Copernicus Sentinel-4 / UVN instrument calibration

system PDR status

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→ SERVING EUROPEAN COOPERATION AND INNOVATION

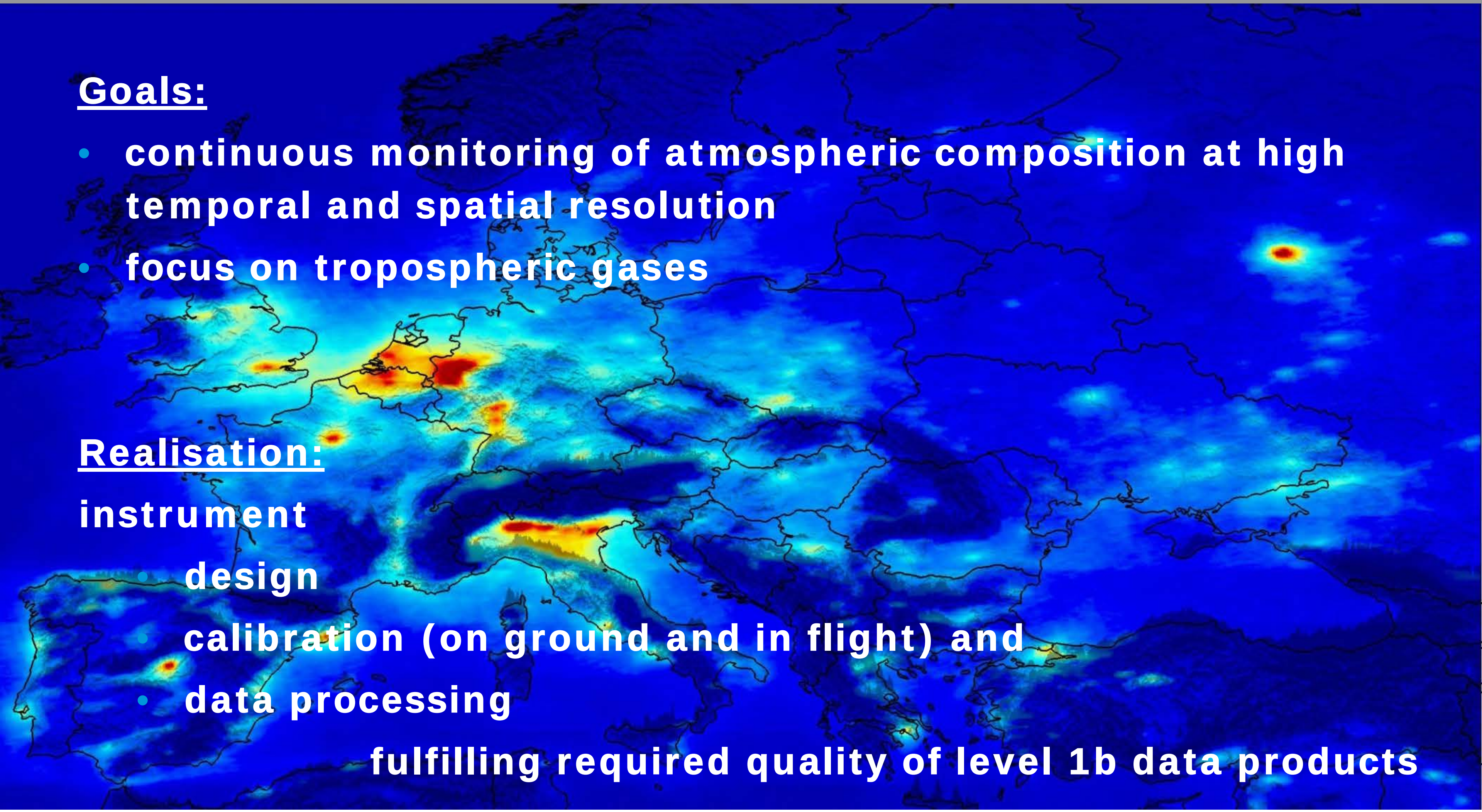
Outline

1. Sentinel-4/ UVN instrument overview
2. apportionment

   instrument design – calibration – L0L1b processing

3. L0 performance verification and calibration
   - example radiometric calibration
   - lessons learnt implementation
   - campaign phase separation
   - post long term storage calibration
4. contamination prevention (optical degradation)

Objective



Goals:

- continuous monitoring of atmospheric composition at high temporal and spatial resolution
- focus on tropospheric gases

Realisation:

instrument

- design
- calibration (on ground and in flight) and
- data processing

fulfilling required quality of level 1b data products

Tropospheric NO_2 2005-2007

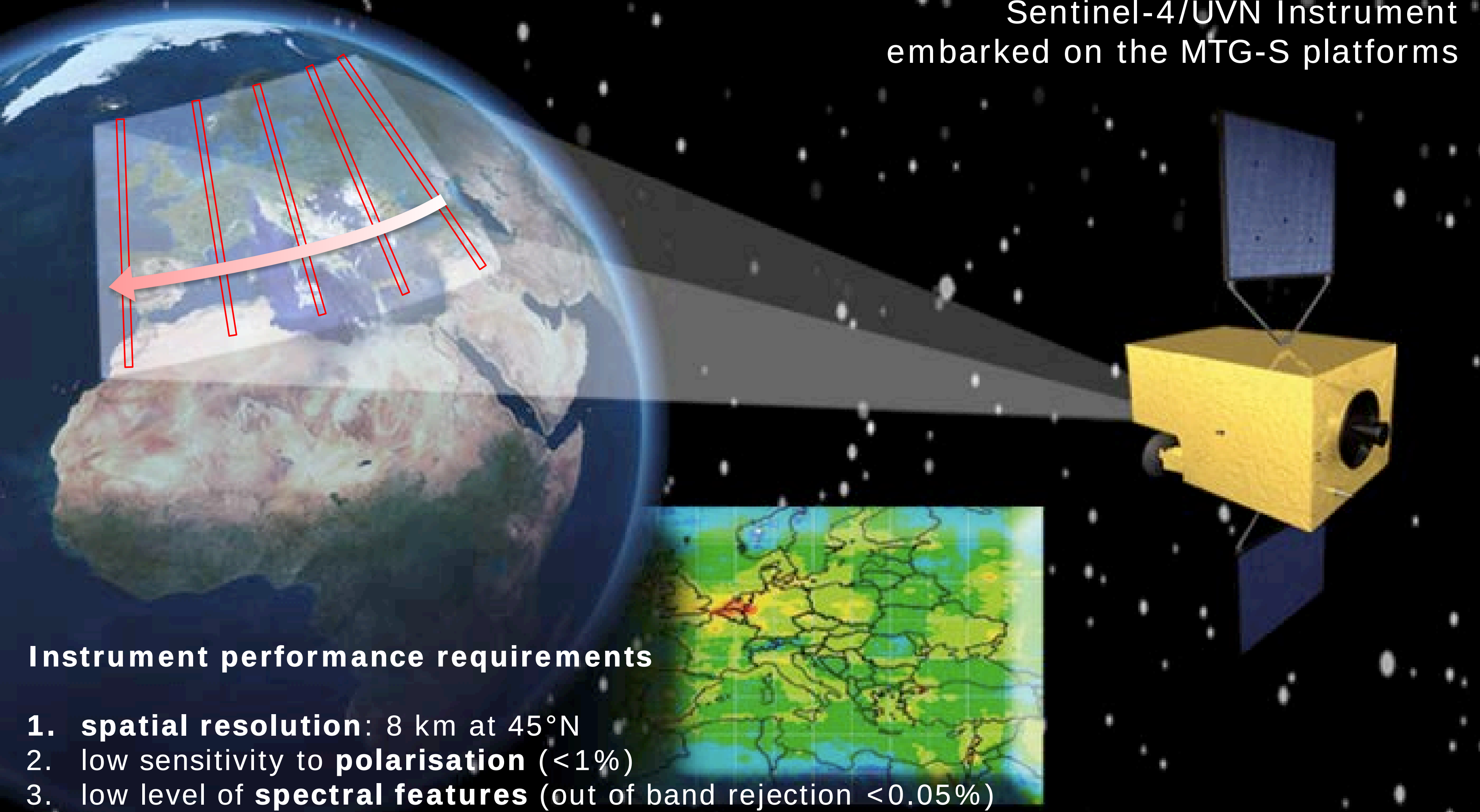
Linear color scale from 0 - $1.3e^{16}$ molecules.cm^{-2}

Courtesy KNMI/OMI

S4/UVN instrument coverage Europe and Sahara

East/ West scan 1 h repeat cycle

Sentinel-4/UVN Instrument embarked on the MTG-S platforms



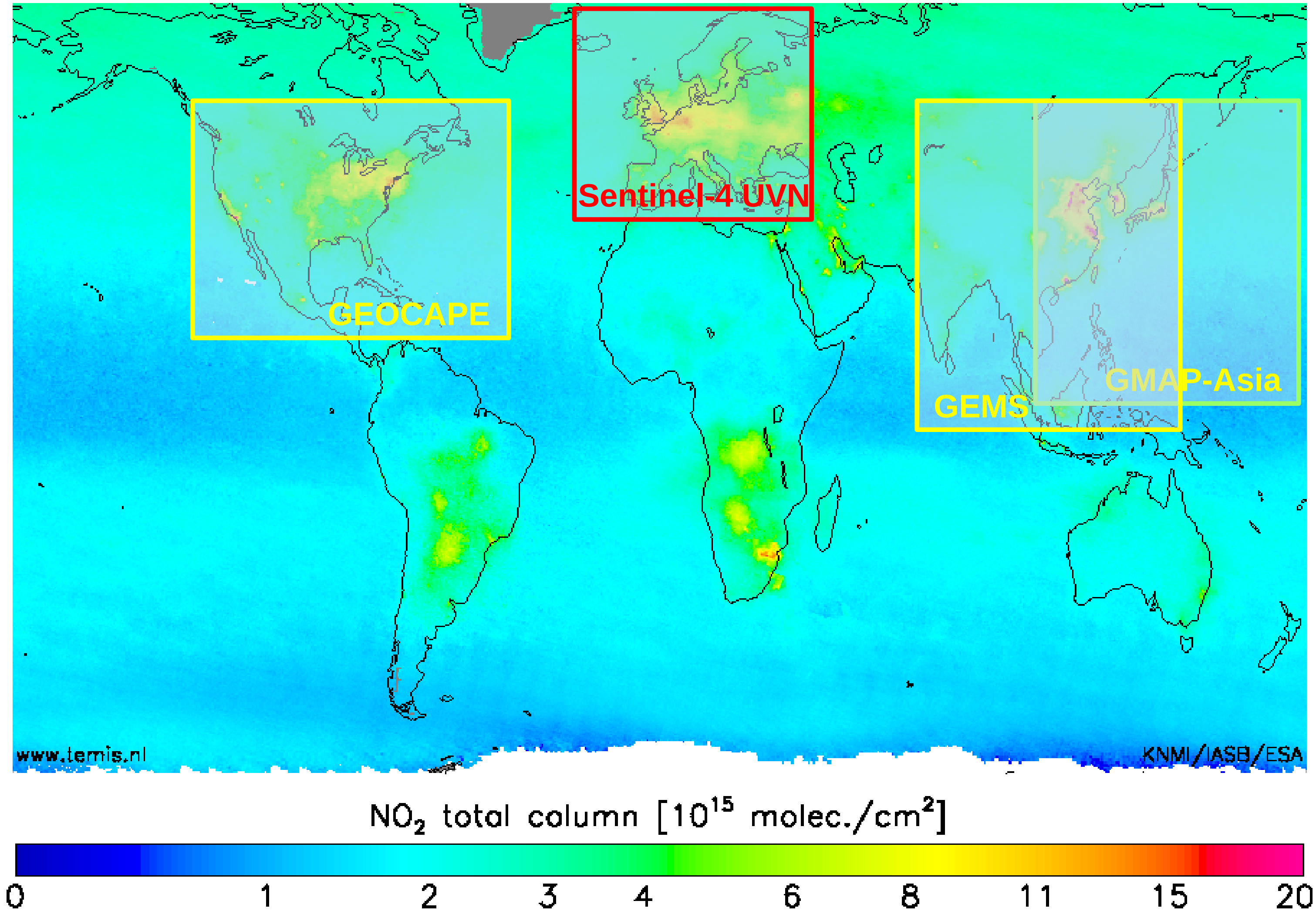
Instrument performance requirements

1. **spatial resolution**: 8 km at 45°N
2. low sensitivity to **polarisation** (<1%)
3. low level of **spectral features** (out of band rejection <0.05%)
4. high **radiometric** accuracy (< 3%, goal < 2%)

Current international plans for geostationary atmospheric missions

SCIAMACHY total NO_2 August 2006

KNMI/IASB/ESA

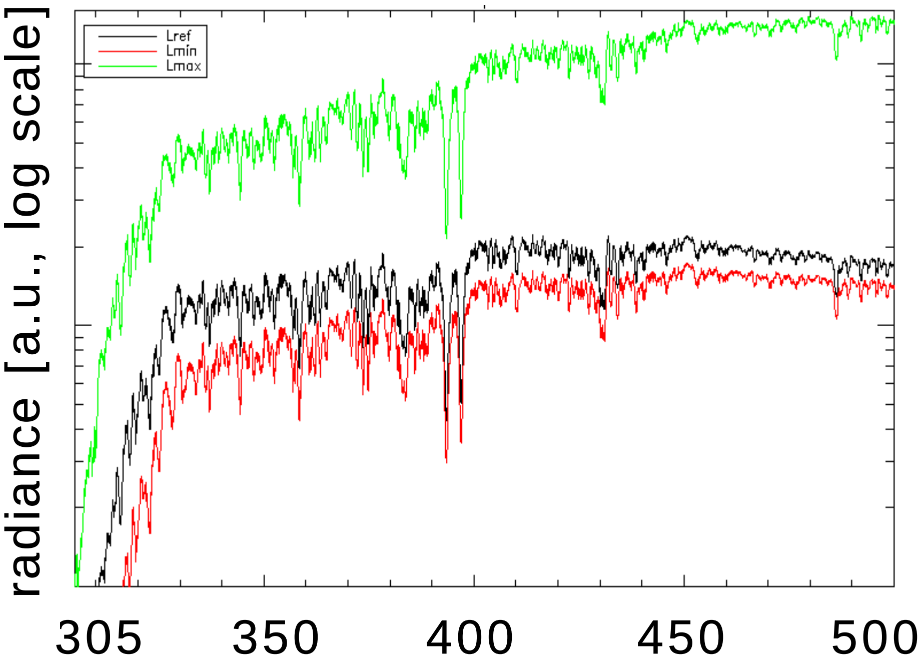


S4/UVN instrument parameters

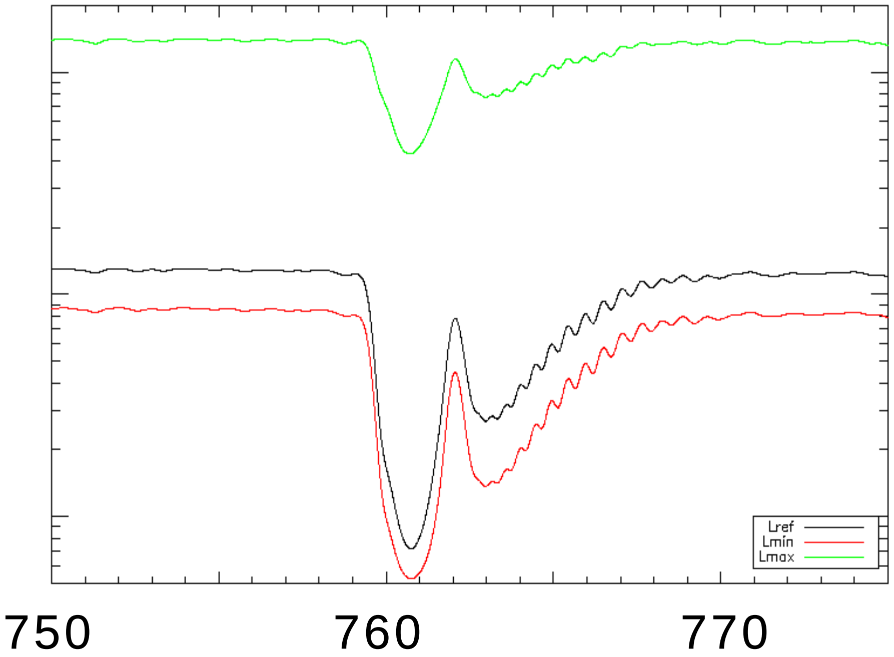
Spectral range	UV-VIS: 305-500 nm NIR: 750-775 nm
Spectral resolution Spectral oversampling	UV-VIS ≤ 0.5 nm NIR ≤ 0.12 nm UV-VIS & NIR ≥ 3.0 pixels
Spatial sampling at 45° North latitude, sub-satellite longitude	≤ 8 x 8 km^2
Number of spatial samples (approx.): N/S (detector pixel) E/W (meas. samples)	 530 570
Operational field of view (approx.): N/S E/W	 4° 11° (possible scan range is larger: 14°)
Temporal resolution (reference area)	60 min
Envelope	1000 x 1000 x 1500 mm^3
Mass	200 kg
Power	180 W
Data rate (nominal operation)	30 Mbps

Signal to be measured by S4/UVN

ultra-violet & visible



near infrared

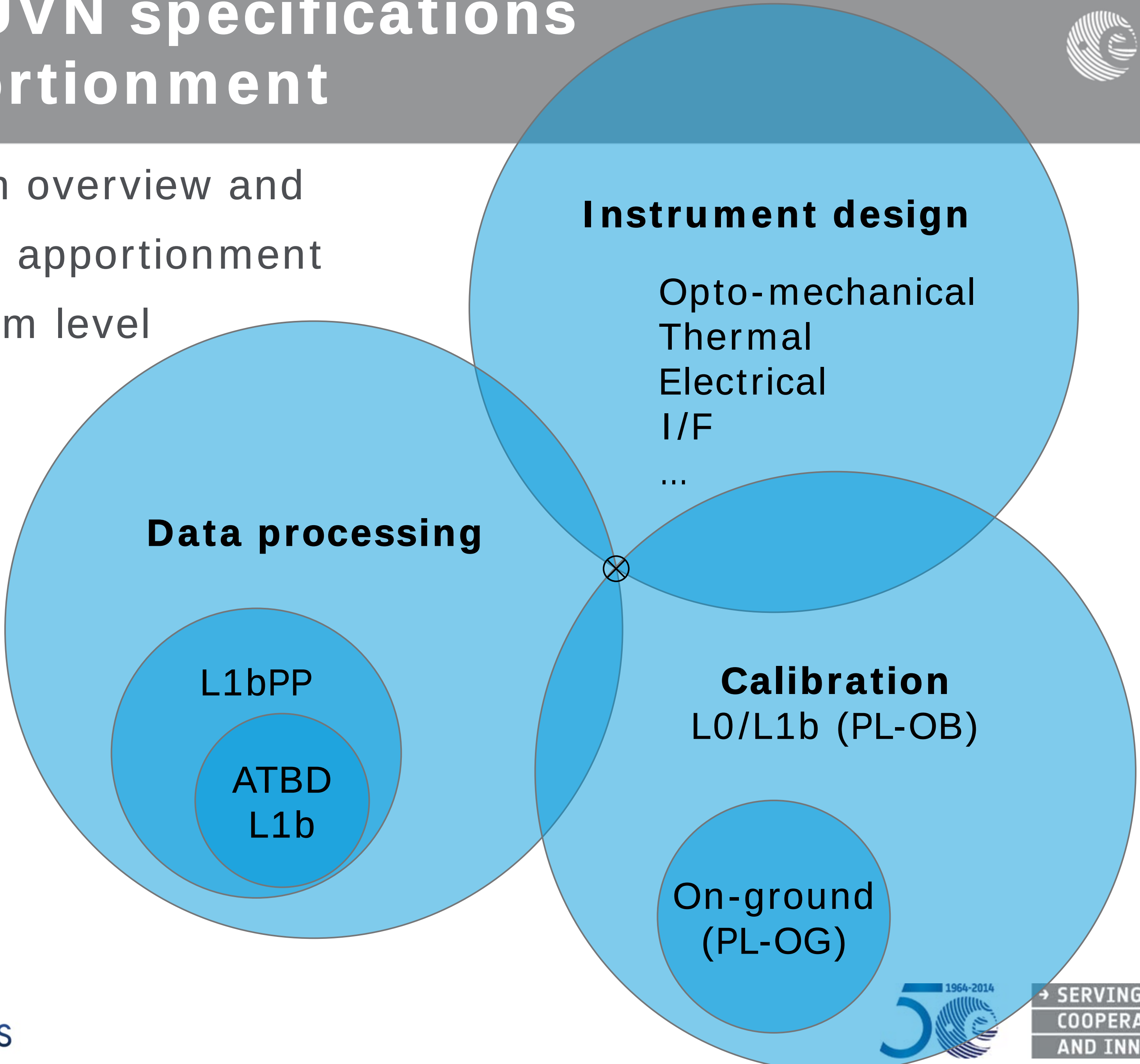


spectral resolution 0.5 nm

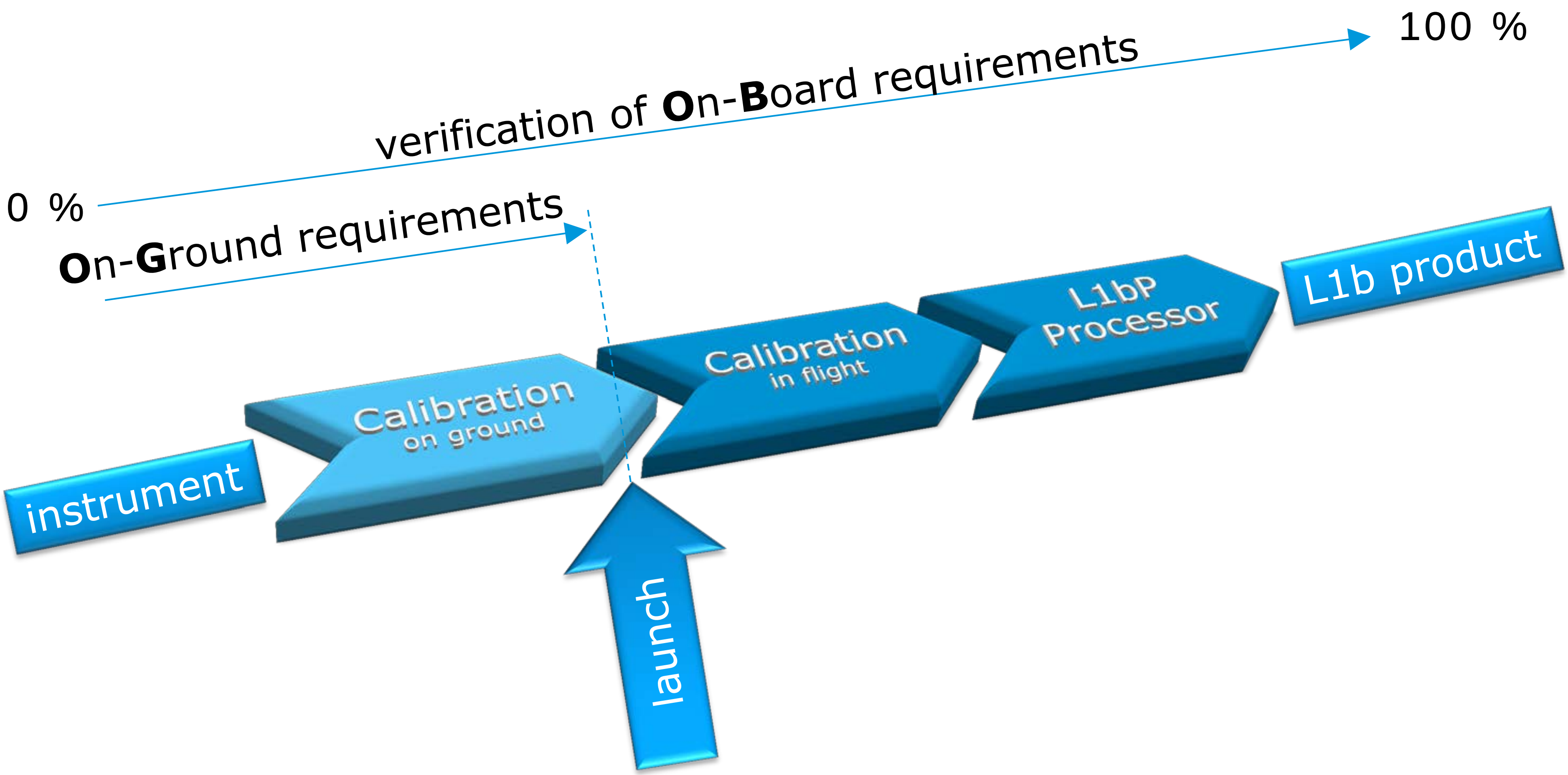
spectral resolution 0.12 nm

S4 / UVN specifications apportionment

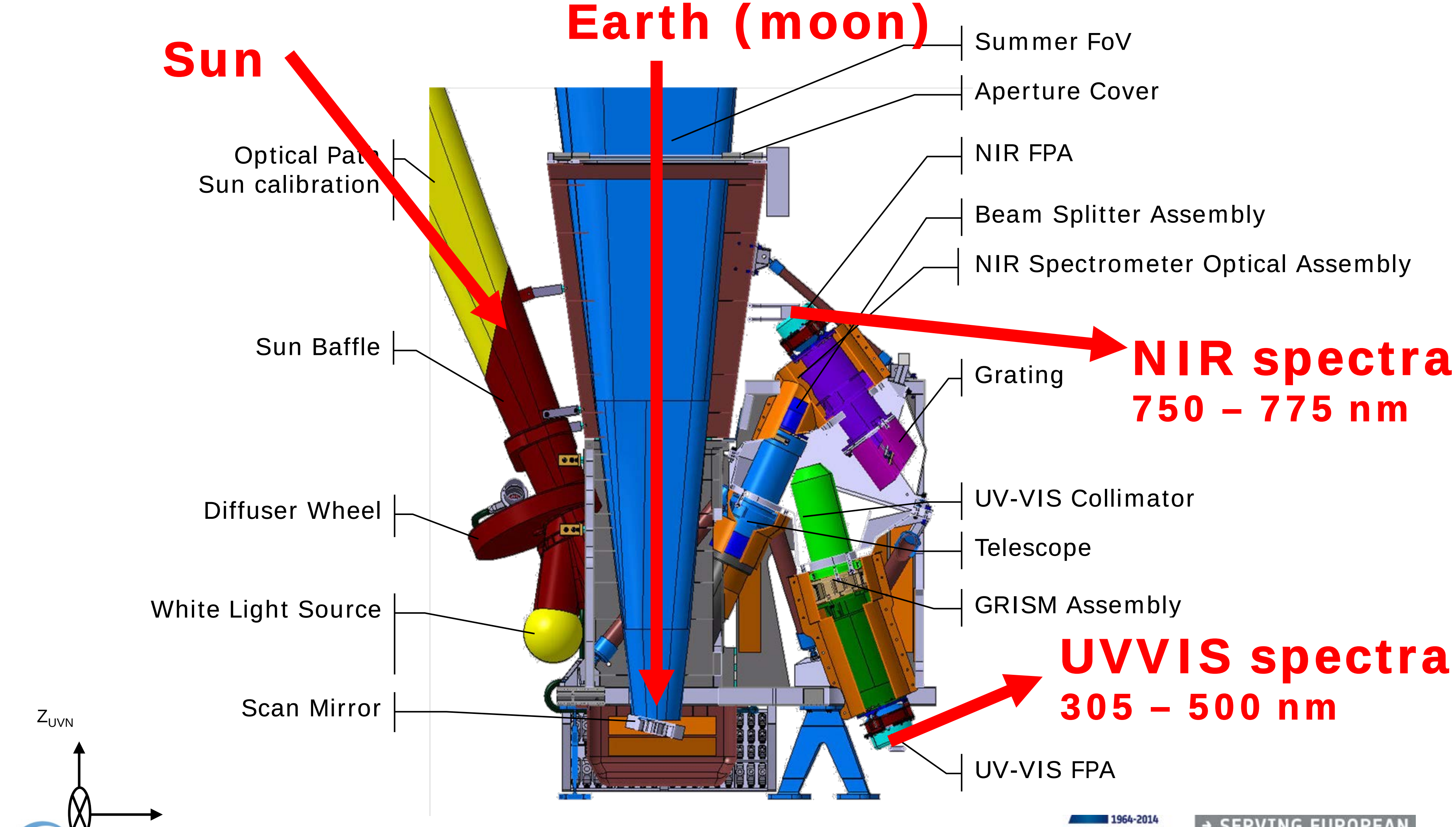
Maintain overview and sensible apportionment at system level



S4/UVN on-ground and in-flight requirements



S4 / UVN instrument

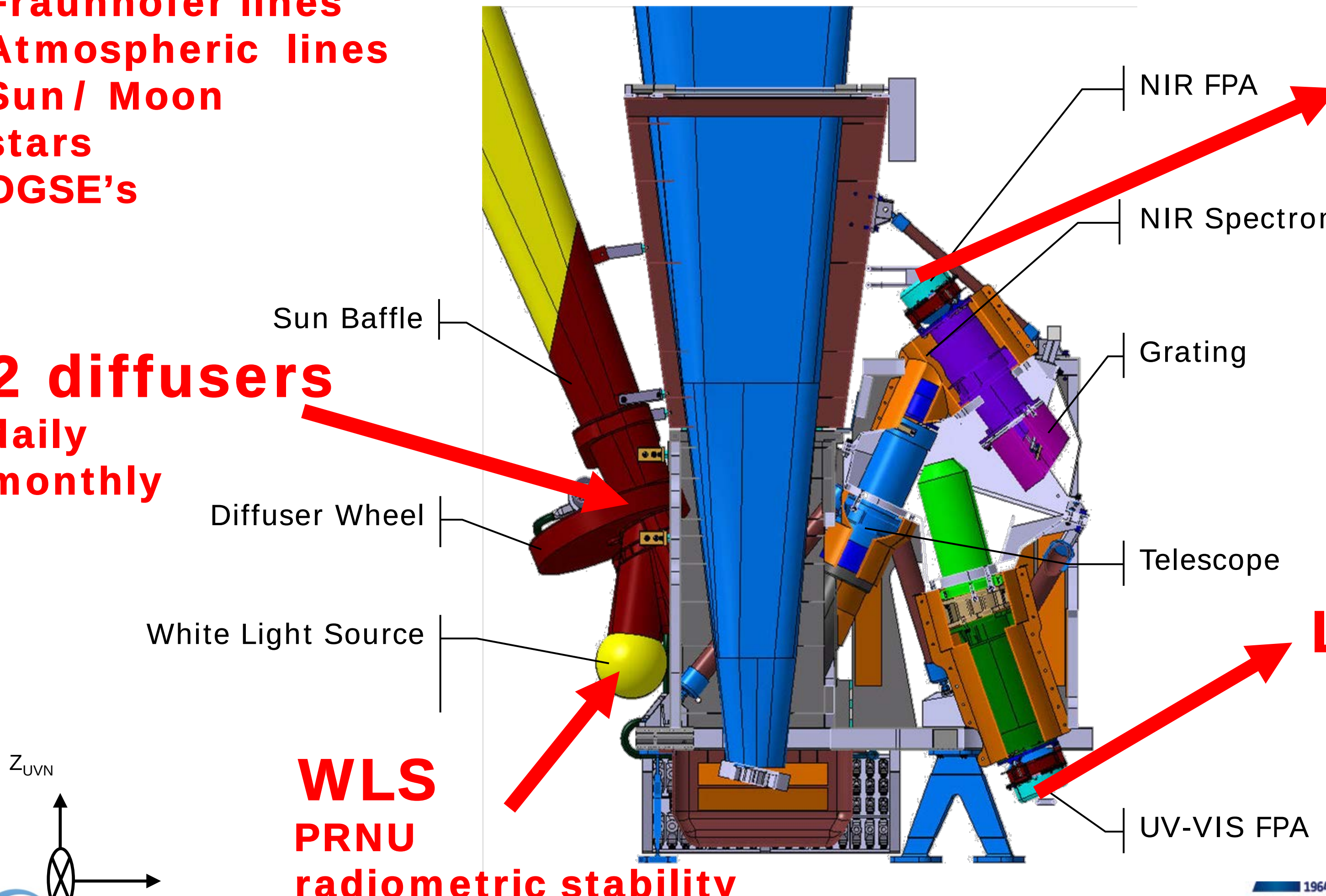


Courtesy of Astrium GmbH

S4 / UVN calibration sources

external
Fraunhofer lines
Atmospheric lines
Sun / Moon
stars
OGSE's

2 diffusers
daily
monthly



LED (red)
dead / bad pixel
pixel gain
pixel linearity

LED (blue)

WLS
PRNU
radiometric stability
degradation

Courtesy of Astrium GmbH

Calibration parameters

1. **radiometric calibration** Earth spectral radiance, Sun spectral irradiance and Earth reflectance (radiance/irradiance)
2. **spectral calibration**
    a. wavelength scale for uniform and non-uniform ground scenes
    b. Instrument Spectral Response Function (ISRF)
    c. optical bench temperature (gradient) dependencies
3. spectral/ spatial **straylight**
4. **electronic** and **detector** calibration parameters
5. **geometric** parameters, co-registration, Image Navigation and Registration (INR), geolocation
6. **polarisation** no correction, verification at level 0 that instrument is sufficiently insensitive to incident polarisation
7. at level 0: no **spectral features** in instrument response that interfere with atmospheric gas absorptions

Flow down to component level

1. **component**
   e.g. characterisation of diffuser, scan mirror
   (transmission, angle dependence, radiation, ...)
2. **sub-system**
   e.g. Focal Plane Assembly sub-system
   (detector, FEE/FSE, FPA housing)
3. **system**
   S4/UVN instrument models
   (EM/oQM, PFM, FM2)

S4/UVN abs. radiometric accuracy

3% (threshold), 2% (goal), accounting for all error contributions (straylight, polarisation, smear,...) at level 1b (after corrections)

Calls for building-up an error budget accounting for contributions from:

- instrument design
- instrument on-ground & in-flight calibration
- signal processing L0 to L1b

Similar requirements exist for on-ground measurements

- instrument response in Sun calibration mode shall be OG calibrated better than **0.8%**
- instrument response in Earth observation mode shall be OG calibrated better than **1.0%**
- instrument response in Earth reflectance shall be OG calibrated better than **1.0%**

Radiometric calibration parameters

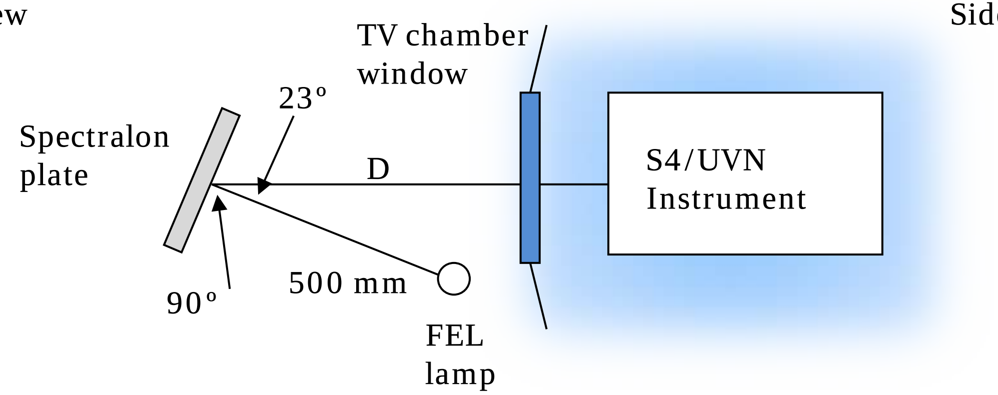
1. absolute Earth spectral radiance
2. absolute Sun spectral irradiance
3. Earth viewing angle dependency
   (North-South on detectors and scan mirror)
4. Sun viewing angle dependence
5. absolute Earth reflectance: Earth radiance/ solar irradiance, using dedicated sources optimised for this parameter

In orbit, relative radiometric degradation monitored and quantified primarily with **Sun irradiance** measurements, but also with **WLS** and **LED,** Earth radiance and moon measurements.

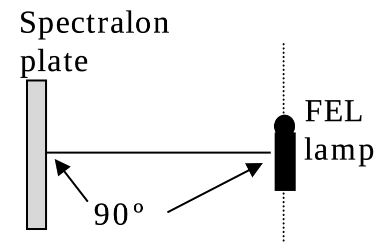
Absolute radiometric radiance calibration - on ground

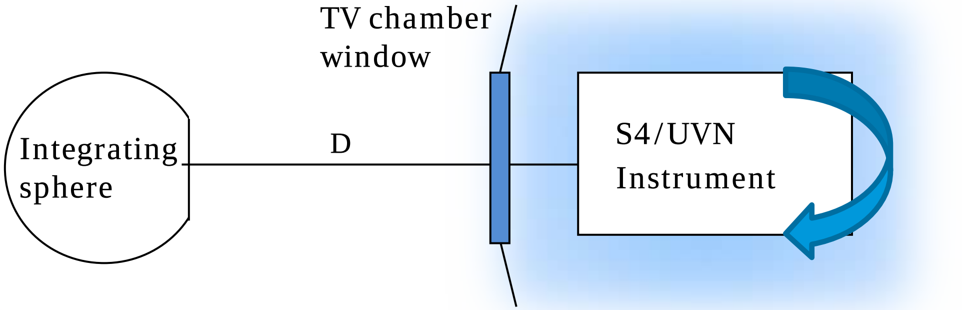
Absolute radiometric radiance calibration measurements using calibrated sources (FEL lamp, integrating sphere) and radiance angle dependency calibration measurements under flight-representative thermal-vacuum conditions

Top view



Side view

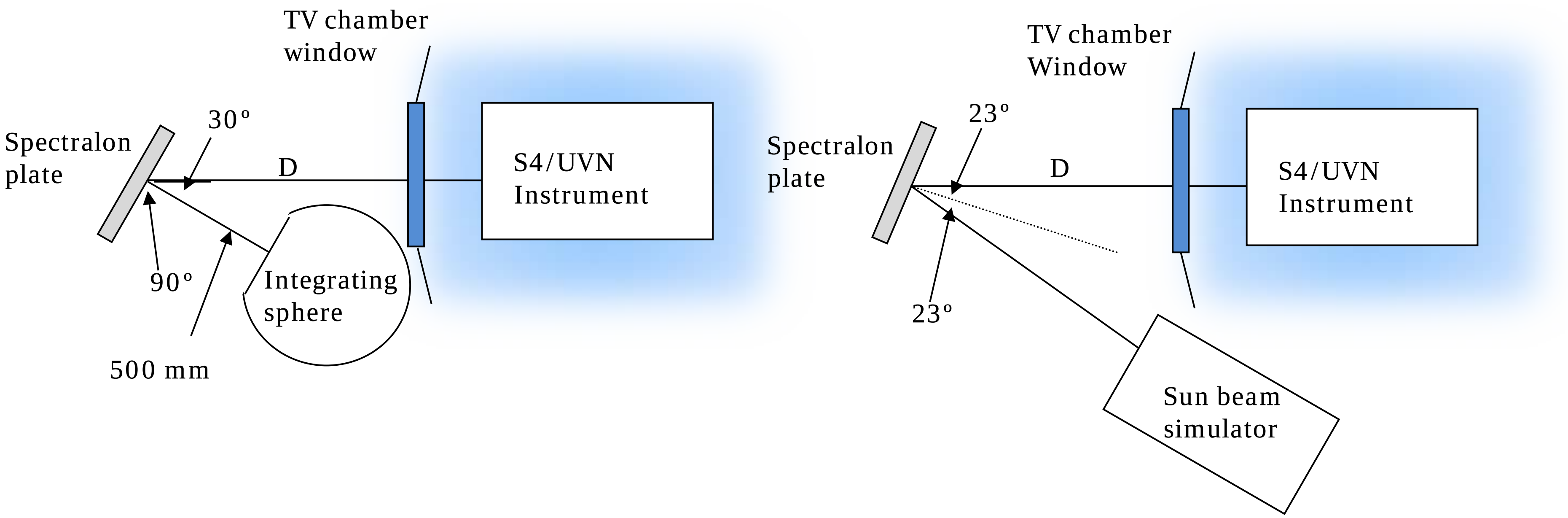




Absolute radiometric radiance calibration - on ground

esa

Absolute radiometric radiance calibration measurements using calibrated source **cross calibration** with respect to FEL lamp



Radiometric measurements

Using different radiometric sources is absolutely essential to obtain required radiometric accuracy and to quantify measurement uncertainties.

Measurement sequence include:

- Absolute radiance/ irradiance/ reflectance
- Irradiance goniometry
- Radiance angular dependency

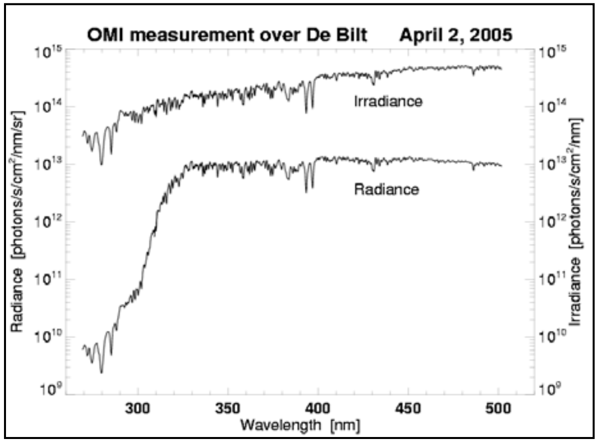
	OGSE	Radiance	Irradiance
1	FEL	1R	1I
2	SBS	2R	2I
3	Integr. Sphere	3R	3I

Product	Msm	Comment
Refl	2I/2R	Best (calibration keydata)
Refl_FEL	1I/1R	Analysis result from measurement expected to be less good
Abs_Rad	1R	Calibration keydata (expected to be the most accurate key parameter to be used for L0 to L1b processing)
Abs_Irrad	Abs_Rad x Refl	Best (expected to be the most accurate key parameter to be used for L0 to L1b processing)
Abs_Irrad_FEL	1I	Analysis result from measurement expected to be less good
Ang_dept _sphere	3R	Radiance angular dependence
Refl_sphere	3I/3R	Instrument BSDF
Abs_Rad´	3R	Radiance angular dependency & calibration keydata (to be used in L0 to 1 processing in case more accurate than Abs_Rad)
Abs_Irrad’	Abs_Rad’ x Refl	Calibration keydata (to be used in L0 to 1 processing in case more accurate than Abs_Irrad)

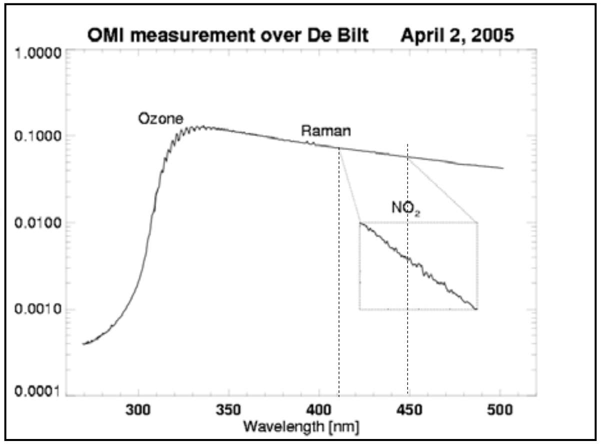
S4/UVN spectral features

DOAS analysis of satellite spectra

Irradiance and Radiance Measurement

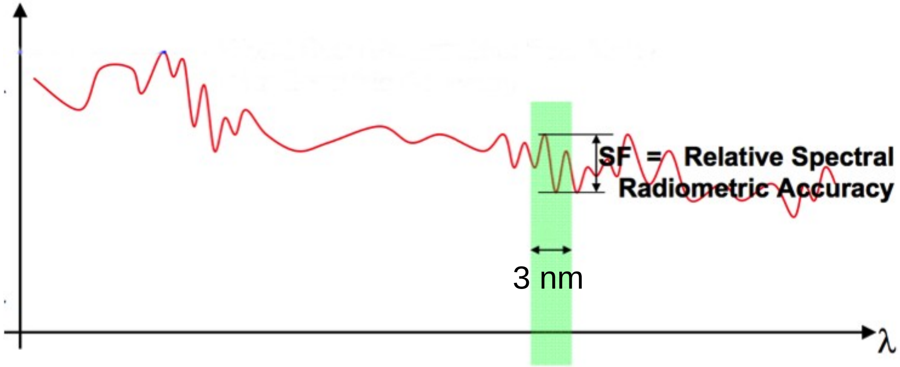


Derived Reflectance



Note how small the NO_2 features are, about 0.5% signal strength of the total signal

Contributors to these **spectral features** are: polarisation scrambler, coatings, gratings, sun diffuser, straylight, gain change, …



< 0.05 %!

Lessons learnt implemented - status system PDR

On ground 'Test as you fly'

→ i.e. thermal vacuum environment with flight representative conditions for pressure, temperatures for detectors and 'optical bench'

EQM prior to flight model

→ calibrated in dry-run campaign, elimination of non-conformances

On ground and in flight

→ several parameters can only be measured with sufficient accuracy on ground, e.g. polarisation, straylight and ISRF

→ Clear split between L0 performance verification and calibration

Instrument built as designed?

→ L0 performance verification

Calibration

→ retrieve calibration key parameters for L0 to L1b processing

Campaign separation
L0 Performance Verification - Calibration

verification phase may necessitate changes to the instrument, OGSE, way the instrument is operated, etc., whereas the **calibration phase requires that no such changes are made**

→ otherwise traceability is lost on what has actually been calibrated and the to-be-launched-configuration differs in crucial aspects from the calibrated one

‘Test as you fly’ [with well-commissioned (=known) OGSE]

→ redoing parts of the calibration every time a change is made to the test configuration is very likely not going to be feasible

Post long term storage calibration

Why calibrating the instrument after storage?

Note: calibration shall not be confused with L0 performance verification

- S4 mission relies on an instrument **calibration transfer from ground to in orbit**
- L1b processing requires accurate knowledge of instrument calibration key parameters (e.g. spectral response function, straylight)
- therefore an accurate and representative **on-ground calibration** is mandatory
- instrument performance are subject to evolution during the long on-ground storage (e.g. GOME-2 FM2 experienced a **4% variation in radiometric calibration** during storage

Decontamination measures to prevent optical degradation (examples)

- **bake-out** after launch (additional heater power)
- protection optical components from e.g. **solar flux**
- **warm-up** possibilities independently for detectors/optical bench
- **protection solar diffusers**
  - no measurements several weeks after launch
  - no measurements after yaw flip
  - no measurements after thrusters' usage
- **purging**
- avoidance **humidity**
- avoid **materials degrading** under space environment (e.g. relevant light fluxes, atomic oxygen, radiation, TV, molecular contamination)

Conclusion and outlook

S4/UVN **instrument design, L0 performance verification** and **calibration** (on ground and in flight) status after system PDR.

Attention for **balance** between L0 **performance**, **calibration** and level 0 to 1b **data processing** to deliver L1b data products within the required specification at End of Life.

S4/UVN instrument well equipped with **on-board calibration hardware**.

Phase C/D ongoing.

Thank you for your attention!

For further information:

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...and many more....