologies
- Detailed design and its implementation revealed many challenging areas
  - spectrometer optics design and AIT
  - thermo-mechanical sensitivity
  - detector and camera technology
  - video data chain handling and processing
  - multi-cameras system operations

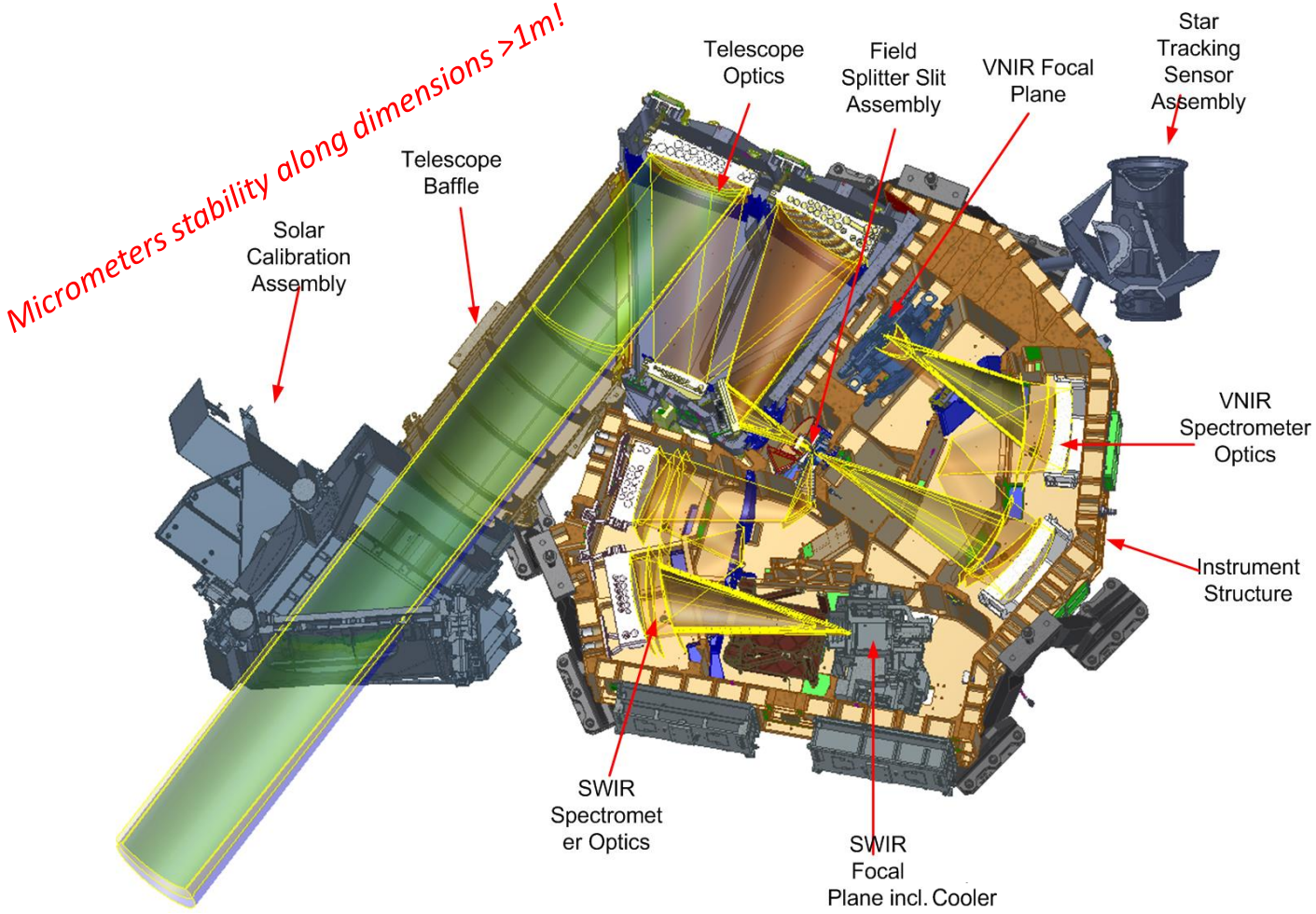
We had to master a demanding learning curve to realize EnMAP

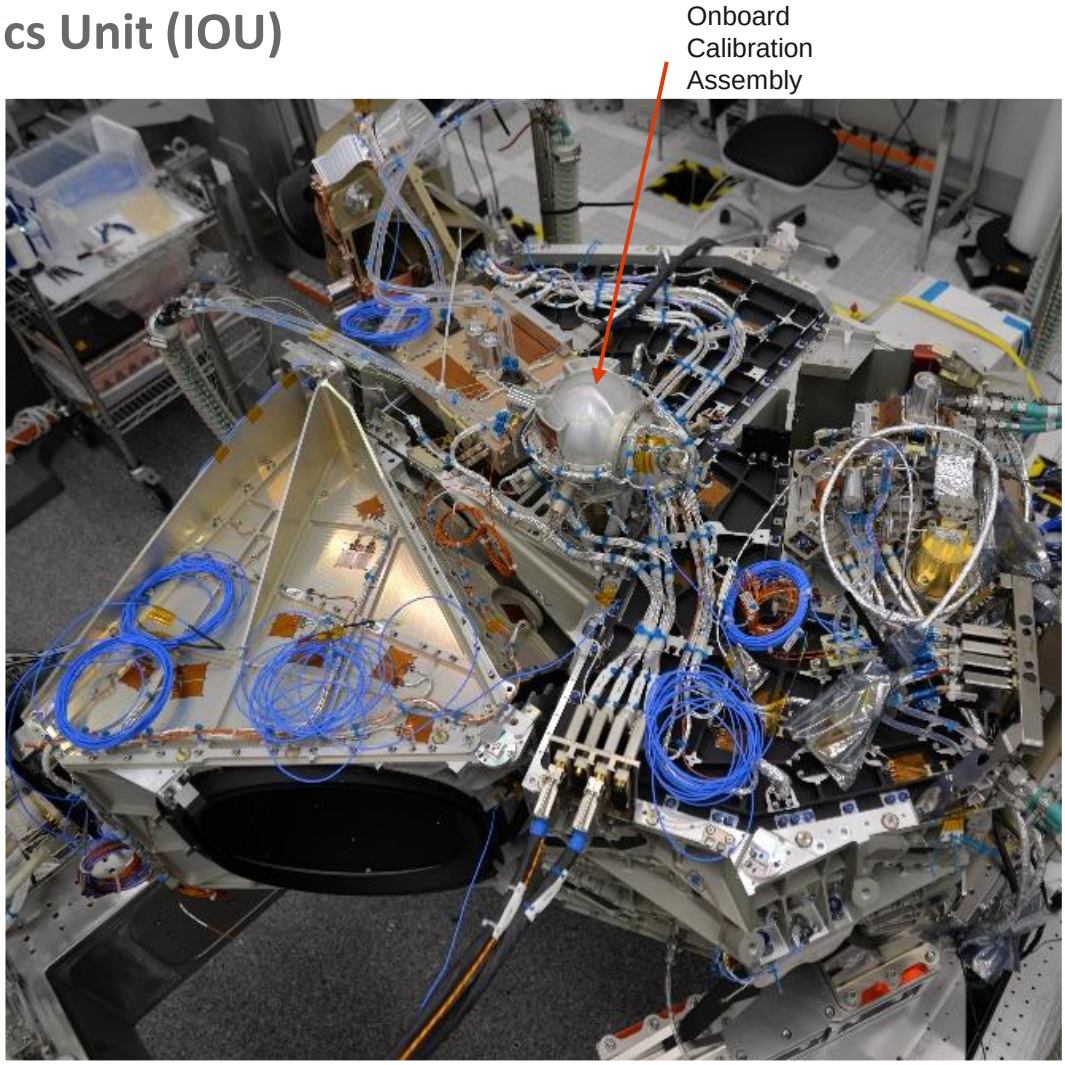


ENMAP – DESIGN OF THE INSTRUMENT'S KEY ELEMENT

TELESCOPE, SPECTROMETERS AND ELECTRO-OPTICAL SENSORS (FOCAL PLANE ASSEMBLIES)

- Core of the EnMAP hyper-spectral instrument: **Instrument Optics Unit (IOU)**

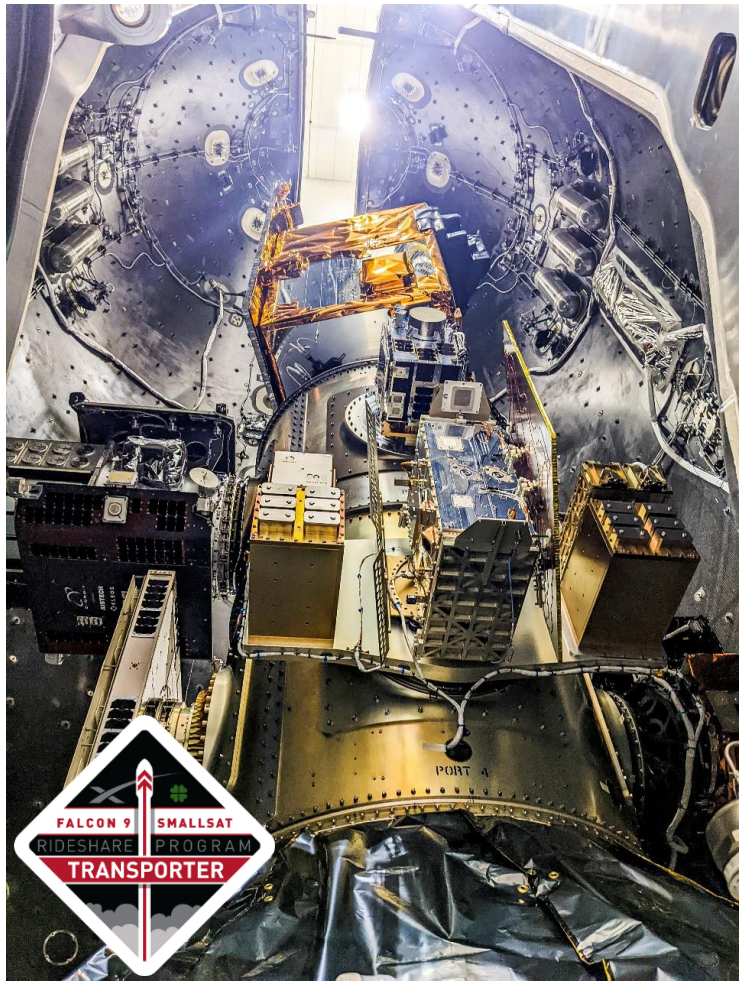




ENMAP – ONE YEAR IN-ORBIT

LOGBOOK OF MAJOR PLANNED *AND UNPLANNED* EVENTS

- **1st of April 2022 (16:24 UTC): Successful launch and precise orbit injection**
- Smooth satellite subsystems checkout and commissioning in line with LEOP plan
- Early power-on of payloads and startup of HSI subsystems checkout sequences
- **14th of April: Orbit installation finished and successful closure of LEOP acc. to plan**
- An issue on one of the 11 loop-heat-pipes (LHP) required rework on procedures and mission planning system which was successfully implemented by ground segment during commissioning phase
- Mass memory (imaging data storage) shows in-orbit sporadic watchdog resets
- **27th of April: EnMAP first light indicates already excellent optical performance**
- 24th of September 2022: VNIR detector latch-up protection triggered
- **12th of October: Successful Flight Qualification & Commissioning Acceptance Review**
- **November 2022: EnMAP mission enters Operational Phase**
- 6th of December 2022: SWIR ROIC configuration monitoring triggered
- 13th of December 2022: HSI watchdog triggered (strong radiation incident assumed)
- **May 2023: Implementation of updated SWIR spectral bands acc. to science request**



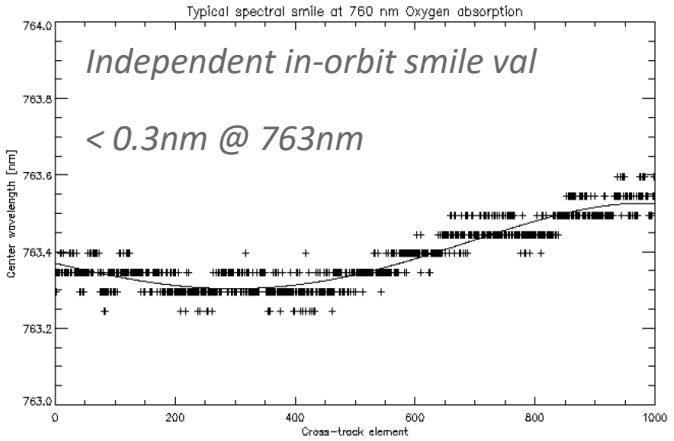
ENMAP PERFORMANCE – SPECTRAL/RADIOMETRIC/GEOMETRIC

ACHIEVED IN-ORBIT PERFORMANCE

- Confirmation of expected performance by validation ***in orbit***
  - very low smile, very high quality of spectral knowledge, other parameters stable wrt on-ground characterization
  - Radiometric accuracy, signal quality very good
  - Geometric data quality beyond expectation, image quality high
- Confirmation of in-orbit calibration concepts and associated HW / ops
- Stability of instrument exceeding expectations
- Some real-world effects noticeable (*but within specifications*)
  - striping / low signal non-linearity *(possible improvements in L1 proc)*
  - VNIR / SWIR mismatching *(recommendation to use SWIR data)*
  - VNIR response changes *(not noticeable above L1c)*
- **EnMAP data quality/performance successfully confirmed in operations**

Parameter	VNIR	SWIR
Geolocation accuracy (nadir)	< 100 m (1σ, level 2)	
Co-registration (nadir)	<= 0.2 GSD	
Spectral range	420-1000nm	900-2450nm
Spectral sampling distance (average)	6.5+/-0.25 nm avg	10+/-0.25 nm avg
Spectral sampling distance (range)	4.7 – 8.3 nm	7.4 – 12.1 nm
Spectral stability (btw. calibrations)	< 0.5 nm	< 0.53 nm
Spectral accuracy (calibrated)	< 0.5 nm	< 1 nm
Spectral shift (over mission life time)	< 5 nm	
Signal to noise ratio	> 500:1 @495 nm	> 150:1 @2200 nm
Radiometric stability (calibrated)	< 2.5 %	
Radiometric accuracy (calibrated)	< 5 %	
Linearity	< 0.5 %	

EnMAP key *performances*



ENMAP ANOMALIES – "*EXPECTED*" INCIDENTS

INCIDENTS FOR WHICH WE WERE PREPARED

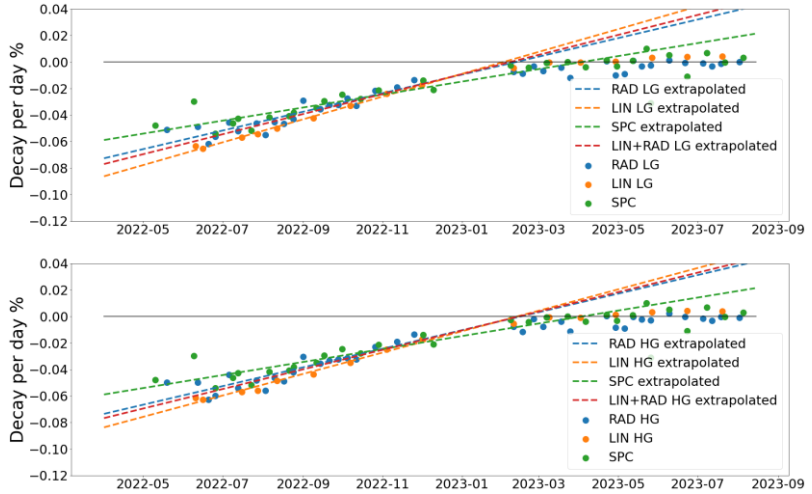
- Several special FDIR features found to be required and implemented during design phase
  - VNIR Camera: Latch-up protection circuit in the VNIR camera triggered once during an image acquisition
  - SWIR Camera: ROIC configuration change detected once during an image acquisition
  - HSI watchdog trigger: HSI autonomous reboot with setup of safe stable conditions (here focus on LHP inhibition concept)
  - Operational procedures to bring HSI back to nominal operations successfully executed (enhanced LHP start-up on-board control procedures)
- Implemented recoveries to a safe stable condition of payload (and satellite) worked as planned for all these exceptional events

HSI functional performance 100% available at this moment (1,5 years after Launch)

ENMAP ANOMALIES – “*UNEXPECTED*” INCIDENTS

INCIDENTS FOR WHICH WE WERE NOT PREPARED

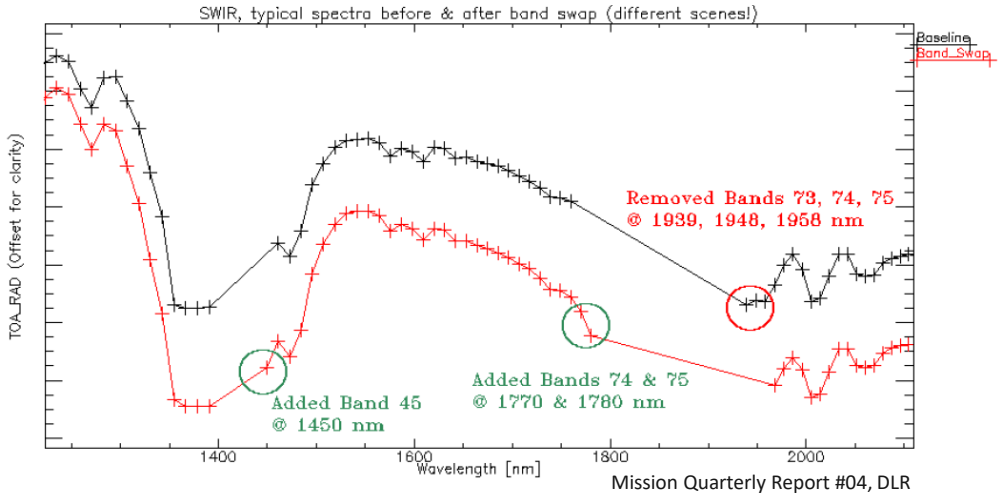
- VNIR signal change detected during in-orbit commissioning
  - Root cause analyses performed by OHB (&DLR: executed power-cycle VNIR camera)…
  - Likely a detector level packaging induced effect
  - Effect has slowed / almost stopped
  - Situation now considered stable
  - Data quality was never affected due to updated calibration coeff



- Data Science Handling Assembly (mass memory) watchdog
  - During commissioning phase sporadic resets of DSHA observed
  - S/W update developed together with DSHA supplier, uploaded and activated
  - Sporadic watchdogs of DSHA could be eliminated

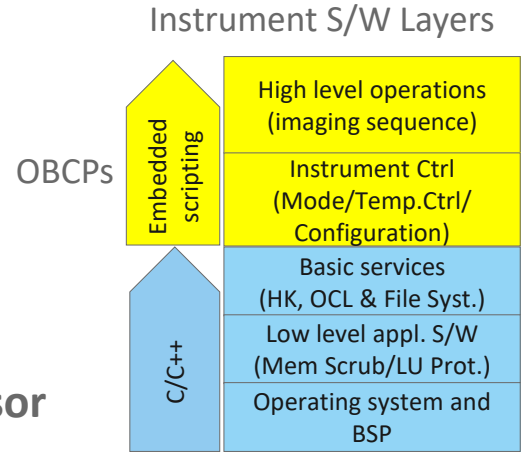
ENMAP EVOLUTION – SWIR CHANNEL BANDS

UPDATES DURING IN-ORBIT OPERATIONS



Mission Quarterly Report #04, DLR

- EnMAP science segment requested change in transferred spectral bands (EN-GFZ-TN-L2A-Bands):
  - Band swap in SWIR spectrum, replacement of three bands
- Embedded scripting for higher level operational sequences (On-Board Control Procedures); e.g. ground and calibration imaging sequences or instrument configuration are stored as OBCP
- This flexible architecture allows efficient updates of operational sequences or selected instrument configurations
  - Informal science user request to ground and space segment, feasibility assessment and (for the case of positive feedback) formal request
  - Development and test of new instrument OBCP on ground (OHB)
  - Upload, storing on-board and test of new OBCP in-orbit (DLR Ground Segment & OHB) (Instantaneous activation of OBCP by operator TC, no instrument S/W reboot required)
  - Implementation of new configuration/sequence into operational system after successful verification (DLR Ground Segment)
- **SWIR band swap was good example of potential refinement capabilities for the EnMAP sensor due to gaining ground or science segment knowledge evaluating EnMAP data**



ENMAP OUTLOOK

ENMAP AS PRE-CURSOR MISSION

OHB has gained enormously in terms of General Technology and Instrument Know-how from EnMAP:

- OHB had gained very valuable knowledge from ENMAP on technologies and manufacturing such as:
  - Optical Coatings,
  - Calibration references,
  - Gluing technologies,
  - Material properties, long term behavior etc.
  - Optical Alignment Technologies
  - Many more……

- Which is of great importance for all future missions of optical instruments.
- This return of experience is applied on all currently ongoing OHB projects

- One prominent example is optical alignment in **MTG**
  - Where we have repeated the EnMAP technology on 10 instruments (FCI & IRS)
- A second prominent example is obviously **CHIME** the European ESA Hyperspectral Mission with OHB acting as instrument prime

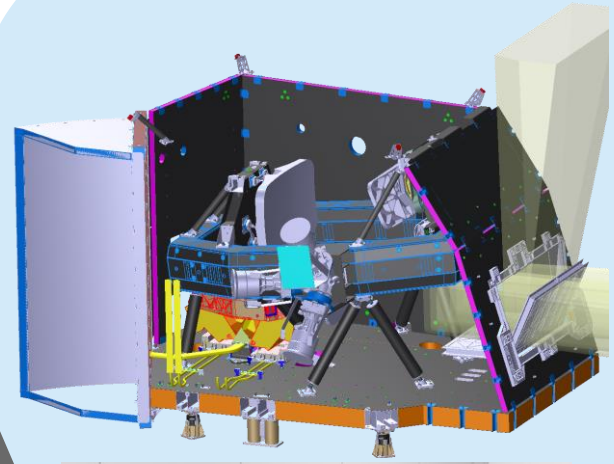
THE CHIME HYPERSPECTRAL INSTRUMENT (HSI)

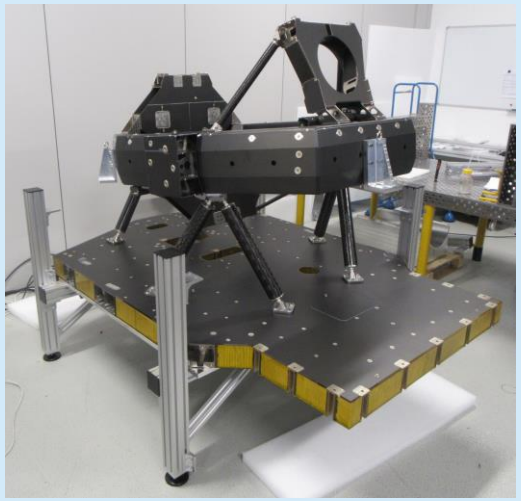
ENMAP AS PRE-CURSOR MISSION

EnMAP
Return of Experience

The CHIME HSI DDVP reflects intensive elaboration of lessons learned and heritage accumulated in the frame of the EnMAP program, such as (list not exhaustive):

- Hyperspectral and detector technology
- Passive cooling
- Modes for SW development and HSI functions
- Electrical architecture
- Design for Performance and Calibration
- AIT lessons learned





CHIME HSI - Key Figures

Compared to these precursor hyperspectral missions, CHIME makes a step forward in many directions, improving in different areas:

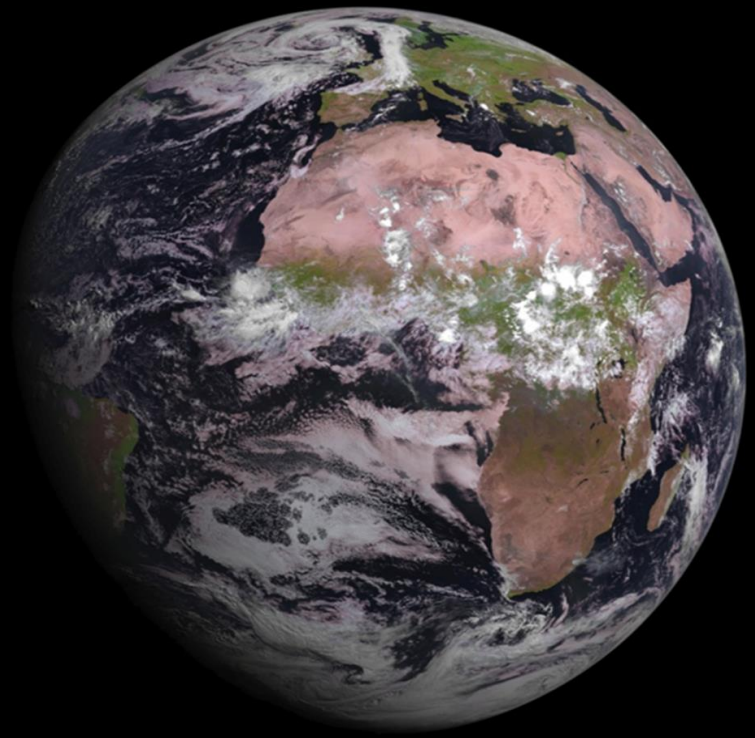
- global coverage of all land & coastal waters between 84°N- 56°S
- reduction in image distortions and “chromatism” e.g. improved spatial co-registration across the spectral bands;
- the radiometric calibration;
- the lifetime of up to 12 years, and over 97% mission availability;
- the revisit of 22 days with 1 satellite, 11 days with 2 satellite;

	CHIME	PRISMA	EnMap	NASA’s SBG VSWIR (TBC)
years	2028-2035+5Y	2019-2024	2020-2025	Not known
SSD	30m	30m	30m	30m
Band	400-2500nm	400-2500nm	420-2450nm	350 or 400-2500nm
spectral resolution	10nm	<12nm depending on frequency	10nm	~10nm TBC
SNR (value at 800nm)	400 TBC	300 TBC	300 TBC	300 TBC
On-ground swath	128km per satellite	30km	30km	Not known-expected similar to CHIME

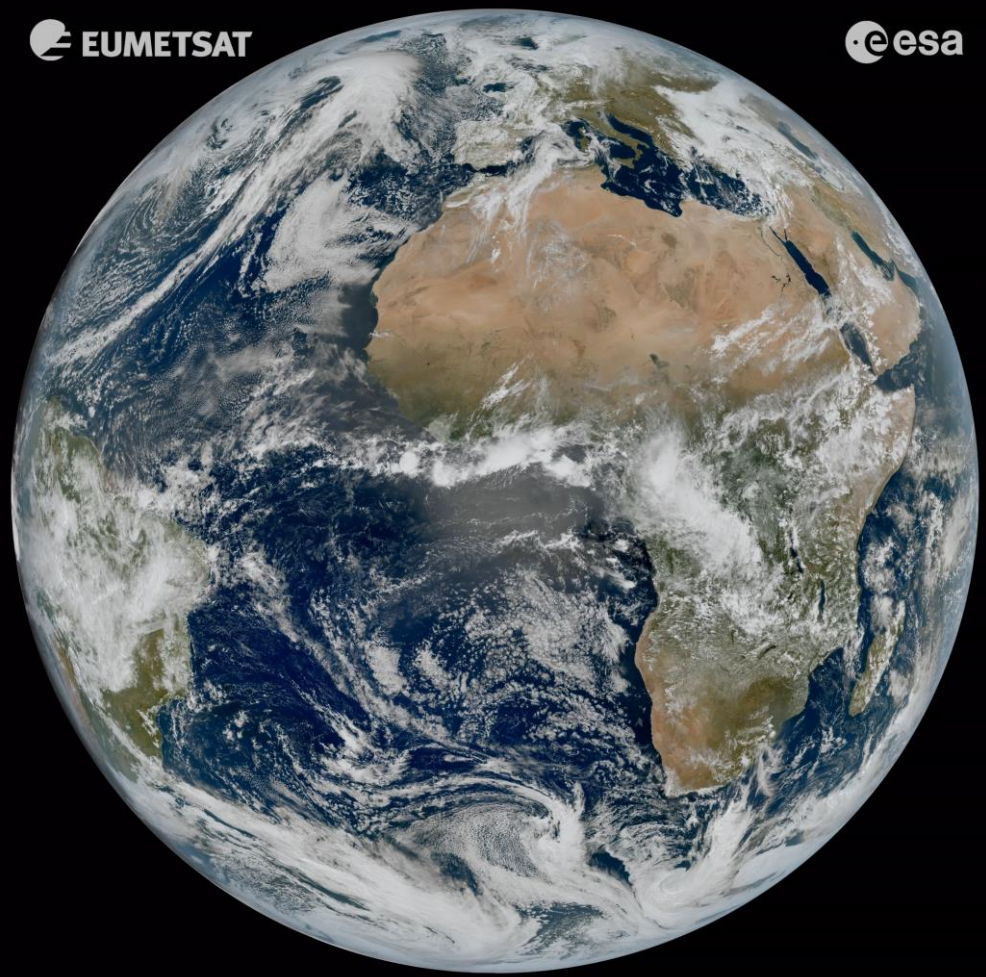
METEOSAT European GEO Imager - Evolution

Meteosat 1 First Image 9th Dec 1977

MSG-4 (MET11) First Image 4th Aug 2015



MTG-I1 (MET12) First Image 18th March 2023



Courtesy TAS. ESA. EUMETSAT

THANK YOU FOR YOUR INTEREST

WE WISH YOU A VERY SUCCESSFUL FIRST ENMAP USER WORKSHOP

WE.CREATE.SPACE.

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