SENTINEL-5

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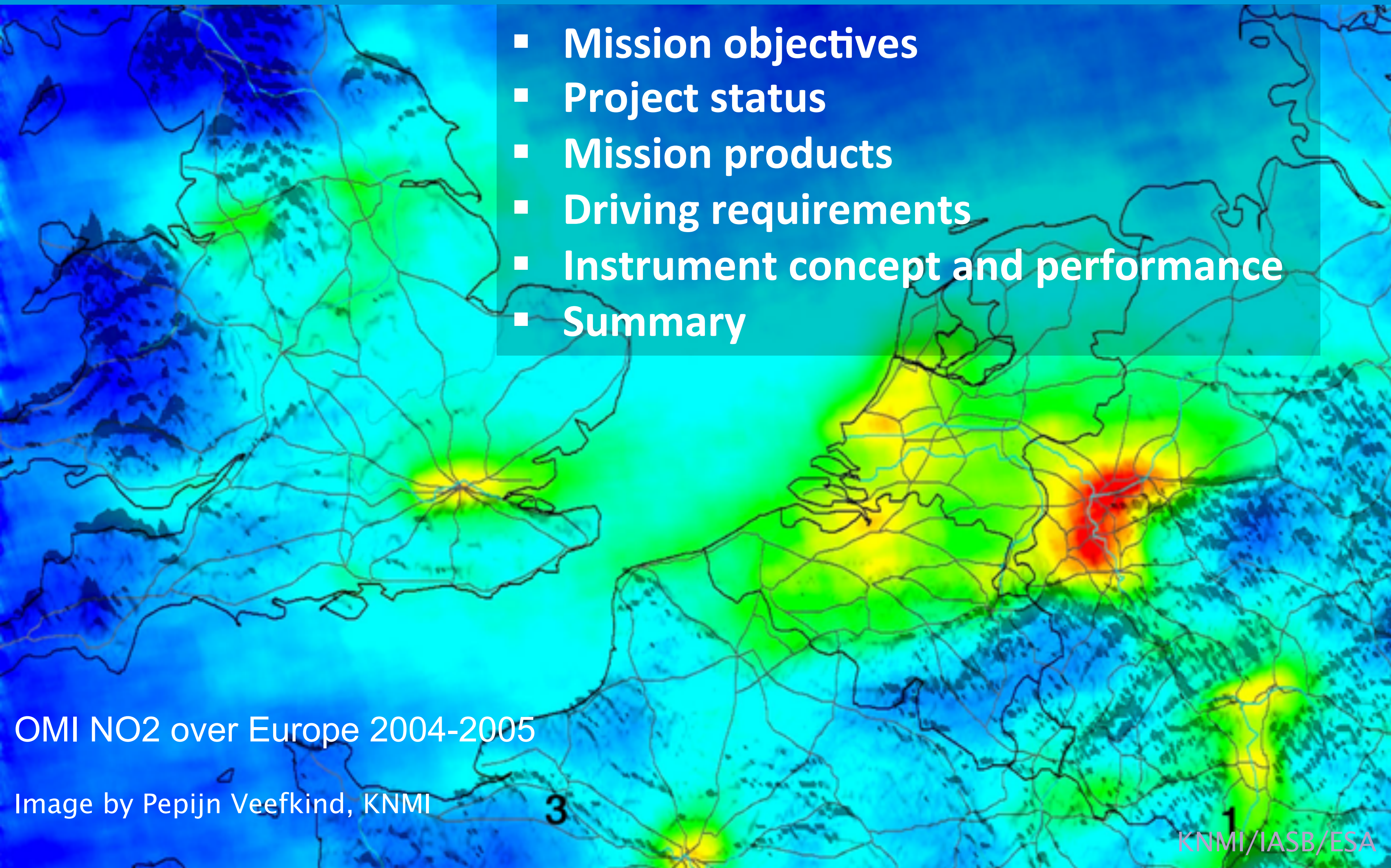
Earth Observation Directorate

Outline

- Mission objectives
- Project status
- Mission products
- Driving requirements
- Instrument concept and performance
- Summary



OMI NO2 over Europe 2004-2005

Image by Pepijn Veefkind, KNMI

Mission Objectives

- Monitoring of the composition of the atmosphere for GMES Atmosphere Services
  - ✓ Sources of trace gases and aerosols impacting air quality and climate
  - ✓ Major target trace gases are O3, NO2, CO, SO2, CH2O and CH4
- Services proposed will cover air quality near real-time applications, air quality protocol monitoring, and climate protocol monitoring
- The Sentinel-5 mission will consist of a
  - ✓ UVNS (Ultra-Violet, Visible, Near Infrared, Short Wave Infrared) spectrometer embarked on the post-EPS platforms *and on the*
  - ✓ Utilization of collocated measurements taken at the same time by METimage, IASI-NG and 3MI which will provide more information on clouds and deliver improved understanding of atmospheric composition, most notably in the troposphere.
- The Sentinel-5 UVNS mission will offer daily global coverage with an unprecedented spatial resolution of 7x7 km2 at nadir as compared to heritage instrument such GOME-2, SCIAMACHY and OMI. The high spatial resolution will enable more accurate detection of emission sources and provide an increased number of cloud-free ground pixels.

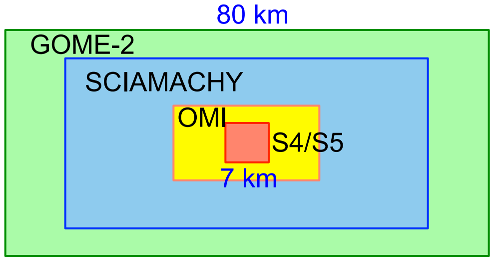
The Current Capabilities

Research missions
SCIAMACHY (Envisat) – OMI (Aura), Scisat, Mopitt (Terra), Gosat

Operational missions
GOME-2, IASI (MetOp), OMPS, CRIS (JPSS)

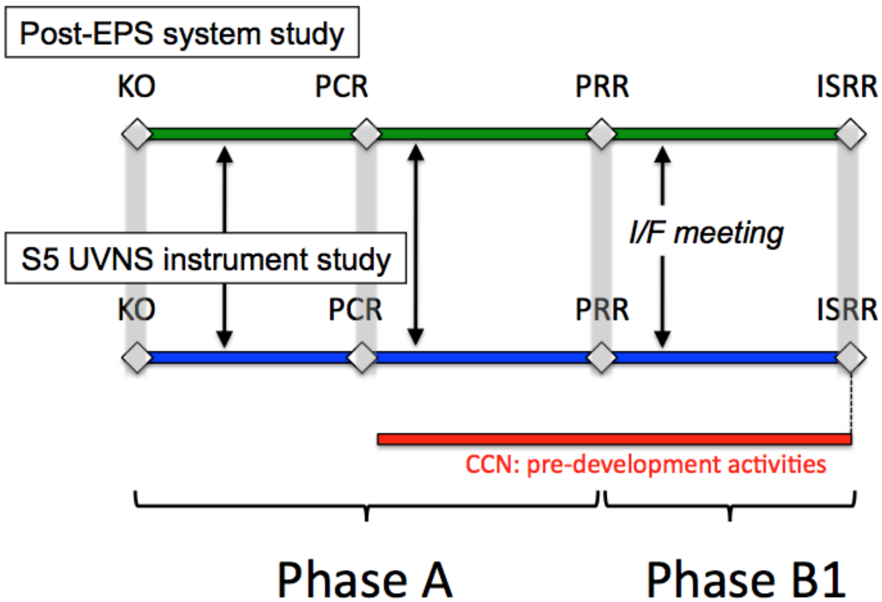
Main gaps in current / planned operational system

- High temporal and spatial resolution (more cloud free-views) space-based measurements of tropospheric (PBL) composition for application to air quality
- High spatial/high precision monitoring of climate gases (CO_2, CH_4 and CO) and aerosol monitoring with sensitivity to the PBL
- High vertical resolution measurements in the UT/LS region for ozone and climate applications



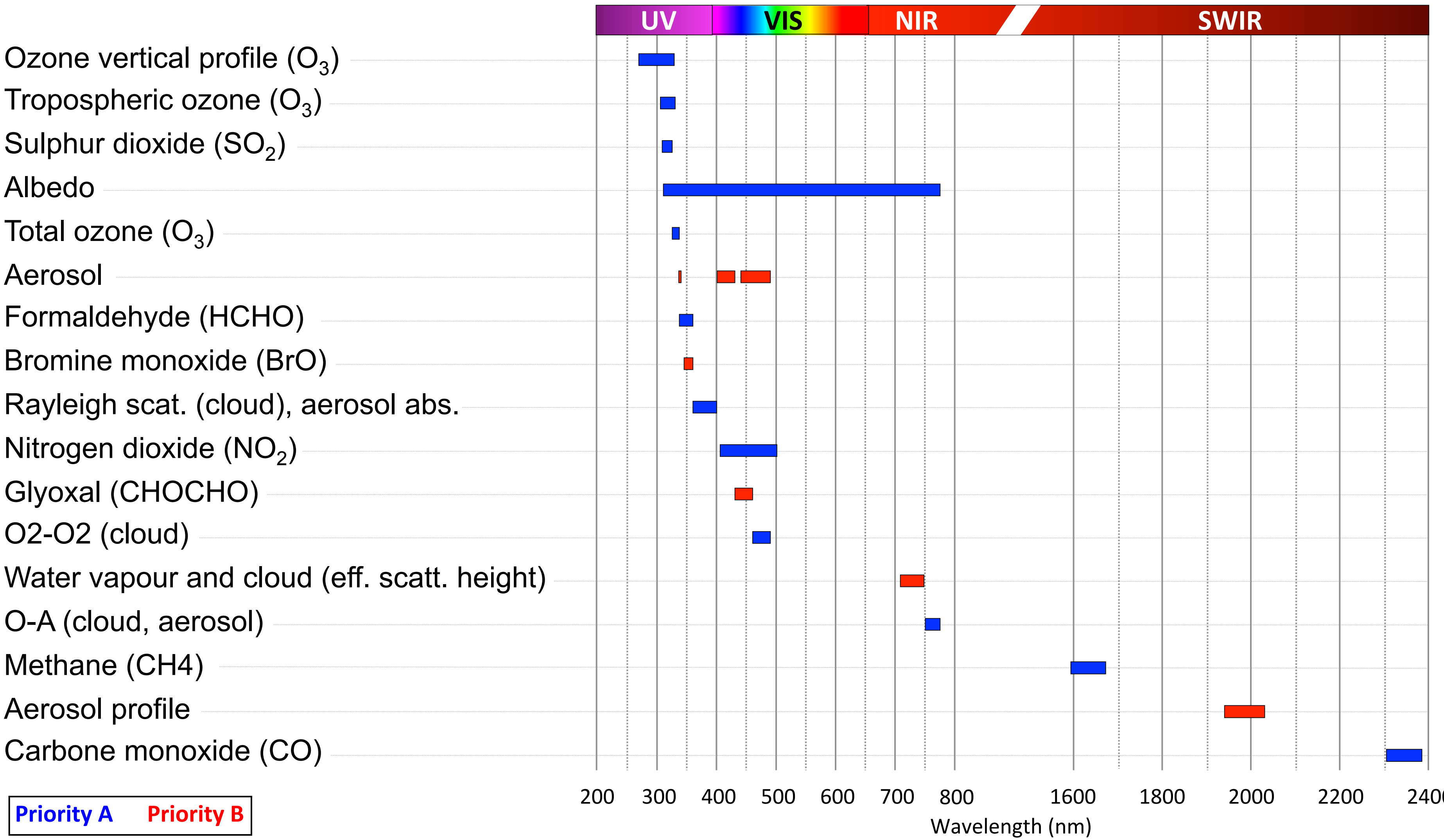
Project Status

- Two feasibility (phase A/B1) studies are running in parallel led by **Astrium GmbH** and **Kayser-Threde**
- Study divided in 3 parts; PCR completed (ASG *JUL* – KT *SEP*)
- Study is synchronised with the system Metop-SG phase A/B1 studies
- Interface constraints specified in the Interface Requirement Document (one ESA document applicable to all the “4 primes”)
- Regular interface meetings with “all primes”;



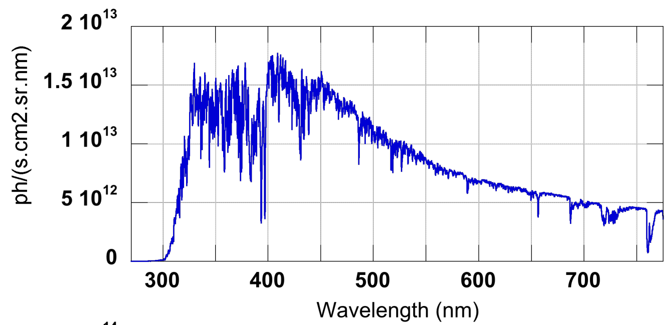
Level 2 Products

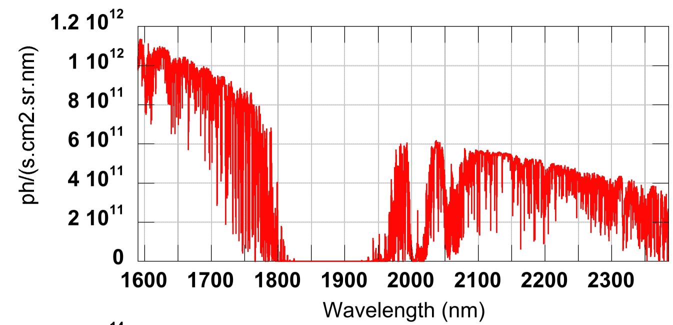
esa



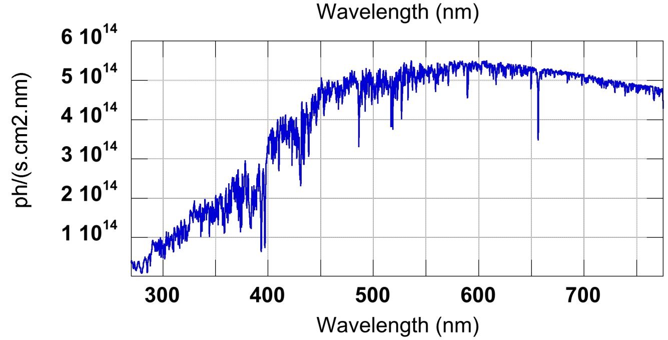
Level 1b Products

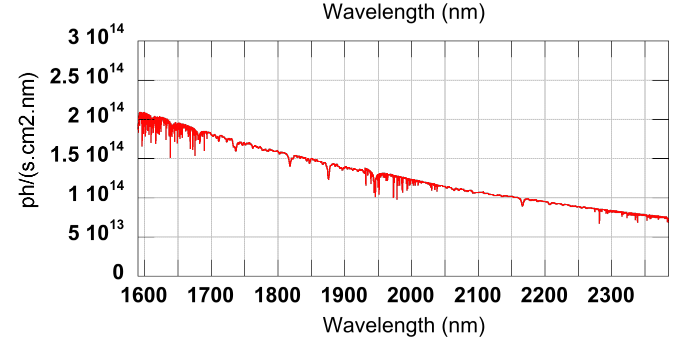
- Earth TOA Radiance





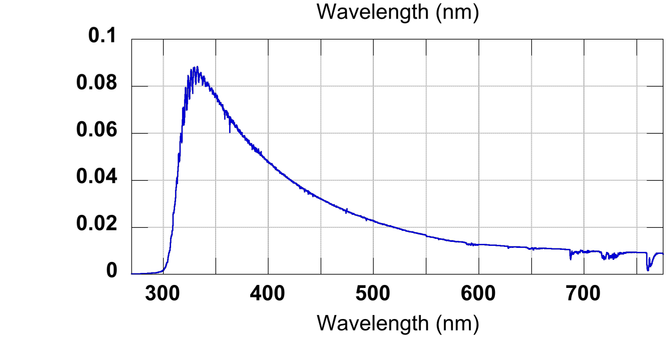
- Solar Irradiance

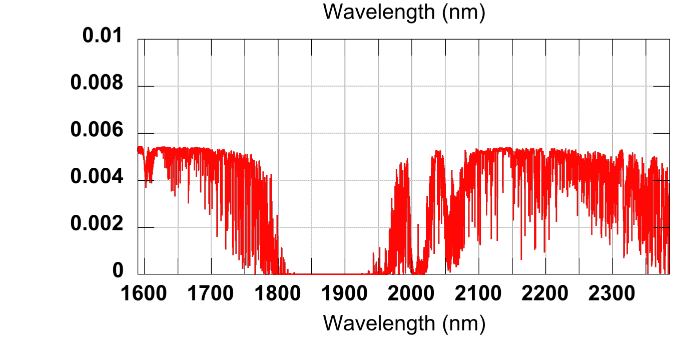




Reflectance

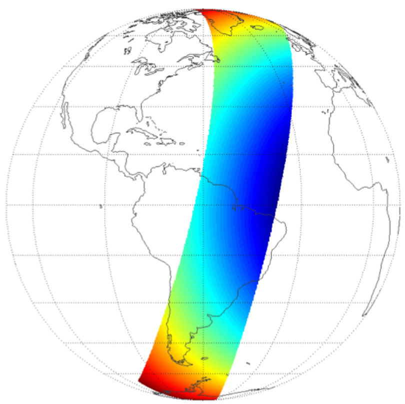
$$“ \frac{\textit{Radiance}}{\textit{Irradiance}} “$$

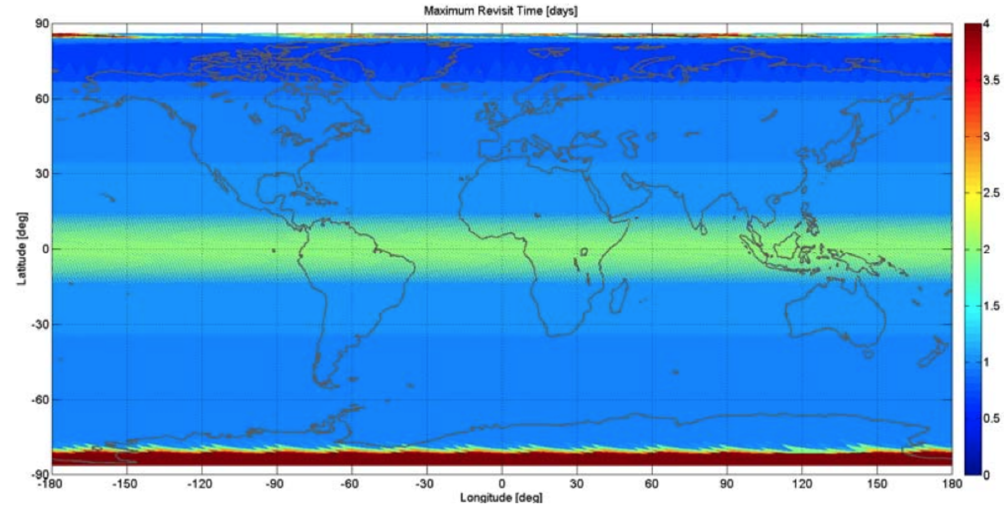




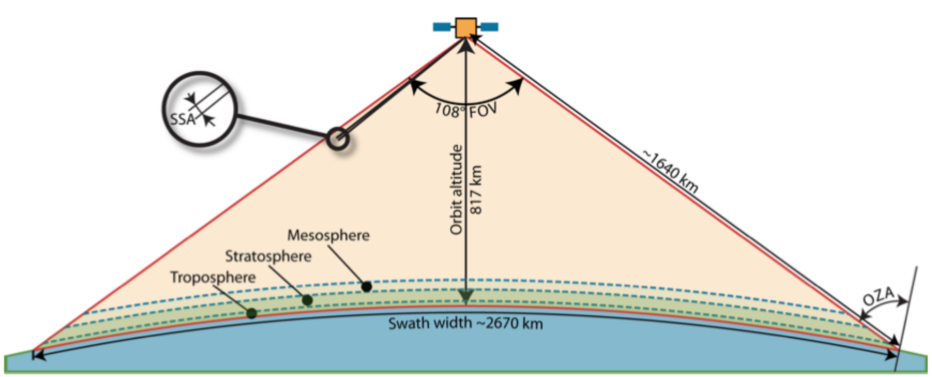
The driving requirements

Daily Global Coverage
(at latitude beyond 20 deg)

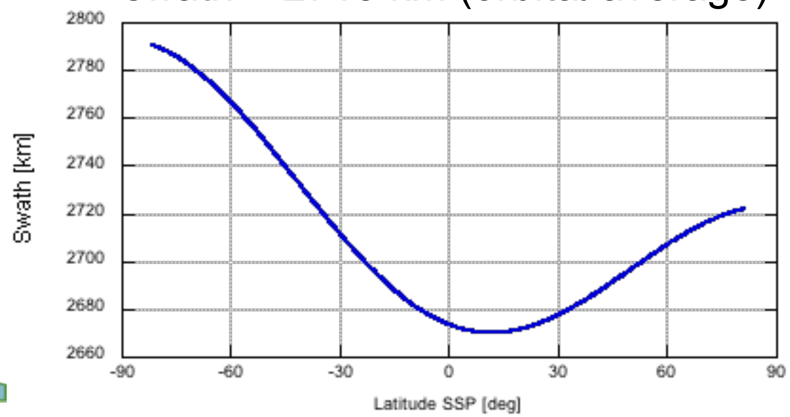




Large field of view required = 108.4°

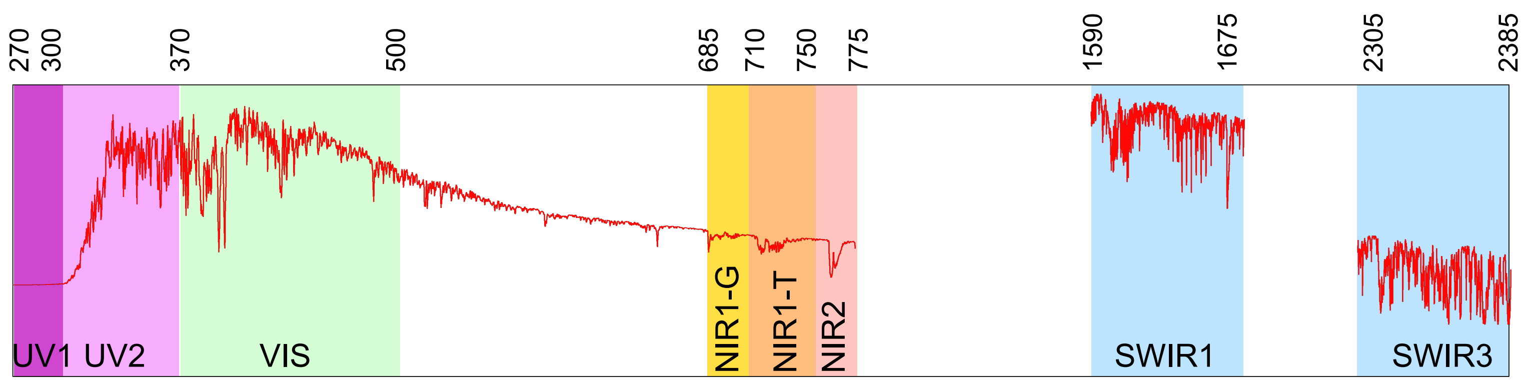


swath = 2715 km (orbital average)

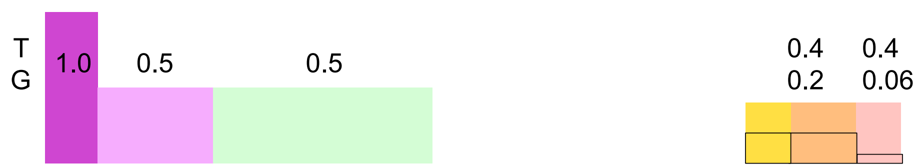


The driving requirements

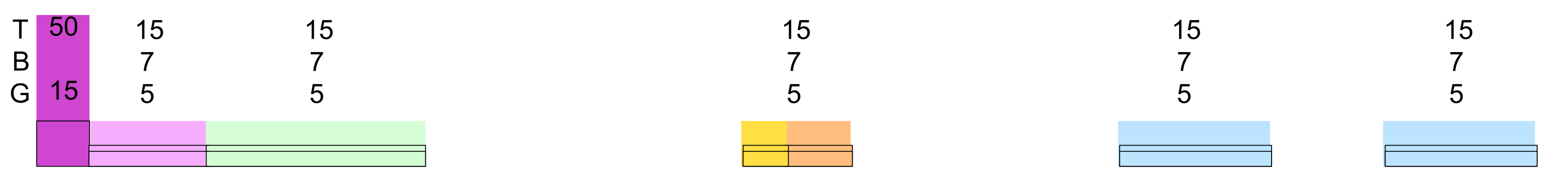
Spectral bands



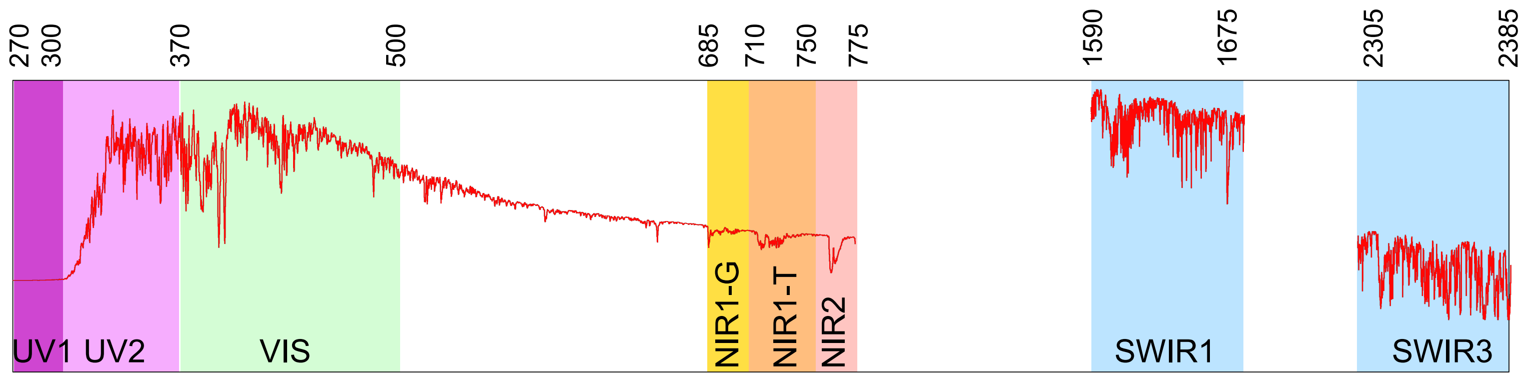
Spectral resolution (nm)



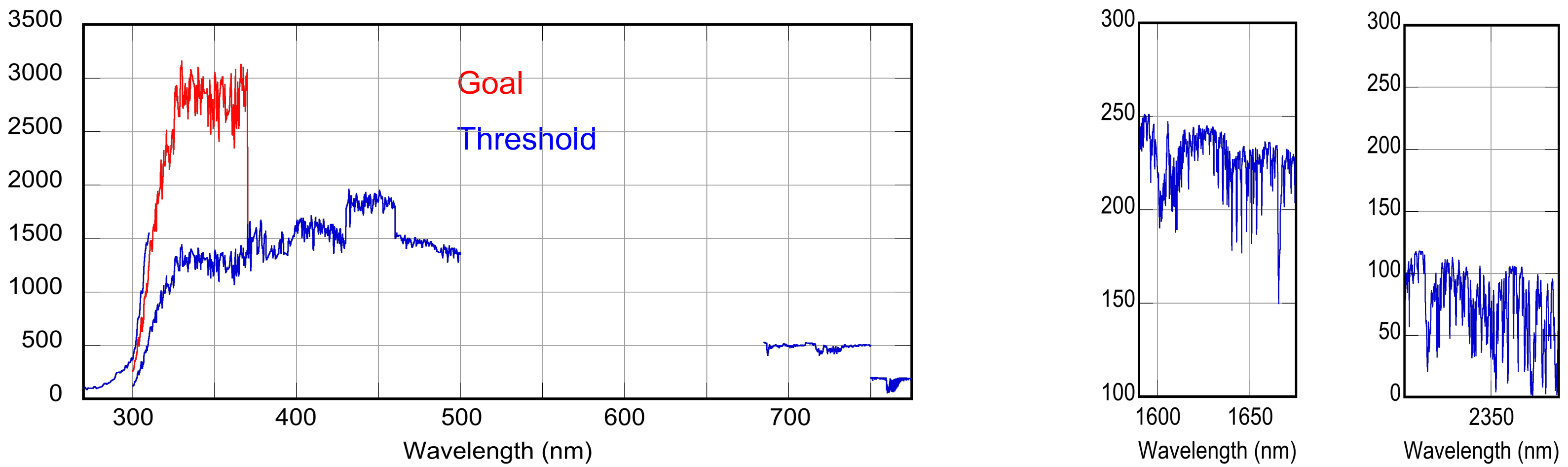
Spatial Sampling Distance (km)



The driving requirements



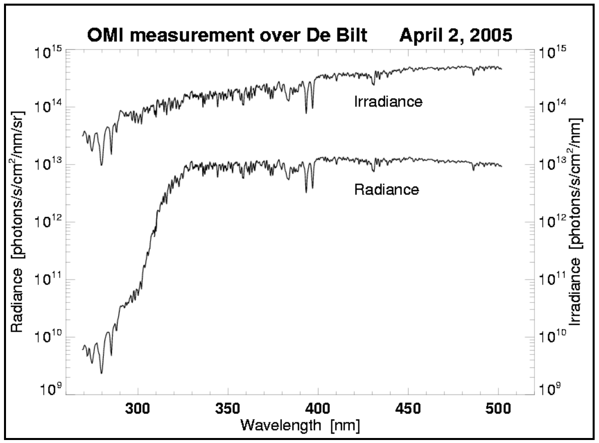
Signal to Noise Ratio (SNR)



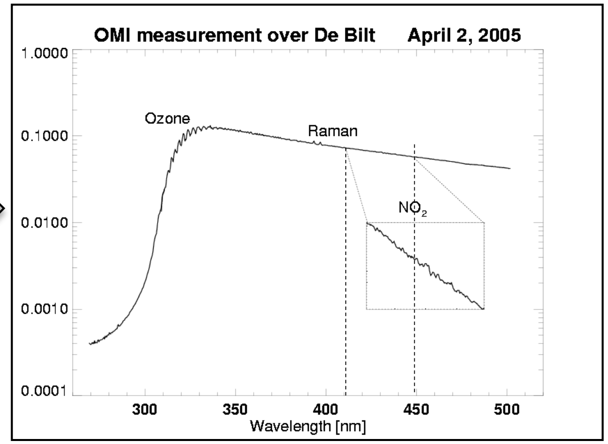
The Instrument Challenge

“Spectral Features”

Irradiance and Radiance Measurement

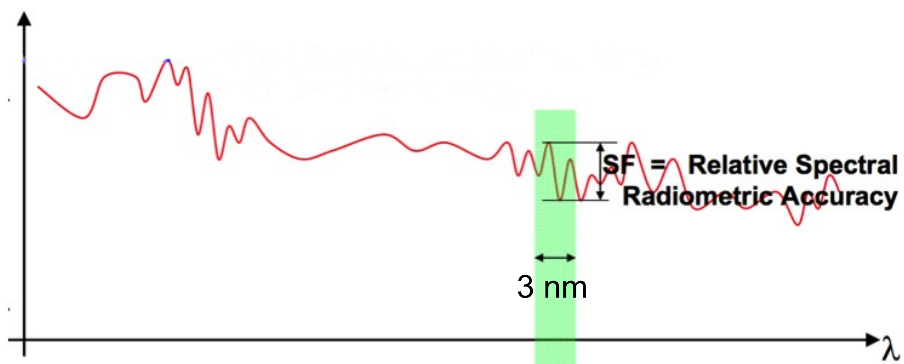


Derived Reflectance



Note how small the NO2 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 %!

The driving requirements

All spectral channels shall "see the same atmospheric volume"

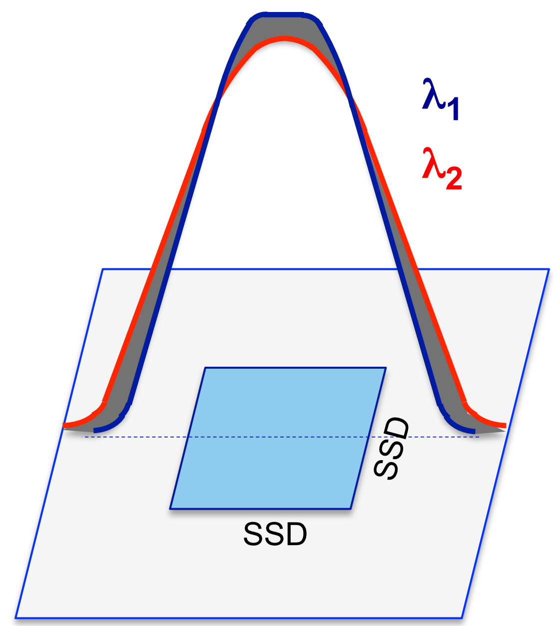
1. Inter-channel Spatial Co-registration

	UV1	UV2	VIS	NIR-1	NIR-2	SWIR-1	SWIR-3
UV1	0.1 (G:0.05)	0.2 (G:0.1)	0.2 (G:0.1)	0.2 (G:0.1)	0.2 (G:0.1)	-	-
UV2		0.1 (G:0.05)	0.2 (G:0.1)	0.2 (G:0.1)	0.2 (G:0.1)	-	-
VIS			0.1 (G:0.05)	0.2 (G:0.1)	0.2 (G:0.1)	-	-
NIR-1				0.1 (G:0.05)	0.2 (G:0.1)	0.2 (G:0.1)	0.2 (G:0.1)
NIR-2					0.1 (G:0.05)	0.2 (G:0.1)	0.2 (G:0.1)
SWIR-1						0.05 (G:0.02)	0.2 (G:0.1)
SWIR-3							0.05 (G:0.02)

In fraction of SSD

0.1 SSD = distance of few microns at detector level!

2. Integrated Energy



$$IE_S(A) = \iint_A SPSF_{i,j}(x - x_i, y - y_i)\,dx\,dy$$

$$IE_S(SSD_{ax}.SSD_{al}) = [0.70 - 0.75]$$

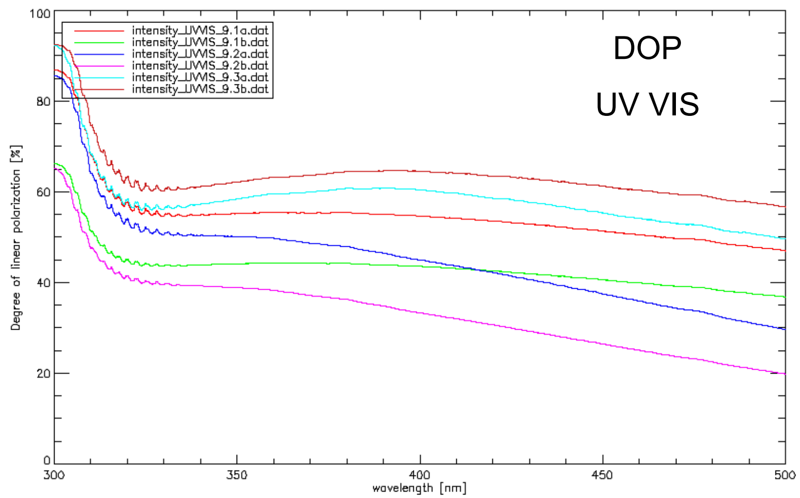
The driving requirements

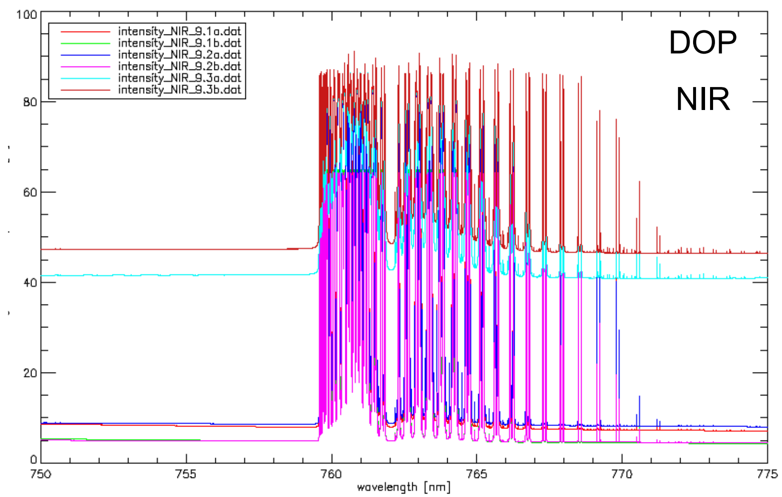
Polarisation (in)sensitivity

Degree of polarisation (DOP) of TOA radiance can be quite high.
S5 has to be insensitive to the TOA radiance polarisation

$$P = \frac{S_{\max} - S_{\min}}{S_{\max} + S_{\min}}$$

P ≤ 0.005 in UV VIS NIR





The driving requirements

Straylight

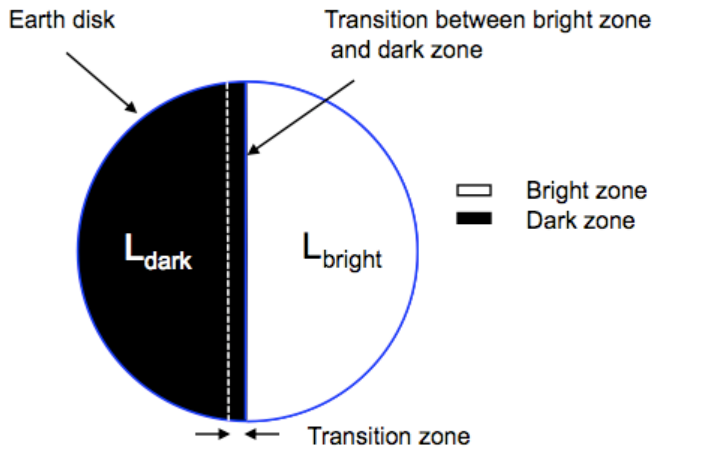
Signal dynamic range up to 10^3 in UV and SWIR-3

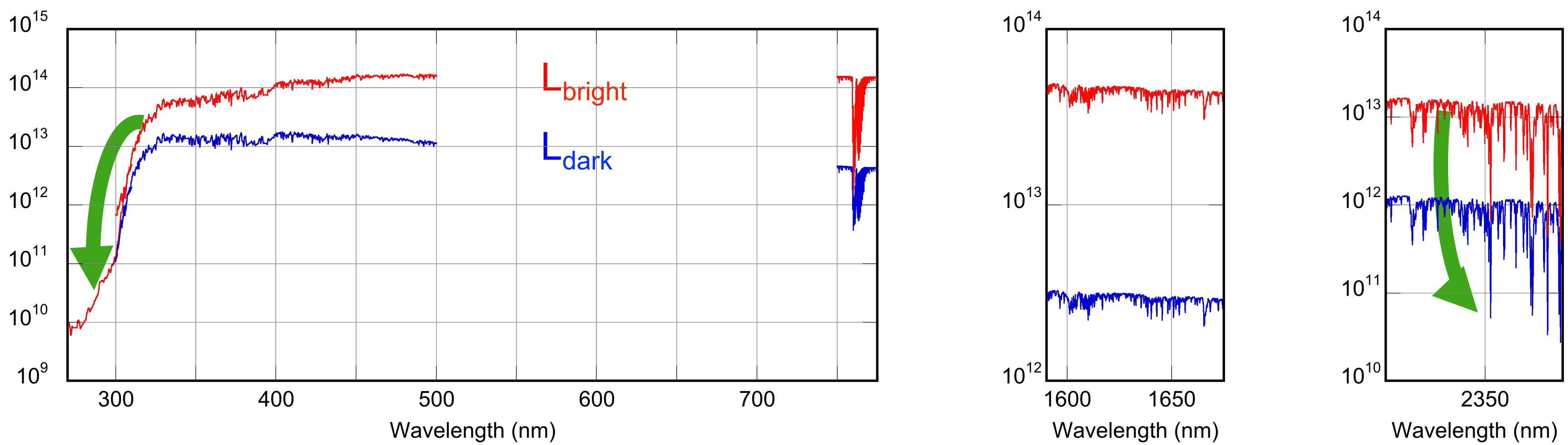
Spectral straylight is an issue for deep absorption lines

Requirement shall be on background signal

Before correction : Straylight < 1% L_{dark}

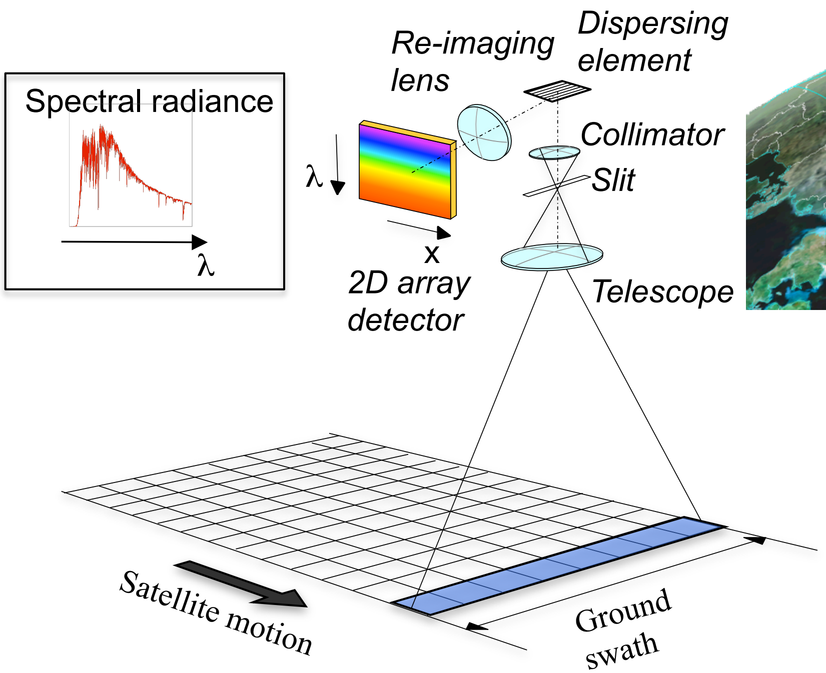
After correction : Straylight < 0.1% L_{dark}

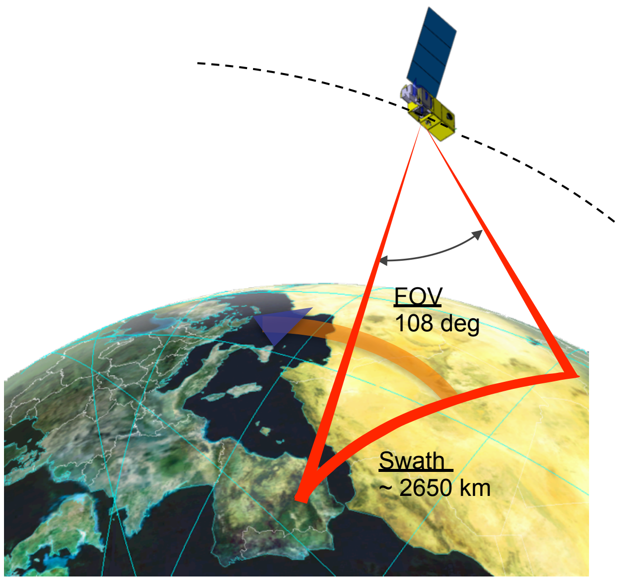




Instrument Concept

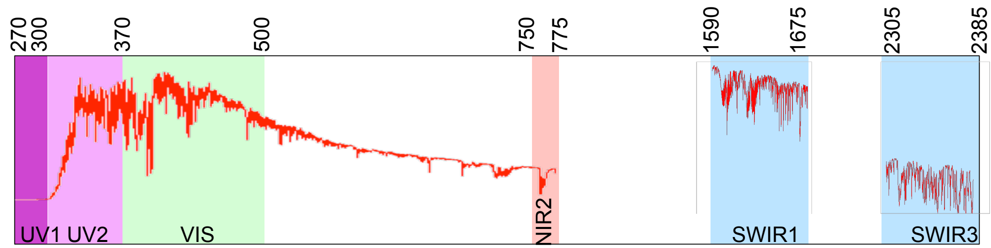
- Pushbroom Imaging
- Dispersive grating spectrometer
- Large heritage (MERIS, OMI, SCIAMACHY)



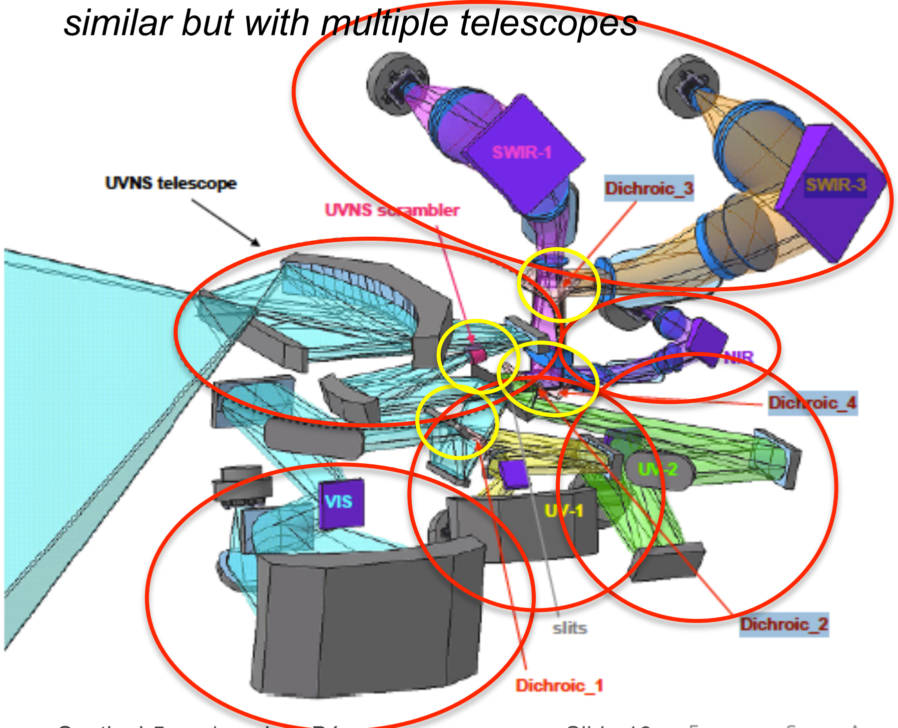


Instrument Concept

- Telescope (in this example a single telescope for all bands)
- UV-1 spectrometer
- UV-2 spectrometer
- VIS spectrometer
- NIR spectrometer
- SWIR spectrometers
- Spectral bands are separated by dichroics
- Polarisation scrambler located in the telescope



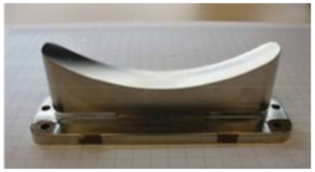
S5 phase 0 concept; phase A concepts are similar but with multiple telescopes



Telescope

- Several telescopes (number TBD) and associated calibration assemblies are proposed to cover the S5 spectral range to optimise
  - The instrument throughput via optimised coatings
  - The polarisation scrambler
  - The calibration diffusers

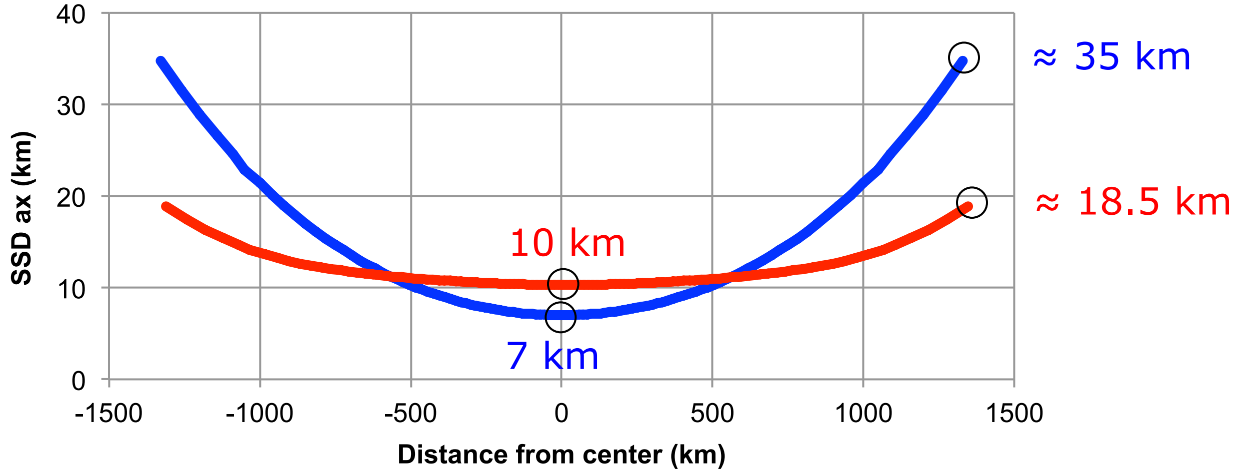
TROPOMI free-form mirror



Courtesy of TNO

- The telescope imaging functions will be identical to ensure the same distortion for all bands, hence a good spatial co-registration

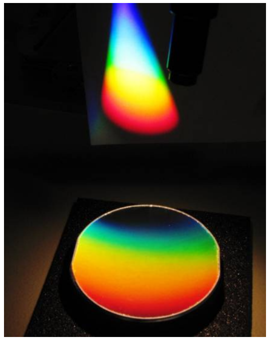
- Two across-track mapping laws are under investigation
  - Equiangular sampling
  - Equidistant sampling



Gratings

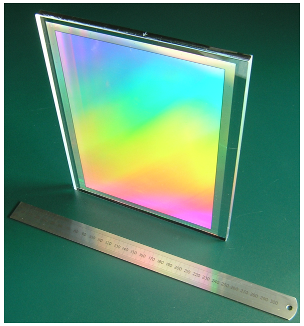
- The core of the spectrometers !
- Often a large source of (spectral) straylight and to polarisation sensitivity
- One dedicated grating per spectrometer
  - ✓ In UV-VIS-NIR: several manufacturers available Europe (Horiba Jobin-Yvon, IOF, Zeiss, TNO)
  - ✓ In SWIR, immersed grating to minimise volume; single source: SRON

VIS grating



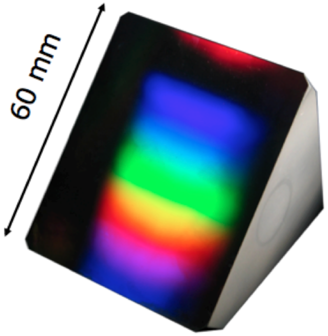
Courtesy of ZEISS

GAIA NIR grating



Courtesy of IOF

TROPOMI immersed SWIR grating



Courtesy of SRON

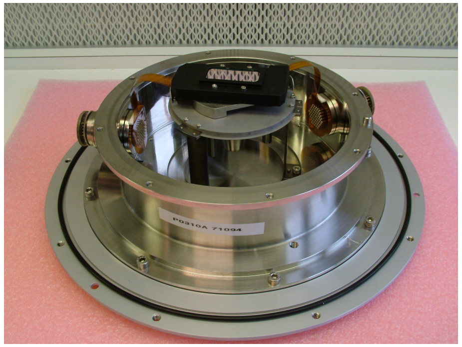
Detectors

- Detectors are the heart of optical instruments
- They are usually driving both the performance and the instrument development schedule
- Detector proposed for Sentinel-5 are
  - Frame transfer **CCD** for UV, VIS and NIR bands
  - **HgCdTe IR CMOS** for SWIR bands
- CCD detectors have excellent performance and maturity. S5 might benefit from on-going development for Sentinel-4 – sources: E2V, DALSA
- SWIR detectors are less mature than CCD in Europe. Space qualified SWIR detectors exist in Europe and are being considered. Detector development, if any, will be based on currently existing technological bricks– sources: SOFRADIR, AIM, Selex

S4 UV-VIS CCD

Courtesy of e2v

SATURN HgCdTe IR CMOS and cryostat

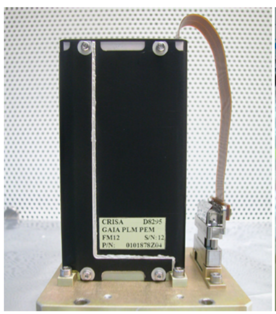


Courtesy of SOFRADIR

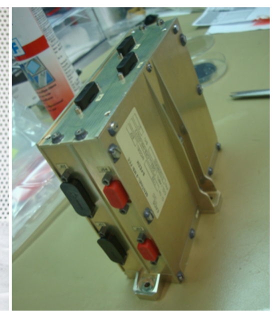
Acquisition Video Chain

- 16 bits, 2 to 5 MHz, low noise video chain
- Large expertise in Europe (RAL ASIC, HIVAC/VASP (MTG), GAIA, S2, …)

GAIA PEM



S2 FEE



Courtesy of Astrium-F

SECCHI Camera Electronics Box

Courtesy of RAL

Instrument Calibration

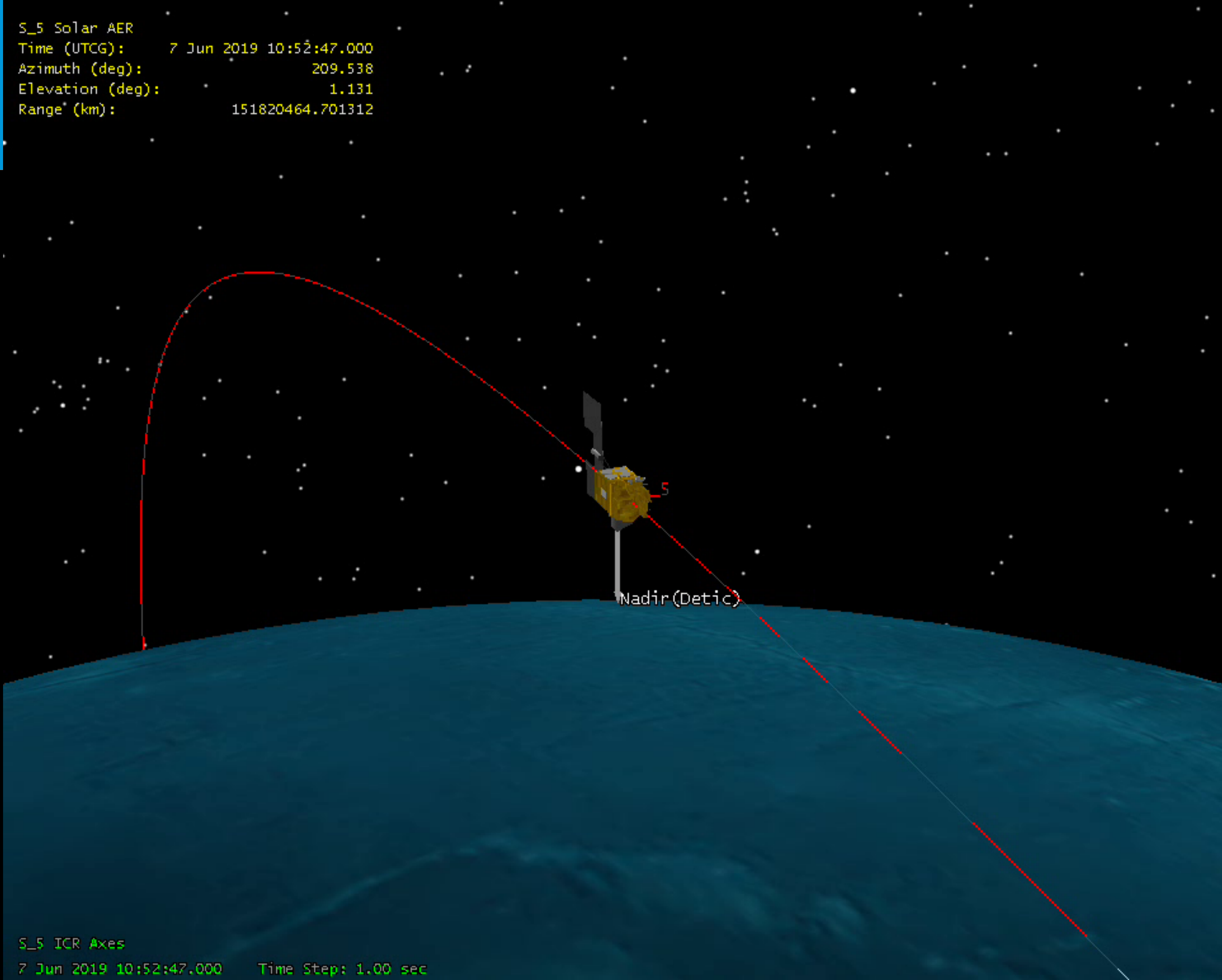
- Instrument state-of-the art calibration is required for meeting the mission objectives
- Both pre-flight and in-orbit calibration principles are based on the successful OMI concept

IN-FLIGHT CALIBRATION

- **RADIOMETRIC**
  - **SOLAR**
    - FULL APERTURE DIFFUSER
      - Absolute Cal
      - Resp. non-unif.
  - **ON-BOARD**
    - WHITE LAMP SOURCE
      - Resp. non-uniformity
      - Non-linearity
      - Relative calibration
    - LEDs in front of detector
      - PRNU
      - Non-linearity
    - NON-ILLUMIN PIXELS
      - Straylight
  - **DARK SIGNAL**
    - SHUTTER
      - Dark signal
      - DSNU
    - MASKED PIXELS
      - Dark signal
      - CCD smear
    - MEASUREM. IN ECLIPSE
      - Dark signal (RTS)
- **SPECTRAL**
  - FRAUHOFER LINES
    - Center wavelength
    - Smile
  - ABSORPTION FEATURES IN RADIANCE SPECTRA
    - Center wavelength
    - Smile
  - SPECTRAL SOURCES (TBC)
    - Spectral response
- **GEOMETRIC**
  - Ground Control Points
    - LOS calibration

GOCI solar QVD diffuser

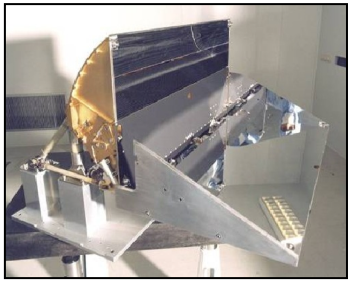
Courtesy of TNO


S_5 Solar AER
Time (UTCG): 7 Jun 2019 10:52:47.000
Azimuth (deg): 209.538
Elevation (deg): 1.131
Range (km): 151820464.701312
5
Nadir(Detic)
S_5 ICR Axes
7 Jun 2019 10:52:47.000 Time Step: 1.00 sec

Instrument Cooling

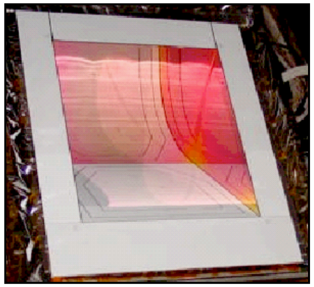
- Cooling is a complexity for the instrument design and testing
- For sentinel-5, the following elements have to be cooled
  - Detectors to minimise the dark current and radiation induced degradation effects
    - UV-VIS-NIR CCD: **200 .. 240 K**
    - SWIR HgCdTe IR CMOS: **135 .. 160 K**
  - SWIR spectrometers to minimise the instrument self-emission: **200 .. 240 K**
- Passive cooling is proposed as opposed to active cooling mainly for their reliability and maturity
- Large experience in Europe

SCIAMACHY radiant cooler
(120 K)



Courtesy Dutch Space

IASI radiant cooler
(90 K)

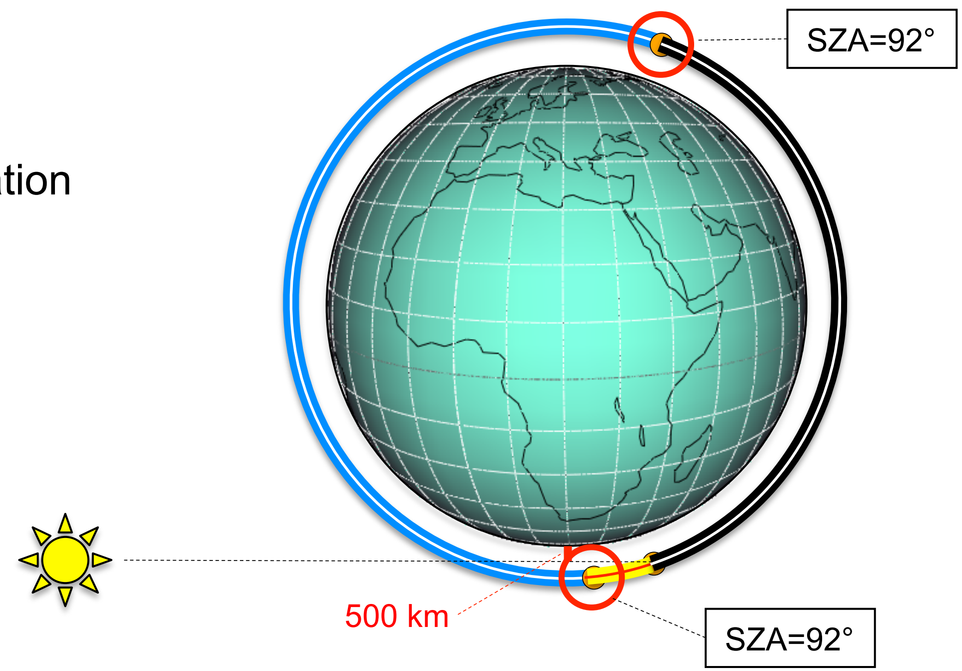


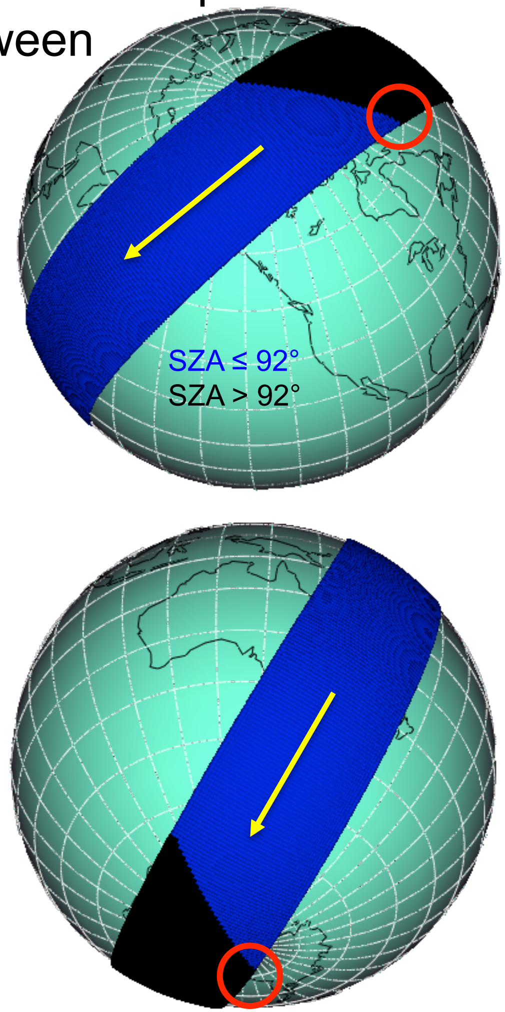
Courtesy Thales Alenia Space

Mission Profile

Instrument operational concept based on autonomous mode switching commanded by timeline. The instrument will always stay in "nominal operation mode" while there are a number of sub-modes to switch between Earth View, Solar Calibration and further calibrations.

- ❑ Earth View
- ❑ Solar Calibration
- ❑ Eclipse





S5 Data Sheet

Concept	Imaging spectrometer	
Host satellite	MetOp-SG (SAT A)	*semi-major axis: 7,195.6 km - LTAN: 21:30*

Level 1b product	Earth TOA Radiance Solar Irradiance

Level 2 product	O3 (vertical profile, tropospheric), SO2, albedo, HCHO, NO2, Clouds, CH4, CO, BrO, CHOCHO

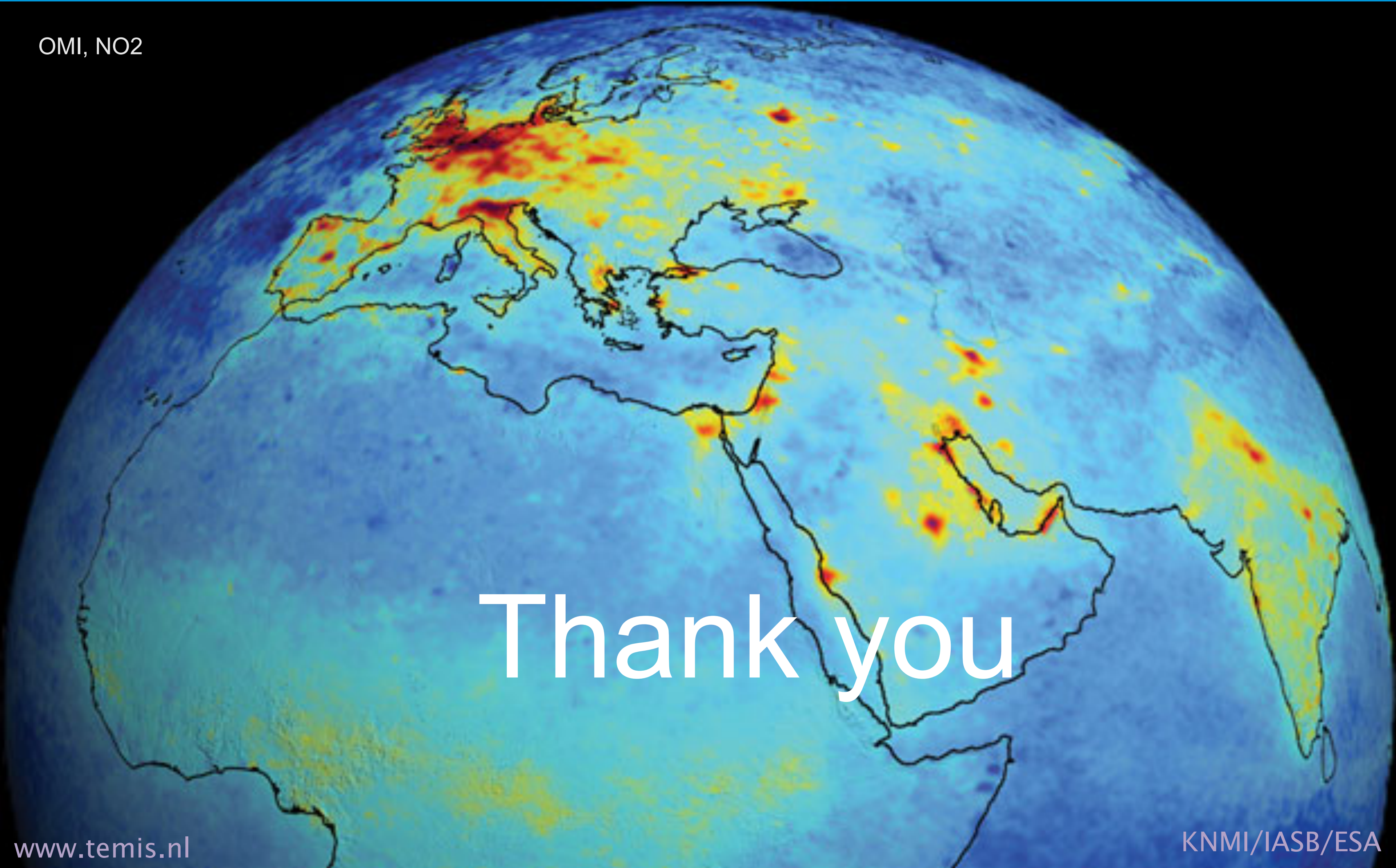
Coverage	1 day	*Poleward of 20° lat*
Swath width	2715 km	
FOV	108.4 °	

	UV1	UV2	VIS	NIR	SWIR-1	SWIR-3
Spectral range	270 - 300 nm	300 - 370 nm	370 - 500 nm	710 - 775 nm	1590 - 1675 nm	2305 - 2385 nm
Spectral resolution	1 nm	0.5 nm	0.5 nm	0.4 nm	0.25 nm	0.25 nm
Spectral oversampling	3	3	3	3	2.5	2.5
Spatial Sampling Distance	28 km	7 km	7 km	7 km	7 km	7 km
SNR in continuum	≈ 100 ...400	≈ 120 ...1400	≈ 1500	≈ 500	≈ 250	≈ 100
Absolute Radiometric Accuracy	2..3%	2..3%	2..3%	2..3%	2..3%	2..3%
Relative Spectral Radiometric Accuracy	0.10%	0.05%	0.05%	1%	0%	0.30%
Polarisation sensitivity	0.50%	0.50%	0.50%	0.50%	20%	20%

Mass	250 kg
Power	220 W
Data rate	20 Mbit/s
Volume	1.2x1.4x1.0 m^3

Summary

- Air pollution is a significant cause of health problems and environment damages worldwide
- Sentinel-5 (and Sentinel-4) will monitor the Earth's atmosphere as part of the Europe Union's Global Monitoring for Environment and Security (GMES) programme
- Industrial feasibility studies of sentinel-5 UVNS instrument are currently on-going; Instrument concept benefits from large heritage (OMI, MERIS, Sciamachy) and is based on existing technology
- Studies are synchronised with PEPS system studies
- Mission will be MetOp-SG satellites for a launch in 2018+ and will be operated by EUMETSAT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