TROPOMI on the Copernicus Sentinel 5 Precursor

instrument performance, the L0-1B processor
and on-ground calibration results

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Sentinel 5 precursor

COPERNICUS ATMOSPHERE MISSION IN POLAR ORBIT

- The ESA Sentinel-5 Precursor (S-5P) is a pre-operational mission focussing on global observations of the atmospheric composition for air quality and climate.
- The TROPOspheric Monitoring Instrument (**TROPOMI**) is the payload of the S-5P mission and is jointly developed by The Netherlands and ESA.
- The planned launch date for S-5P is 2016 with a 7 year design lifetime.

TROPOMI

- UV-VIS-NIR-SWIR nadir view grating spectrometer.
- Spectral range: 270-500, 675-775, 2305-2385 nm
- Spectral Resolution: 0.25-1.1 nm
- Spatial Resolution: 7x7km2
- Global daily coverage at 13:30 local solar time.

Contribution to Copernicus

- Total column O_3, NO_2, CO, SO_2, CH_4, CH_2O, H_2O, BrO
- Tropospheric column O_3, NO_2
- O_3 profile
- Aerosol absorbing index & layer height

Picture: Airbus DS UK

TROPOMI

TROPOMI

- Organization
- Instrument
- Level 0-1B Development
- On-ground Calibration

Picture: Airbus DS NL

TROPOMI

Project Man.
JPT (ESA-NSO)

MAG

Principal Investigator NL
KNMI (PI), SRON (co-PI)

Geophysical Validation
ESA, KNMI, SRON, BIRA, IUP-Bremen, MPI Mainz, S5PVT

Level 1-2
KNMI, SRON, DLR, IUP-Bremen BIRA-IASB, MPI Mainz, RAL, FMI

Level 0-1B
KNMI

Ground Segment
DLR, KNMI

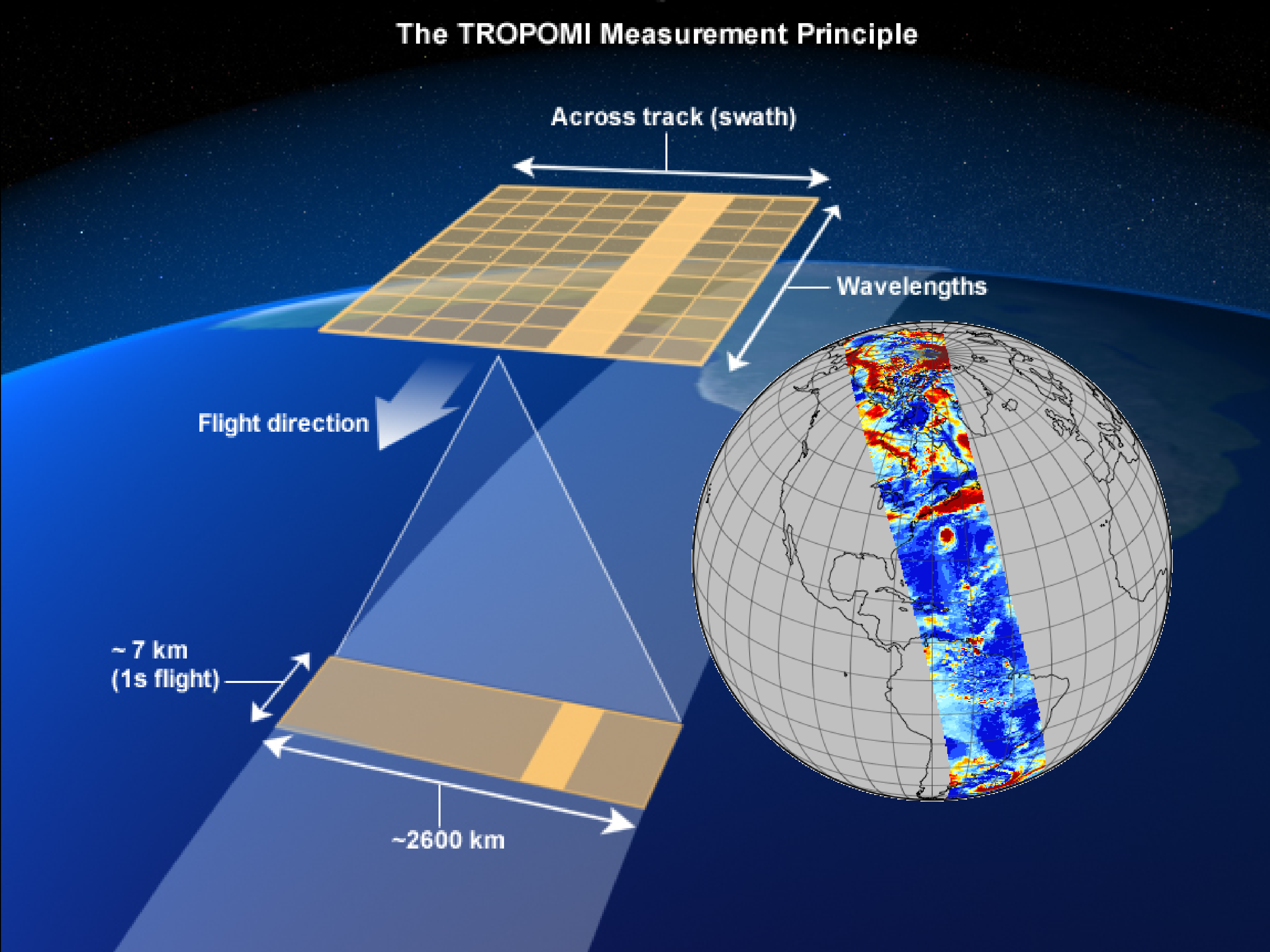
Operations
KNMI, ESOC

Calibration
KNMI / SRON
Airbus DS NL / TNO

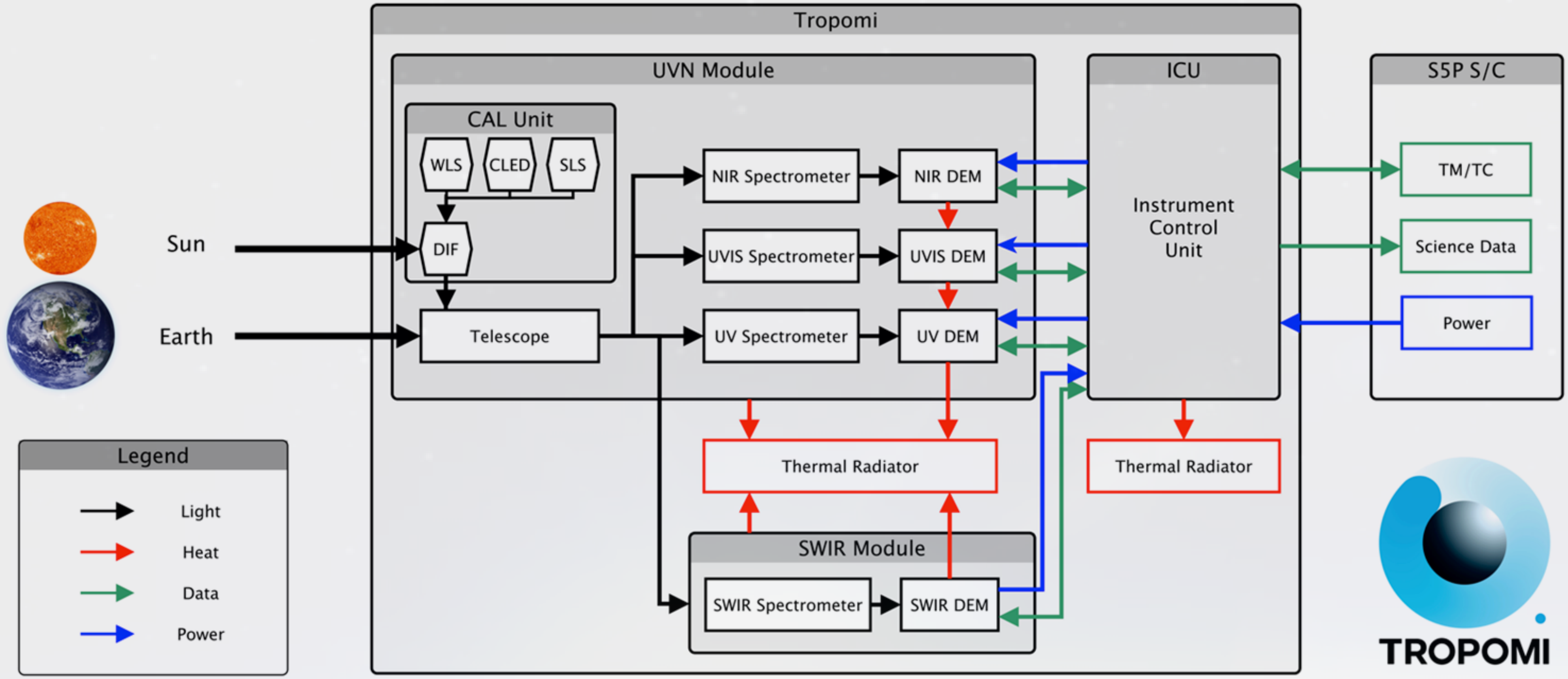
Instrument
prime Airbus DS NL

International Co-operation

- TROPOMI/S5P is part of the CEOS AQ Constellation
  - TROPOMI provides the global coverage
  - Act as a “travelling standard” between the GEOs
- S5P will fly in “loose formation” with Suomi NPP
  - Primary objective is to use the VIIRS data for cloud clearing


The TROPOMI Measurement Principle
Across track (swath)
Wavelengths
Flight direction
~ 7 km
(1s flight)
~2600 km

Functional Diagram



Animation: NSO

	UV		UVIS		NIR		SWIR	
Band	1	2	3	4	5	6	7	8
Spectral coverage [nm]	270 – 320		320 – 495		675 - 775		2305 – 2385	
Full spectral coverage [nm]	267 - 332		303 - 499		660 - 784		2299 - 2390	
Spectral resolution [nm]	0.49		0.54		0.38		0.25	
Spectral sampling ratio	6.7		2.5		2.8		2.5	
Spatial sampling [km^2]	7 x 28	7 x 7				7x3.5	7 x7	

EOL SNR for 2% albedo scene

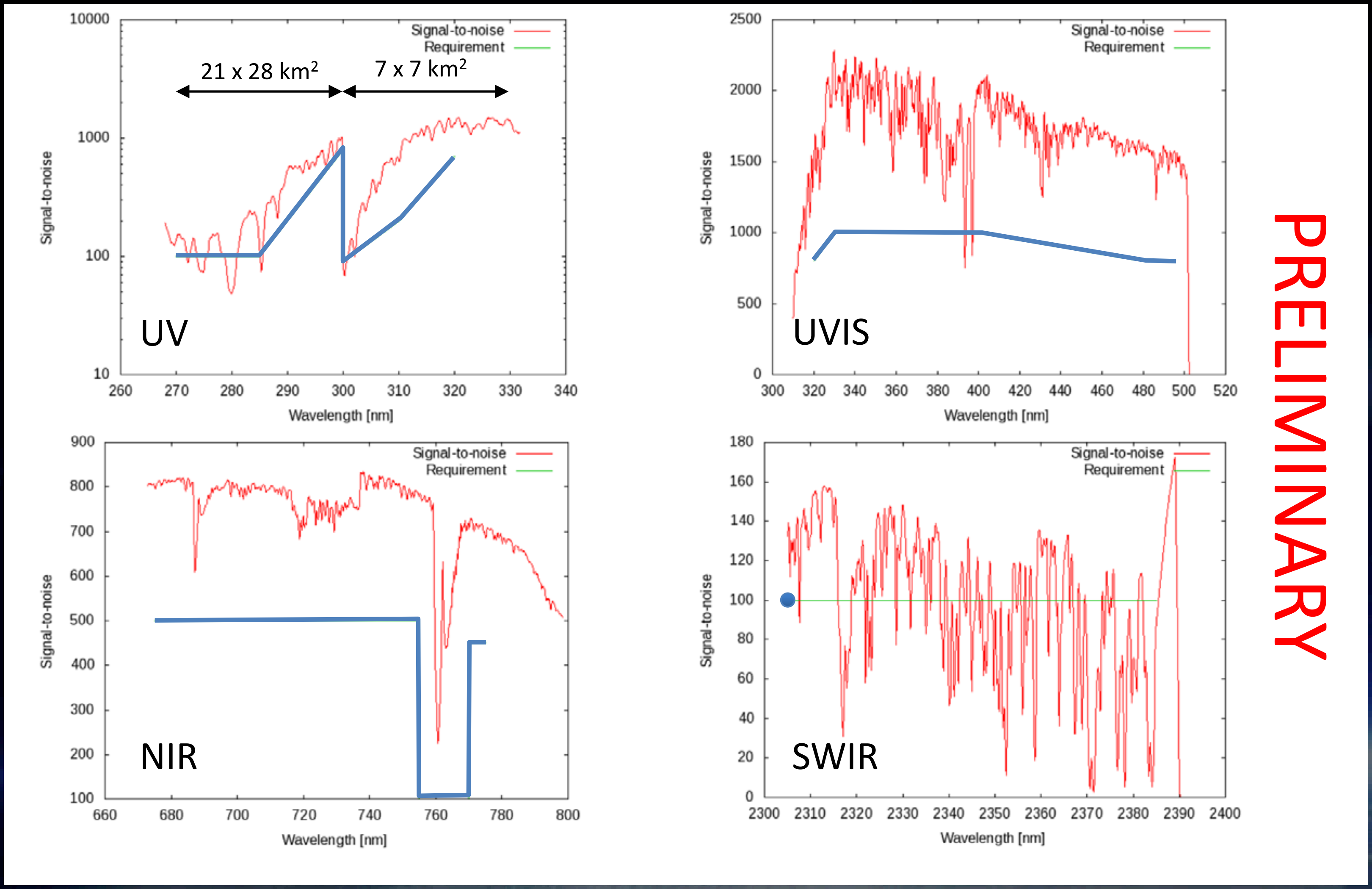
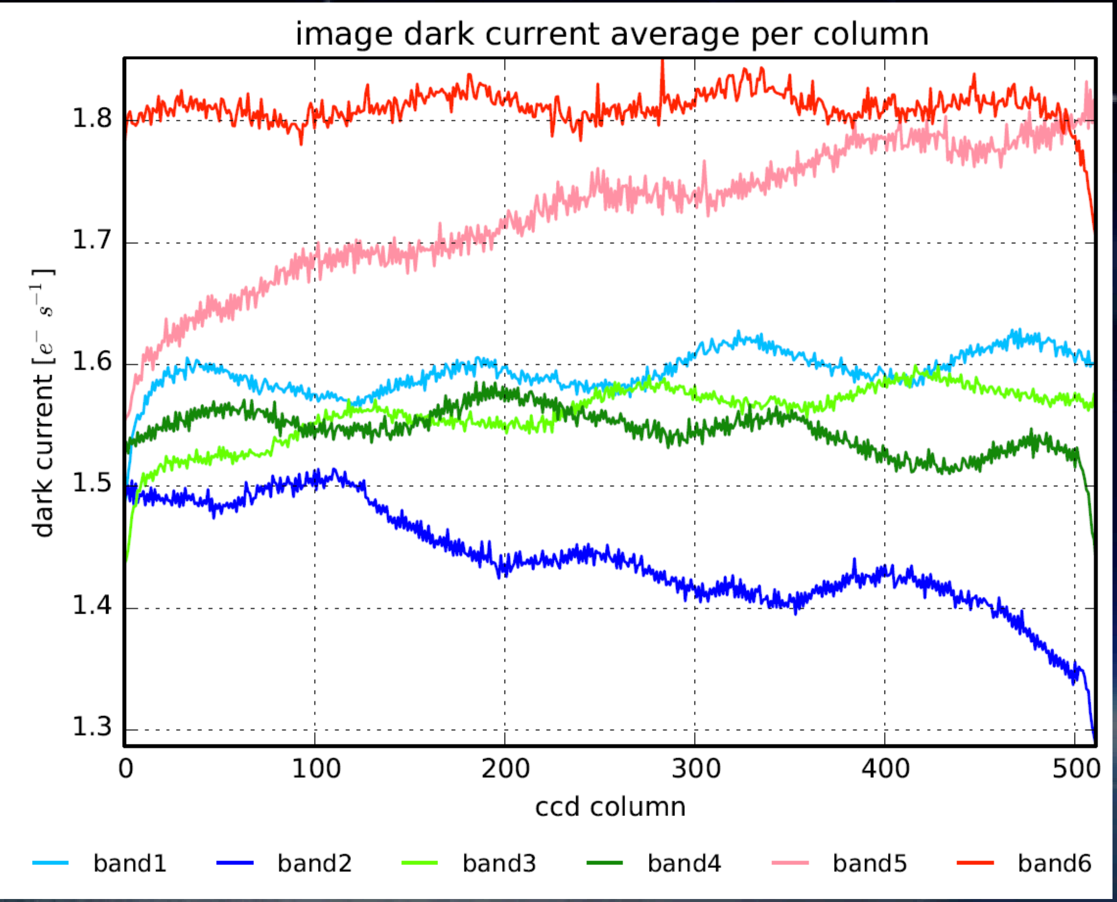


Figure: Johan de Vries, Airbus DS NL

Dark Current

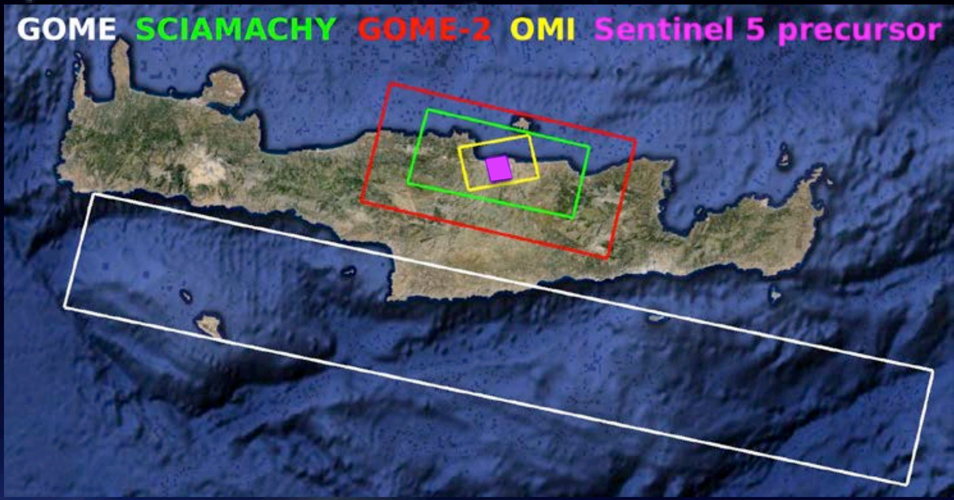
Dark currents in Bands 1-6 lower than 2 e/s

band	dc e/s
1	1.622
2	1.477
3	1.593
4	1.579
5	1.759
6	1.849



From OMI to TROPOMI

- **6x higher spatial resolution**
  7x7 km2 vs. 13x24 km2
- **1-5x higher signal-to-noise** per ground pixel
- **Much lower dark current**
  detector temperatures much lower
- **Better cloud information**
  oxygen A band added
- **CO and CH_4 observations**
  SWIR band added
- *Many lessons learned from 11 years of OMI data*

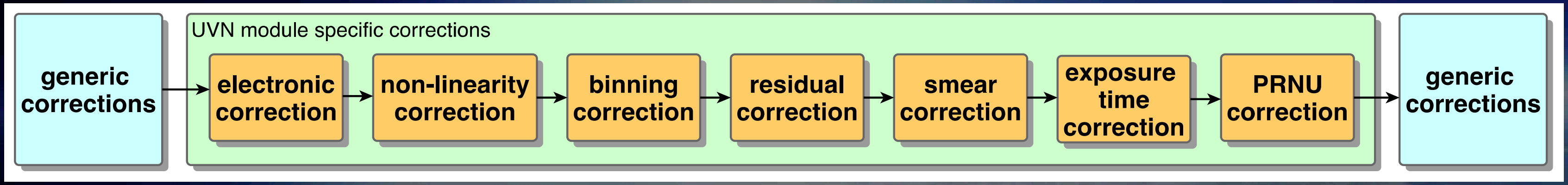


Level 0-1B Processor

L0-1B processor and calibration developed by one team

TROPOMI

- Multi-threading
- Multi-pass
- Algorithms are pluggable at run-time
- Full error propagation (noise + systematic errors)
- L1B product ~35 Gbyte / 100 min
- S/W design can be re-used



On-ground Calibration

- All measurements done in vacuum.
- Automated processing system for quick-look and key data analysis, using L0-1B processor.
- Calibration period of 127 days of continuous measurements.
- Strong involvement of KNMI/SRON:
  - On-site science support team
  - Data analysis team

Optical Stimulus	Calibration Key Data
Star stimulus	Geolocation
Lasers (UVN/SWIR)	ISRF, Stray light
Echelle grating stimulus	UVN ISRF
Spectral filters	Stray light
Spectral Line Lamps	Spectral calibration
FEL lamp + diffuser	Absolute radiometric calibration
Black bodies	Absolute radiometric calibration
CO, CH_4 gas cells	Spectral calibration SWIR
Integrating Sphere	Relative radiometry, BSDF
Sun simulator	Relative radiometry, BSDF
Internal LEDs	Detector parameters
Internal WLS	Relative radiometry
Internal laser diodes	ISRF

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Use of L01b processor for on-ground calibration

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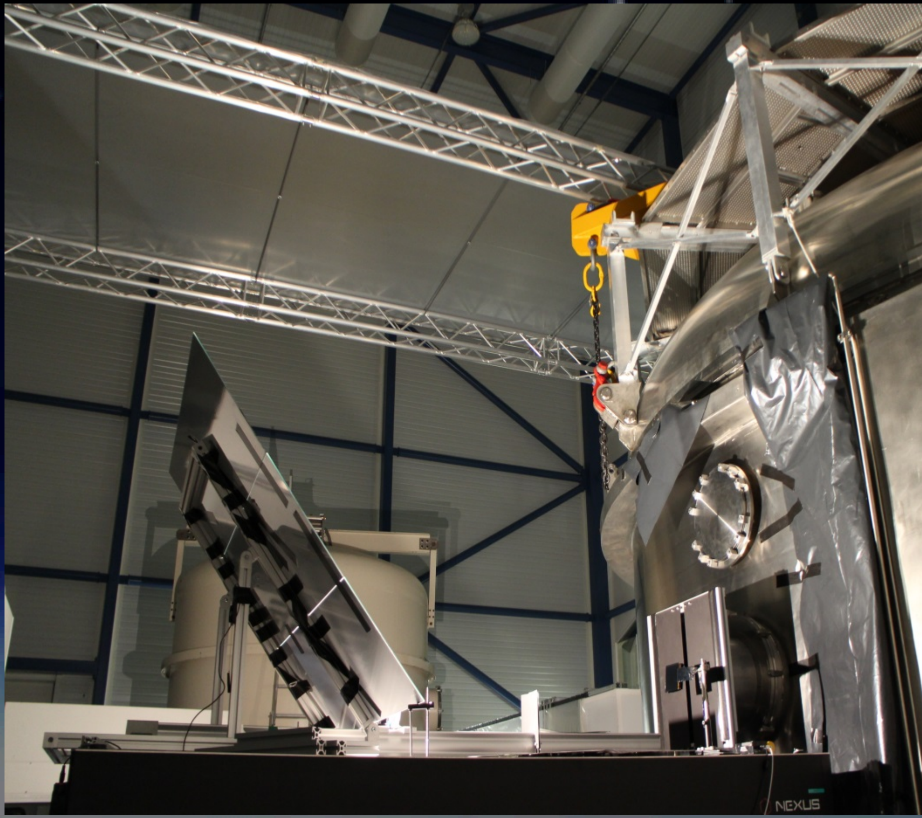
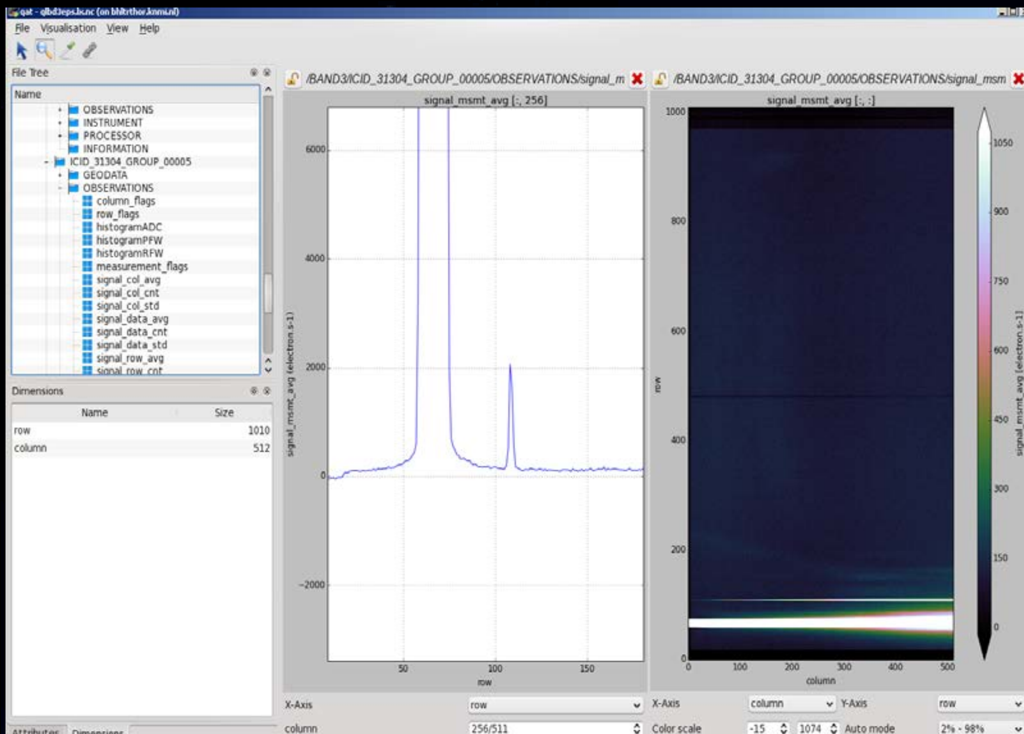
- Implemented latest knowledge in processor during campaign
- Processing to different correction steps possible
- Quality check of measurements possible within minutes
- For all derived keydata:
  - Self consistency check
  - Traceability



Calibration framework and quicklook

TROPOMI



Basic measurement analysis of the L01b converted files (netcdf) using python:

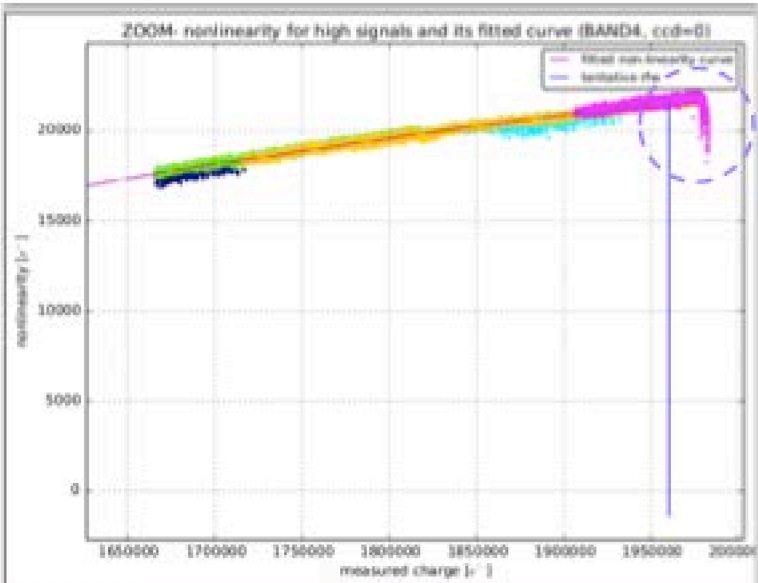
- Averaging of frames with identical settings
- SNR estimate
- Background subtraction

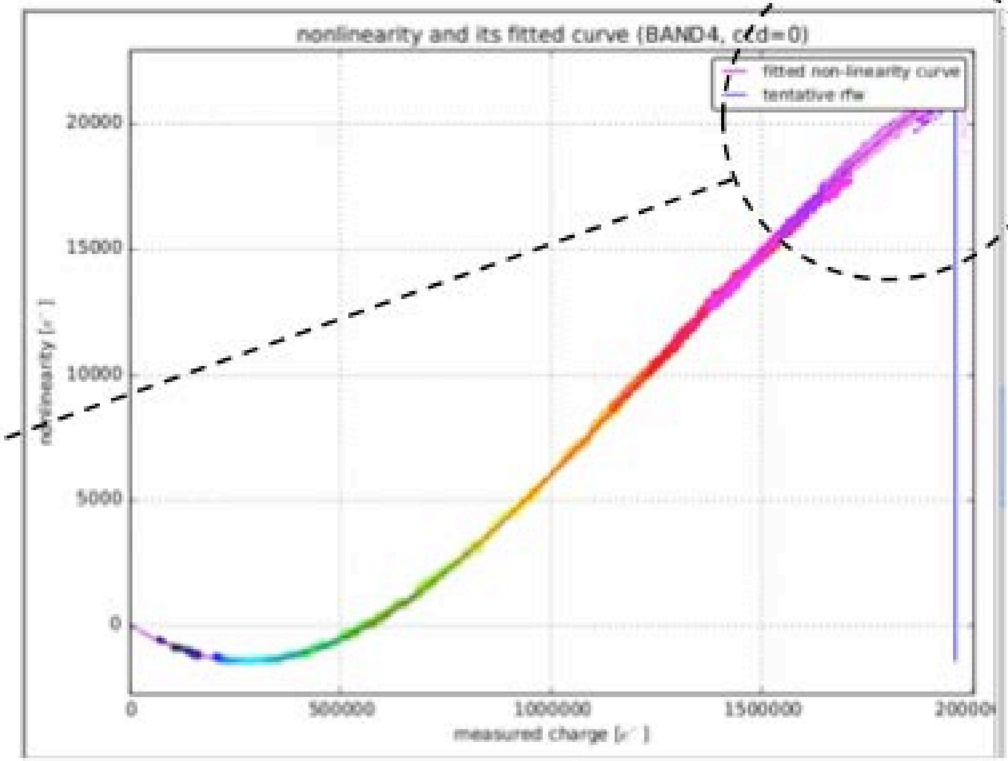
Custom made netcdf viewer for:

- Frame by frame inspection
- Instrument and ground support equipment settings

Electronic non-linearity

- Relative nonlinearity is less than 1.5%, while remaining relative residual < 0.1 %
- Calibration key data is a fitted curve, defined by polynomial coefficients and domain interval





Pixel response non-uniformity (PRNU)

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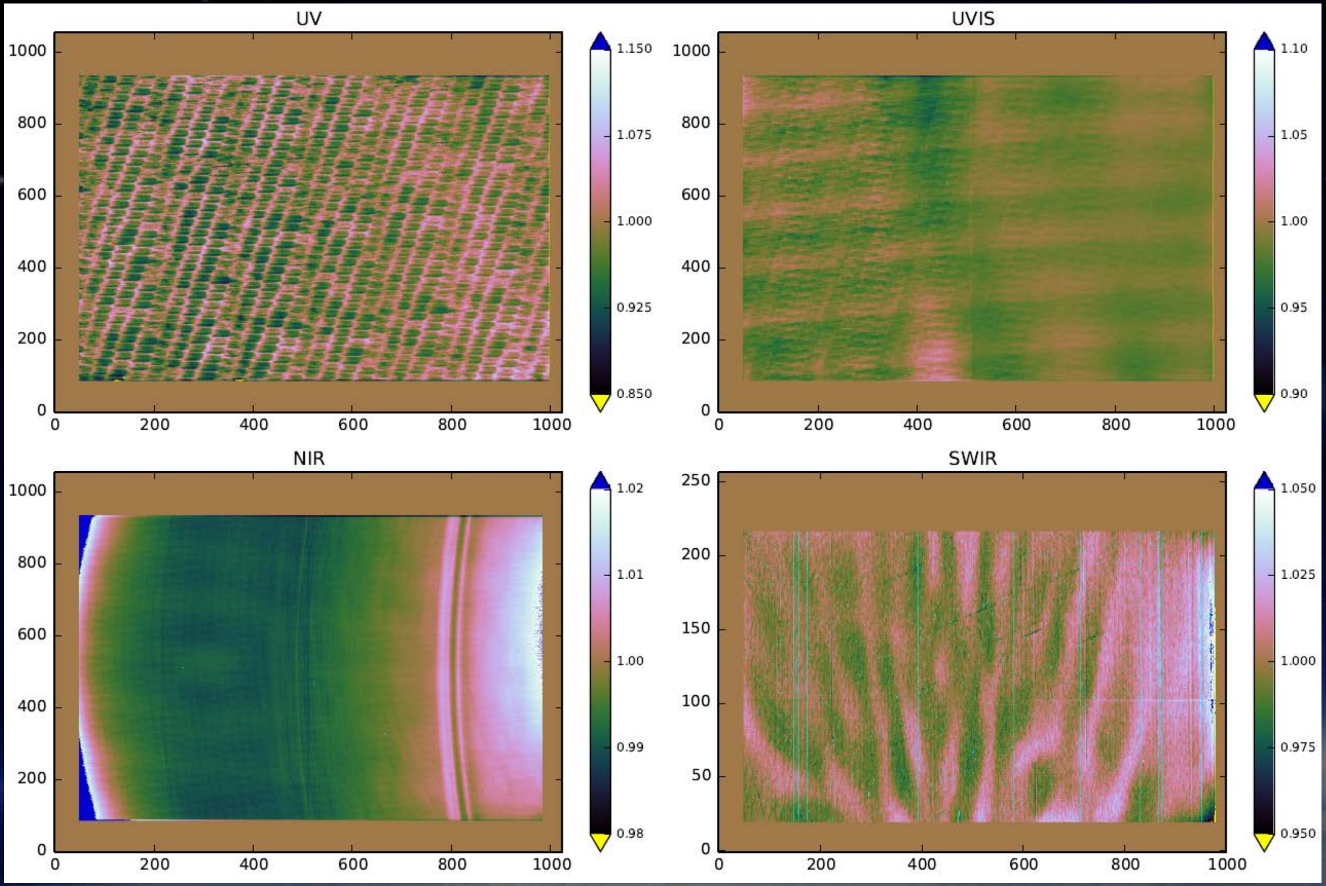
before correction:

Rows = swath direction

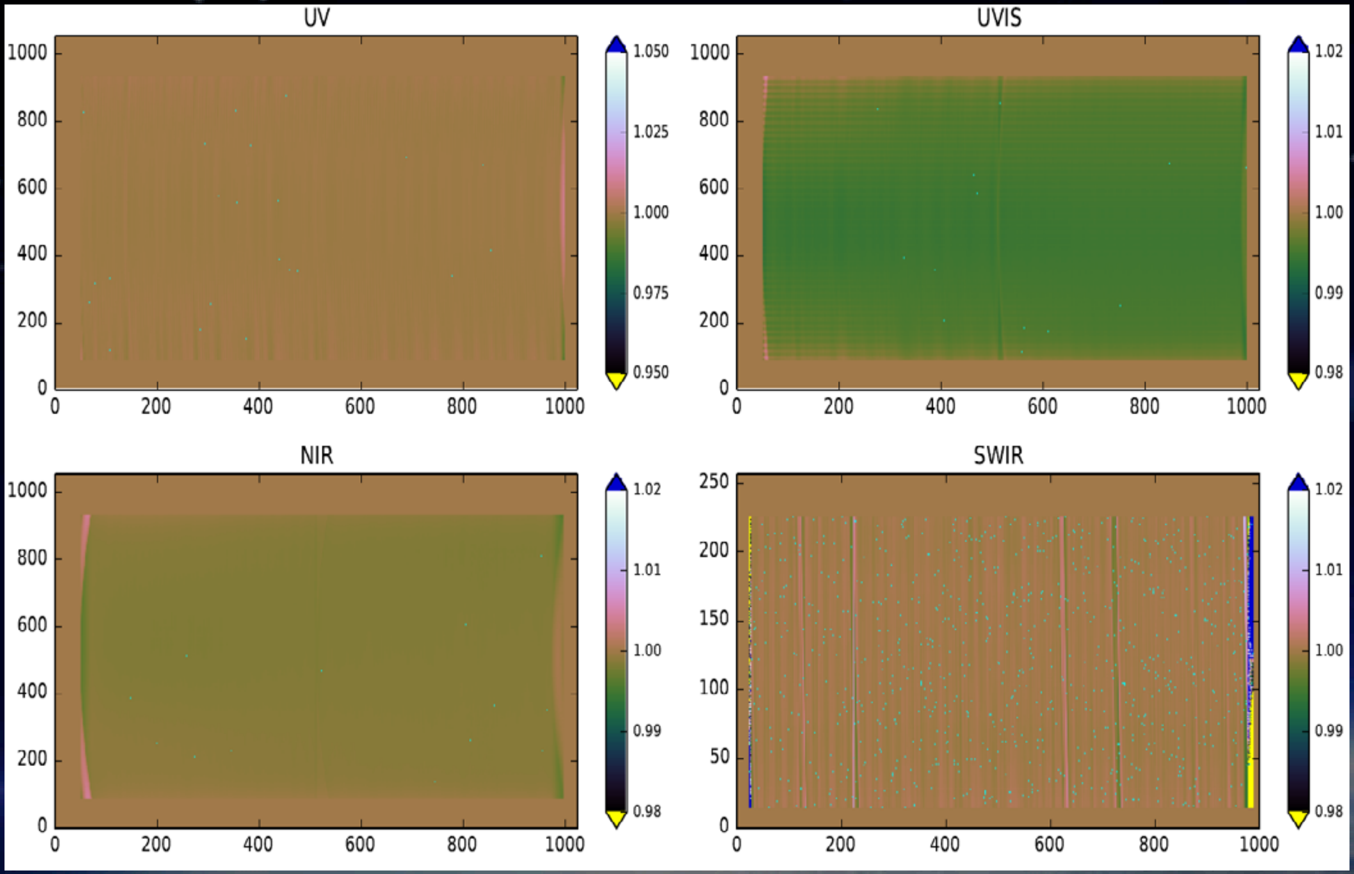


Columns = spectral direction

Pixel response non-uniformity (PRNU)

after correction:

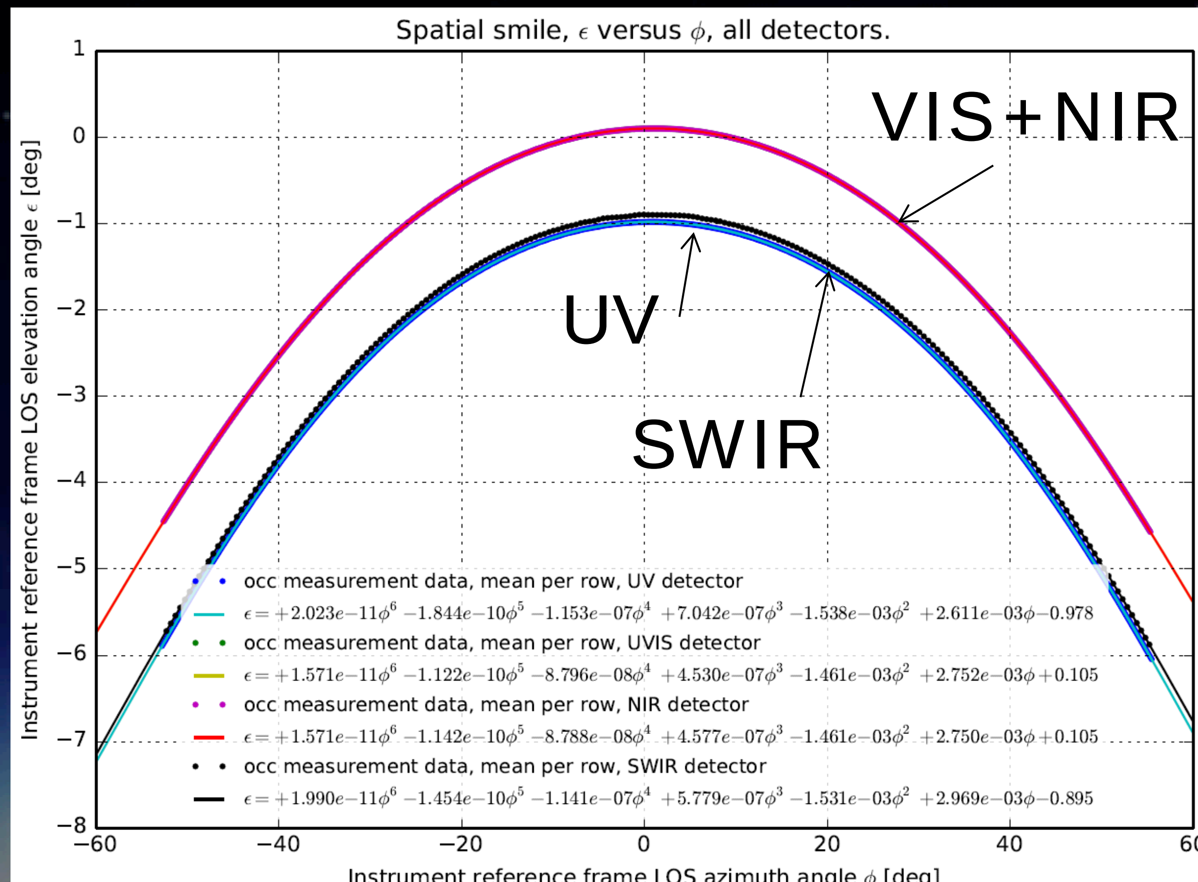
Rows = swath direction



Columns = spectral direction

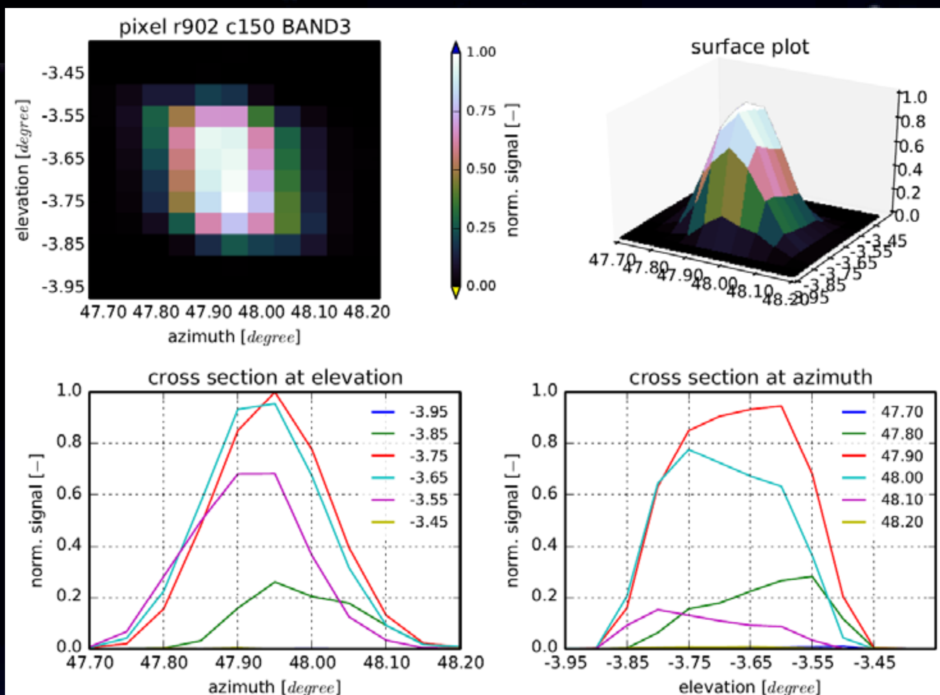
Geolocation: spatial smile

- 2 week long measurement
- Fast analysis vital for further calibration
- Using a weighted mean method
- 6^{th} order polynomials result in smallest residuals.

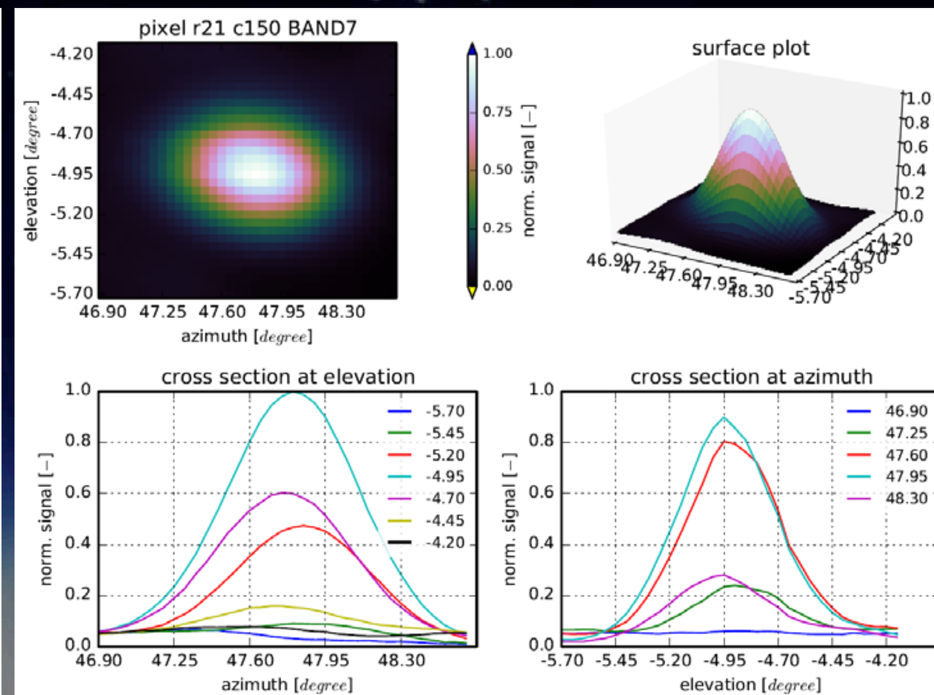


Geolocation: pixel response function

UV



SWIR



Stray light for UV, VIS, NIR spectrometers

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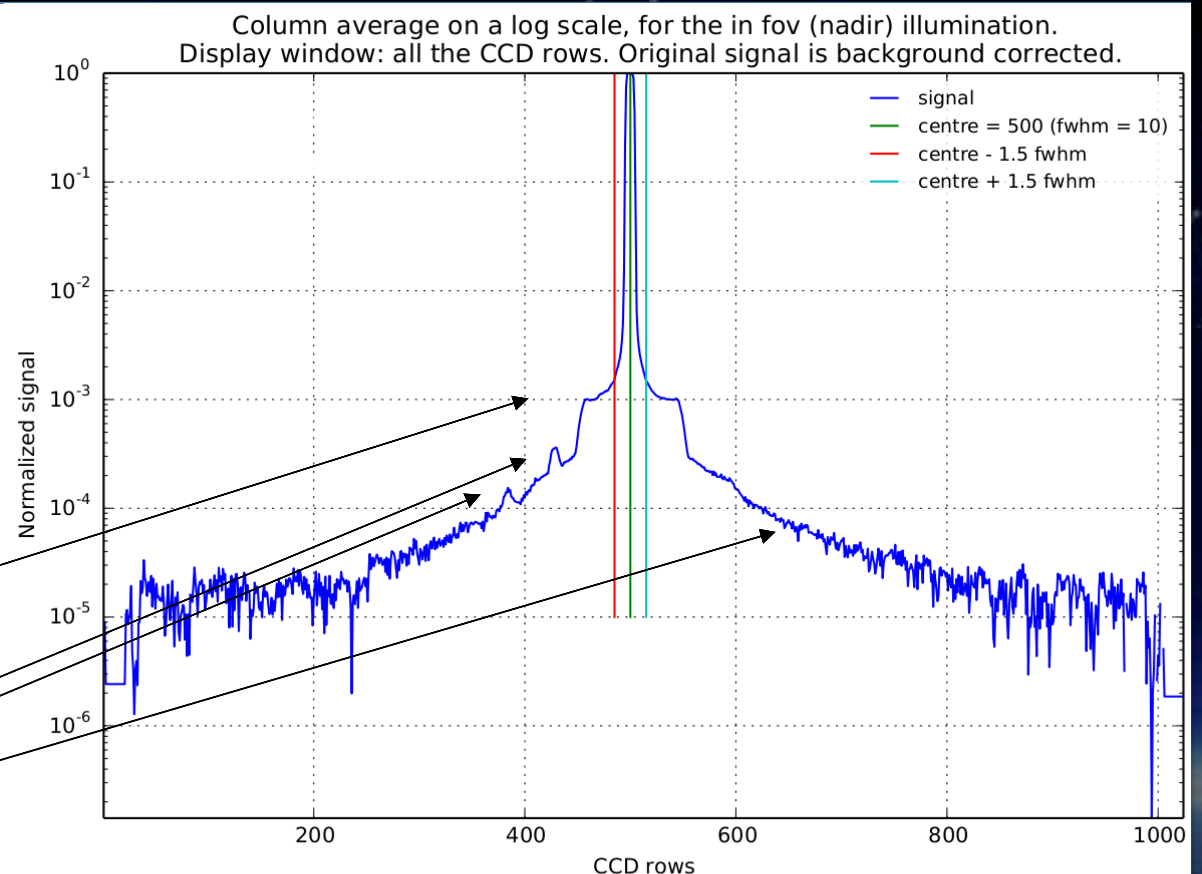
Three methods:

- external white light source
- bandpass filter
- laser

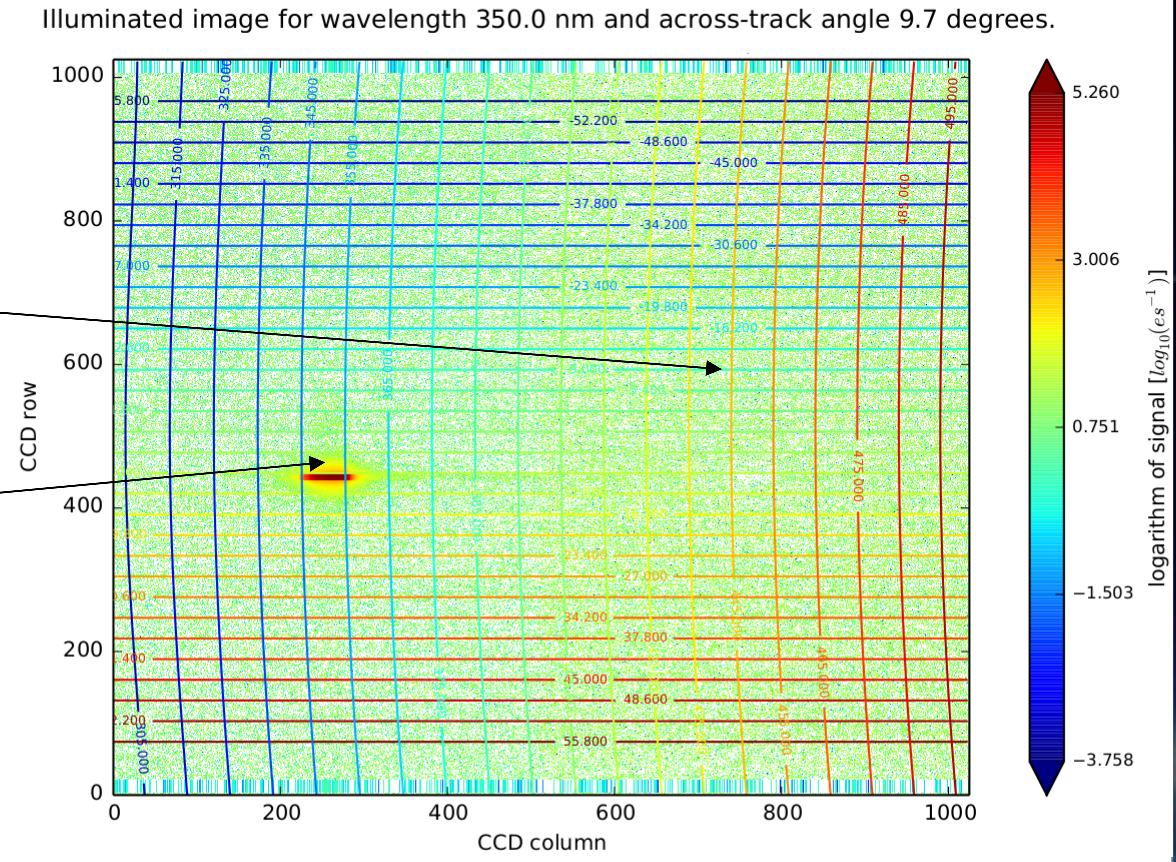
White light source:

- near-to-mid-field ghost.
- scrambler ghosts
- scattering

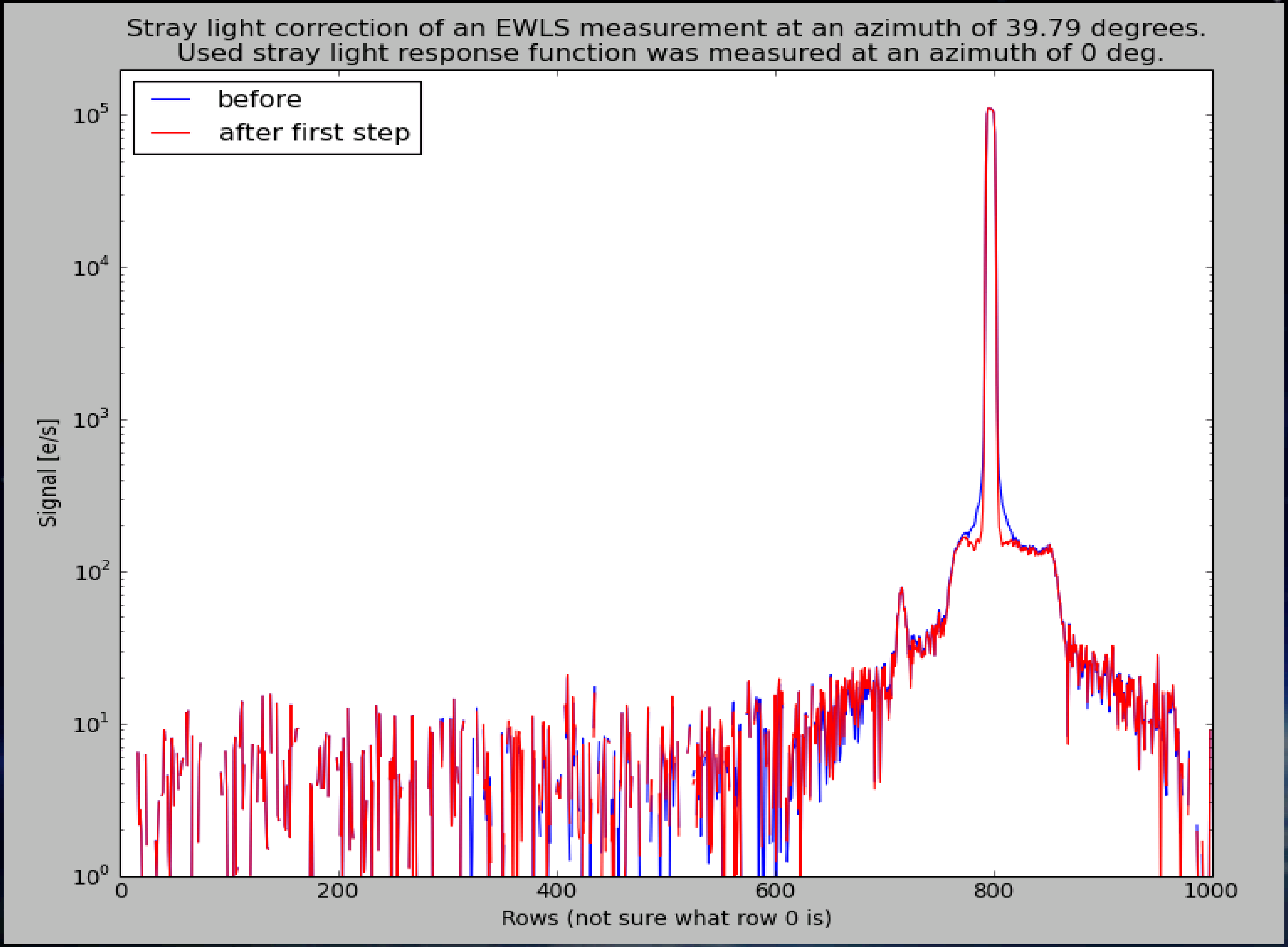


Stray light: result from filter measurements

- Far-field stray light buried in noise.
- Near-field stray light above noise.
- Near-field stray light dominates over the far-field stray light.



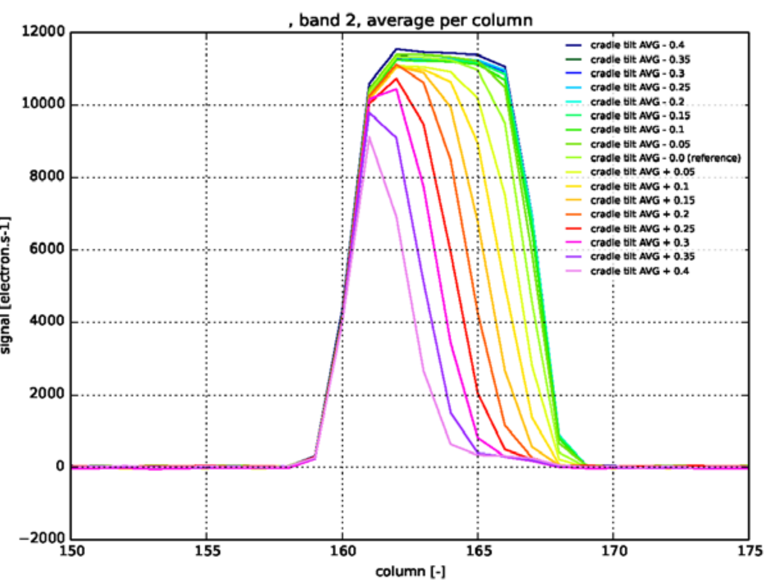
Stray light correction possible with laser data



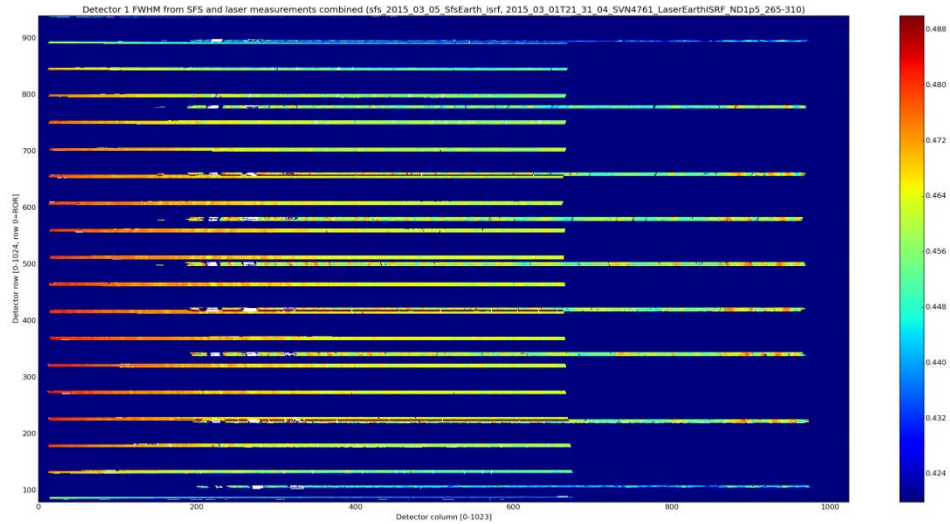
ISRF Measurements

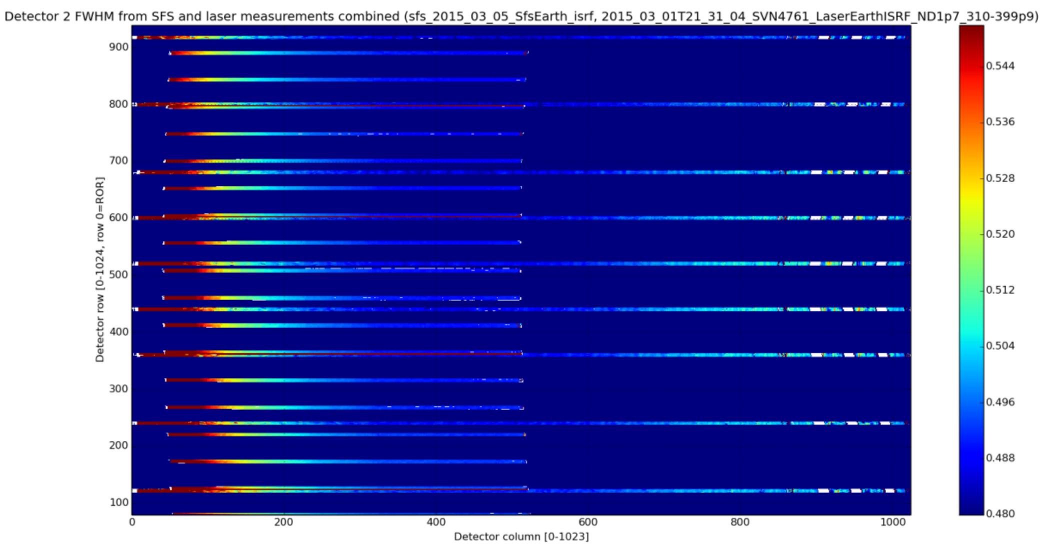
- UV: FWHM ~0.45 -0.48 nm
- UVIS FWHM ~0.48-0.54 nm
- VIS: FWHM ~0.33 nm
- NIR: FWHM ~0.38 nm

Inhomogeneous slit filling

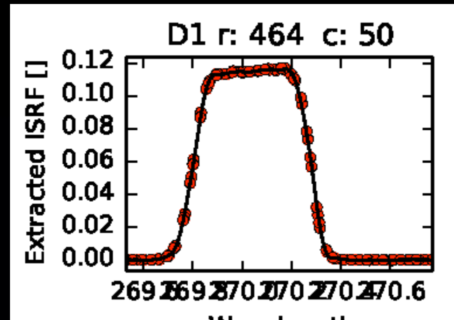


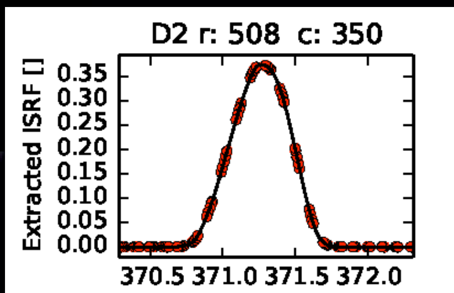
Rows = swath direction

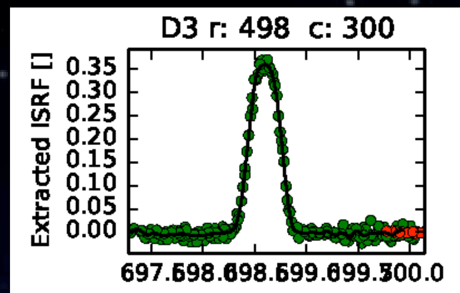




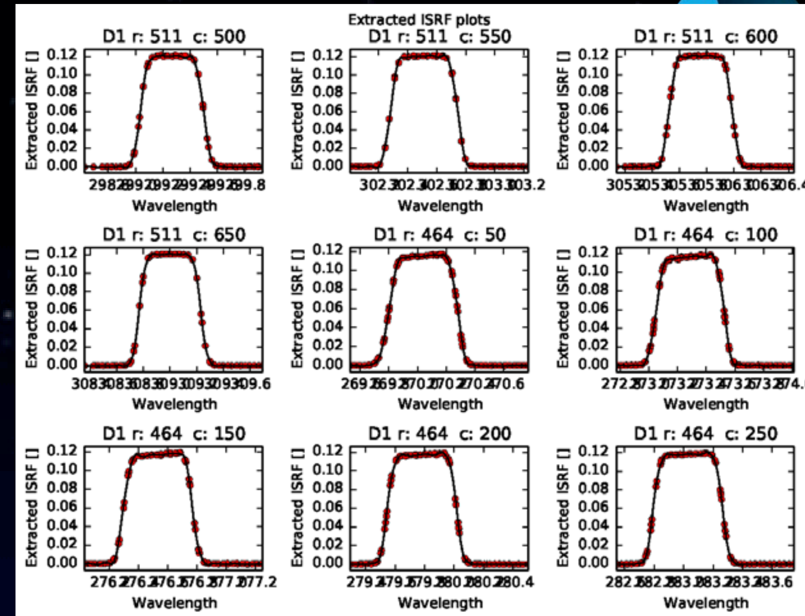
Columns = spectral direction



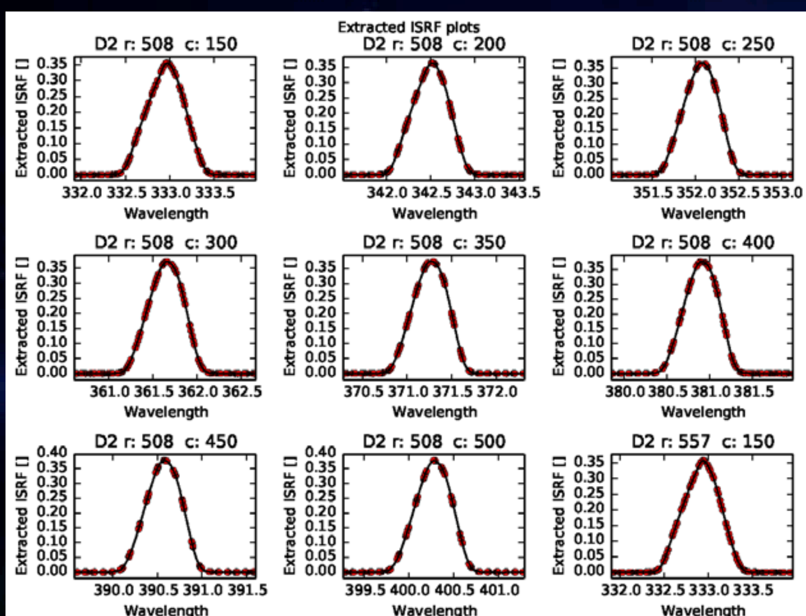




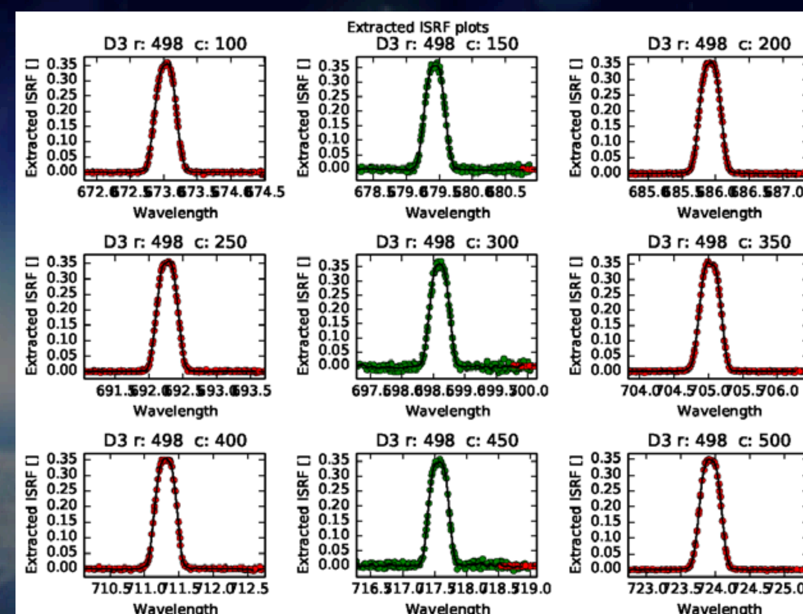
UV: laser measurements



UVIS: laser measurements



NIR: SFS measurements



Summary & Outlook

TROPOMI

- TROPOMI will be a major step forward for atmospheric composition observations due to improved spatial resolution & sensitivity.
- The on-ground calibration has been finalised; calibration analysis is ongoing.
- L0-1B development is on-track and the processor was an essential part of the on-ground calibration campaign.
- We are counting down for a launch in 2016!

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www.knmi.nl/omi

sentinel.esa.int/s5p

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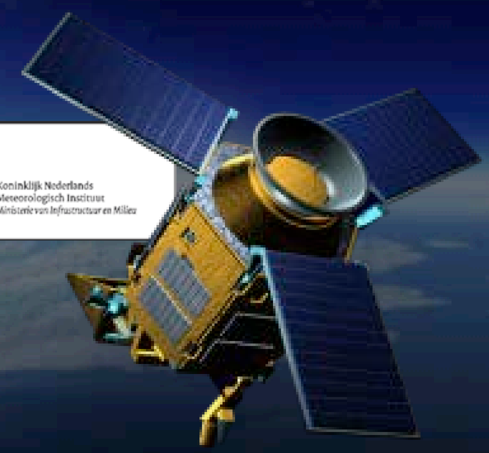

KNMI L0-1B/Calibration Team

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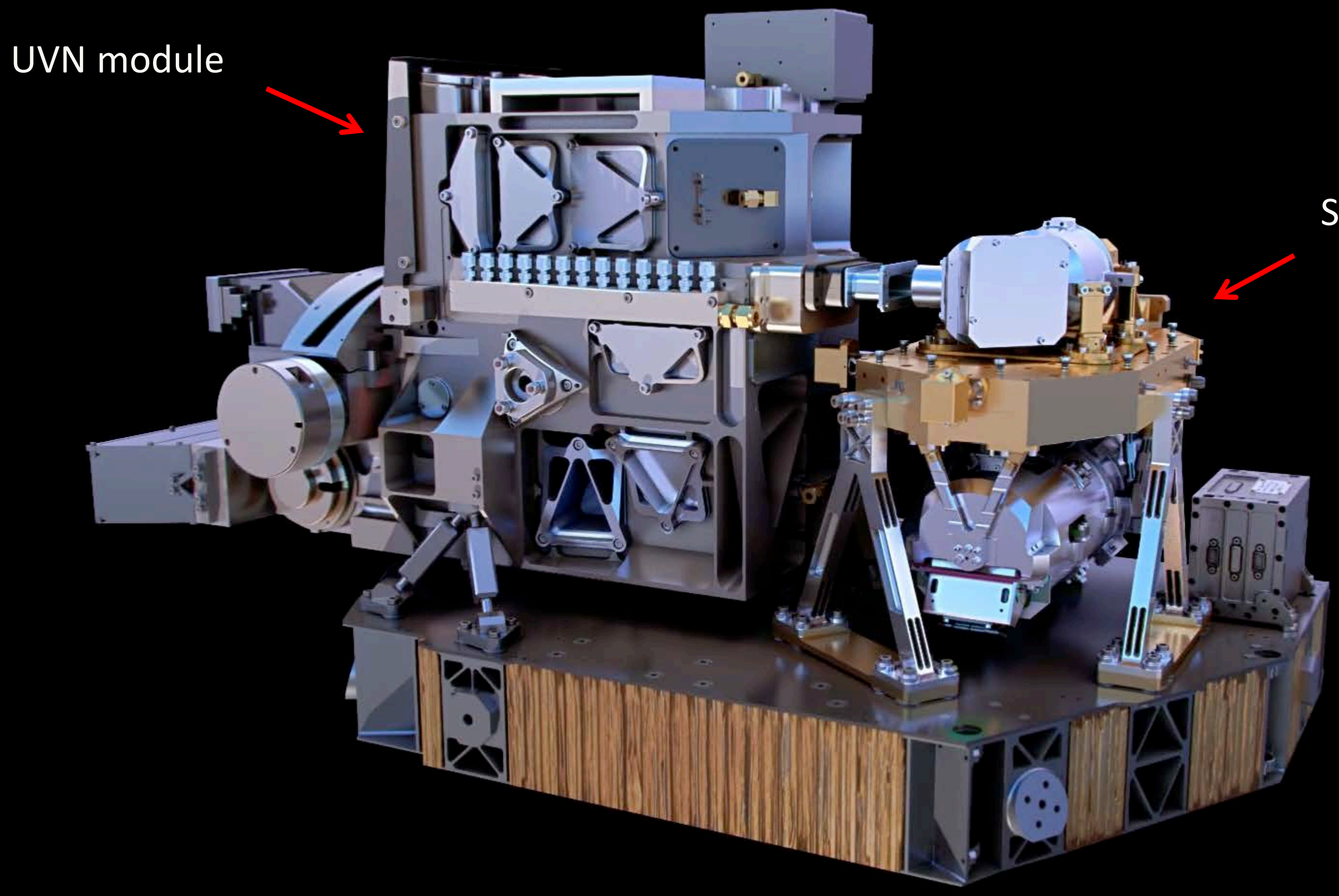
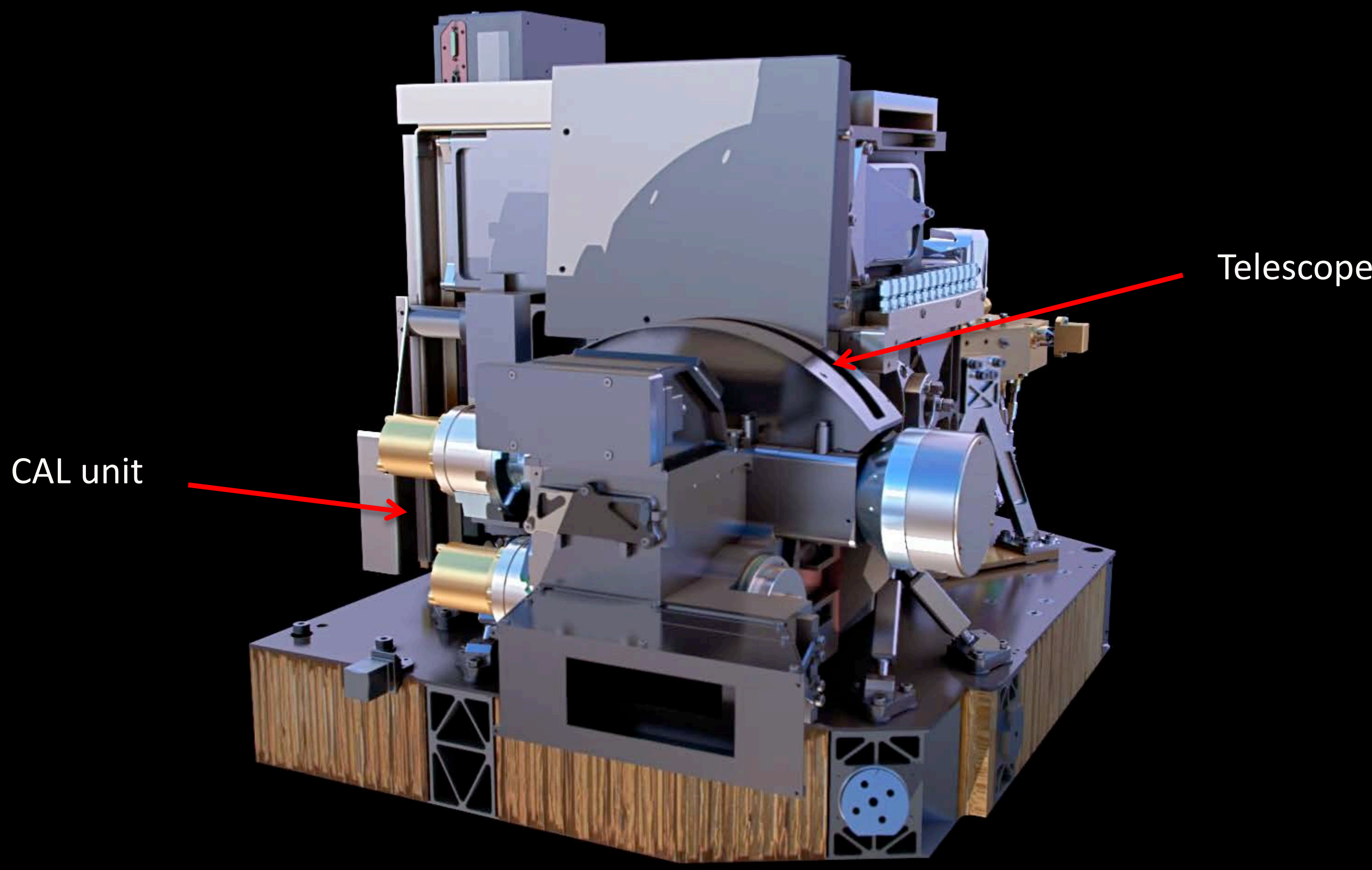

UVN module
SWIR module


Telescope
CAL unit

TROPOMI