CHIME Cal/Val Methodology & Status @ PDR

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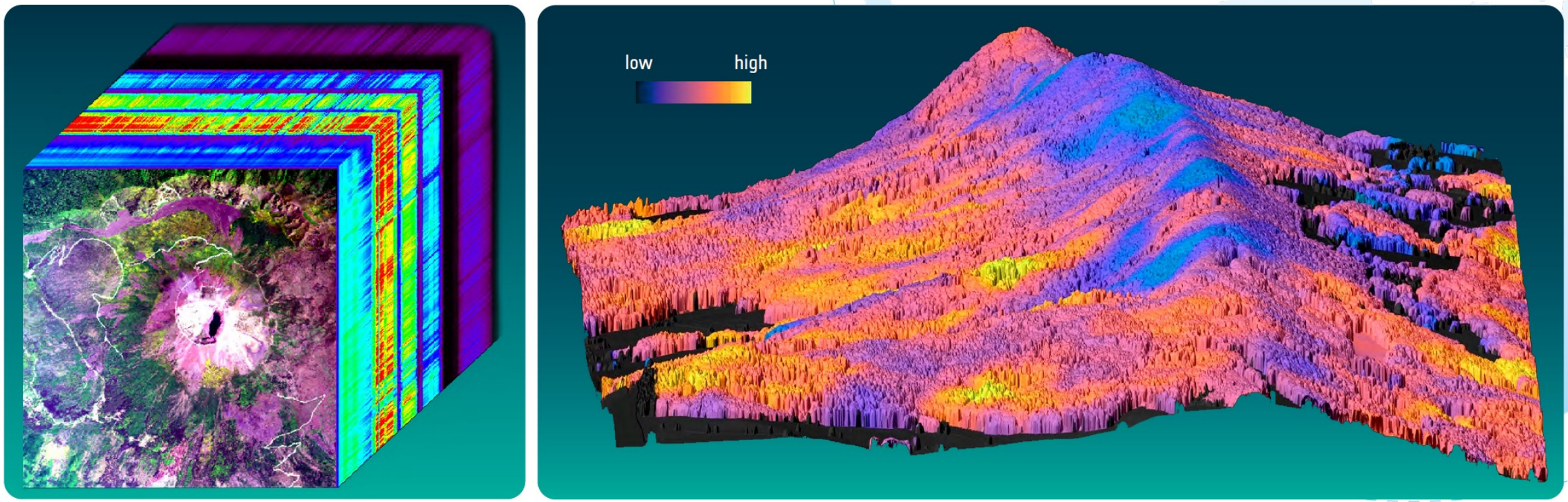
CHIME Mission Objectives

- Provide routine hyperspectral measurements in support of EU- and related policies for the management of natural resources & assets
- Support food security, agriculture and raw materials, soil properties
- Secondary Applications: biodiversity and ecosystem sustainability, forestry management, environmental degradation, lake/coastal ecosystems and water quality, snow grain size/albedo, snow impurities)



Physiological diversity of a temperate forest (Airborne imaging spectroscopy APEX data - Schaepman, Jehle et al. 2015)

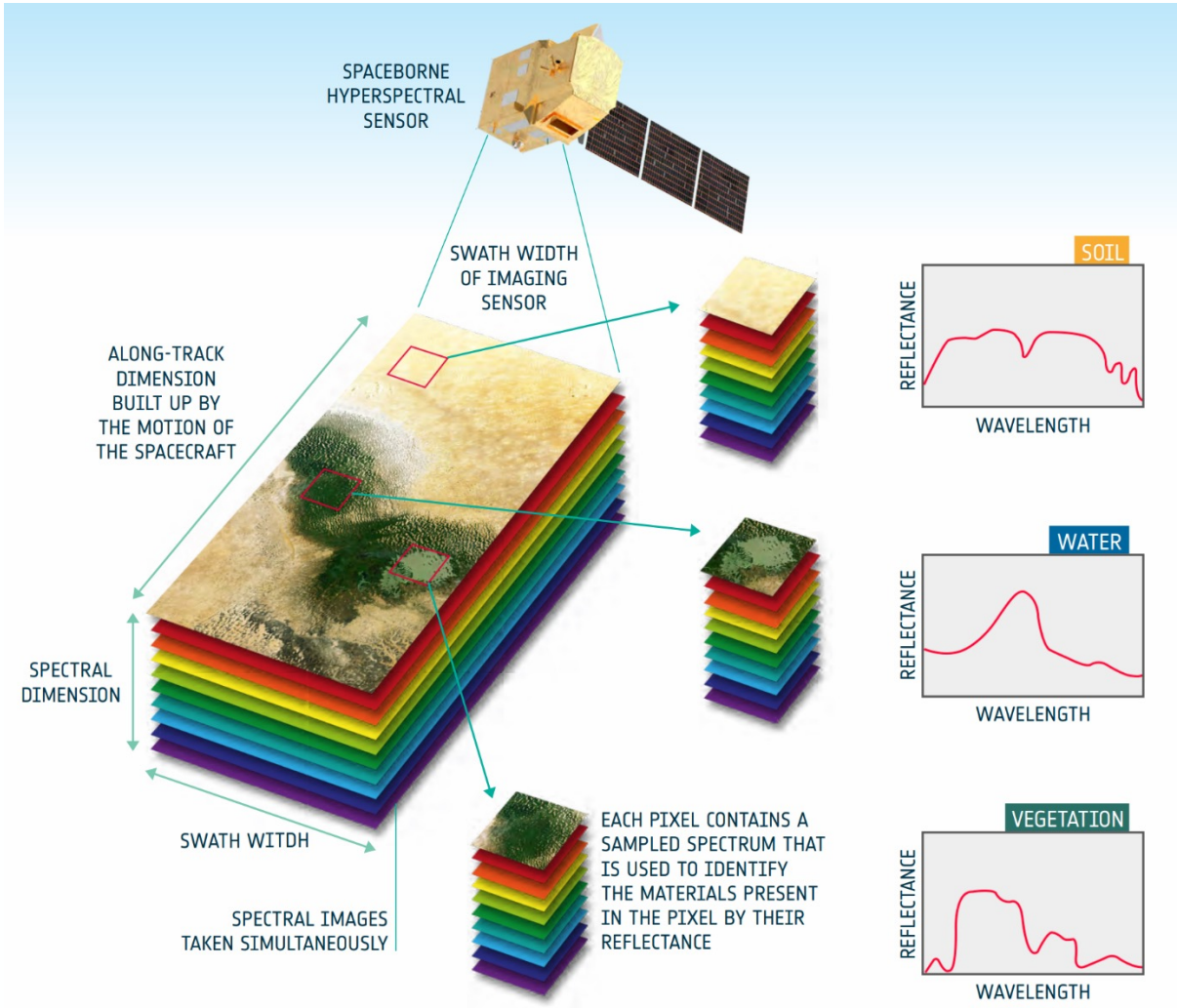
CHIME Key Requirements

Operational hyperspectral observations of land and coastal areas
Spectral range: 400 – 2500 nm
Spectral bandwidth and SSI ≤ 10nm
Ground Resolution: 30 m
Revisit 12.5 days (2 satellites)
High radiometric accuracy, low spectral/spatial mis-registration
High SNR

Matching performance of parallel missions (e.g. EnMAP, PRISMA, SBG)

Core data products:

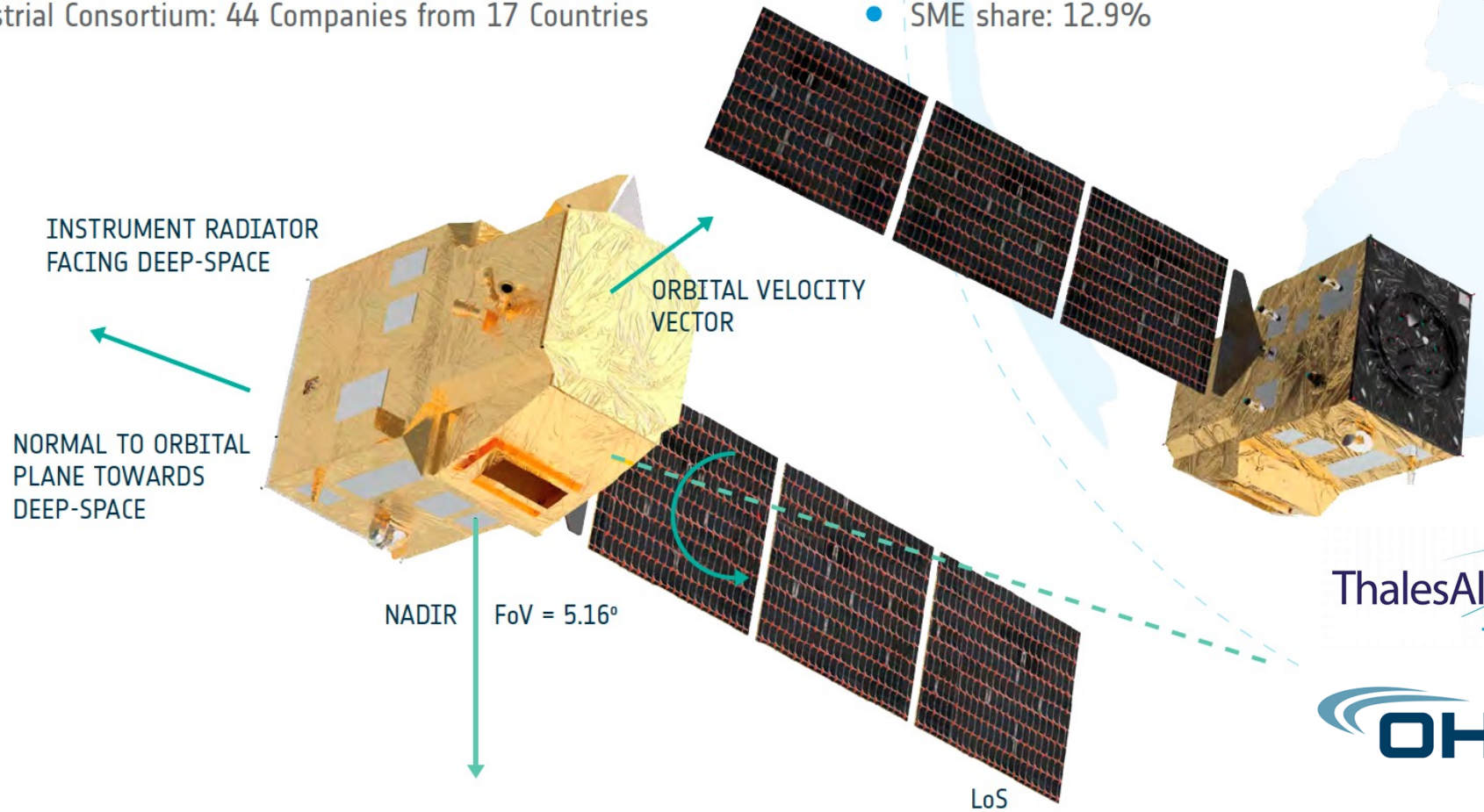
L1-B Top-of-atmosphere (TOA) radiance
L1-C Ortho-rectified TOA reflectance
L2-A Ortho-rectified bottom-of-atmosphere (surface) reflectance



CHIME Space Segment

Full Consortium Established for Space segment Development B2/CD (for PFM + FM2)

- Prime Contractor: Thales Alenia Space France (TAS-F)
- Industrial Consortium: 44 Companies from 17 Countries
- Instrument Prime: OHB (DE) with
  - LEONARDO (IT) for Focal Planes & E2E Calibration
  - AMOS (BE) for 3 x spectrometer, gratings and slits
- SME share: 12.9%

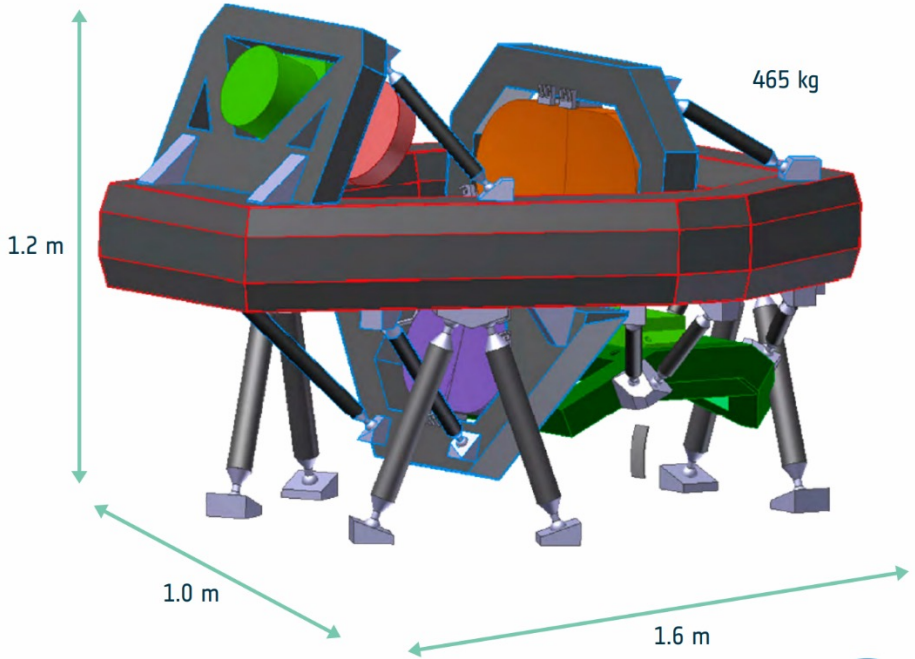


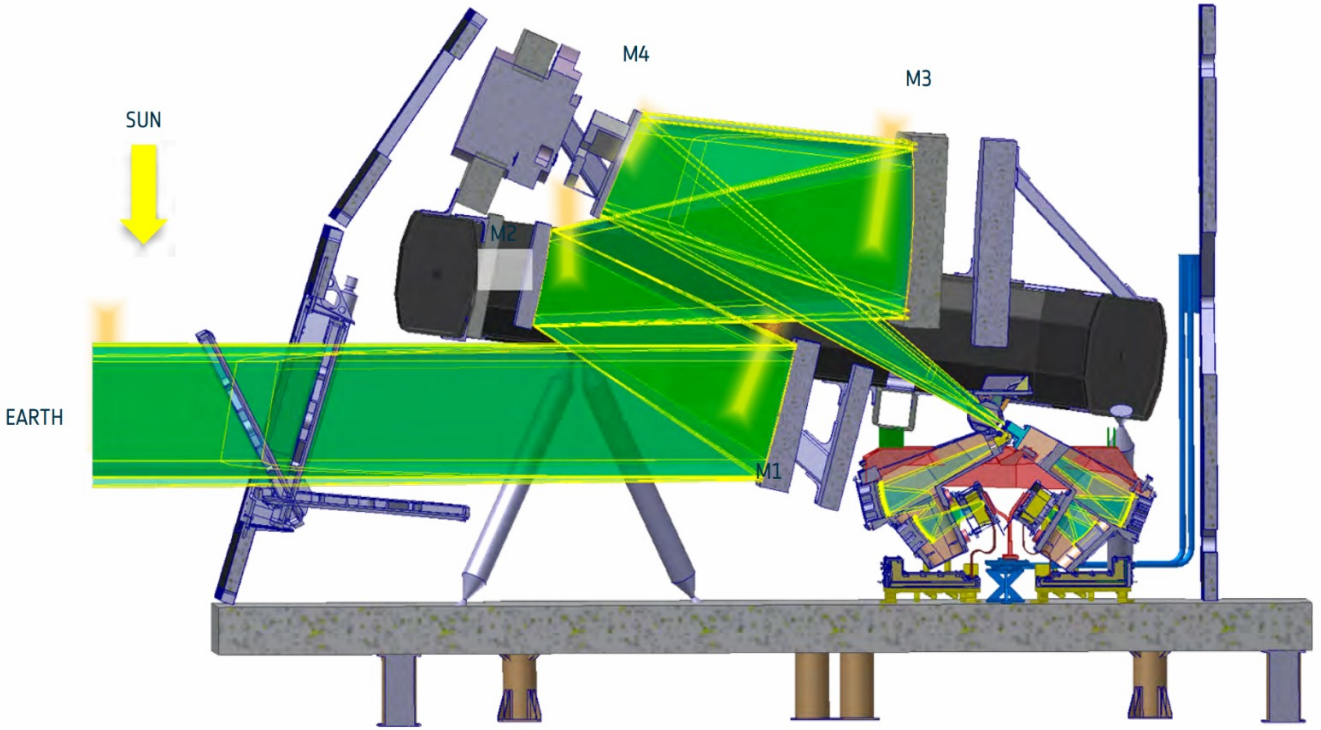
ThalesAlenia Space

OHB

CHIME Programmatic Status

- System PDR Board held 15th July 2022
- Instrument HSI PDR started
- PDR Closeout expected in October 2022
- Start of Phase C/D expected in Q4 2022
- CDR expected Q2 2025
- QAR PFM: mid 2028, FAR FM2: mid 2029





Conceptual design for the optical accommodation of telescope and spectrometers for the staggered slit design

CHIME High Priority Prototype L2-B Products

DOMAIN	THEMATIC AREA	VARIABLES CHPPP	CHIME Candidate Algorithms
AGRICULTURE / FOOD SECURITY	 Assessment of biophysical and biochemical variables related to the crops and of agronomic interest	Leaf/Canopy Pigment Content	Semi-empirical modelling based on narrow-band vegetation indices; Hybrid methods based on ANN/LUT or other machine learning algorithms applied to vegetation canopy radiative transfer models outputs (e.g. PROSAIL).
		Leaf/Canopy Nitrogen Content	Narrow-band vegetation indices; Hybrid methods based on ANN/LUT or other machine learning algorithms e.g. GPR methods applied to vegetation canopy reflectance models (e.g. PROSAIL).
		LAI	
		Canopy Water Content	
		Leaf/Canopy Pigment Content	
		Leaf Mass/Area	
	 Topsoil properties	Soil organic carbon content	Chemometrics modelling (e.g. PLSR); Spectral analysis; Spectral indices; Machine learning (e.g. Random Forest)
		Soil texture (clay, silt, sand)	
GEOLOGY & MINERALS	 Raw material detection	Mineral identification / classification (Kaolinite, Smectite, Jarrosite, Dolomite)	Sub-pixel linear unmixing Tetracorder type (EnGeoMap/PRISM)
		Hematite – Goethite distribution	
		Ferric oxide content	
		Kaolin Cristallinity	

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CHIME Calibration Methodology

→ **Pre-launch calibration/characterisation** of key instrument performance (proper traceability, documentation)

→ **Post-launch calibration**

- **In-flight calibration:**
  Allowing monitoring of performances, adjustment, modeling, etc.

- **Vicarious calibration:**
  - ✓ Equipped sites
  - ✓ Pseudo invariant calibration sites (PICS)
  - ✓ Rayleigh
  - ✓ Deep Convective Clouds
  - ✓ others

→ **Validation**

→ **Data quality checks and characterisation**

Overview Of CHIME Calibration Concepts (1/3)

CHIME SYSTEM CALIBRATION, CHARACTERISATION AND VALIDATION PLAN, Thales Alenia Space

Memo	Calibration	Method	Frequency and Operation duration estimation	Orbit part	Satellite slew	Acquisition mode	Data rate	Platform constraints
Sun Calib	On-Board Absolute Radiometric Calibration	Full Aperture Diffuser Equipment (FADE): Absolute radiometric reference by measurement of the on-board solar diffuser included in the FADE.	Once per week max	North pole	No	NOM	Binned (2x2)	none (TBC) Calibration mode
Shutter Dark Calib	On-Board Dark Calibration	Internal Calibration Switching Unit (ICSU): Dark acquisition and offset calibration by blocking light path with the ICSU.	Twice per orbit	before and after observation	No	NOM	Binned (2x2)	none (TBC) Calibration mode
Linear Calib	On-Board Linearity Calibration	Linear Calibration Source Unit (LCSU): Illuminate detector with LEDs in LCSU and perform integration time scan	Once per week	Eclipse	No	NOM	Binned (2x2)	none Calibration mode
Spectral Calib	On-Board Spectral Calibration	Spectral Calibration Source Unit (SCSU): measurement of absortion features from ion doped filter-glass illuminated with sun light via the FADE	Once per week Embedded in Sun Calib sequence	Eclipse	No	SPECCAL	Spectrally unbinned (2x1) 1 frame/3	none Calibration mode
Sun Equal	On-Board Gain Equalization	Full Aperture Diffuser Equipment (FADE): Relative measurement on the on-board solar diffuser in FADE in order to derive the equalization gains for sub pixel	Twice per year	North pole	No	FULLRETINA	Unbinned 1 frame/5	none (TBC) Calibration mode
Shutter Dark Equal	On-Board Dark Equalization	Internal Calibration Switching Unit (ICSU): Dark acquisition and offset for sub-pixel by blocking light path.	Twice per year	North pole	No	FULLRETINA	Unbinned 1 frame/5	none (TBC) Calibration mode
Desert Equal Calib	Desert Radiometric Equalization	Vicarious: Radiometric field-of-view equalization by measurement of desert targets with a 90° yaw	Twice per year	Observation	Yaw	NOM	Binned (2x2)	guidance and Satellite pointing

Overview Of CHIME Calibration Concepts (2/3)

Memo	Calibration	Method	Frequency and Operation duration estimation	Orbit part	Satellite slew	Acquisition mode	Data rate	Platform constraints
Geom bias Calib	LOS Bias between instrument frame and satellite control frame	Vicarious: Scenes acquired on Regions of Interest at different latitudes Matching with references (GCPs or well-located images)	Routine verification - potential re-calibration 6 months (TBC) for seasonal effect	Observation	No (TBC)	NOM	Binned (2x2)	None (TBC) Instrument in pushbroom over observation areas
Lunar Calib	Radiometric calibration	Vicarious: Manoeuvre to point field centre to moon. Perform scan with 5 times spatial along track oversampling.	Twice per month	Eclipse	3 axis slew	NOM	Binned (2x2)	Pointing sequence around eclipse
Deep Space Calib	Dark Calibration	Vicarious: Acquire frames during lunar calibration manoeuvre while pointing to deep space.	Twice per month	Eclipse	3 axis slew	NOM	Binned (2x2)	Pointing sequence around eclipse
Dark Ocean Calib	Dark Calibration	Vicarious: Dark scene and offset calibration by measurements during eclipse above dark ocean scene (e.g. in North or South pacific ocean)	Once per revisit	Eclipse	No	NOM	Binned (2x2)	None Instrument in push broom over observation zone

"CHIME SYSTEM CALIBRATION, CHARACTERISATION AND VALIDATION PLAN", Thales Alenia Space

Overview Of CHIME Calibration Concepts (3/3)

Memo	Calibration	Method	Frequency and Operation duration estimation	Orbit part	Satellite slew	Acquisition mode	Data rate	Platform constraints
Lunar Verif	MTF & Straylight verification	Vicarious: Manoeuvre to point field centre to moon. Perform scan with 5 times spatial along track oversampling.	Commissioning	Eclipse	3 axis slew	GEOCAL	Spatial Unbinned Spectral binned 1x4	Pointing sequence around eclipse
Desert Spectral verif	Desert Radiometric Equalization	Vicarious: Radiometric field-of-view equalization by measurement of desert targets with a 90° yaw for spectral verification purposes	Commissioning	Observation	Yaw	SPECAL	Spectrally unbinned (2x1) 1 frame/3	guidance and Satellite pointing
Geom static LOS Calib	LOS model of each pixel of the reference channel	Vicarious: Scenes acquired on RoI Matching with numerous GCPs spread all over the swath or dense correlation on reference images	Commissioning – Cal/Val Phase no re-calibration expected	Observation	No (TBC)	GEOCAL	Spatial Unbinned Spectral binned 1x4	None Calibration mode - Instrument in pushbroom over observation areas

CHIME calibration and verifications performed during commissioning

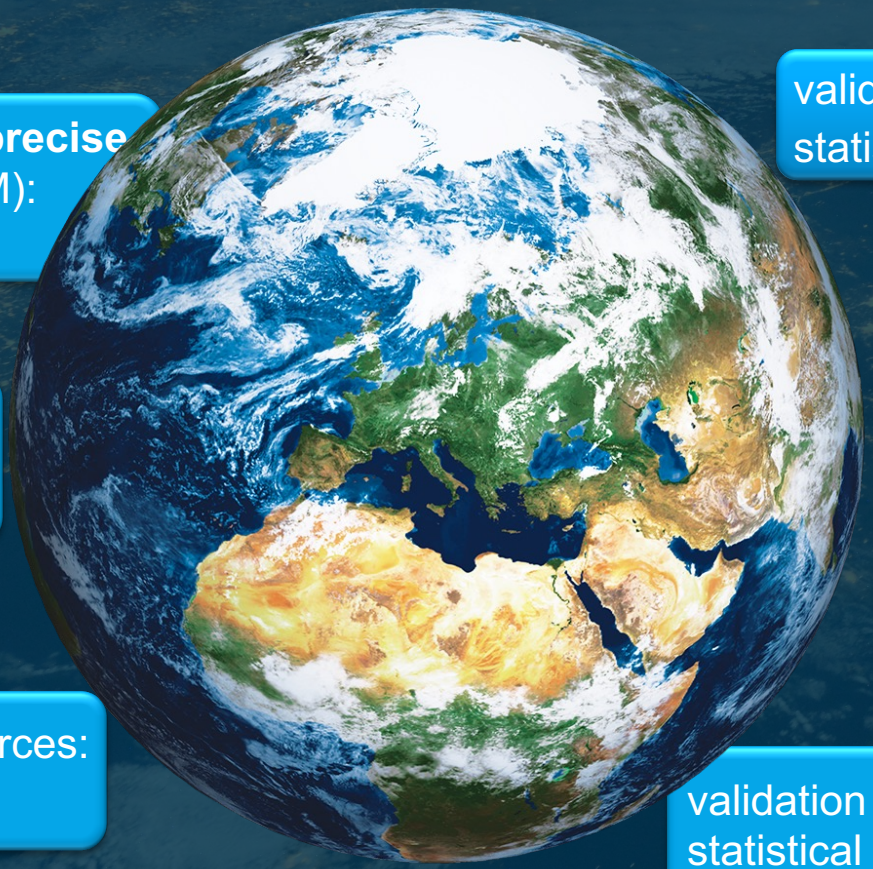
Data Quality activities for CHIME and other optical missions

ESA Validation Program is composed by a set of different complementary activities bringing elements that need to be combined together.

Inter-comparison against tailored and precise Fiducial Reference Measurements (FRM): few points but precise

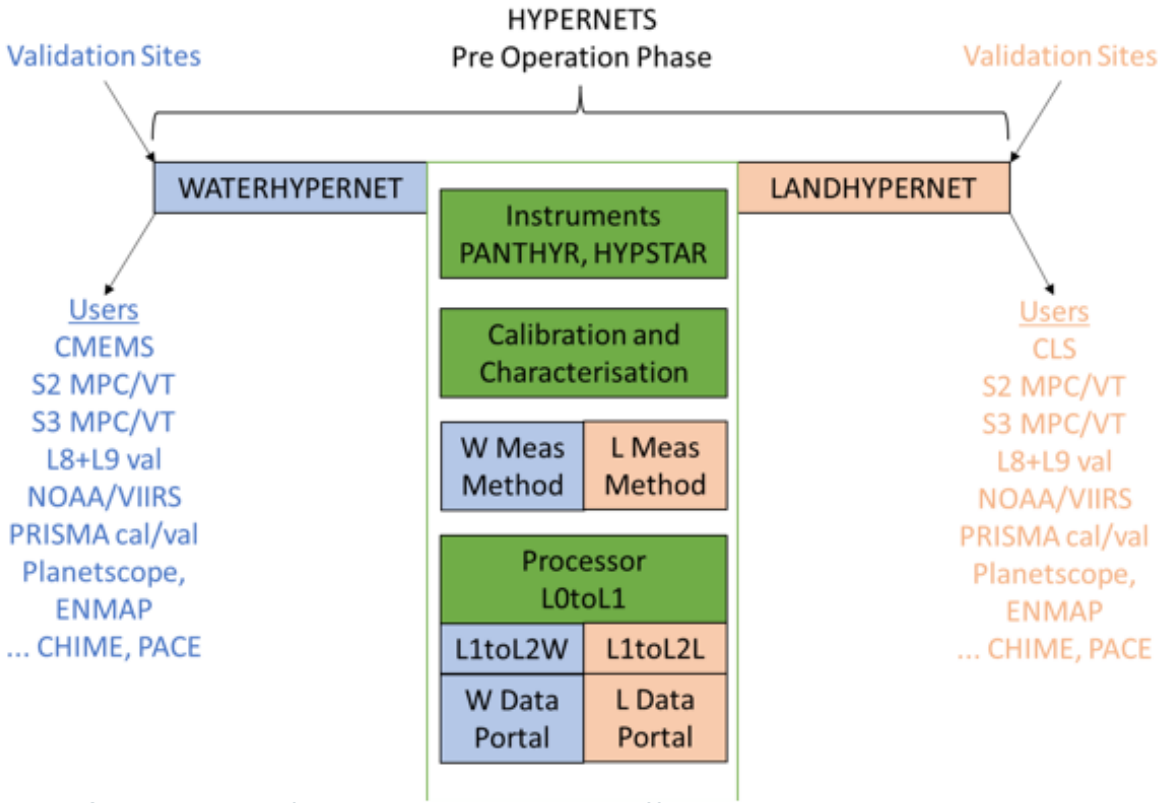
Inter-comparison against in-situ measurements: more points less precise

validation against others sources: **inter-satellite** comparison



validation using **monitoring tools**: statistics, trend, systematic quality control, etc.

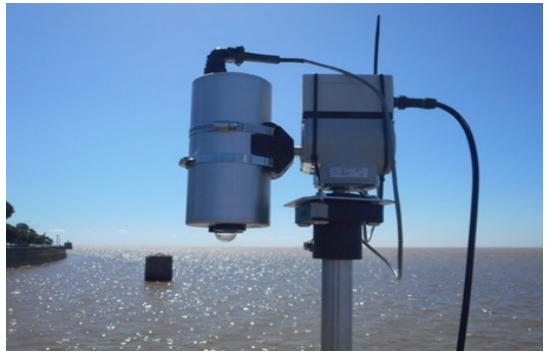
validation using **Level 3** data: statistical comparison between various Level 3 from various sensors for a cross-validation of the products



Overview of synergies and differences between water reflectance and land surface reflectance activities with common activities (green), water-specific activities (blue) and land-specific activities (beige).

- for land, measuring upwelling radiance from multiple nadir and azimuth angle to build up information on the Hemispheric-Directional Reflectance Function (HDRF) (Schaepman-Strub et al. 2006; Kuester et al. 2014); and

- (both water and land), scanning the skydome to check for clouds and/or obstructions or to estimate aerosol properties.



(PANTHYR radiometer System and HYPSTAR® radiometer system. Cable tie spikes are used for bird avoidance.

Next Generation Hyperspectral Radiometric Validation Networks for Water and Land Surface Reflectance - the HYPERNETS project – PI Kevin Ruddick (RBINS)

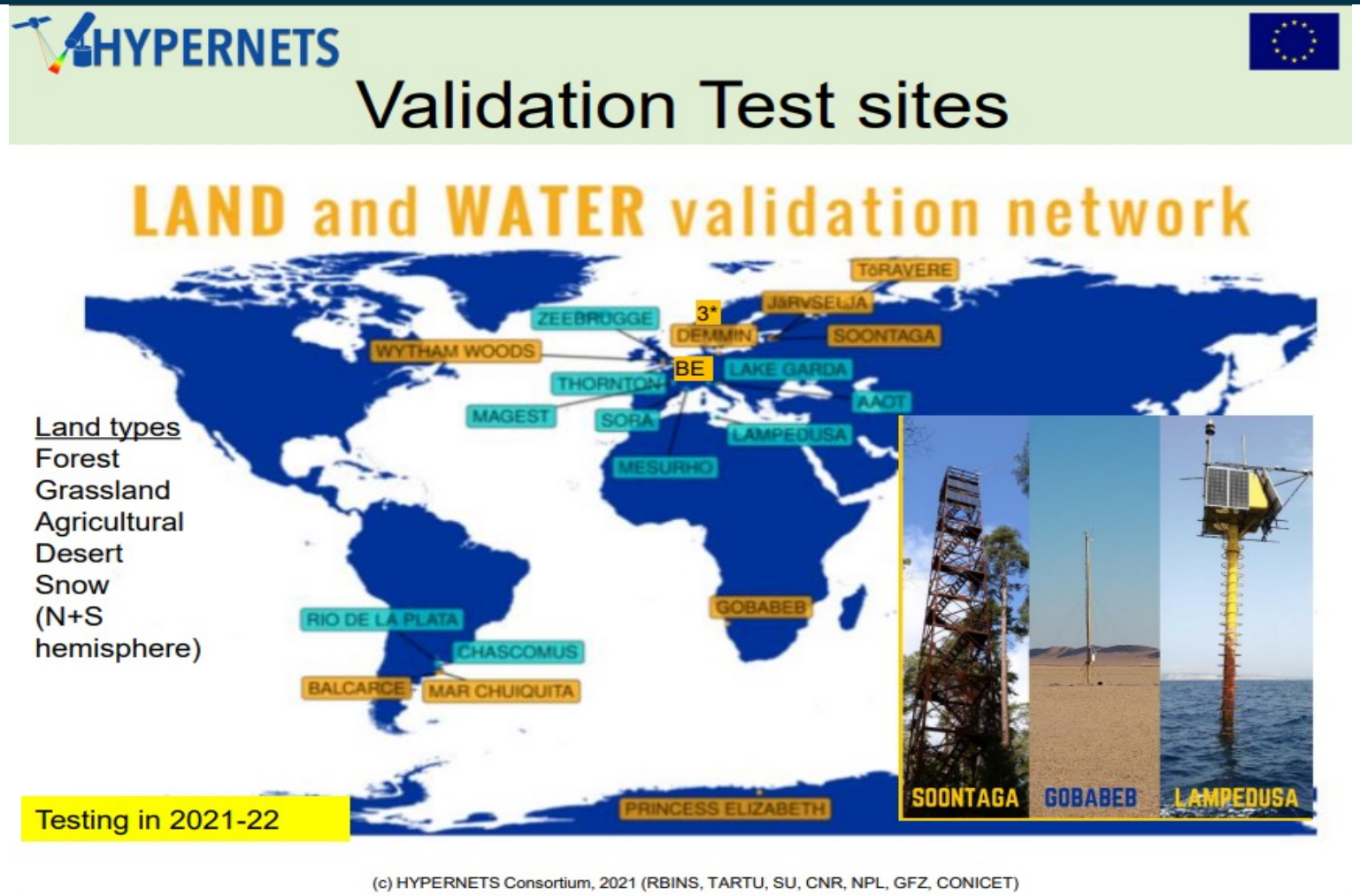
Based on the success of the AERONET-OC federated network for multispectral measurement of water reflectance, the HYPERNETS concept is to operate a:

- Hyperspectral radiometer(s) with both radiance and irradiance heads, on a Pan-and-tilt pointing system, with
- A control system comprised of computer, electronics and auxiliary sensors, power supply and communications (e.g. Ethernet/2G/3G/4G) ensuring data acquisition and transmission, deployed over an
- International network of autonomous sites, acquiring data following a
- Standardised measurement method, and transmitting data for
- Standardised data processing and web portal data distribution, backed up by SI traceable laboratory calibration and characterisation of radiometers, and Full estimation of measurement uncertainties, according to Fiducial Reference Measurement (FRM) principles.

While this approach clearly follows closely the prior AERONET-OC organisation (G. Zibordi et al. 2009) the following differences are noted (in addition to the obvious multispectral/hyperspectral difference):

- **Two types of hyperspectral radiometer** (and associated pan-tilt and control systems) are accepted in the network: the TRIOS/RAMSES radiometer (a mature, high performance COTS radiometer available since 2000 with radiance and irradiance variants) or the HYPSTAR® radiometer (a new prototype twin-head radiance/irradiance radiometer currently being tested within H2020/HYPERNETS to be commercialised from 2023).
- **Land surface reflectance** is measured in addition to water reflectance

HYPERNET Validation Sites – Growing Number of Sites



Satellite/Instrument	Agency	Launch date	Spectral coverage
Sentinel-2/MSI	ESA (Copernicus)	A: Jun 2015 B: Mar 2017 C: 2024? D: ?	442-2202 nm Multispectral
Sentinel-3/OLCI	EUMETSAT/ESA (Copernicus)	A: Feb 2016 B: Apr 2018 C: 2024? D: ?	400-1020 nm Multispectral
PRISMA	ASI (Italy)	Mar 2019	400-2500 nm Hyperspectral
ENMAP	DLR (Germany)	Apr 2022	420 to 2450 nm Hyperspectral
Landsat-8/OLI	NASA/USGS	Feb 2013	423-2300 nm Multispectral (+thermal infrared)
Landsat-9/OLI	NASA/USGS	Sep 2021	423-2300 nm Multispectral (+thermal infrared)
VIIRS	NOAA	Oct 2011	402-2275 nm Multispectral (+thermal infrared)
Doves Superdoves Skysats	Planetlabs	2015 + many	430-885 nm Multispectral
Pléiades	CNES/EADS	1A: Dec 2011 1B: Dec 2012 Neo3-6: Apr 2021+	450-915 nm Multispectral
CHRIS-PROBA	ESA	Oct 2001	400-1050 nm
MTG (geo)	EUMETSAT	I1: Nov 2022 ? I2/I3/I4: ?	400-2200 nm Multispectral (+thermal infrared)
CHIME	ESA	2028	Hyperspectral
PACE	NASA	?	Hyperspectral
SBG	NASA	?	Hyperspectral
GLIMR (geo)	NASA	?	Hyperspectral
Newspace	Various	?	Multispectral/ Hyperspectral?
Many others ...	Various	?	Various

- Growing Number of Sites
- Multi Missions

CEM-PAL

The purpose of the Expansion Mission Product Algorithm Laboratory (or CEM-PAL) is to provide an environment for efficient prototyping of algorithms used to generate Expansion Missions Level 2 products, including algorithm modification, hosted processing, qualification functionalities and scientific validation environment.

The prototypes/processors/libraries/specific tools/validation data will be provided by external entities (i.e. specific contract for Product Algorithm Definition for each mission).

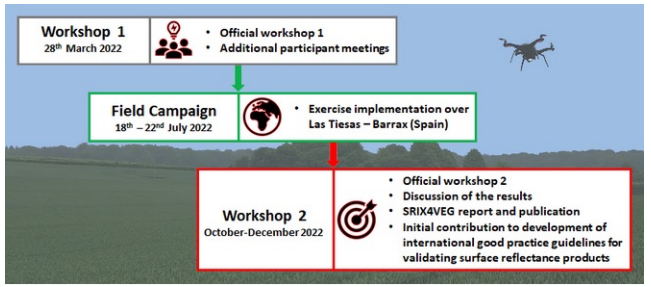
The ultimate goal is to allow the efficient development of extensions to the processing capabilities of the mission, especially the definition of improved or new core products and their migration to the ground segment

PAL = central role for the data quality activities - cal/val, processing algorithms improvements

SRIX4Veg – Surface Reflectance Inter-comparison eXercise for Vegetation

SRIX4Veg is an ESA-funded joint effort **to ensure consensus on a Surface Reflectance Validation Protocol using UAV-mounted hyperspectral imagers.**

It has been endorsed by CEOS and is conducted in the framework of the ESA FRM4Veg project.



Objectives:

- Testing user-based differences in surface reflectance UAV-based measurements (including instrument and operator biases as well as measurement collection procedures);
- Helping design field measurement protocols that are clear and can be easily applied by all users;
- Ensuring international buy-in and consensus on the field measurement protocols for global SR validation.

Endorsed by: CEOS Committee on Earth Observation Satellites

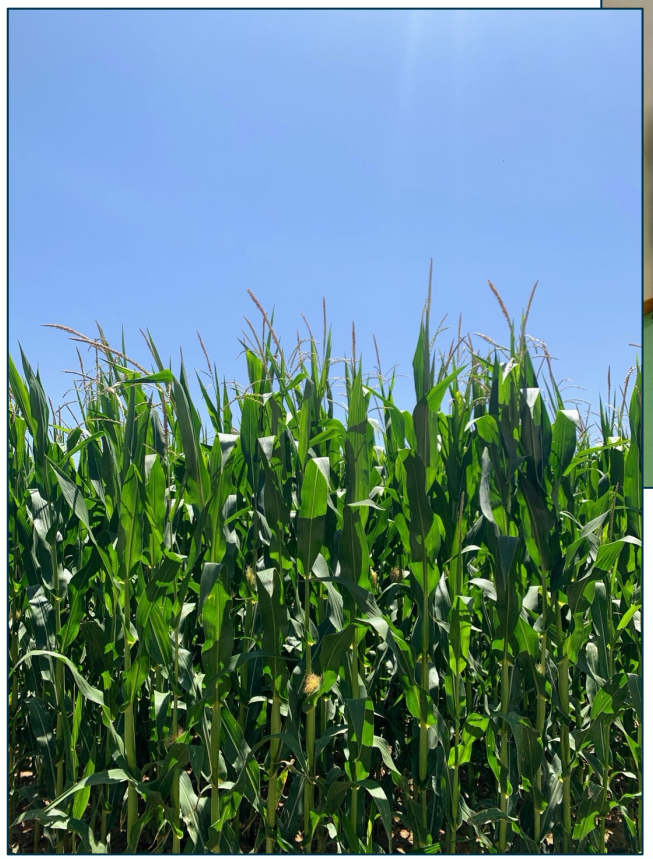
Funded by: esa

In cooperation with: Australian Government Geoscience Australia, USGS science for a changing world, CSIRO Australia's National Science Agency, ASI, DLR

In partnership with: UCLM Universidad de Castilla-La Mancha, ITAP

Project partners: NPL National Physical Laboratory, EOLAB, University of Southampton

SRIX4Veg – Surface Reflectance Inter-comparison eXercise for Vegetation



Pictures from the

SRIX4Veg field campaign

last July

CAL/VAL Park Concept

- ✓ Dedicated to **VHR** and **HR** optical missions;
- ✓ Open to both **multi-spectral** and **hyperspectral** missions;
- ✓ For both **TOA radiance and reflectance** and **BOA reflectance**;
- ✓ Open to be used by both the **"institutional space"** and the **"commercial/new space"**;
- ✓ Common "playground" to test and run **new cal/val methodologies, instruments, and initiatives**;
- ✓ Open to include **temporary and long-term instrumentation** and initiatives;
- ✓ **Scalable** (as far as possible) to accommodate new needs and new types of EO missions that may come in the next years;
- ✓ Building on already existing cal/val technologies AND new technologies and methods;
- ✓ Able to support the ever growing European and international EO industrial ecosystem;
- ✓ **Multi-Agency joint effort**;
- ✓ Synergetic approach not to duplicate efforts (and budgets).

- ❖ The "Cal/Val Park" concept is under **definition phase**.
- ❖ Discussions are on-going for a **joint ESA-ASI effort** (interest from other space agencies and institutions to be investigated).

Conclusion

- ✓ CHIME development is progressing well
- ✓ First Cal/Val plan proposed by TAS/OHB and currently under review (part of PDR)
- ✓ Additional Cal/Val activities and concepts are under development
- ✓ The ESA Cal/Val plan (incl. phase E2) will be established for CDR