Processing Chain, Calibration and Data Quality Procedures of the Future Hyperspectral Satellite Mission EnMAP

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EnMAP
Hyperspectral Imager

Deutsches Zentrum
für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

… but first a few words on airborne hyperspectral in Europe:

EUFAR – European Facility for Airborne Research

http://www.eufar.net

- Objective: **Trans-national access to research infrastructure**
- Total of 33 European institutions, 22 instrumented aircrafts
- All major PAFs for airborne hyperspectral data in Europe & Israel included
  - PML/NERC, INTA, DLR, VITO/RSL, USBE, TAU, FUB (ONERA associated)
  - Access to 6+ hyperspectral instruments
- Flight hours, instrument & processing costs covered by European Commission (FP7)

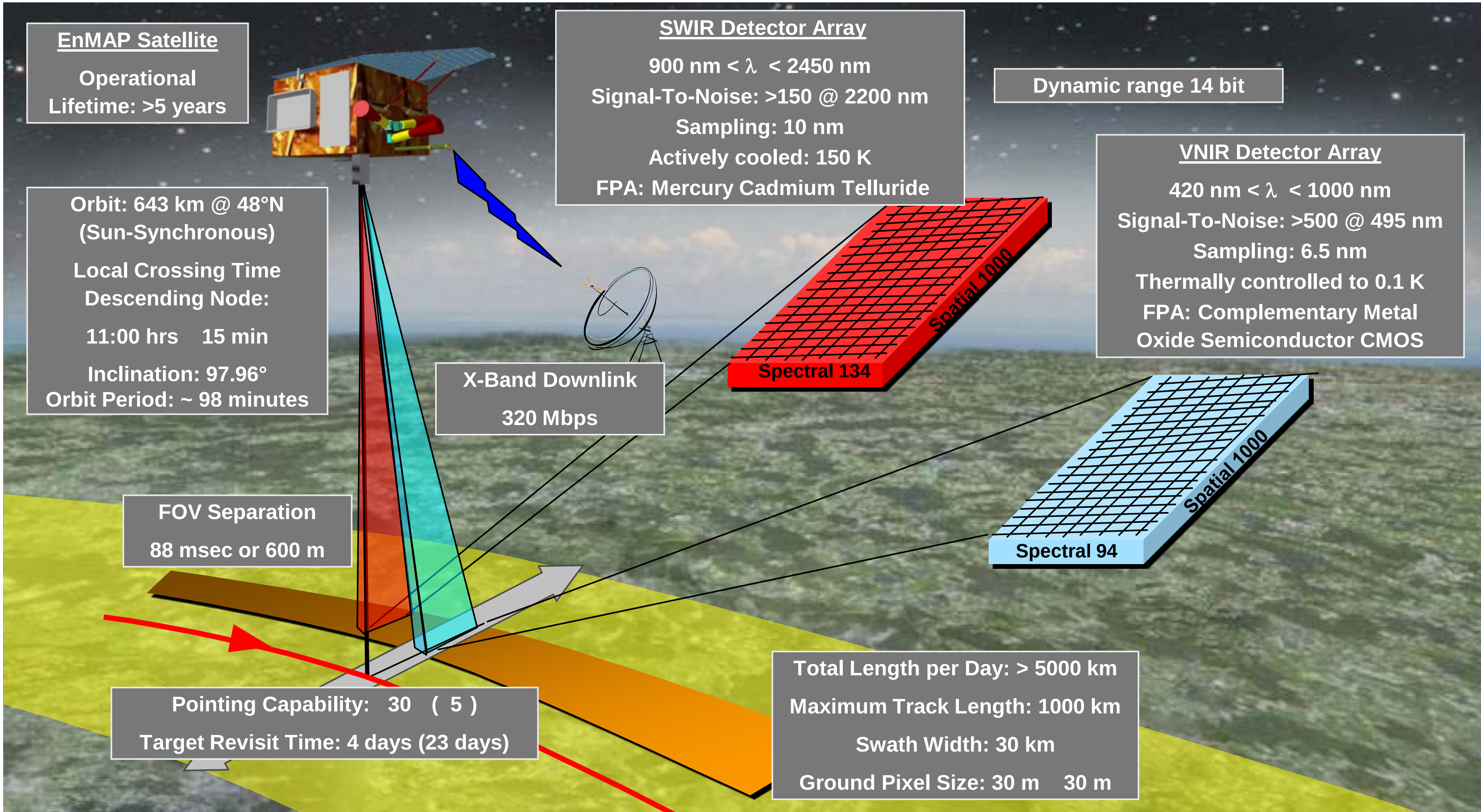
- **Joint Research Activities** – for Hyperspectral:
- To develop **quality indicators and quality layers** for airborne hyperspectral imagery
  - Uncertainty propagation studies for pre-processing
  - Harmonization of data QIs
  - Recommendation on algorithms
- In addition: **Standards & Protocols** ("best practice") for airborne research

EnMAP (**En**vironmental **M**apping and **A**nalysis **P**rogram) is a German hyperspectral satellite mission providing high quality hyperspectral image data on a timely and frequent basis. Main objective is to investigate a wide range of ecosystem parameters encompassing agriculture, forestry, soil and geological environments, coastal zones and inland waters.

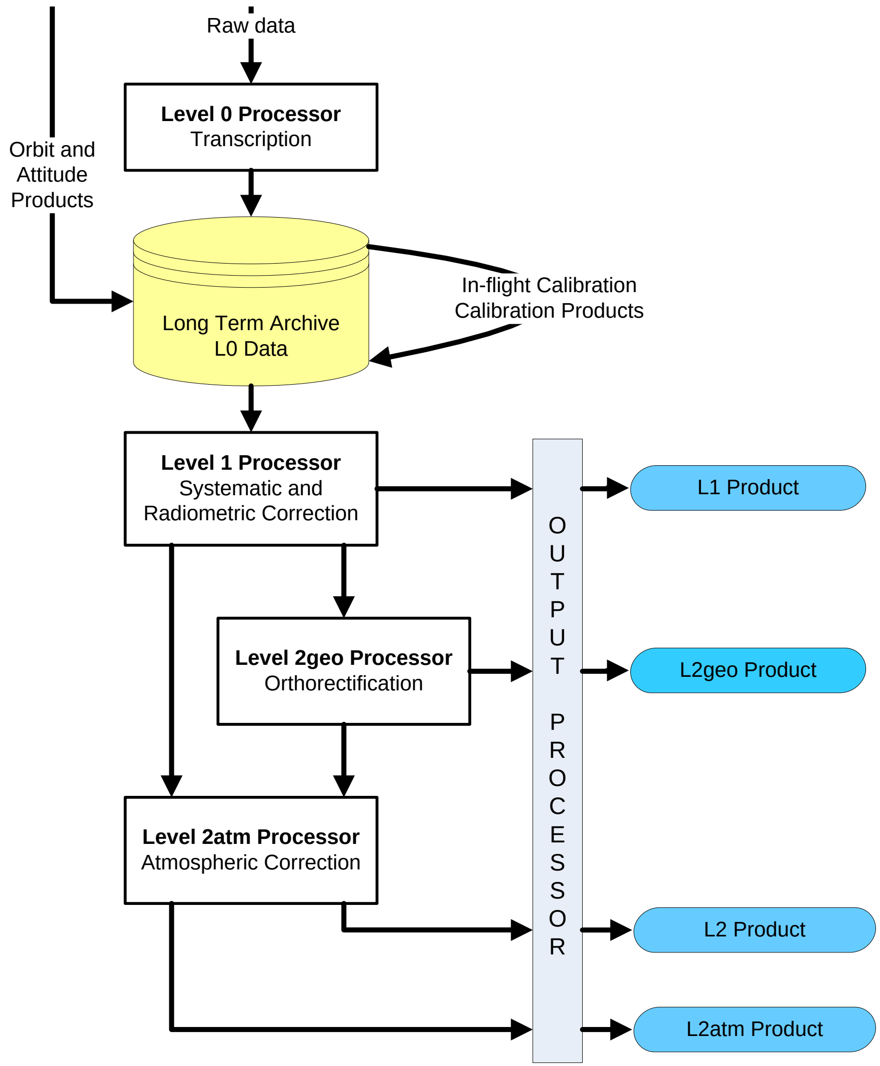
OUTLINE

- EnMAP mission (Characteristics, Elements)
- Automatic and operational processors for product generation
- Mission status

Mission and Instrument Characteristics



Overview Processing Chain



Level 0 Processor

The transcription processor de-compresses and collects information from different data streams, extracts and interprets information, performs screening, generates image tiles, adds data quality information

Level 1 Processor

The systematic/radiometric correction processor converts raw image pixels values to at-sensor radiance physical values

Level 2geo Processor

The geometric correction processor orthorectifies images using different methods (with and without automatically extracted GCPs)

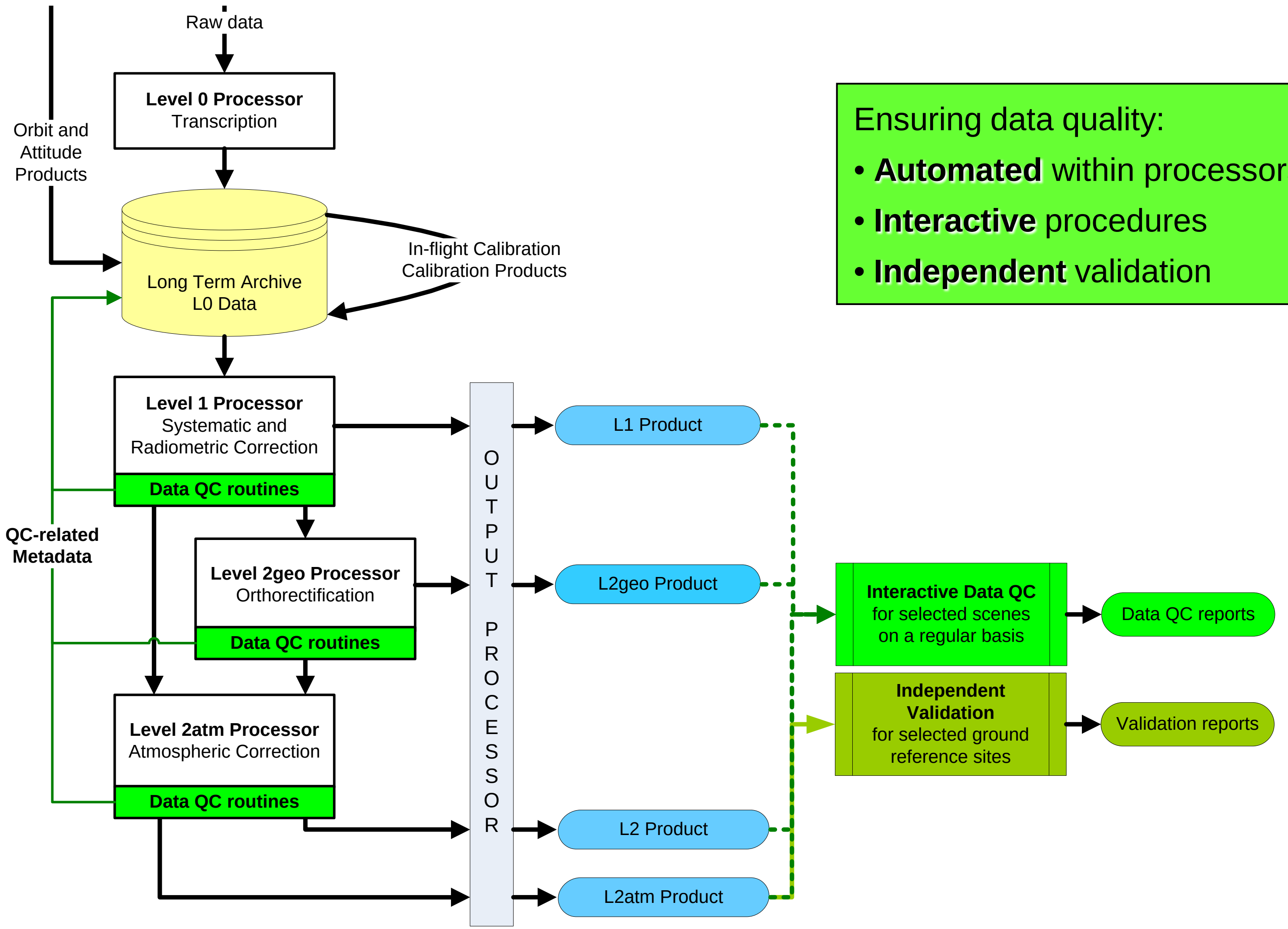
Level 2atm Processor

The atmospheric correction processor produces reflectance values for land and water areas and generates cloud masks.

Output Processor

The output processor generates the product, the metadata and derives the log information from the information produced by the logging service.

Overview Processing Chain



Ensuring data quality:
- **Automated** within processors
- **Interactive** procedures
- **Independent** validation

EnMAP Level 1 Processing

Performs:

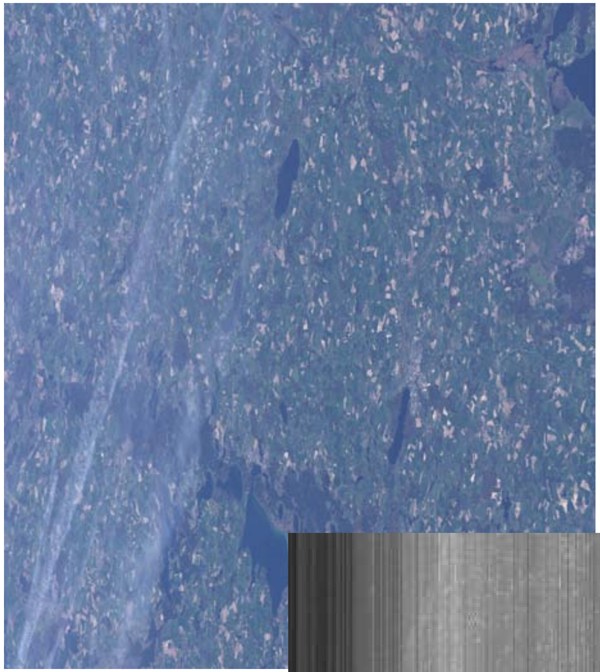
Systematic Correction

Radiometric Correction

Creates:

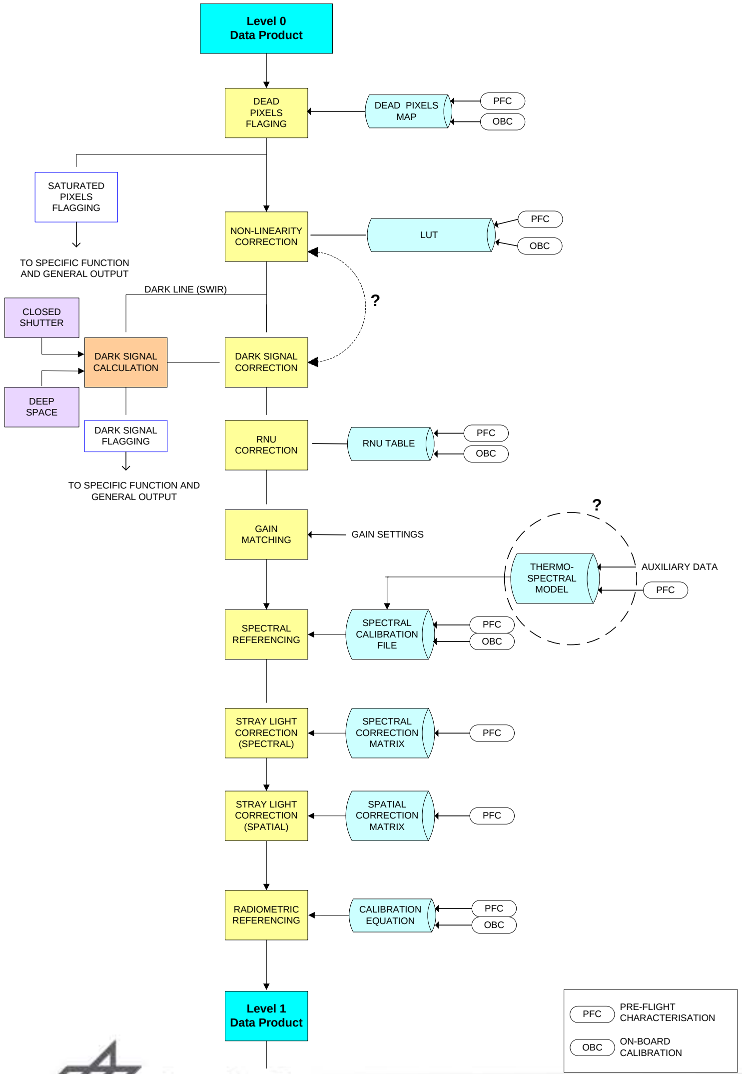
At-sensor radiance

Metadata for further processing



Example: ALOS Processor on behalf of ESA

EnMAP Level 1 Processing – detailed steps



- Bad (dead & suspicious) pixel flaging
- Non-linearity correction
- Dark signal correction
- RNU correction
- Gain Matching (VNIR)
- Spectral referencing
- Spectral straylight correction
- Spatial straylight correction
- Radiometric referencing

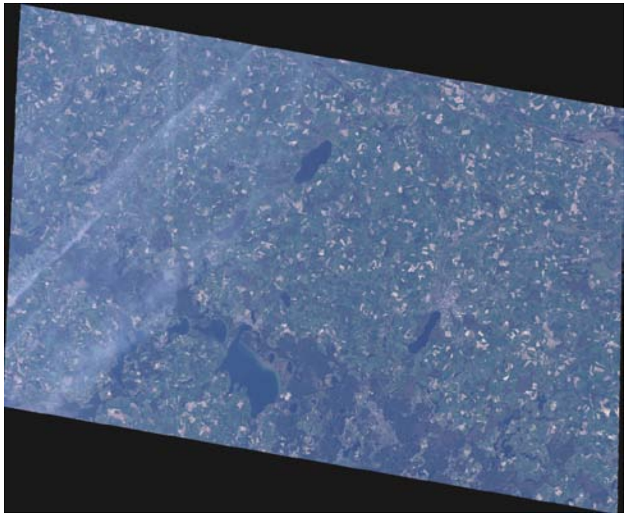
EnMAP Level 2geo Processing

Performs
Geometric image corrections realized by different process flows

Creates
Orthoimages
Acc. < 3 GSD without Ref.
< 1 GSD with Ref.

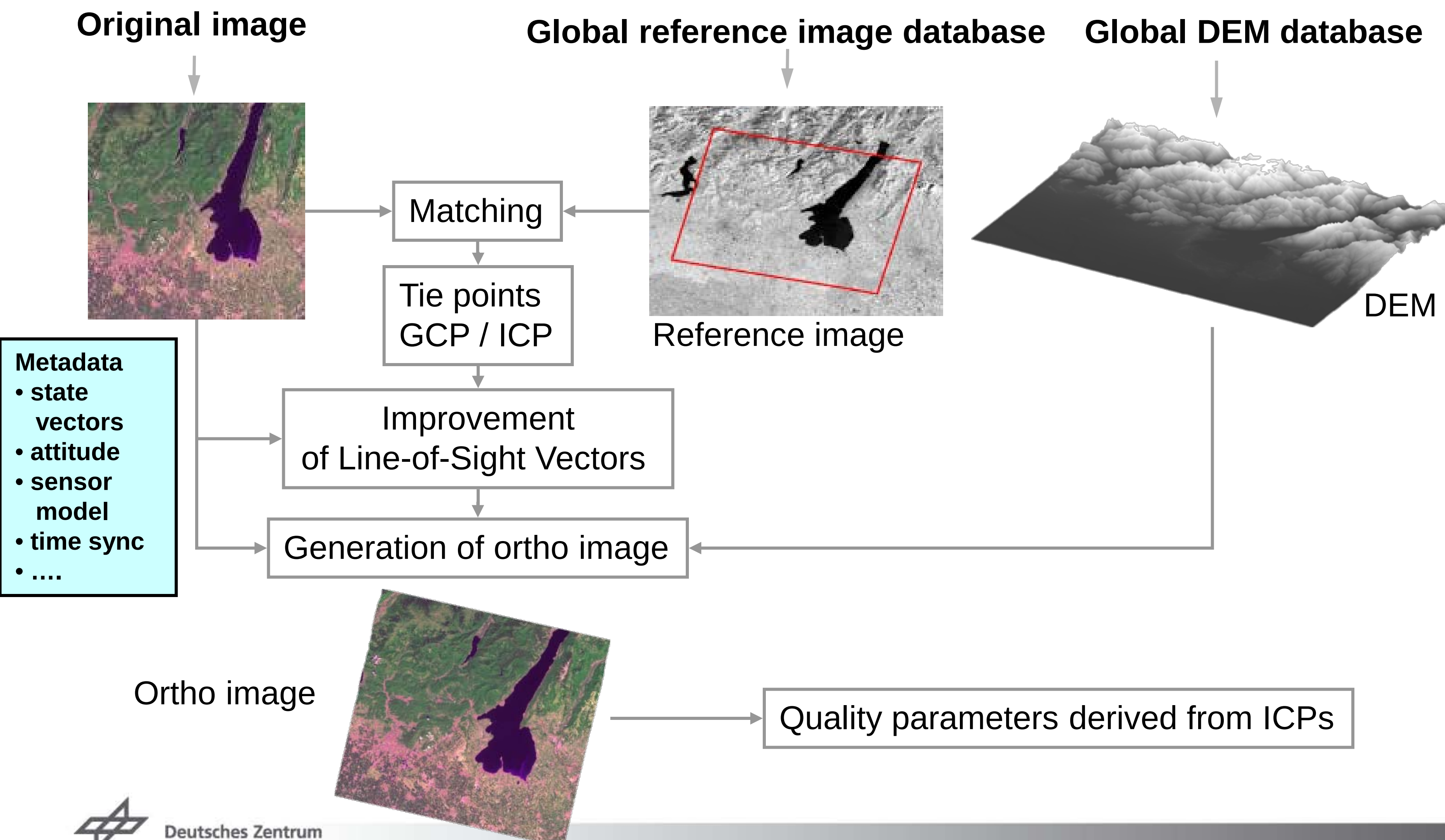
Selectable Parameters
Projection:
UTM (Zone of center) (± 1 zone)
Geographic

Resampling:
Bi-cubic
Bi-linear
Nearest Neighbour



Example: ALOS Processor on behalf of ESA

EnMAP Level 2geo Processing using Reference Scenes



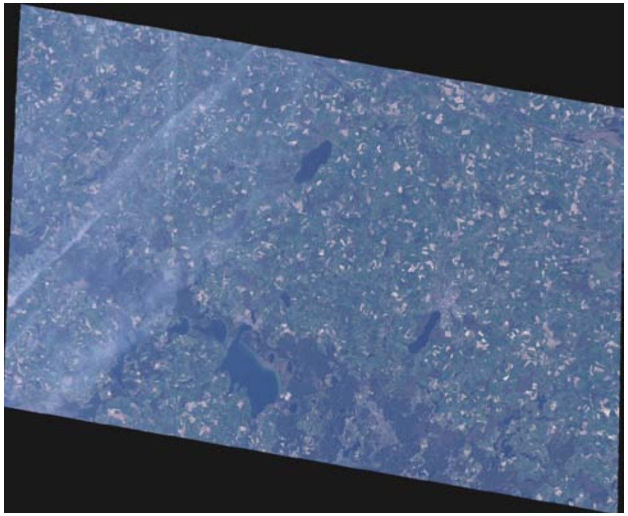
EnMAP Level 2geo Processing
with automatic GCP extraction – heritage

European Mosaick (~3700 Scenes)

- IRS-P6 LISS III
- SPOT 4 HRVIR
- SPOT 5 HRG

Overall mean accuracy w.r.t. reference data set (~450 ICPs per 1000 km²)
RMSE$_{x/y}$ ~ 10 m (CE64 ~14m)

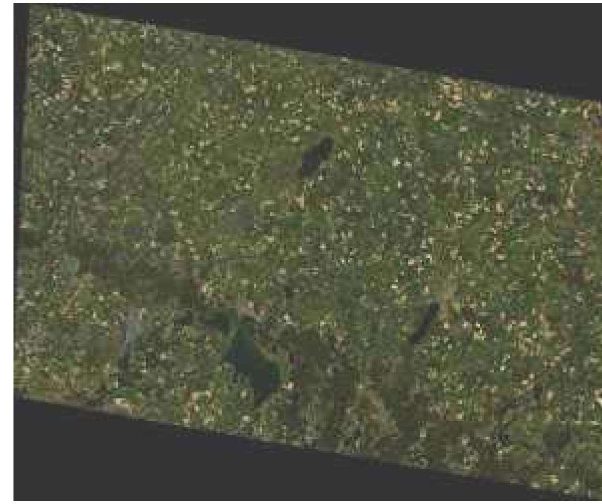
EnMAP Level 2atm Processing



Performs
Atmospheric Correction over land and water
Haze / Cirrus Removal based on
- ATCOR (Land)
- MIP (Water)

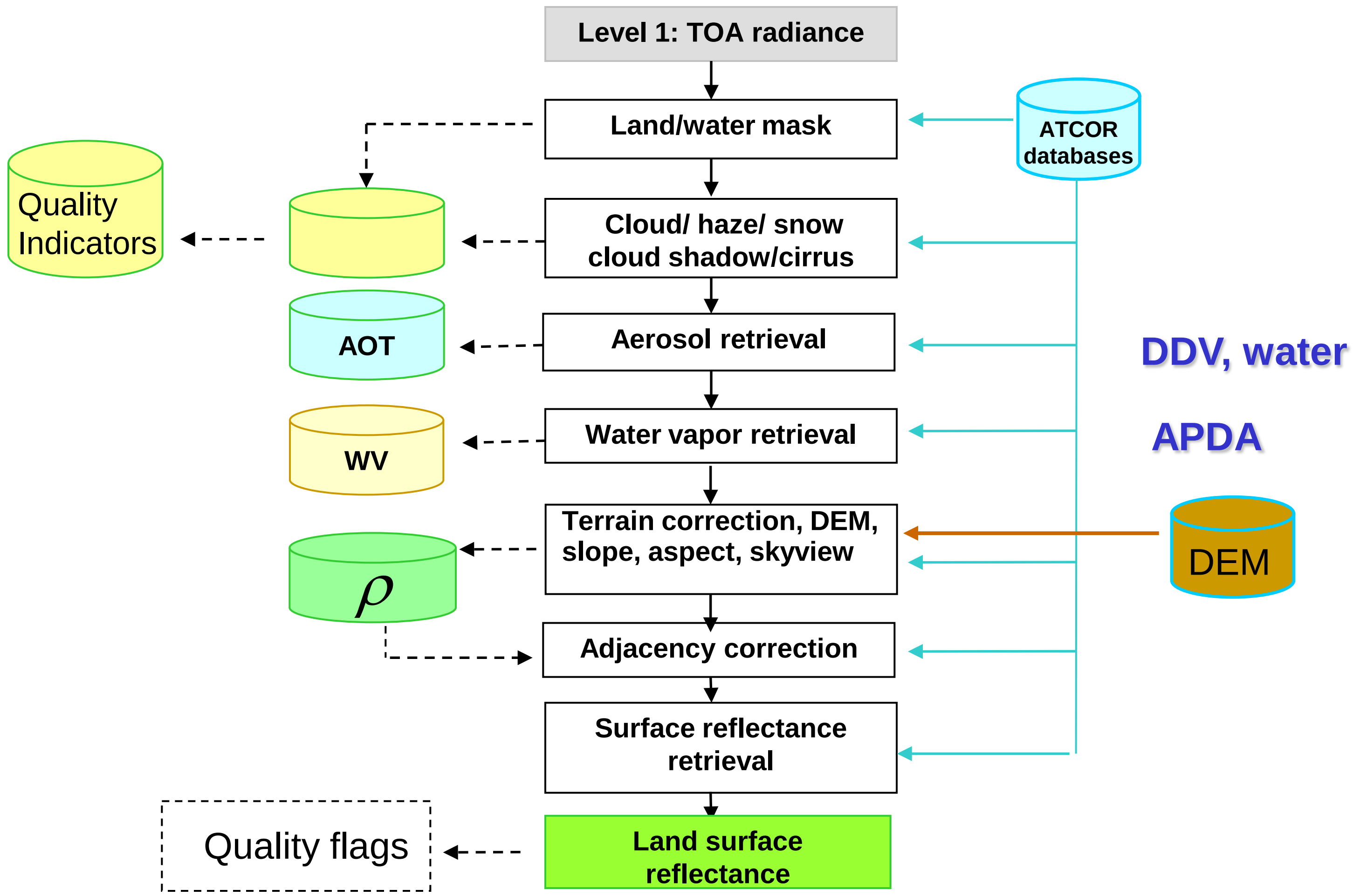
Creates
Surface Reflectance
haze/cloud/water/land mask

Selectable Parameters
Only land / water
Combined product (if appl.)
Haze / cirrus removal
Flat / rugged terrain
Water type (clear / turbid)
…

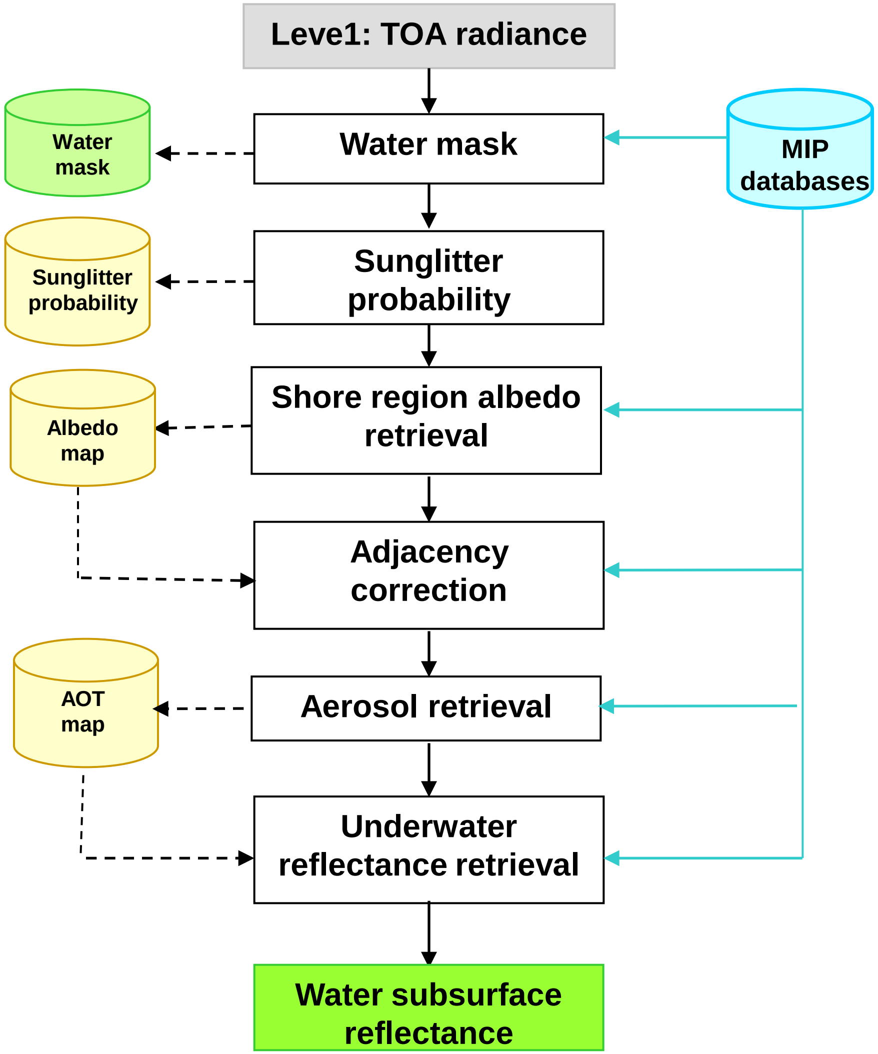


Example: ALOS Processor on behalf of ESA

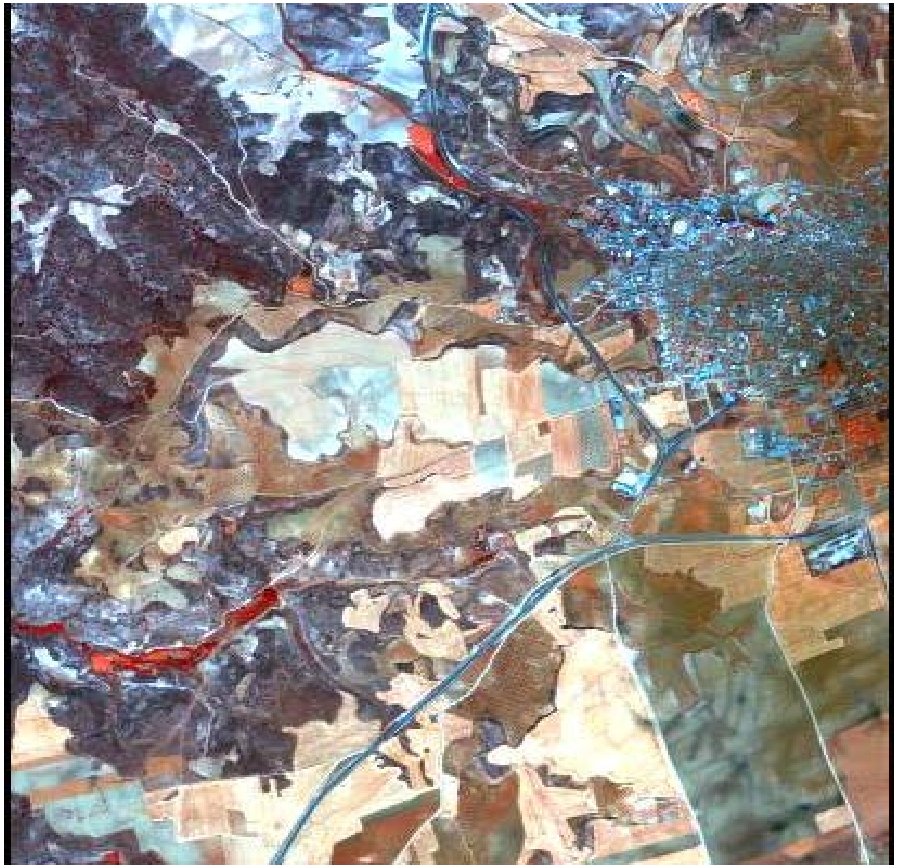
Level 2atm Land Surface Processing



Level 2atm Water Surface Processing



ATCOR : Example of Cloud Shadow Removal



HyMap scene, Chinchon, Spain, 12 July 2003, RGB=878, 646, 462 nm

Ref: Richter & Mueller, 2005

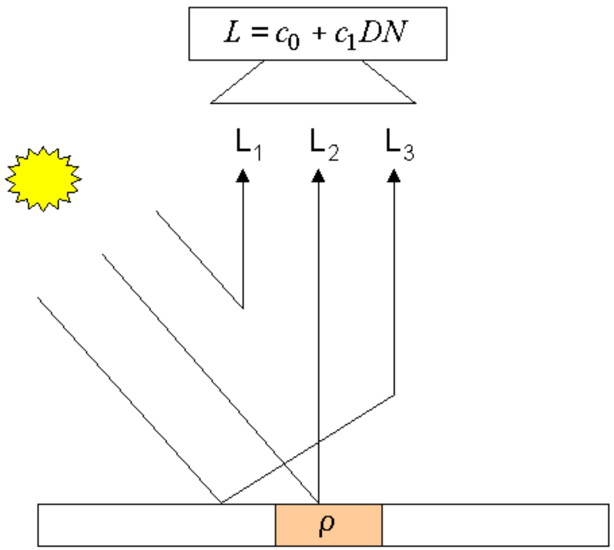
ATCOR : Example of Cirrus Removal

AVIRIS scene, Bowie MD, 7 July 1996, RGB=634, 547, 458 nm

Ref: Gao et al., 2002

EnMAP Level 2atm Processing
flat terrain vs. rugged terrain atm. correction

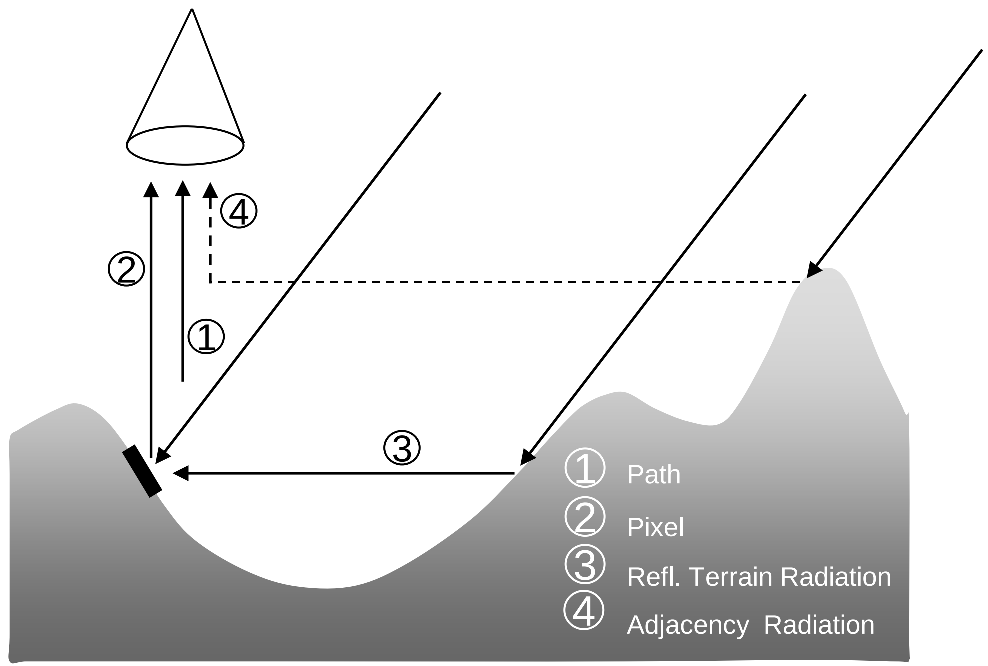
Radiation components flat terrain



Surface reflectance

$$\rho = \frac{\pi\,(L - L_1)}{\tau\,(E_{dir}\,\cos\theta_s + E_{dif})}$$

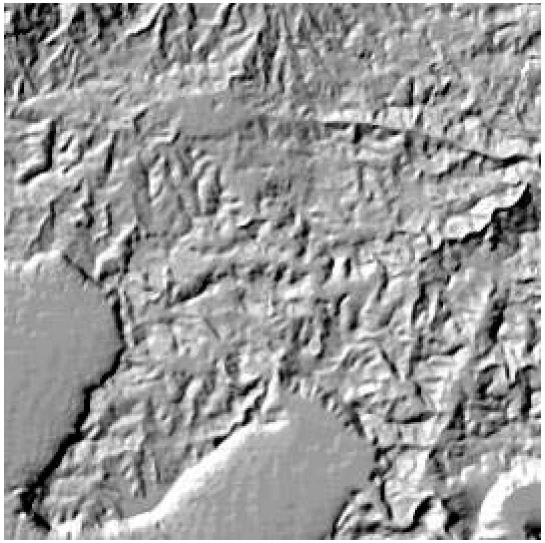
Radiation components rugged terrain



EnMAP Level 2atm Processing

high geometric accuracy necessary for topo correction

illumination map cos(local SZA)



atm + topo corrected

Geom. Acc. < 1 pixel

atm + topo corrected
3 pixel shift →

Data QI Example: EnMAP L2_atm product

EnMAP Hyperspectral Imager

QC Entry	Parameter	Category	Report format	Metadata (DIMS IIF)	
				Internal	Public
			(**R**)eport (**L**)ayer		
overallQuality	**Overall data quality**	all	R	Y	Y
processorLog	Warning messages in processor log	IMG	R	Y	
sceneSZA	**Solar zenith angle**	IMG	R	Y	Y
sceneSunglint	Sun glint / sun glitter probability	IMG	R	Y	
cloudCover	**Percentage clouds**	ATM	R, L	Y	Y
hazeCover	Percentage haze	ATM	R, L	Y	Y
cirrusCover	Percentage cirrus	ATM	R, L	Y	Y
cloudShadow	Percentage cloud shadow	ATM	R, L	Y	Y
sceneWV	**Average scene WV**	ATM	R	Y	Y
sceneVIS	Average scene visibility / AOT	ATM	R	Y	Y
sceneAtmParam	**Validity of atm. correction**	ATM	R	Y	
sceneTerrain	DEM artifacts in terrain correction	ATM	R, L		
internalMasking	**Masks** generated during processing (cloud, shadow, haze, land / water)	ATM	R		
specCal	Artifacts related to spectral calibration / ATCOR LUTs	SPEC, ATM	R		

Blue: implemented in L2_atm land / L2_atm water processor

Mission Status

2003: Call for Proposals for a future Earth observation mission by DLR Agency

2004: EnMAP selected for Phase A study

2005: Phase A: study accomplished successfully (SRR)

2006: EnMAP selected for Phase B study

2007: Phase B: study accomplished successfully (PDR)

2008-2010: Phase C: Detailed Design (GS CDR passed in July ‘10) ✓

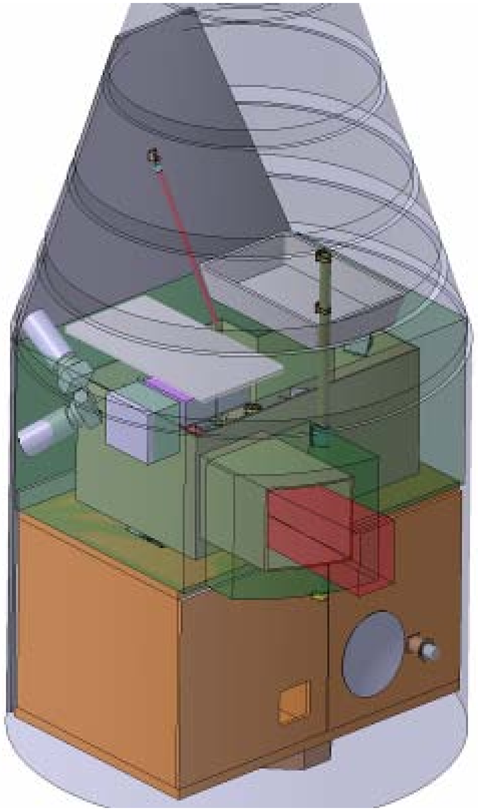
2010-2013: Phase D: Production, Test, Verification, Validation (ORR)

2014: EnMAP Launch with PSLV (LEOP & Commissioning Phase)

2014-2019: Operations Execution

2019- : De-orbiting

Thanks for your attention



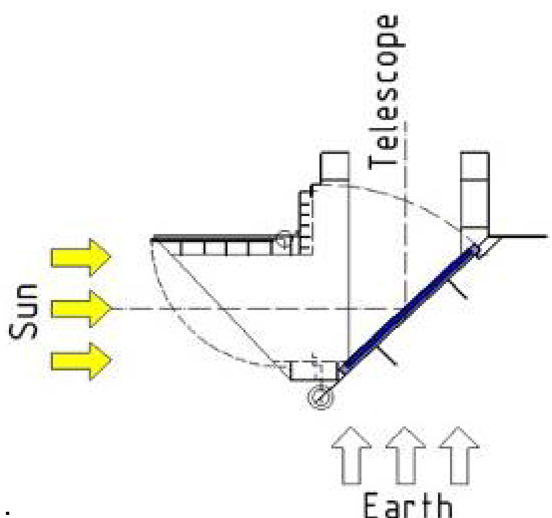
www.enmap.org

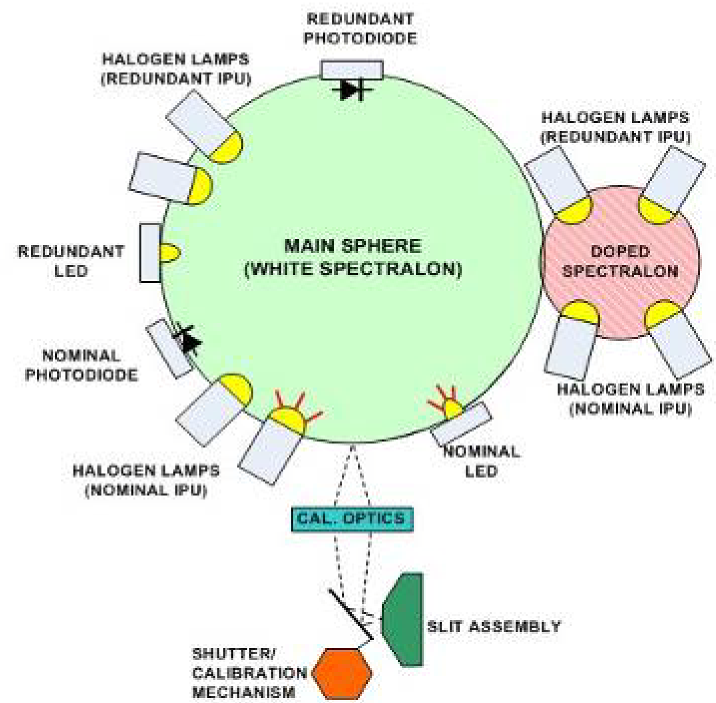
Backup Slides …

On-Board Calibration Means

Technical tools and operational modes to perform the necessary measurements for on-orbit calibration (and monitoring of instrument properties) throughout the mission:

- Shutter/calibration mechanism for dark value and calibration measurements
- Full aperture diffuser for Sun calibration (radiometric, absolute)
- Main integrating sphere (white Spectralon®) for relative radiometric assessment
- Secondary sphere (doped Spectralon®) for spectral calibration assessment
- Focal plane LEDs for linearity measurements





HSI in-flight calibration means
except focal plane LEDs

(drawing © Kayser-Threde)

Calibration measurements

Summary of calibration measurements

Calibration type	Time	Frames	Data Volume	Frequency
Dark (shutter)	23 sec	2 * 128	0,27 GB	each datatake
Dark (deep space)	30 sec	1 * 1024	1,38 GB	every 3 months
Relative radiance calibration	17 min 13 sec	1 * 512 (5steps)	1,66 GB	weekly
Sun calibration	140 sec	2 * 1024	1,38 GB	monthly
Spectral calibration	5 min13 sec	1 * 1024	0,83 GB	monthly
Linearity measurement	< 5 min	2 * 128 * 40	5.8 GB	monthly

Data Quality Control

Including Quality Indicators (QI) for

General sensor characterization
(e.g., spectral smile)

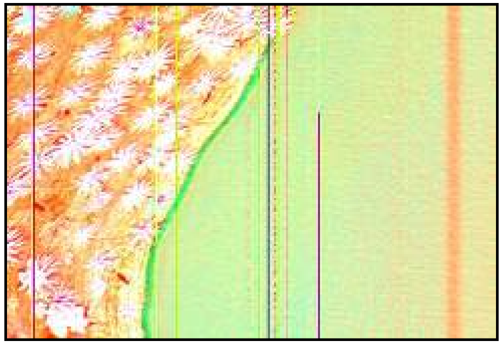
Sensor calibration issues
(e.g., striping in pushbroom sensors)

Sensor performance during data acquisition
(e.g., data drops)

External conditions during overflight
(e.g., cloud coverage)

Processing
(e.g., uncertainty of geo-location)

Quality of auxiliary data used in processing
(e.g., DEM accuracy)



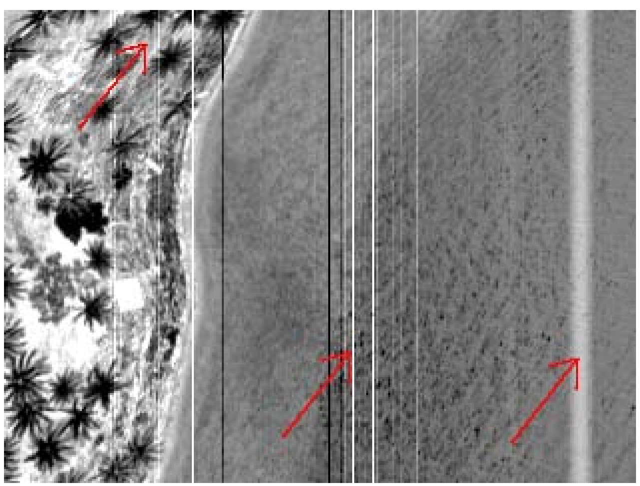
Addressing data QC related to radiometry

Tasks: assessment of **Data Properties** related to radiometry (**QC flag, QC report**), indication to trigger on-board calibration (S-320) and instrument monitoring (S-340)

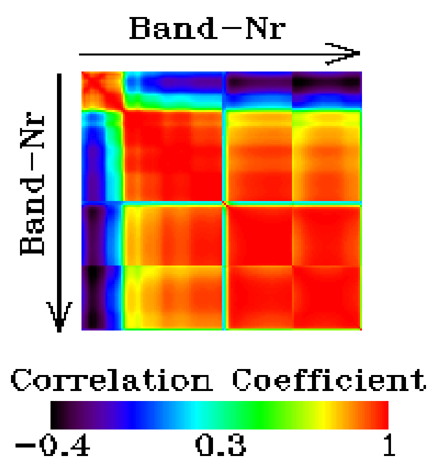
Issues: incorrect or instable radiometric calibration (gain & offset values), contamination of detector elements

Approach for **automated** Data QC within L1 processor:

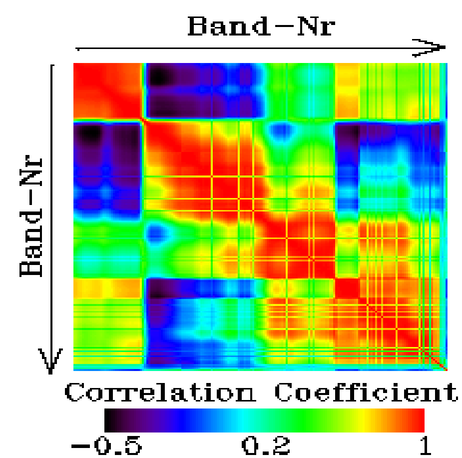
- Tests for scene / scene subset homogeneity
- Comparison with nominal values for:
- Difference in column mean DN / mean radiance and STDEV (=> **striping**)
- Correlation of neighboring bands within one column (=> **single detector failures**)
- Overall band-to-band correlation matrix (=> **stability of radiometric calibration**)



Striping in Pushbroom sensor data (MNF-transformed)



Band correlation matrix (no band defects)



Band correlation matrix (known de-calibration issues)

QC Entry	Parameter	Category	Report format	Metadata (DIMS IIF)	
				Internal	Public
			(**R**)eport (**L**)ayer		
overallQuality	Overall data quality	all	R	Y	Y
stripingBanding	Artifacts related to **radiometric calibration**	RAD	R	Y	
dualGain	Artifacts related to dual gain	RAD	R, L		
saturationCrosstalk	Saturation, cross-talk, blooming	IMG	R, L	Y	Y
generalArtifacts	Other **artifacts** / suspicious pixel	IMG	R, L	Y	
sensorLog	Warning messages related to sensor	IMG	R	Y	
processorLog	Warning messages in processor log	IMG	R	Y	
internalMasking	**Masks** generated during processing (cloud, shadow, haze, land / water)	ATM	R		
specCal	Artifacts related to **spectral calibration**	SPEC	R		
signalToNoise	Signal-to-noise estimate	IMG	R		

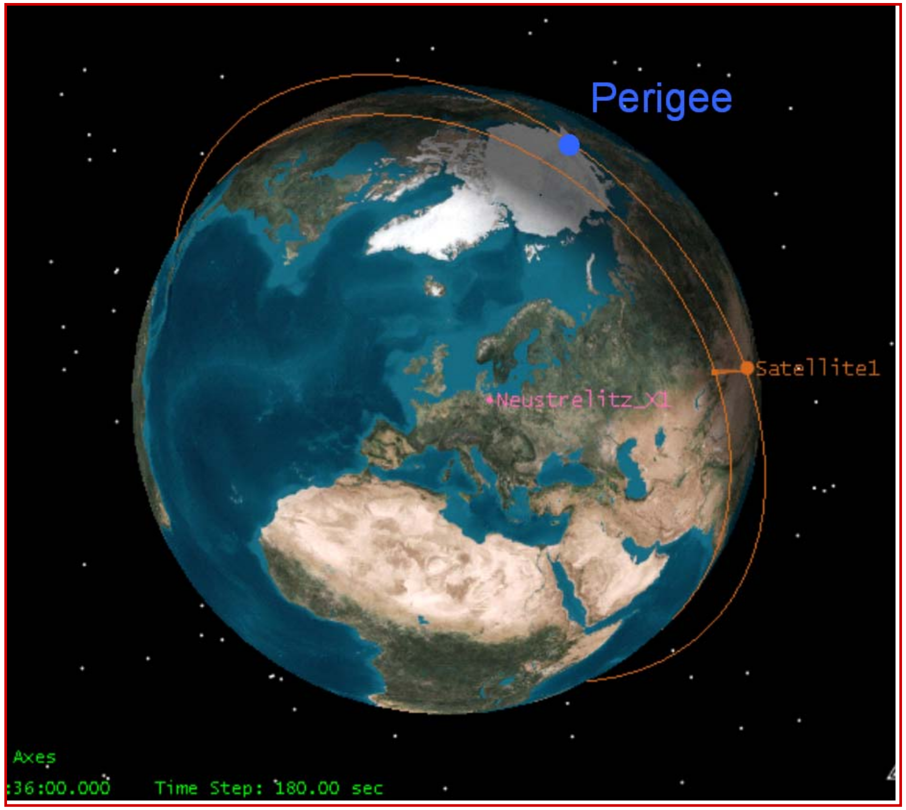
Blue: implemented in L1 processor

EnMAP Data QC for L2_geo products

QC Entry	Parameter	Category	Report format	Metadata (DIMS IIF)	
				Internal	Public
			(R)eport (L)ayer		
orthoTerrain	DEM-related displacements	GEO	R	Y	
orthoRMSE	**Geometric accuracy** of the orthoimage (I)	GEO	R	Y	Y
orthoResidual	Geometric accuracy of the orthoimage (II)	GEO	R	Y	

Blue: implemented in L2_geo processor

Mission parameter



Sun-synchronous, 11:00 LTDN LEO – reference altitude 653km

3 axis stabilized platform with OCS

mass 850 kg / power 550 W avg.

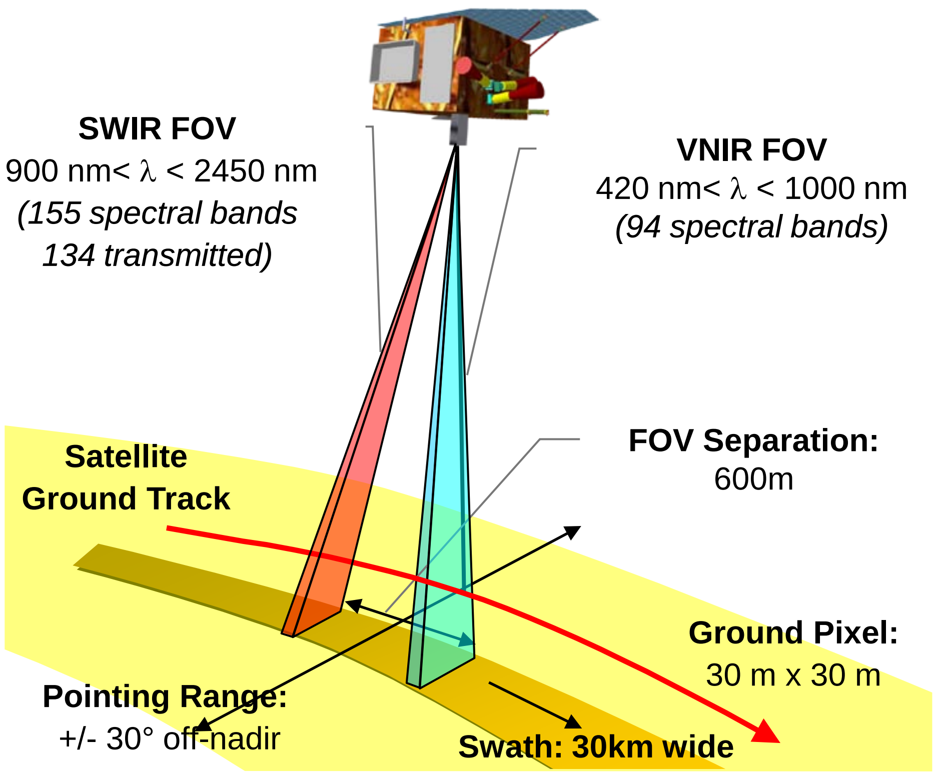
512 Gbit mass memory / 320 Mbit/s X-band science data downlink

4 day global accessibility (30 off-nadir)

4 day target revisit capability

up to 50 data takes per day / total length 5000km

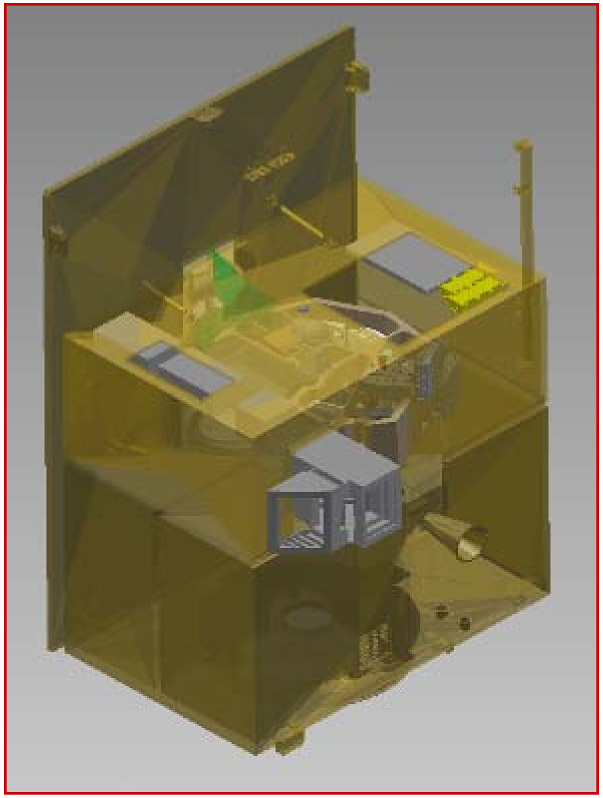
Sensor Parameter



schlanke Kontur - Leitfarbe

- Pushbroom type hyper spectral imager
- Wavelength 420 - 2450 nm
- 30m GSD, 30 km swath (nadir)
- 228 spectral bands
- VNIR 6.5 nm sampling
- SWIR 10 nm sampling
- SNR > 150 @ 2200nm (ref. radiance)
- Polarization sensitivity < 5%
- Smile and Keystone < 0.2 pix
- Pointing knowledge 100m
- Radiometric accuracy 5%
- Radiometric stability 2.5%
- Response Linearity 0.5%
- Spectral accuracy 0.5nm / 1nm

Satellite Design



Total Weight: ca. 850 kg

Aver. Power: 450 W

512 Gbit mass memory

3 axis stabilized platform

Pointing Stability: 1,5 m / 4 ms

Pointing Knowledge: 100 m

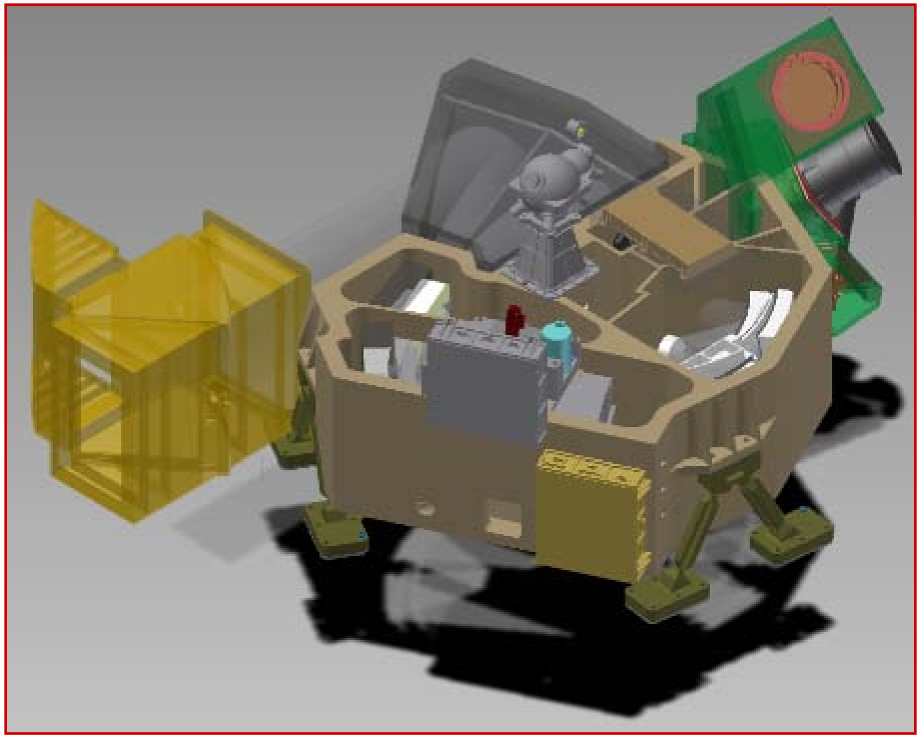
30 off nadir pointing for observation

Hydrazine propulsion system for orbit maintenance & disposal

320 Mbit/s X-Band science data downlink

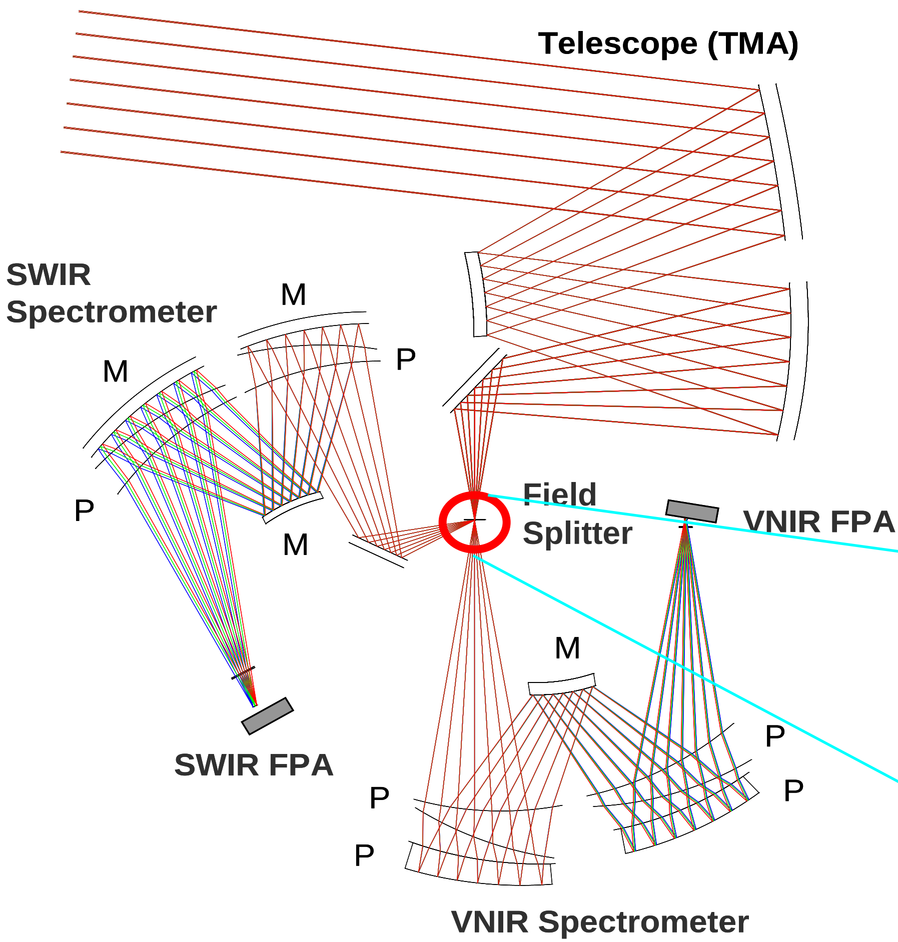
Lifetime in Orbit: > 5 years

Instrument Optic Unit Design



- Polished NiP coated Aluminum mirrors
- Monolithic Aluminum structure
- Quasi-isostatic mounting to platform
- Starcameras attached to IOU for pointing knowledge
- Redundant SWIR FPA due to cryocooler without flight heritage
- Gravity release < 5µm – opt. elements
- Eigenfreq. > 100 Hz
- Active thermal stabilization to 21 C ± 1K

Instrument Optic Design

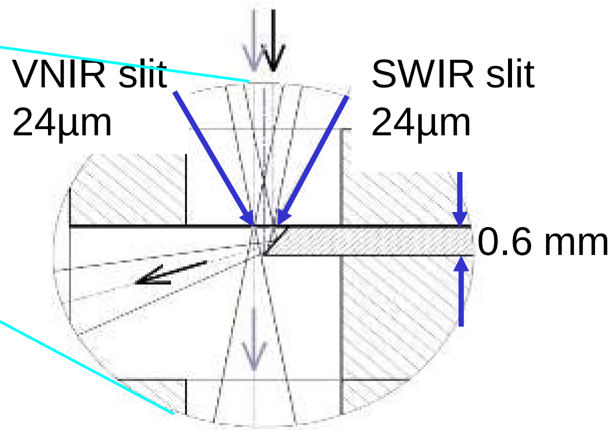


175mm EPD
F3 - unobscured

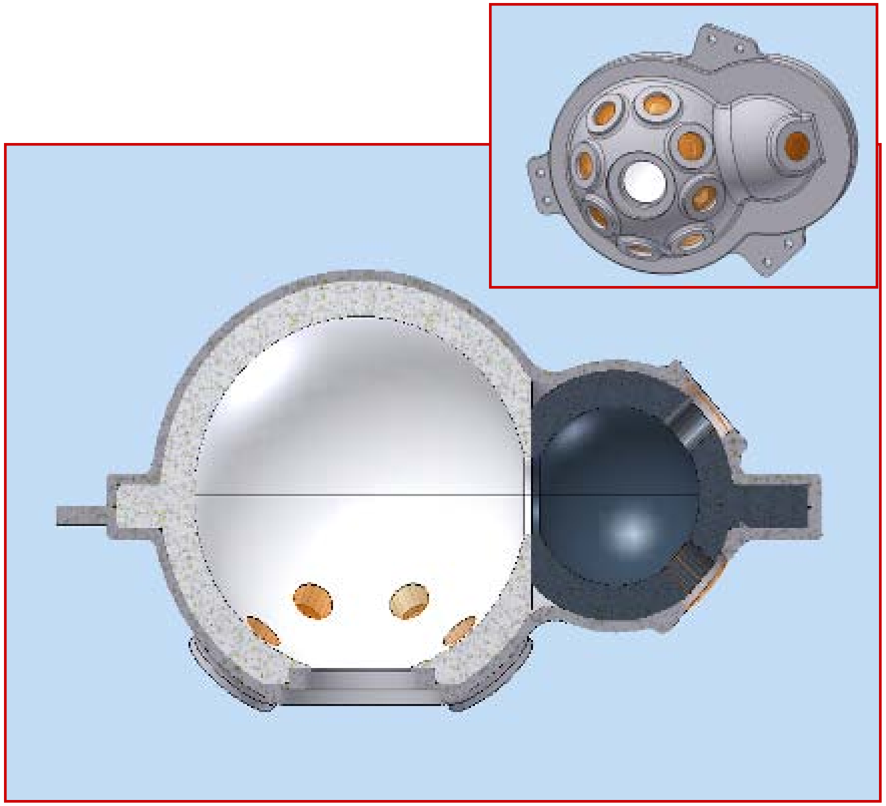
Novel spectrometer design

Dual, field separated spectrometer concept

good imaging performance



On-Board Calibration



Integrating Sphere (KT design)

Radiometric stability check: “integrating sphere with sources at different levels”

Sources: 10W Halogen lamps
white high power LEDs

Coupling to spectrometers via imaging optics

Different levels by driving varying currents

………..

FAD?

EnMAP
Hyperspectral Imager

Mission Elements