

# EnMAP – Calibration and Validation Activities

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<sup>1</sup>DLR, <sup>2</sup>OHB

# EnMAP – Mission

Parameter	Value
Spectral Accuracy	0.5 nm (VNIR); 1.0 nm (SWIR)
Radiometric Accuracy	<b>5.0% (absolute); 2.5% (relative)</b>
Geometric Accuracy	100 m (30 m with control points)



## • On-Board Calibration Equipment

- Orbit: Sun-synchronous, 11:00, 398/27
- Launch: 12/2021

### VNIR

420 nm <  $\lambda$  < 1000 nm  
(95 spectral bands, 6.5 nm)  
SNR > 500 @ 495 nm

### SWIR

900 nm <  $\lambda$  < 2450 nm  
(135 spectral bands, 10 nm)  
SNR > 150 @ 2200 nm

Satellite  
Ground Track

Pointing Range  
 $\pm 30^\circ$  off-nadir

Ground Pixel Size  
30 m  $\times$  30 m

Swath  
30 km wide

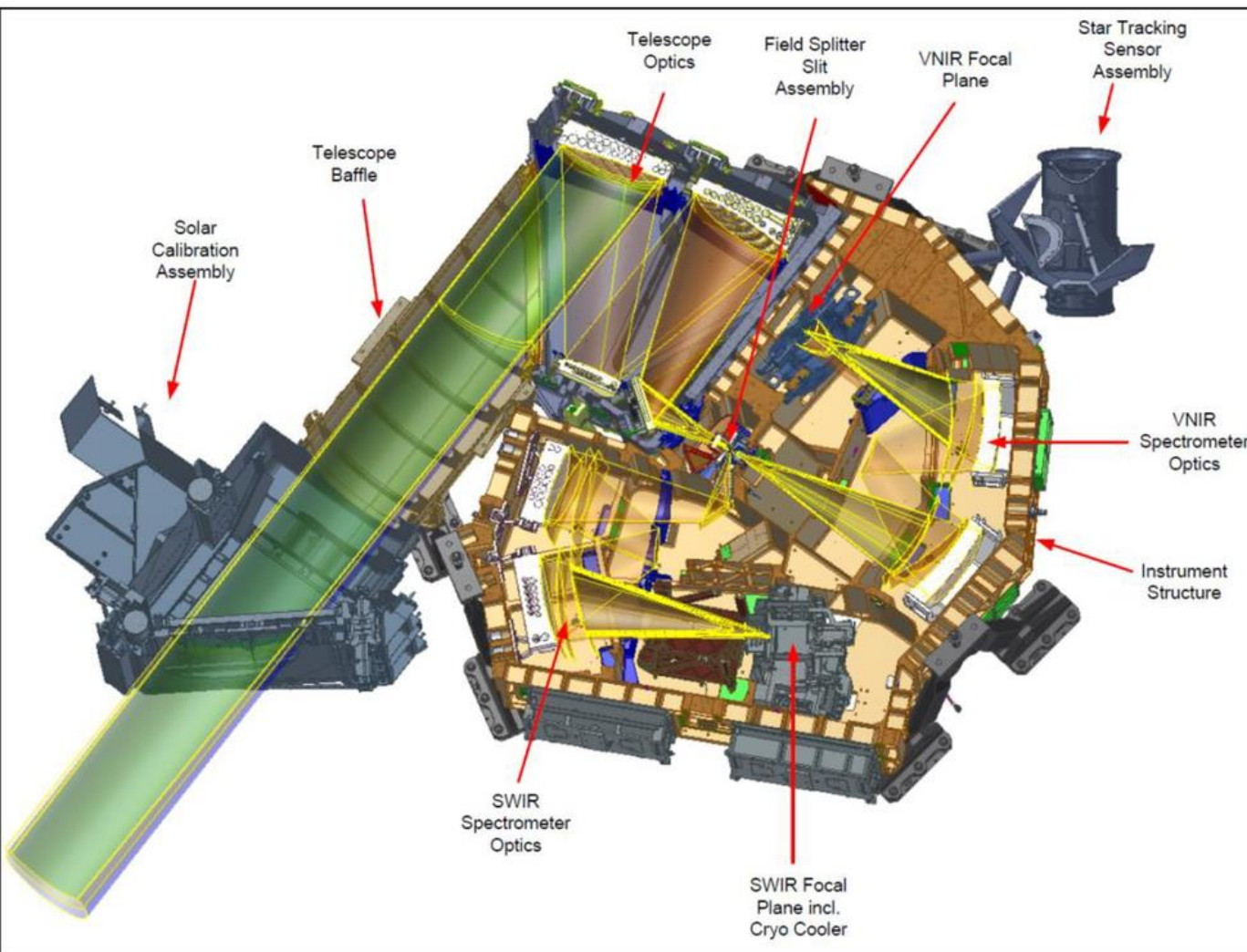
Covered Area/Day  
5000 km  $\times$  30 km

Source: DLR, OHB

# EnMAP – Hyperspectral Instrument

- Three mirror anastigmatic telescope  $\pm 1.3^\circ$  across track
- Independent VNIR and SWIR spectrometers
- Curved prism design
- 2D focal planes acquiring 14 bit resolution data at 230 Hz

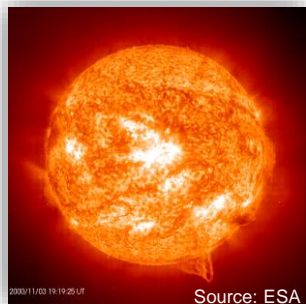
Guanter et al. Rem. Sens. (2015)



# EnMAP – On-Board Calibration

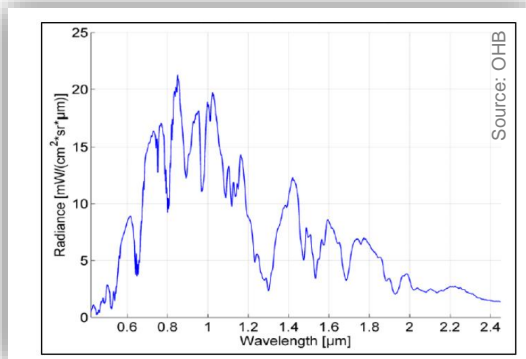
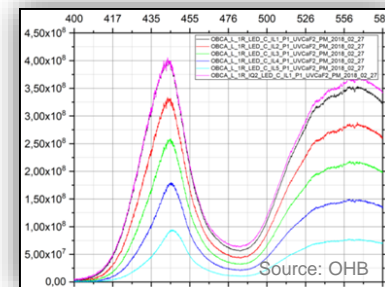


- ← • Closed Shutter [dark]
- Deep Space [dark] →



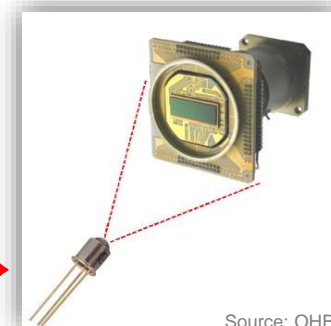
- ← • Sun Calibration [absolute radiometric]

- White Spectralon [relative radiometric] →



- ← • Doped Spectralon [absolute spectral]

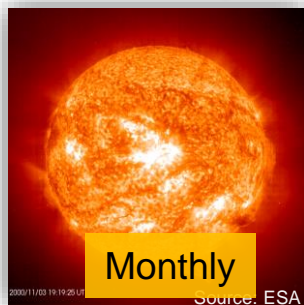
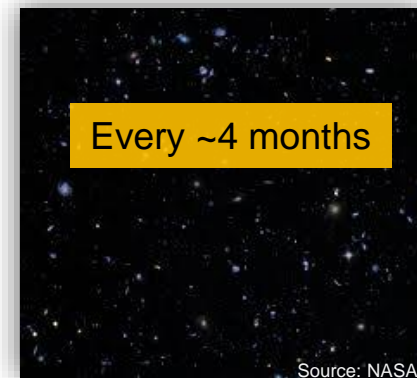
- Focal Plane LED [linearity] →



# EnMAP – On-Board Calibration

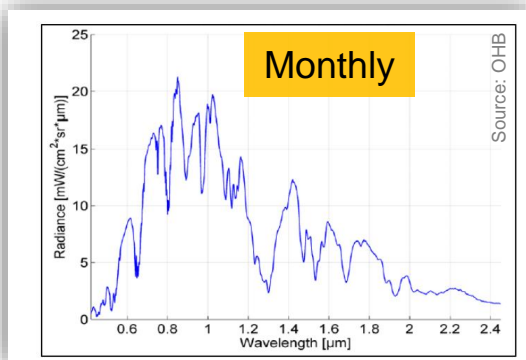
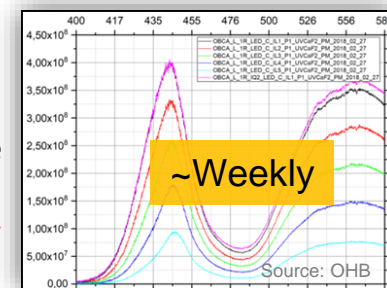


- ← • Closed Shutter [dark]
- Deep Space [dark] →



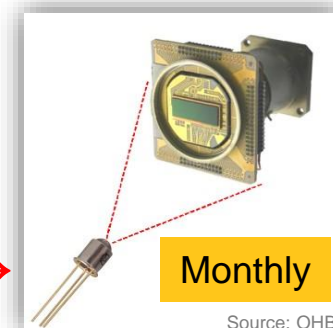
- ← • Sun Calibration [absolute radiometric]

- White Spectralon [relative radiometric] →

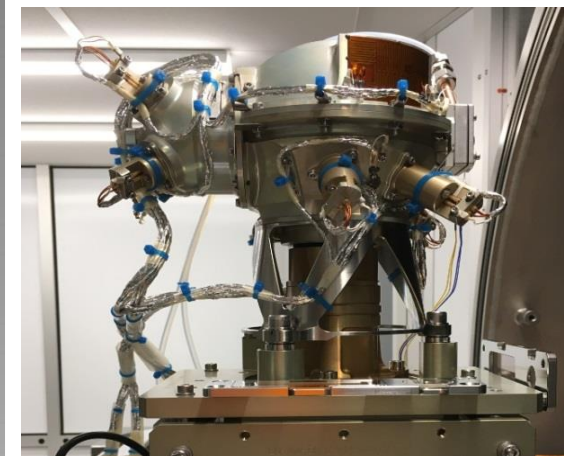
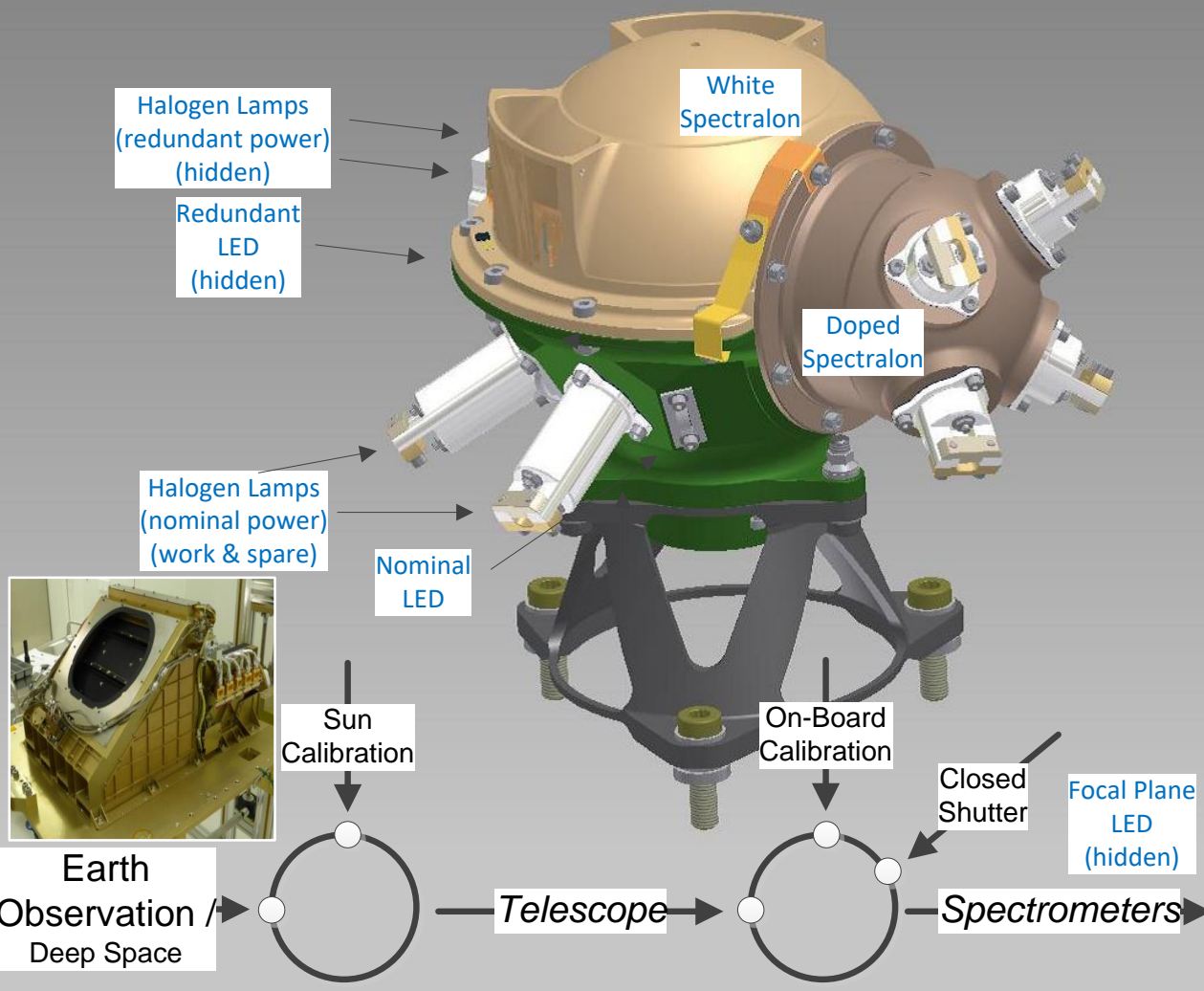


- ← • Doped Spectralon [absolute spectral]

- Focal Plane LED [linearity] →



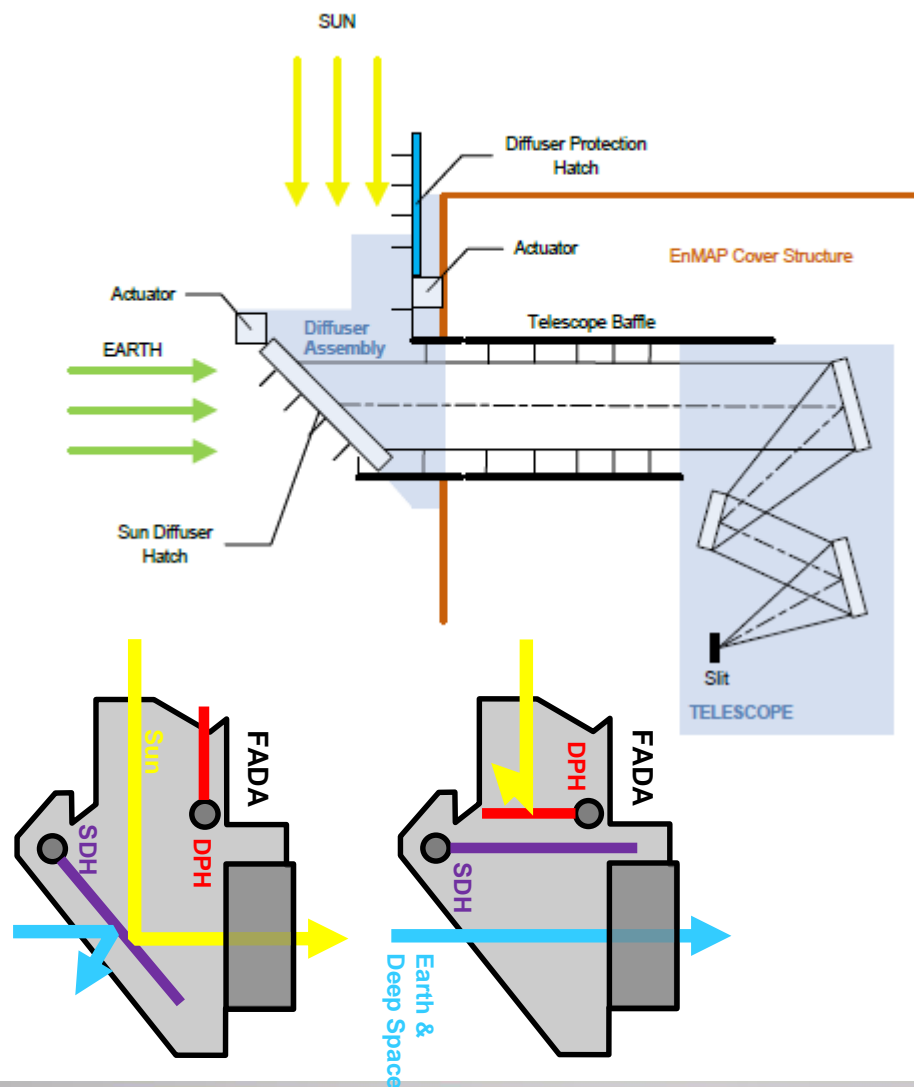
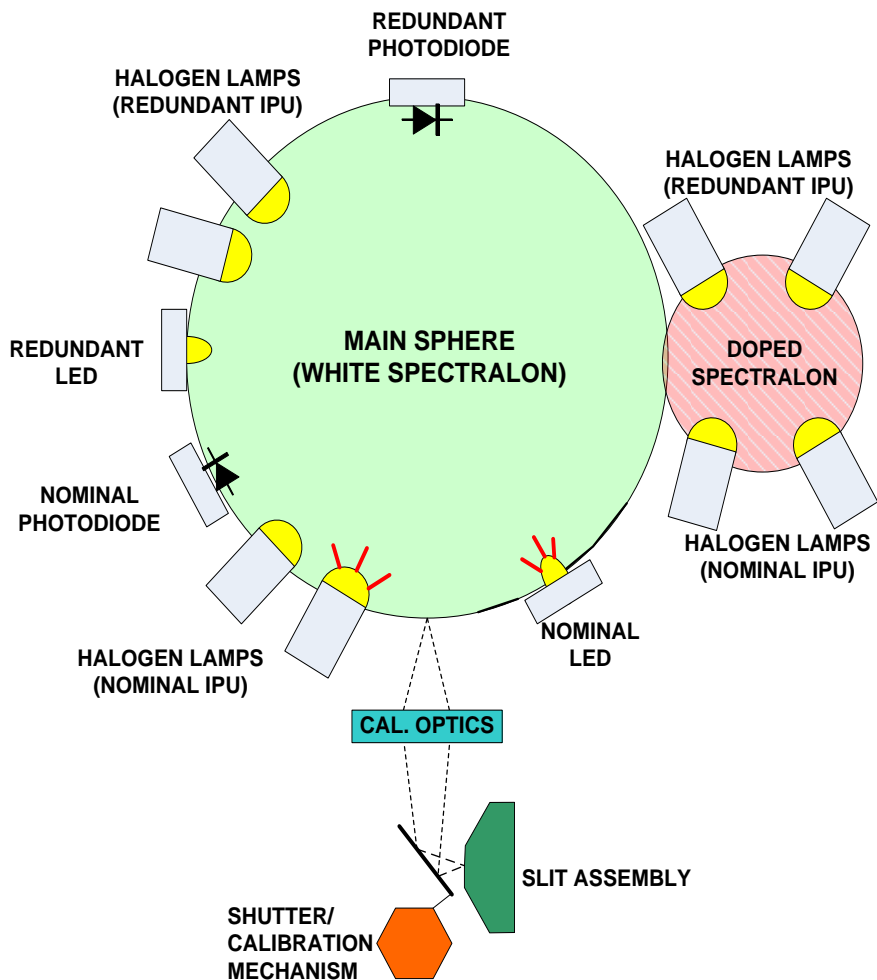
# EnMAP – On-Board Calibration Equipment



- White Spectralon [relative radiometric]
- Doped Spectralon [absolute spectral]
- Focal Plane LED [linearity]

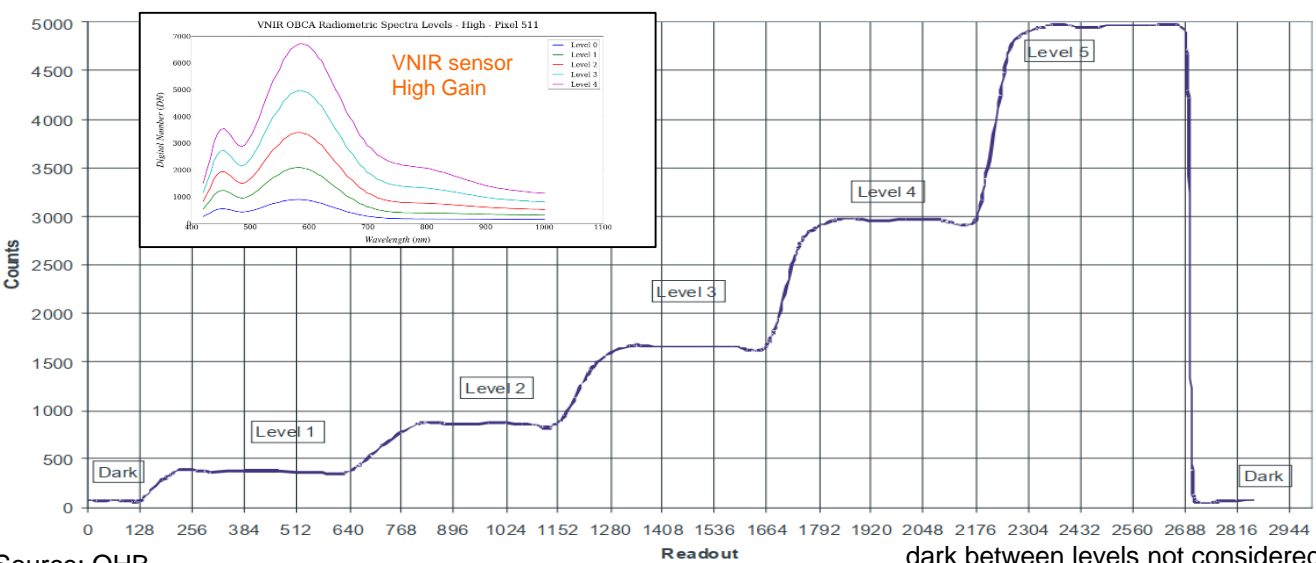
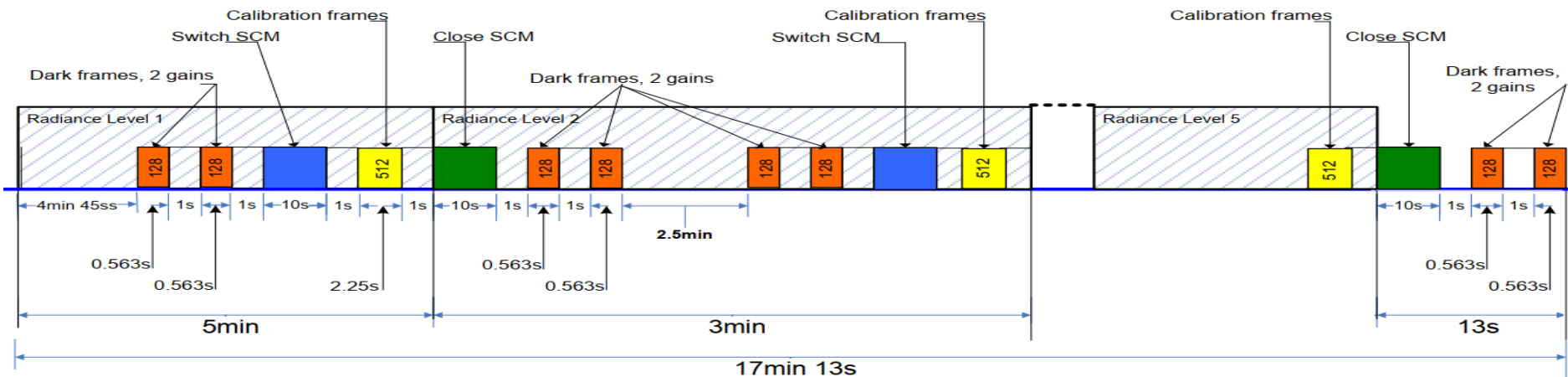
Source: OHB

# EnMAP – On-Board Calibration Equipment



Source: OHB

# EnMAP – White Spectralon [In-Flight]



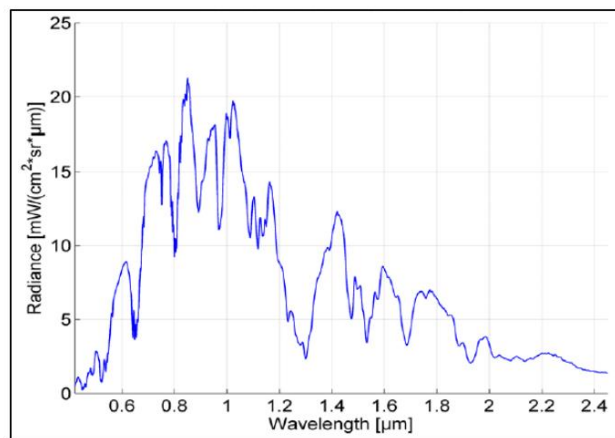
- White Spectralon [relative radiometric]
  - Weekly
  - Full optical system: Not telesc.
  - Aging known: Medium
  - For Calibration Coefficients: No

Source: OHB dark between levels not considered

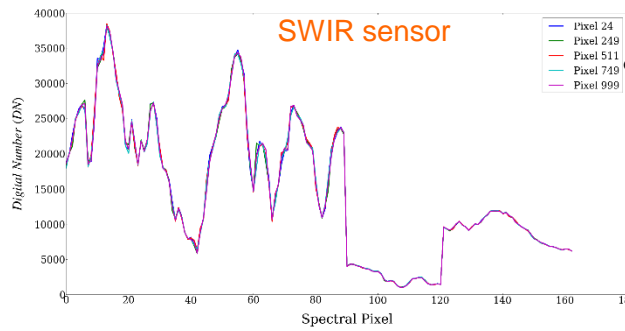
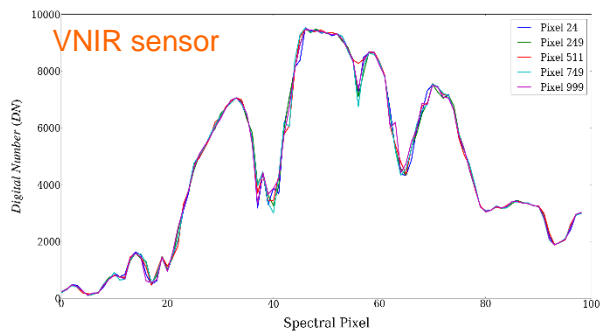
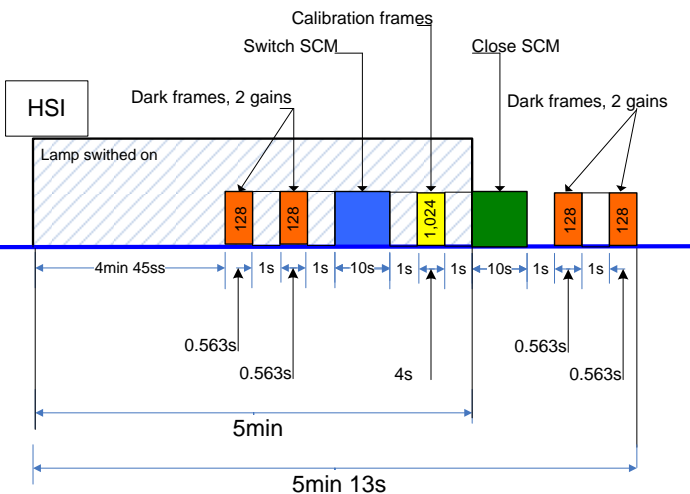


# EnMAP – Doped Spectralon [In-Flight]

High Definition spectra of doped spectralon

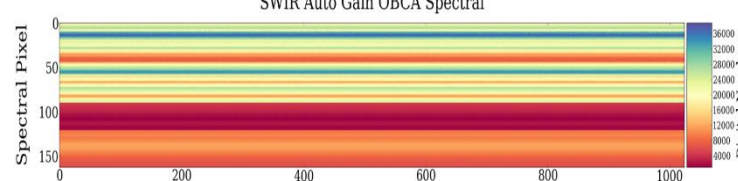
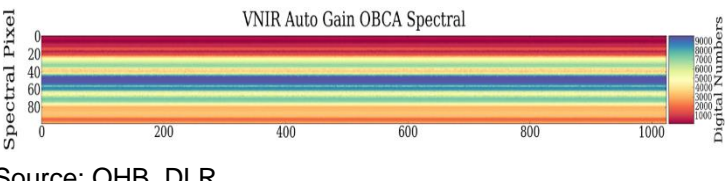


M. Mücke et al. Proc. SPIE 11180, ICSO 2018, 1118067 (2019)



## Spectral Calibration [absolute spectral]

- Monthly (or less)
- Full optical system: Yes
- Aging known: Medium
- For Calibration Coefficients: Yes

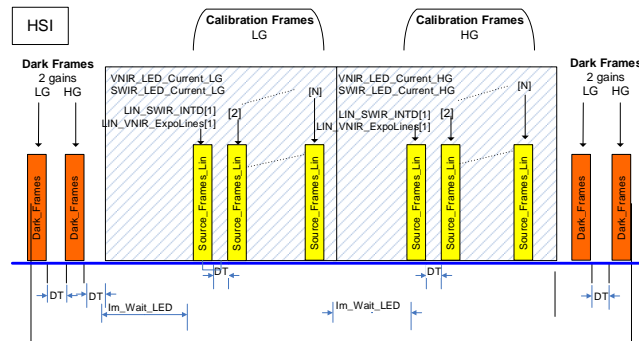
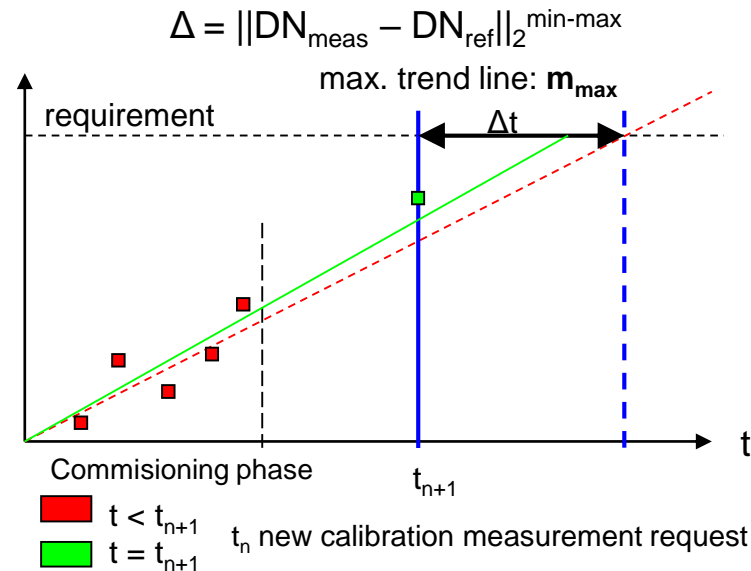
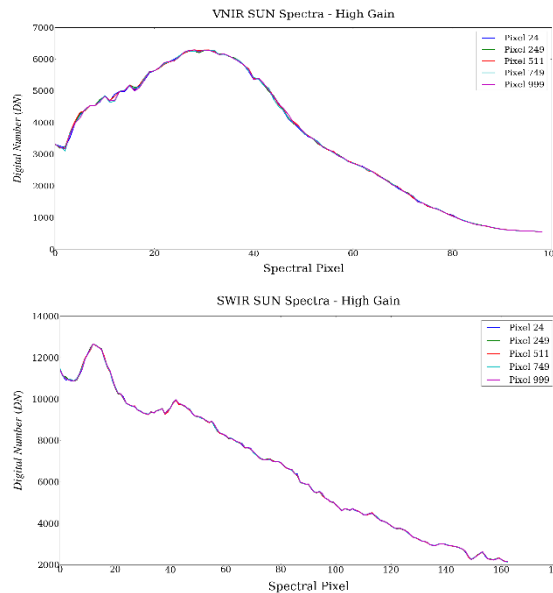


Source: OHB, DLR

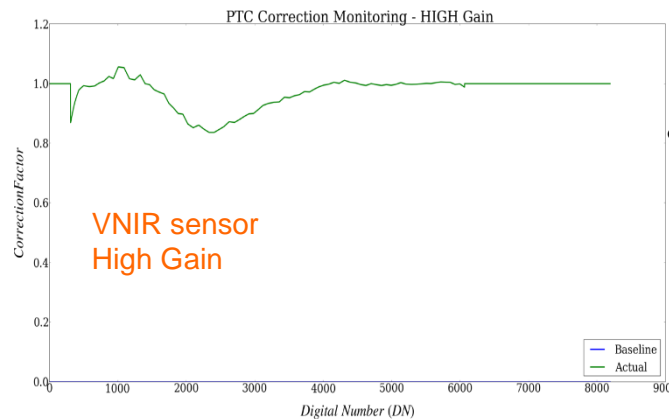
# EnMAP – Sun [in-Flight] & Linearity [In-Flight]

## Sun Calibration

- Monthly (or less)
- Full optical system: Yes
- Aging known: High
- For Calibration Coefficients: Yes



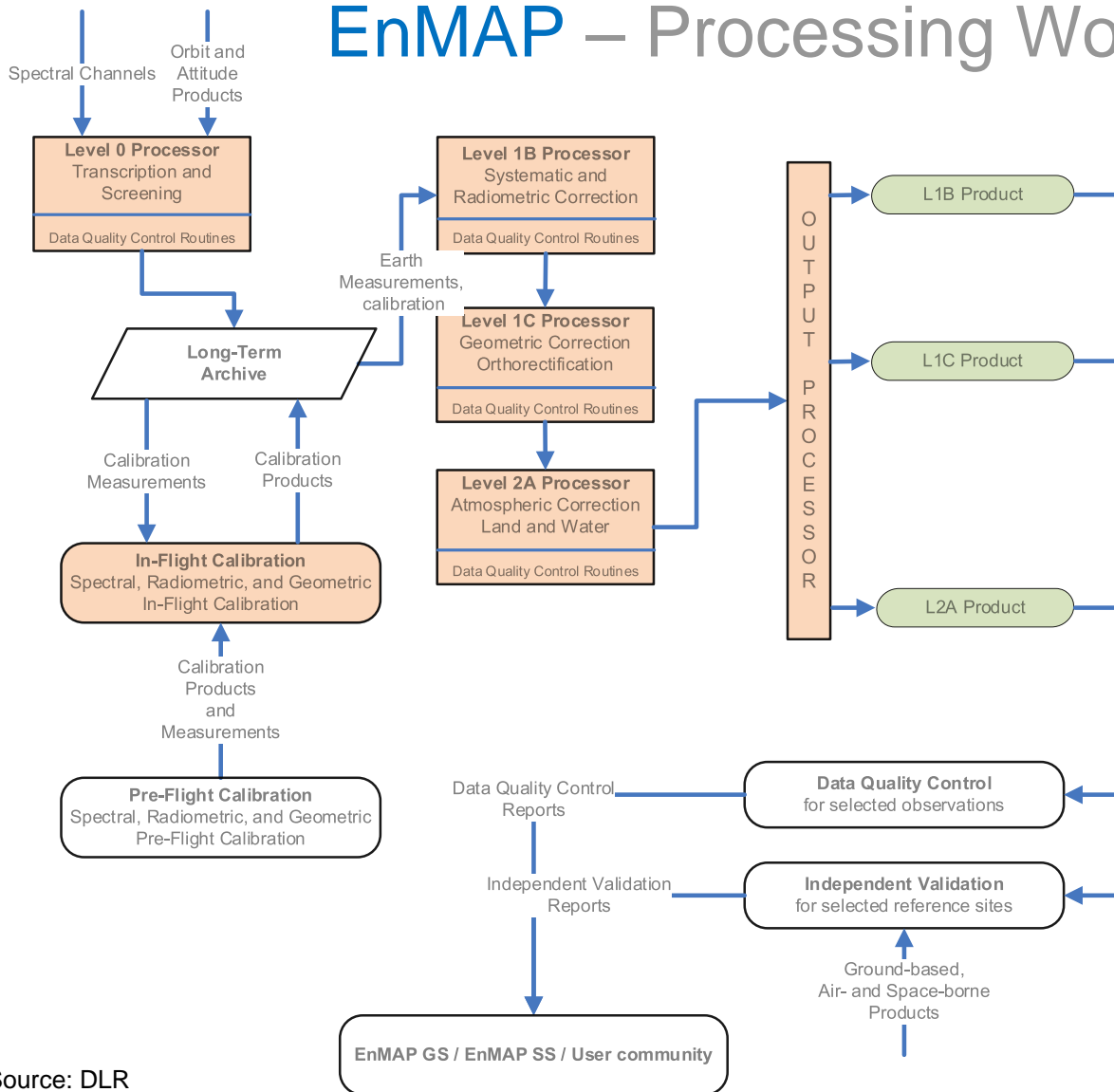
Source: OHB, DLR



## Linearity Calibration

- Monthly (or less)
- Full optical system: Not telesc.
- Aging known: Medium
- For Calibration Coefficients: No

# EnMAP – Processing Workflow



- In-flight calibration observations are processed to generate updated calibration tables
- Three level of users products can be ordered (L1B / L1C / L2A) from Earth observations
- User products annotated with quality information (metadata) plus periodic quality and validation reports
- Quality Control (GS) and Independent Validation (GFZ) performed on user products

Source: DLR

# EnMAP White Spectralon [In-Flight]

VNIR Calibration coefficient table	Calibration coefficients for: Low Gain VNIR (LV), High Gain VNIR (HV)	for (channel) for (pixel) GetGainMatchingCoeff(float) for (pixel) GetRNU(float) for (channel) CalCoeff(float)	(256 x 1056 x 2 + 256) x 4 Bytes Gain matching coefficients and RNU per pixel, Cal coefficients per channel Type SINGLE
<b>Calibration Coefficients</b>			
SWIR Calibration coefficient table	Calibration coefficients for: Low Gain (L), High Gain (H) nominal SWIR (S), redundant SWIR (R)	for (channel) for (pixel) GetGainMatchingCoeff(float) for (pixel) GetRNU(float) for (channel) GetCalCoeff(float)	(256 x 1024 x 2 + 256) x 4 Bytes Gain matching coefficients and RNU per pixel, Cal coefficients per channel Type SINGLE

Relative Radiometric Reference

Update Relative Radiometric Reference

Request for (repeated) White Spectralon or Sun Calibration

Repeatable: No

Repeatable: Yes

not OK

OK

Comparison Ref. and Measurement

Averaging for each Illumination Level

Stray-Light Correction

Gain Matching

Dark Signal Correction

Non-Linearity Correction

Saturated and Dead Pixels Flagging

Dead Pixels Map

Non-Linearity LUT

Closed Shutter Measurements

Stray-Light Matrix

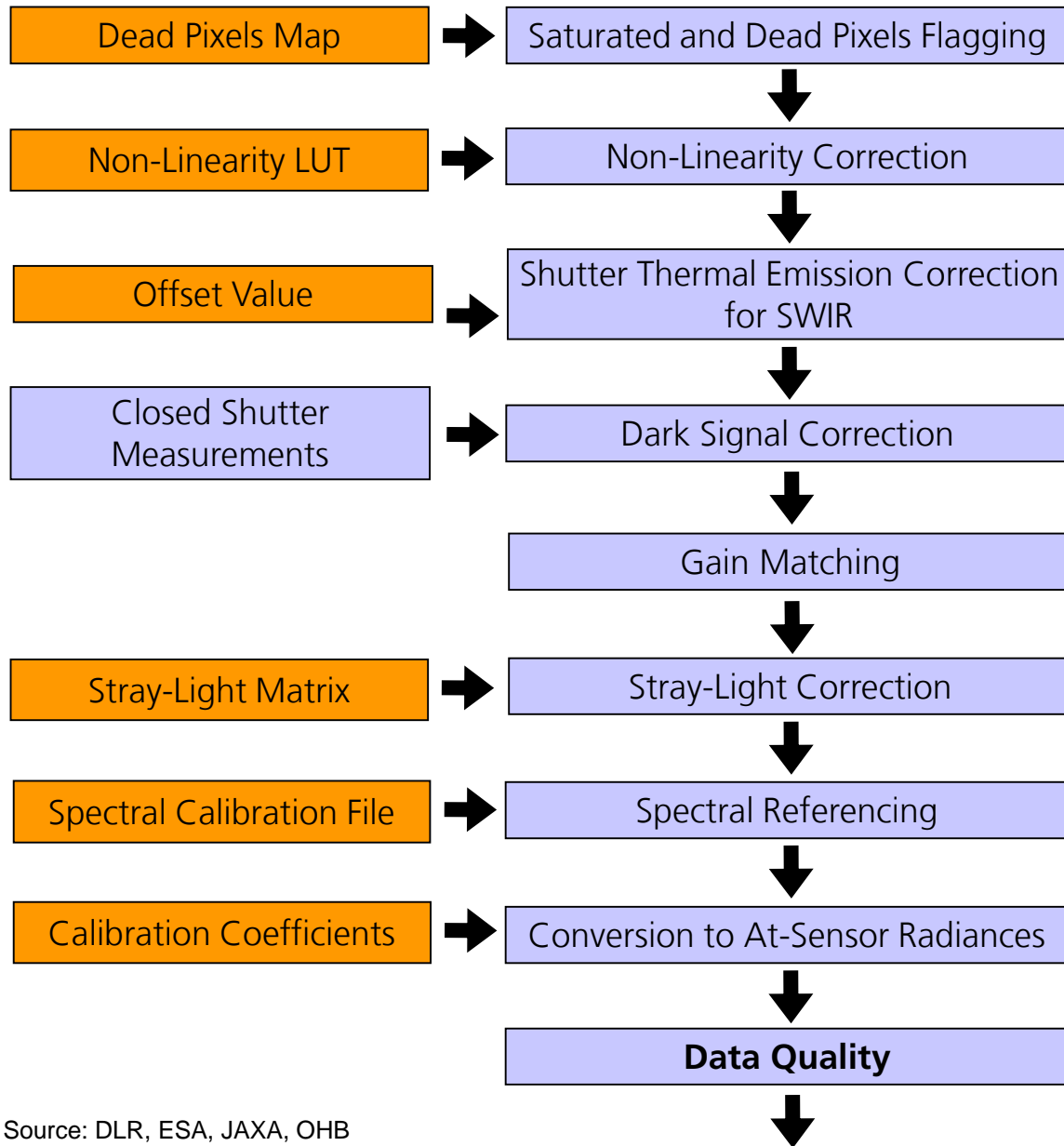
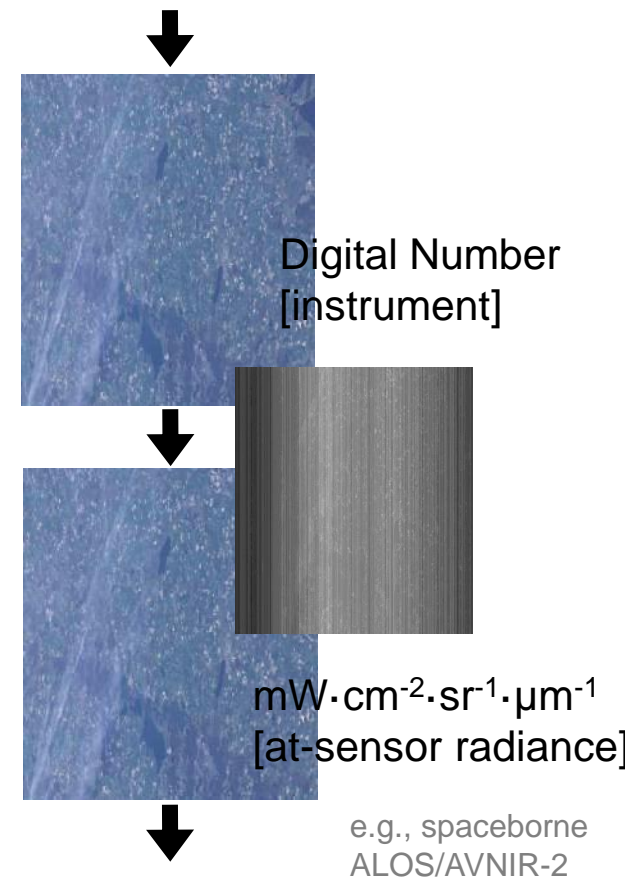
used for: Dead Pixels Map, Signal-to-Noise Information

Relative Radiometric Reference

(1<sup>st</sup>: based on (radiometric) pre-flight calibration campaign)

# EnMAP

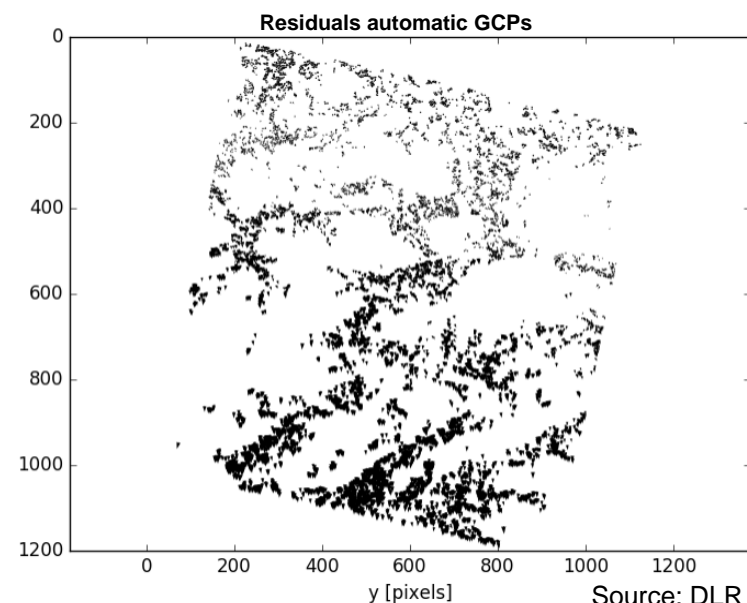
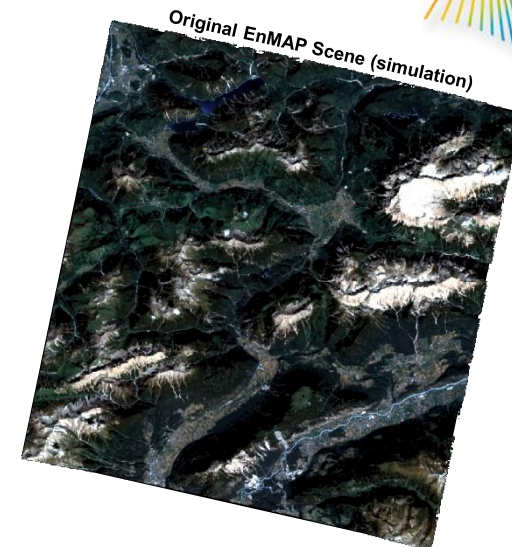
## Earth Observation Calibration



Source: DLR, ESA, JAXA, OHB

# EnMAP – Geometry Calibration and QC

- Like spectral and radiometric characterization, extensive geometric pre-flight characterization in laboratory
- But launch, vibrations and gravitational release demand monitoring of geometric performance and the possibility of geometric calibration
- Boresight misalignment angles can be computed on Earth observations based on automatically extracted GCPs on EnMAP scenes and reference Sentinel-2 scenes
- Assessment on quality of geometric data based on automatically extracted GCPs



# EnMAP – Geometry Calibration and QC

- Like spectral and radiometric characterization, extensive geometric pre-flight characterization in laboratory

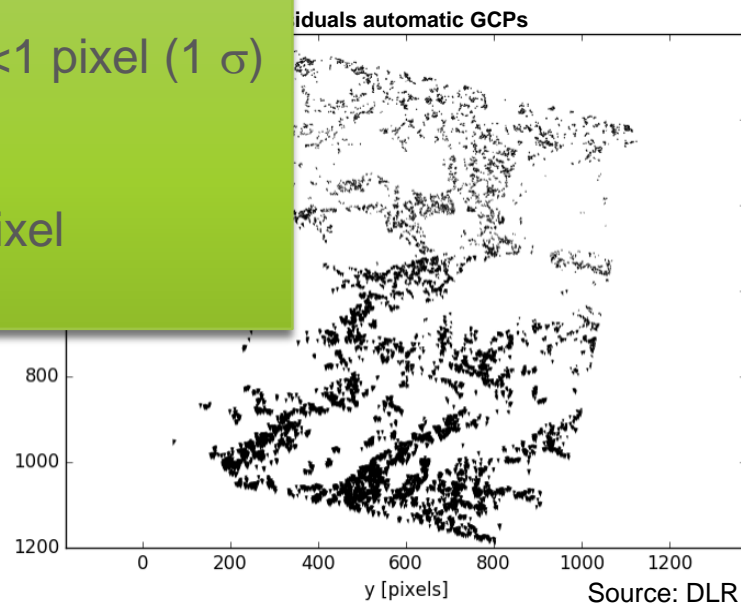
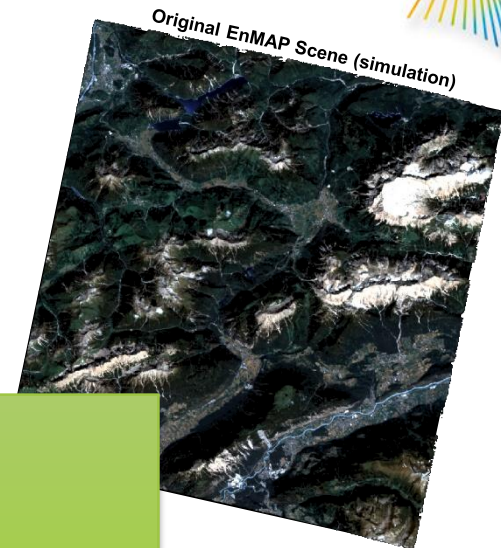
- But launch demand more and the potential

- Boresight on Earth of extracted GCPs on EnMAP scenes and reference Sentinel-2 scenes

- Assessment on quality of geometric data based on automatically extracted GCPs

**EnMAP Geometric requirements**

- Geolocation accuracy at nadir look  $< 1$  pixel ( $1 \sigma$ ) w.r.t. reference images
- VNIR / SWIR co-registration  $< 0.2$  pixel



# EnMAP – Product annotation

- EnMAP products metadata
- CARD4L self assessment: „**Threshold**“ will be achieved with foreseen metadata update

GENERAL METADATA						
#	Item	Threshold (minimum requirements)	COMMENTS BY			
1.1	Traceability	Not required				
RADIOMETRIC AND ATMOSPHERIC CORRECTIONS						
#	Item	Threshold (minimum) requirements	COMMENTS BY PCV			
3.1	Measurement	Pixel values that are expressed as a measurement of				
PER-PIXEL METADATA						
#	Item	Threshold (minimum) requirements	COMMENTS BY PCV	Target (desired) requirements	COMMENTS BY PCV	
1.2	Metadata					
1.3	Data collection					
1.4	Geographic information					
1.5	Coordinates					
1.6	Map projection					
1.7	Geometric distortions					
1.8	Geometric distortions					
3.2	Measurement uncertainty					
3.3	Measurement Normalization					
3.4	Aerosol corrections					
3.5	Water vapour corrections					
3.6	Ozone corrections					
3.7	Directional scattering in the atmosphere	Not required	-	-	-	-
3.8	Aerosol optical depth parameters	Not required	-	-	-	-
2.1	Metadata machine readability	Metadata is provided in a structure that enables a computer algorithm to be used to consistently and automatically identify and extract each component part for further use.	ok	As threshold, but metadata is formatted in accordance with ISO 19115-2.	ok, as ISO 19115 (plus ISO 19119) are INSPIRE, so conformity is given	
2.2	No data	Pixels that do not correspond to an observation ('empty pixels') are flagged.	ok	As threshold.	ok	
2.3	Incomplete testing	The metadata identifies pixels for which the per-pixel tests (below) have not all been successfully completed. <i>Note 1: this may be the result of missing ancillary data for a subset of the pixels.</i>	ok (= > flag overall quality, bits (0-1) as "11: not produced")	The metadata identifies which tests have, and have not, been successfully completed for each pixel.	could be added by extending the quality flags	
2.4	Saturation	Metadata indicates where one or more spectral bands are saturated.	ok	Metadata indicates which pixels are saturated for each spectral band.	can be easily done. But this would imply that the quality quicklook will largely increase in size.	
2.5	Cloud	Metadata indicates whether a pixel is assessed as being cloud	ok	As threshold, with referencing (DOI) to a peer-reviewed algorithm for cloud detection.	can be done - currently no publication available for "land"	
2.6	Cloud shadow	Metadata indicates whether a pixel is assessed as being cloud shadow.	ok	As threshold, with referencing (DOI) to a peer-reviewed algorithm for cloud shadow detection.	can be done - currently no publication available for "land"	
2.7	Land/water mask	Not required	ok	The metadata indicates whether a pixel is assessed as being land or water. The metadata references a citable peer-reviewed algorithm, expressed as a DOI.	can be done - currently no publication available for "land"	
2.8	Snow/ice mask	Not required	ok	The metadata indicates whether a pixel is assessed as being snow/ice or not. The metadata references a citable peer-reviewed algorithm, as a DOI.	the mask is called "snow" but actually flags both snow and ice. Both are indistinguishable in the current software. Reference documentation the same as for the rest of masks.	
2.9	Terrain shadow mask	Not required	-	The metadata indicates pixels that are not directly illuminated due to terrain shadowing	can be done - but only possible when DEM is provided and the accuracy will depend on the DEM itself.	
2.10	Terrain occlusion	Not required	-	The metadata indicates pixels that are not visible to the sensor due to terrain occlusion during off-nadir viewing.	currently not possible.	
2.11	Illumination and viewing geometry	Not required	-	The solar incidence and sensor viewing angles are identified for each pixel, including coefficients used for terrain illumination correction.	currently, we are providing these values for the corners and the center of the scene. Could be extended.	



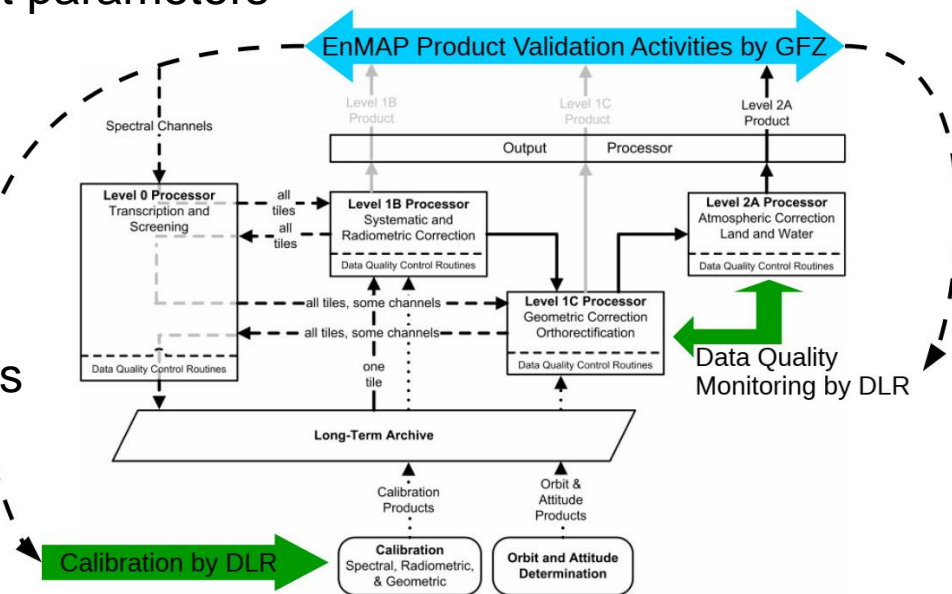
# EnMAP – Quality control and Validation

## EnMAP GS (DLR): Operational

- Delivers user products (L1B, L1C, L2A) to end-users using latest calibration
- Monitors and updates calibration parameters using in-flight calibration
- Performs Quality Control activities on user products
- Performs Monitoring of Instrument parameters

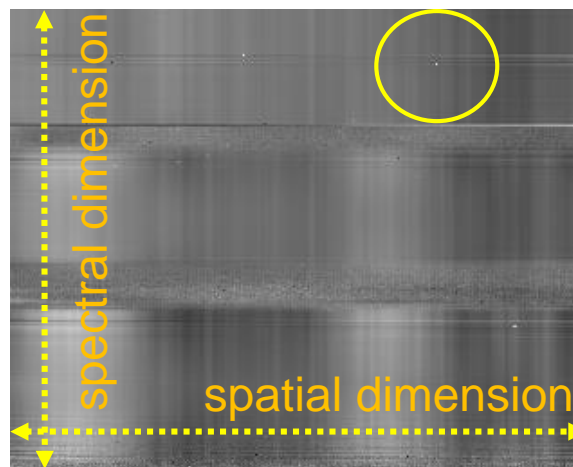
## Validation Entity (GFZ):

- Comparison of user products to absolute references at selected reference sites
- Validation of atmospheric products
- Activities considered ‘scientific’ rather than ‘operational’
- Use of flight campaigns



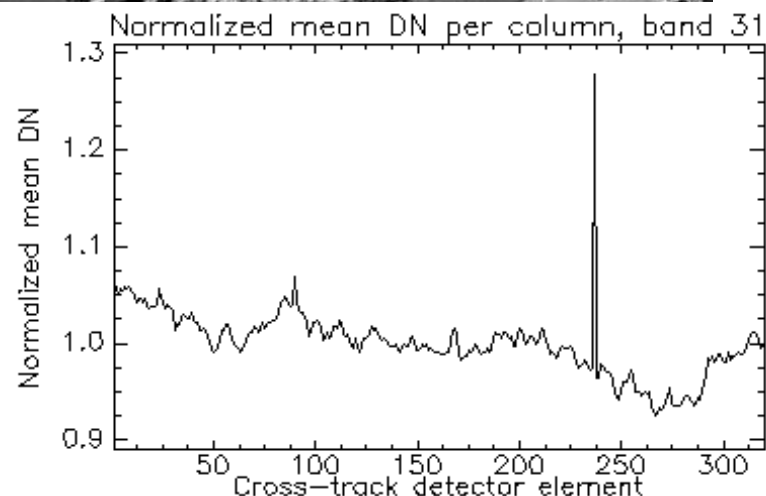
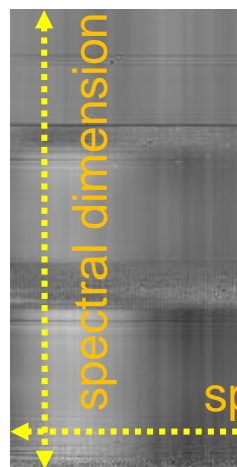
# EnMAP – GS Quality Control

- Checks:
  - Radiometric performance
  - Spectral performance
  - Geometric performance
  - Quality of L2A products
  - In depth analysis of selected scenes
  - Anomalies
- Combination of automated processes for each product
  - e.g. striping artefacts
  - meta and image data
- And interactive procedures for selected products
  - e.g. cloud classification
  - reports



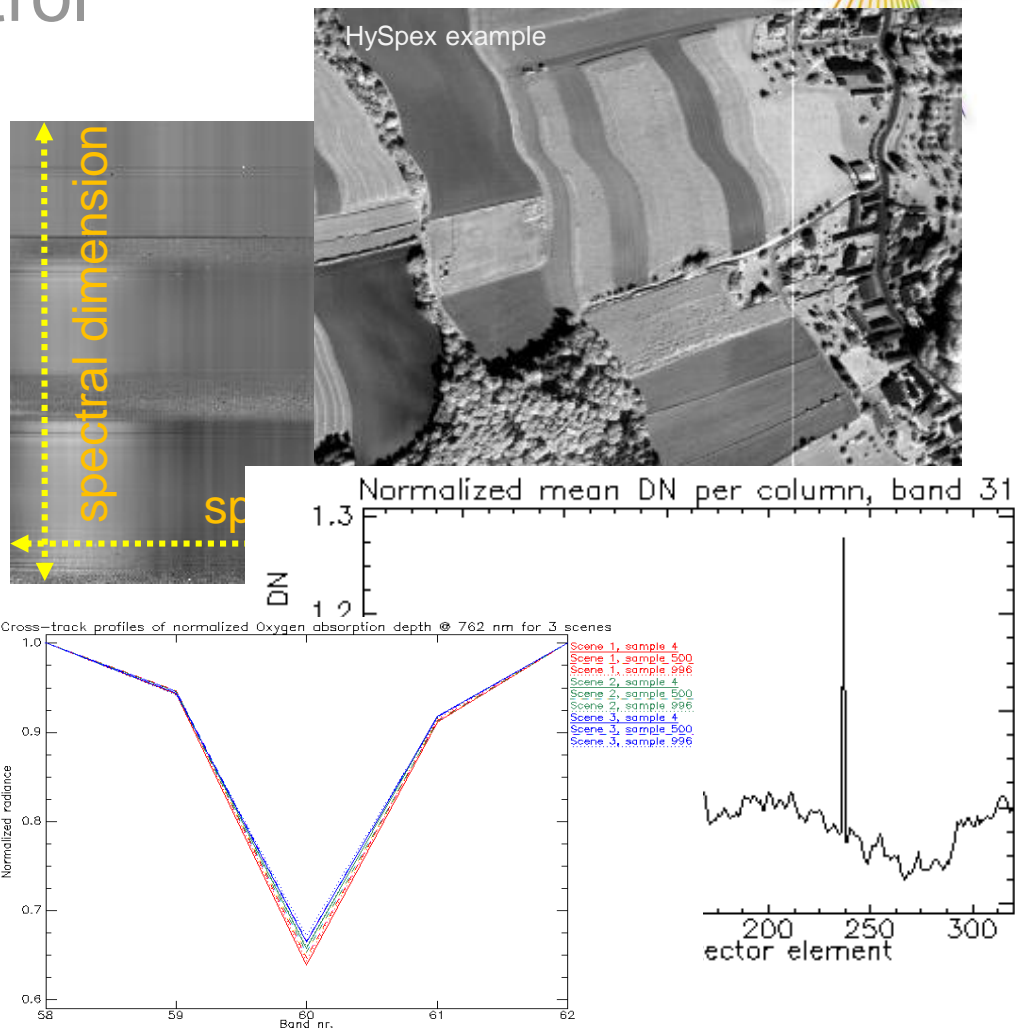
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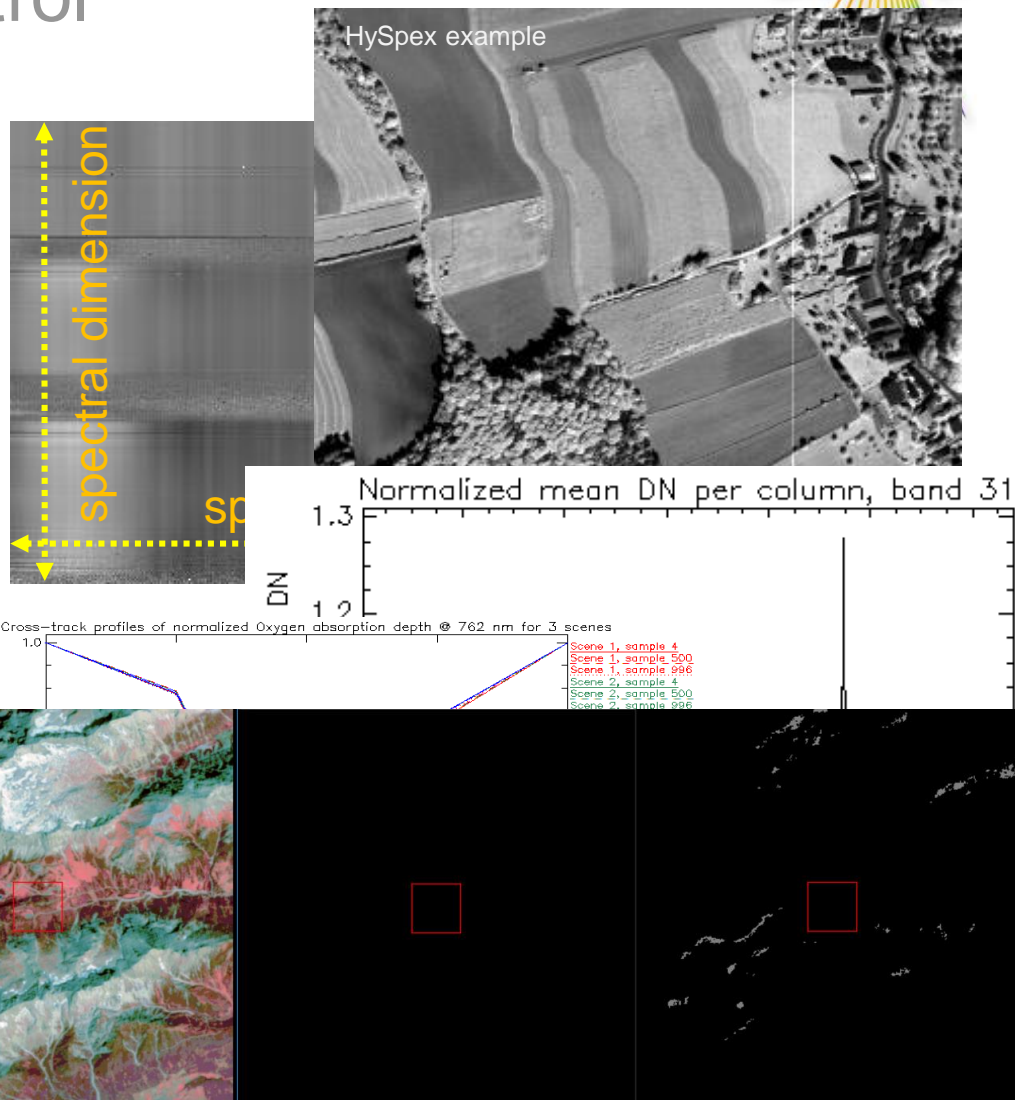
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Source: DLR

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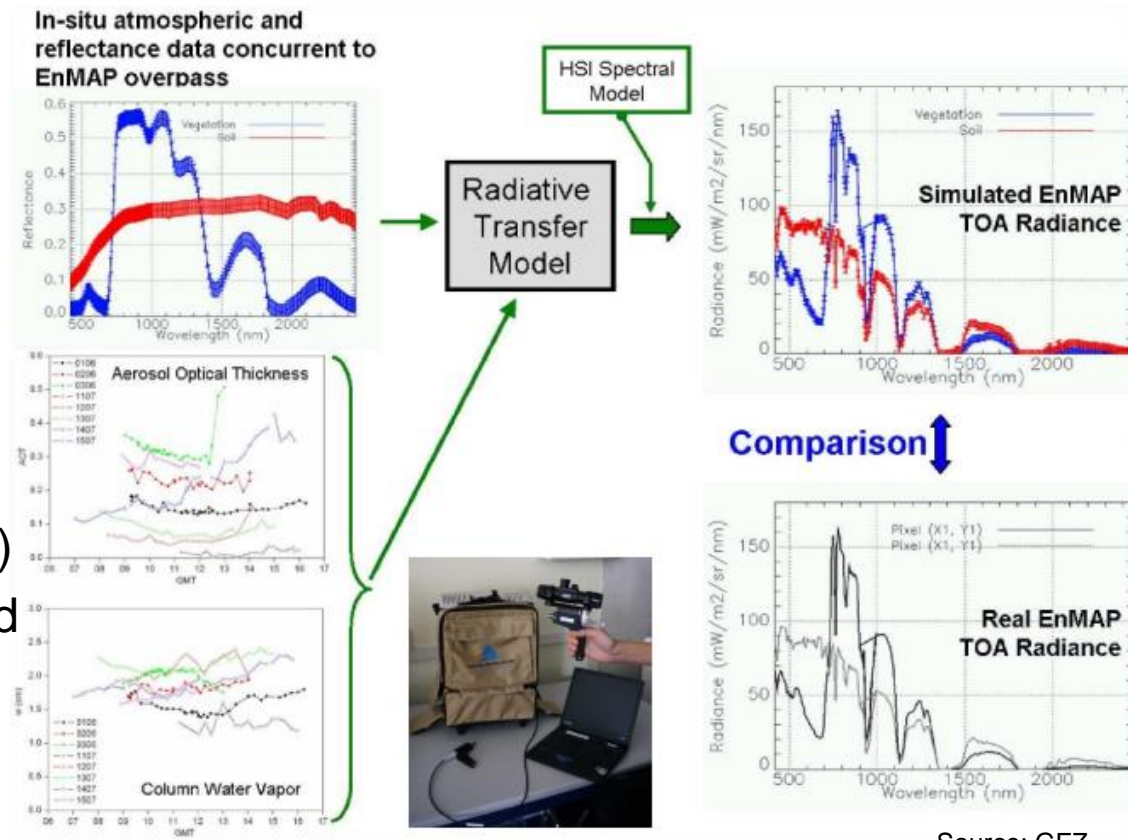


Left: CIR composite of affected area in [L1B-2], nonlinear image stretch. Center: Snow mask (empty) for same area. Right: Cloud shadow mask for same area containing terrain shadows.

Source: DLR

# EnMAP – Independent validation by GFZ

- Validation from scene-based data analysis
  - Sophisticated models / processing not part of operational activities by EnMAP GS
- Comparison of EnMAP user products to in-situ measurements (land or water)
- More data sources considered (Aeronet, RCN, AERONET-OC, MOBY, partners/collaborators)



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- Campaign information on the EnMAP campaign portal

## Field Guides

- > Spectral Measurement
- > LAI Measurement
- > Chlorophyll Measurement
- > Soil Moisture Measurement
- > Campaign Layout and Sampling Strategies

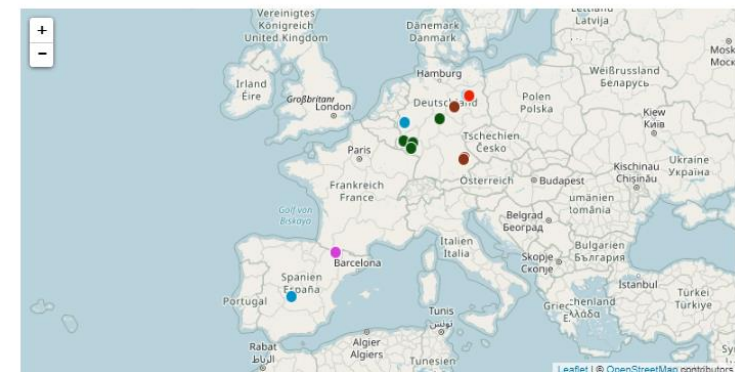
EnMAP Test Data Products

Simulated EnMAP Data

## EnMAP Campaign Portal

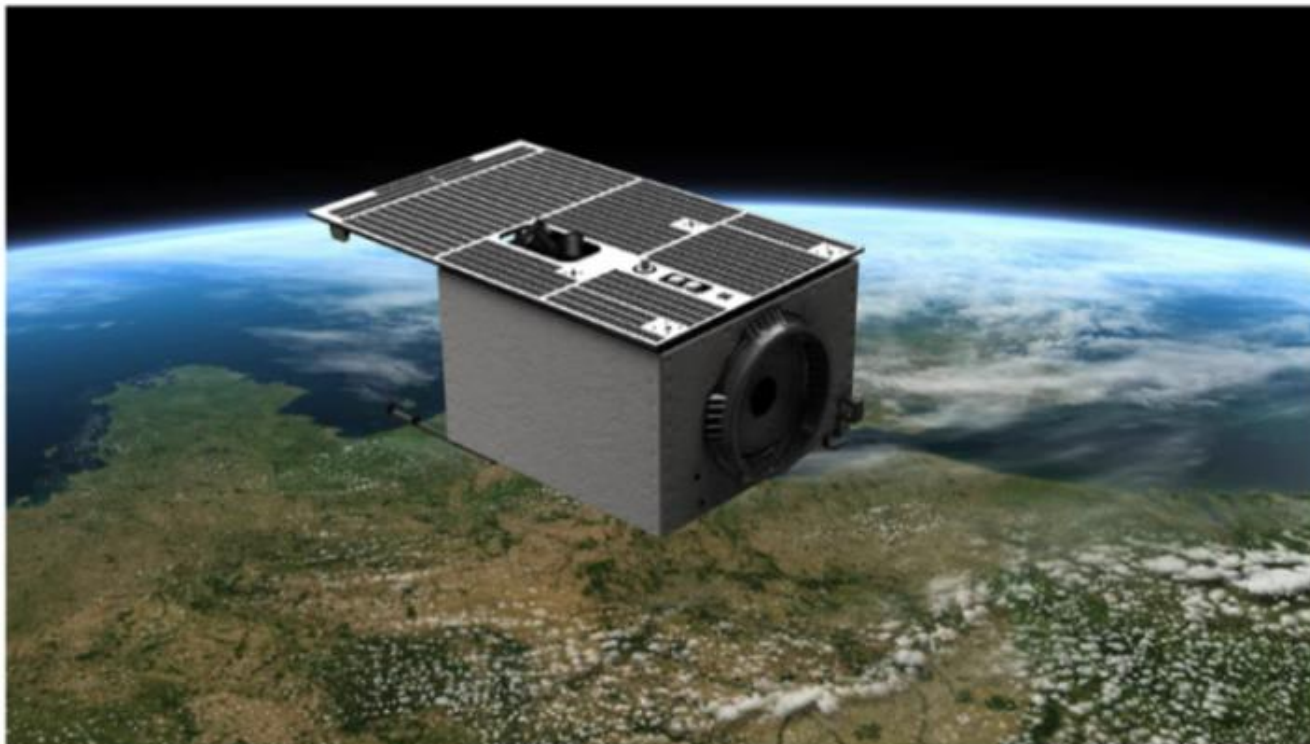
Hyperspectral airborne campaigns have been carried out in the frame of the data exploitation and application development program of the German Environmental Mapping and Analysis Program (EnMAP) to support method and application development in the pre-launch phase of the EnMAP satellite mission. A metadata portal (EnMAP Campaign Portal) has been set up providing general information about the campaigns, recorded airborne hyperspectral data sets, other data associated to the respective campaigns like field and laboratory measurements and a number of field guides for in-situ data acquisition. Furthermore, it informs about the availability of simulated EnMAP and Sentinel-2 data for the respective campaign region. Further description of the EnMAP Campaign Portal can be found here: DOI

All data on this website are provided free of charge and under a Creative Commons Attribution-ShareAlike 4.0 International License and is subject to the following terms and conditions:



Name	Application	Sensor	Product-Level	Date	DOI
Donnersberg (DE)	Forest	HySpex VNIR-1600 HySpex SWIR320m-e	L2	Jul 3, 2014	DOI
Idarwald/Hochwald (DE)	Forest	HySpex VNIR-1600 HySpex SWIR320m-e	L1	Jun 9, 2014	.
Hunrück-Hochwald (DE)	Forest	HySpex VNIR-1600 HySpex SWIR320m-e	L1 L2	May 5, 2014	DOI
Pfälzer Wald/Merzaben (DE)	Forest	HySpex VNIR-1600 HySpex SWIR320m-e	L1	Apr 16, 2014	.
Idarwald/Hochwald (DE)	Forest	HySpex VNIR-1600 HySpex SWIR320m-e	L1	Apr 10, 2014	.
Neusting (DE)	Agriculture	AVIS-3	L2	Sep 8, 2012	DOI
Neusting (DE)	Agriculture	HySpex VNIR-1600 HySpex SWIR320m-e	L2	Aug 12, 2012	DOI
Hainich (DE)	Forest	aisaHawk	L1 L2	Jul 24, 2012	.
Neusting (DE)	Agriculture	AVIS-3	L2	Jun 16, 2012	DOI
Neusting (DE)	Agriculture	AVIS-3	L2	May 25, 2012	DOI
Köthen (DE)	Agriculture	aisaDual	L1 L2	May 24, 2012	DOI
Neusting (DE)	Agriculture	HySpex VNIR-1600 HySpex SWIR320m-e	L2	May 8, 2012	DOI

[www.enmap.org](http://www.enmap.org)

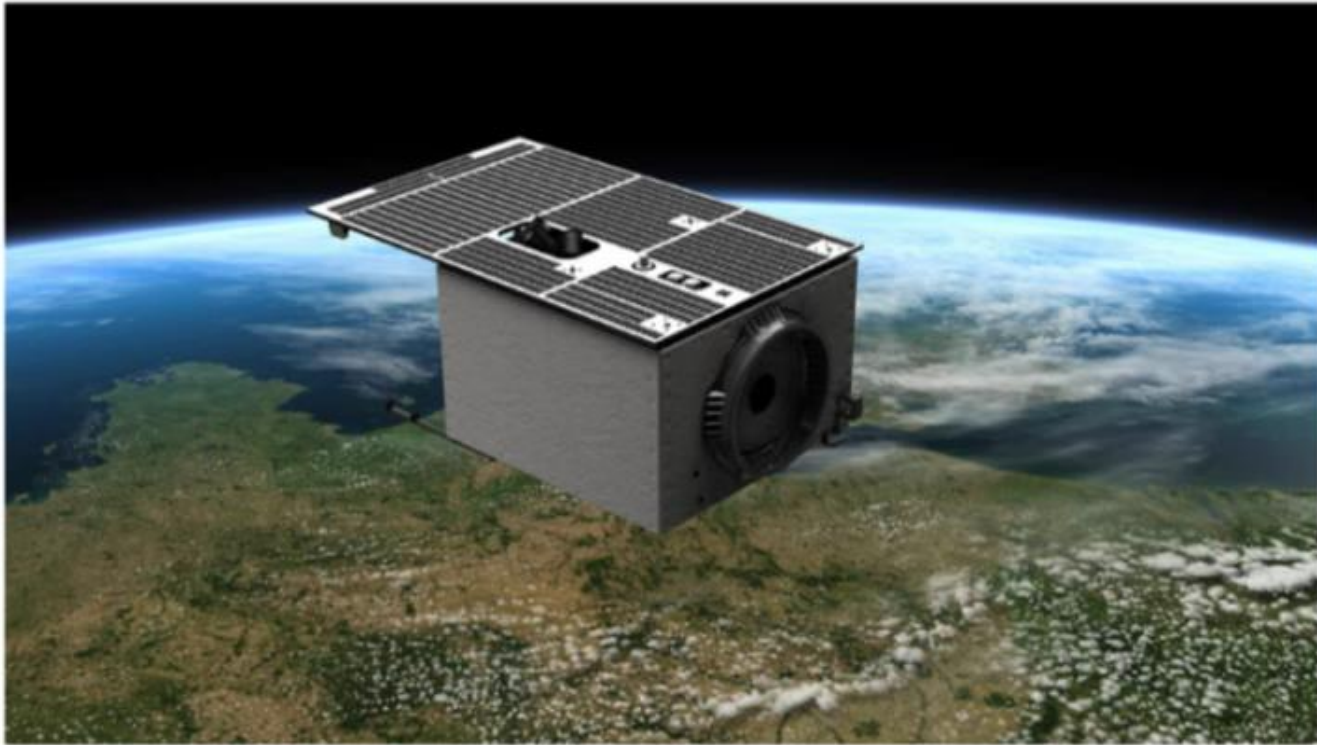


- More information on Mission & Applications
- Campaign Portal
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Source: DLR, OHB





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Source: DLR, OHB

Processing details

- L1B: Default
- L1C: UTM projection, Bilinear Interpolation
- L2A: UTM projection, Bilinear Interpolation, Land Mask, no Cirrus or haze removal, with Terrain Correction, Season Summer, Ozone Column: 300

Tile 1  
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Tile 2  
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Tile 3  
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Arcachon, France, 08.11.2017 (subset) | 44.44 N, 1.16 W

This simulated EnMAP tile is located just south of the commune Arcachon in France. The geometric simulation of this dataset was in Nadir view and the spectral simulation was performed based on a Sentinel-2 scene from November, 2017. Land pixels are simulated EnMAP Science segment simulation and water pixels with CDMAP GmbH & Co. KG visualization. The L2A product was produced in 'core mode', meaning land and water areas were processed using the atmospheric processing software for land and water respectively to reflectance values for land pixels and underwater reflectance values for water pixels.

Processing details

- L1B: Default
- L1C: Geographic projection, Bilinear Interpolation
- L2A: Geographic projection, Bilinear Interpolation, Combined Mode, no Cirrus or Haze removal, with Terrain Correction, Season: Ozone Column: 300

Tile  
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