Royal Netherlands
Meteorological Institute
*Ministry of Transport, Public Works
and Water Management*

Tropospheric Monitoring Instrument

# Level 1 lessons learned from OMI and TROPOMI

Quintus Kleipool
Antje Ludewig
Pepijn Veefkind
Marcel Dobber

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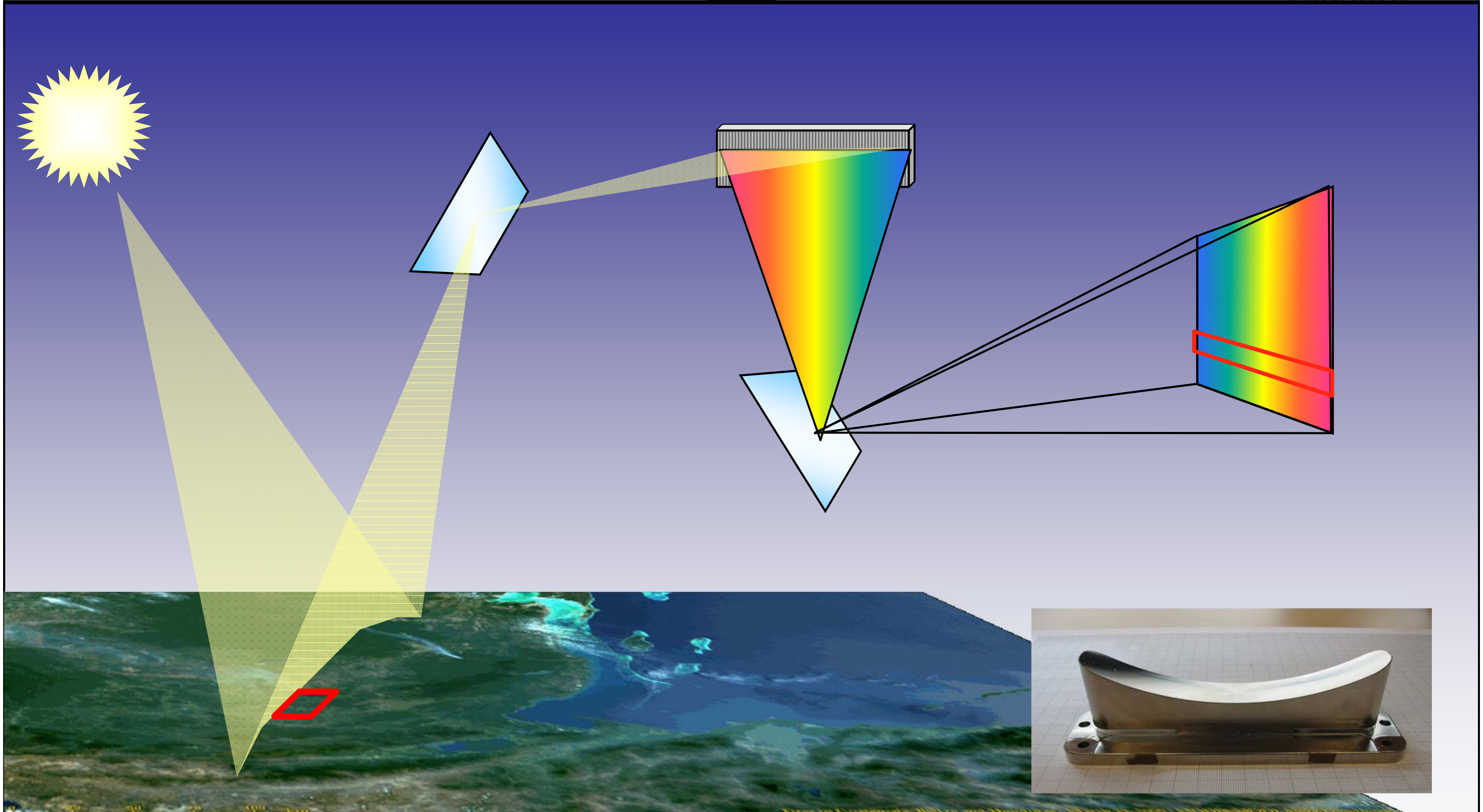
# outline

- general introduction to OMI and TROPOMI
- OMI lessons learned
- the TROPOMI program
- OMI lessons incorporated in TROPOMI
- TROPOMI challenges - conclusion

# general introduction to OMI and TROPOMI

- hyper-spectral imagers make images in multiple spectral bands (3D data cubes)
- three different techniques used to realize a hyperspectral image:
  - scanning an image spatially - capturing full spectral data sequentially
  - scanning an image spectrally - capturing full spatial information sequentially
  - capturing all the spectral and spatial information at once.
- no scanning mirrors cross track
- scanning in flight direction
- wide field of regard
- 2D detectors needed (CCD/CMOS)
- typically higher straylight levels than scanners like GOME, SCIAMACHY

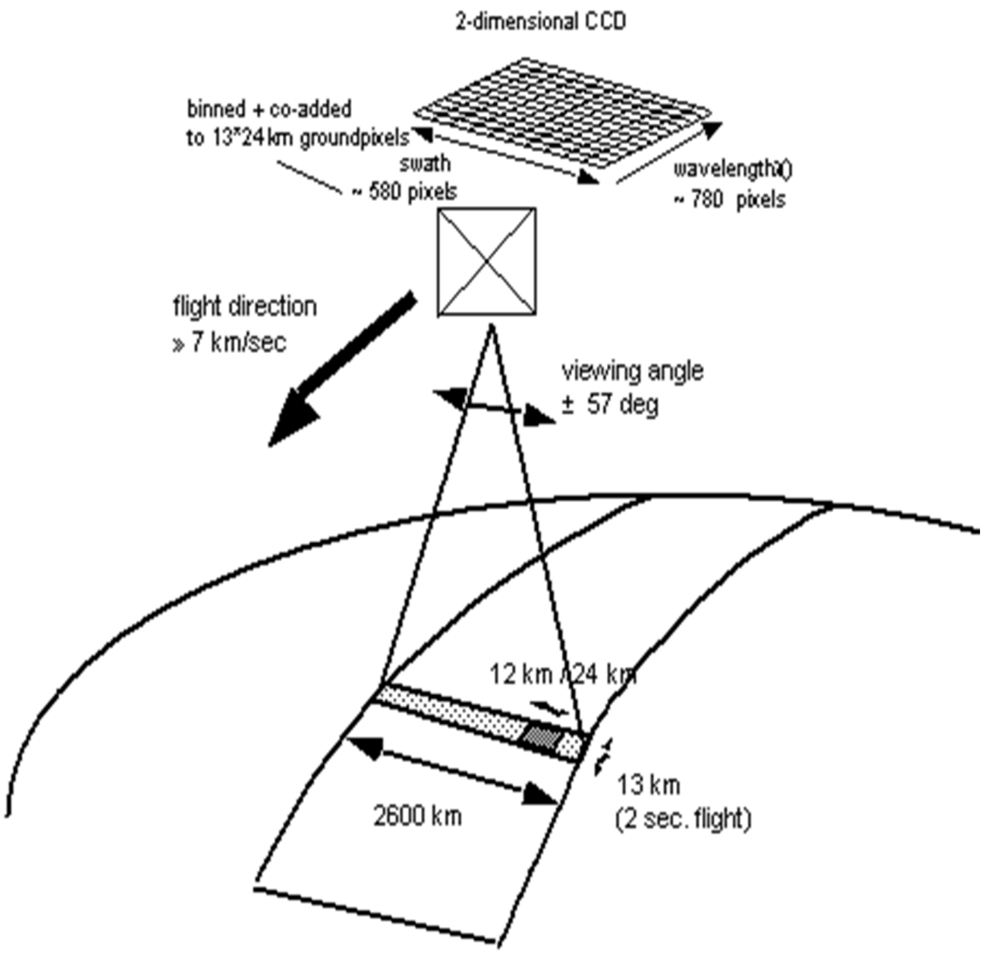


- Solar backscatter
- 2D field of view
- Push broom

- Wide cross flight IFOV
- Narrow along flight IFOV
- 2D grating spectrometer

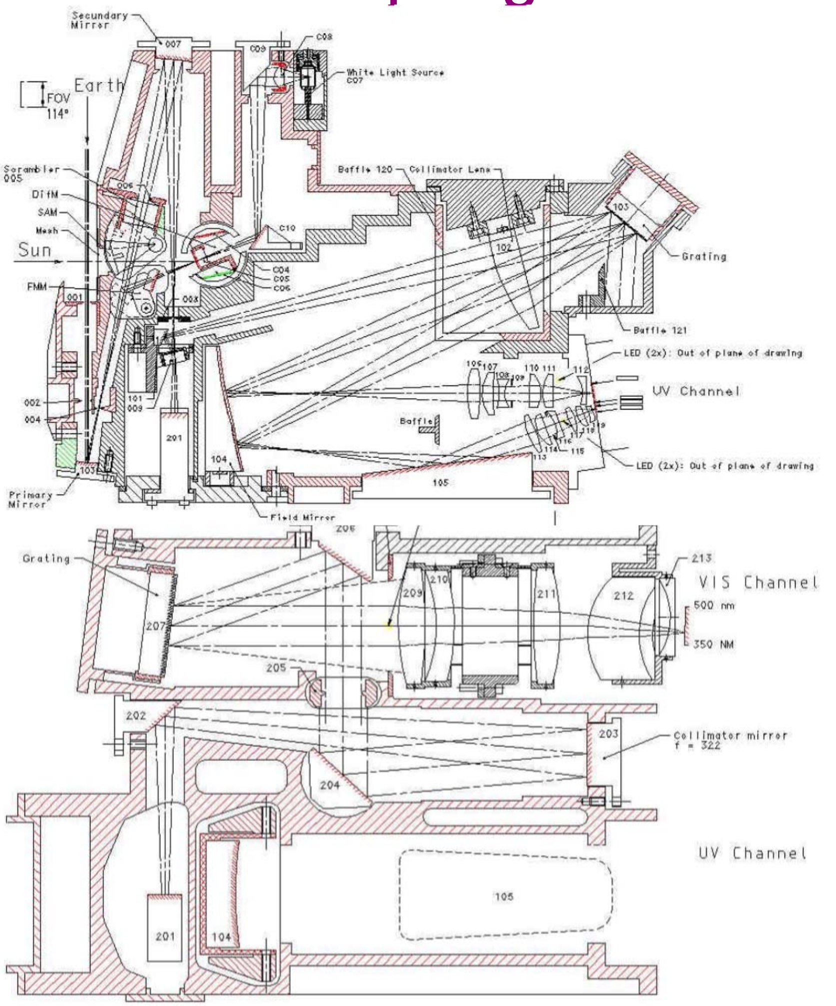
- 2D detector
- High data-rate
- High stray light

# the OMI instrument




| | |
|---|---|
| wavelength range (UV)(VIS) | (270 – 380) nm<br>(350 - 500) nm |
| viewing angle of the telescope | 114° x 1° |
| Cross track swath width | 2600 km |
| daily global coverage | 14.5 orbits<br>(1 day) |
| Nadir ground pixel size | 13 km × 24 km |
| Polarization sensitivity | depolarized using a scrambler |
| altitude | 705 km |
| spectral resolution<br>(UV1, UV2, VIS) | 0.63, 0.42, 0.63 nm |

# the OMI program

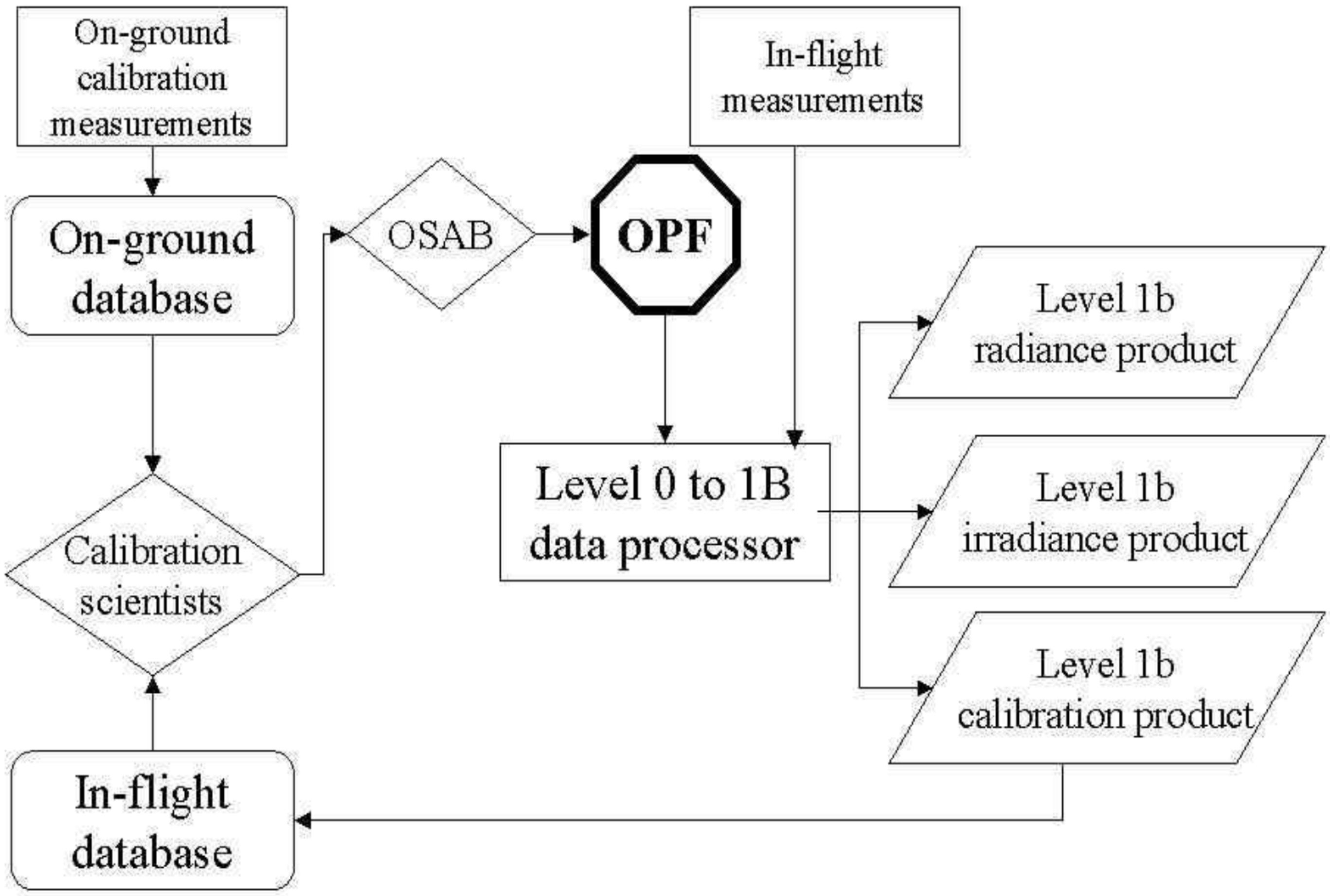



| | |
|---|---|
| Program management | NSO (NIVR) |
| Financed by | NSO (NIVR)<br>Finnish Meteorological Institute (FMI) |
| Prime contractor | Dutch Space and TNO Science & Industry |
| subcontractors | VTT<br>Patria Finavitec |
| L01b data processor | Dutch Space |
| onground calibration | TNO Science & Industry |
| operations | KNMI |
| inflight calibration | KNMI / NASA |

# OMI onground calibration issues

- Wrong assumptions in calibration approach
- no 2 axis turn / tilt cradle available for thermal vacuum chamber
- onground calibration partly under ambient conditions, limited measurements at operational temperature 265 K (CCD and OBM)
- nadir BSDF measurements in TVC at operational temperature
- radiance swath dependence in ambient - with higher noise and darkcurrent
- diffuser BRDF also in ambient - with higher noise and darkcurrent
- measurements poorly executed resulted in unphysical algorithms in calibration and L01b processing
- poor communication between teams in the end lead to mismatch between L01b processor and Calibration Key Data

# OMI inflight calibration method




OPF

=

calibration key data

=

L01b model parameters

=

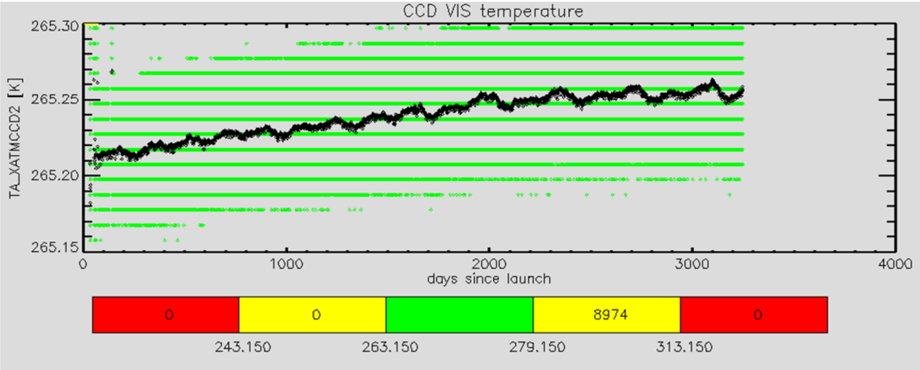
M-factors

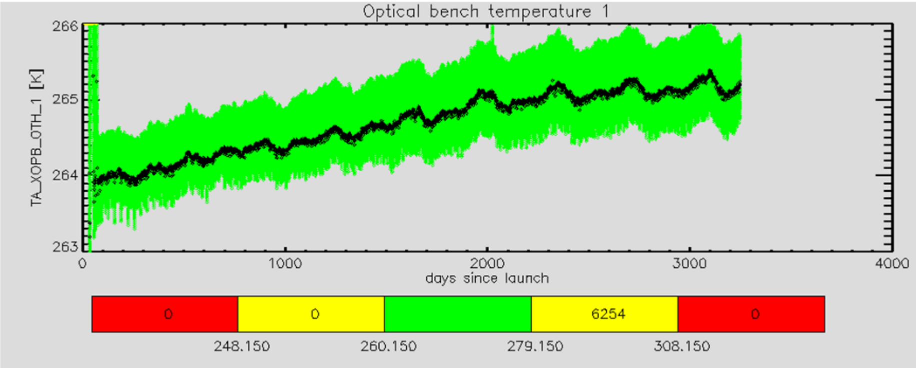
# OMI inflight calibration monitoring

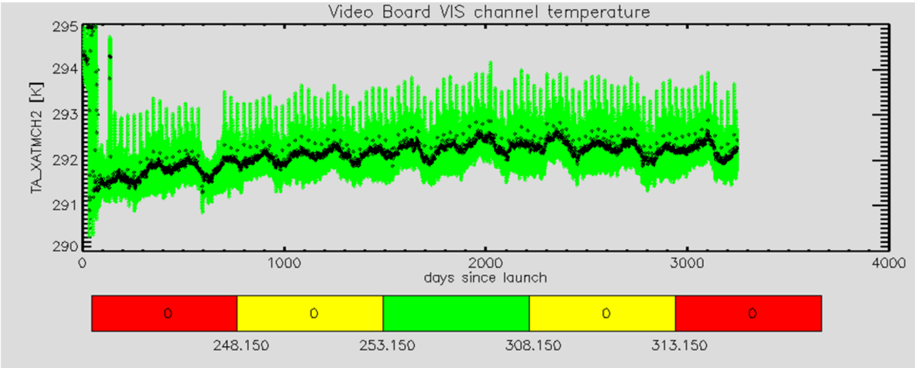
- inflight calibration measurements scheduled at regular intervals
- measurements processed by L01b processor
- calibration products moved to KNMI database
- additional automatic analysis in TMCF
- updated OPF send to processing site at NASA
- calibration measurements include Sun, WLS and LED
- monitored features are Darkcurrent, RTS, Pixel Quality, PRNU, non-linearity, gain and degradation
- also visualized is thermal behavior, engineering parameters and L01b quality statistics.

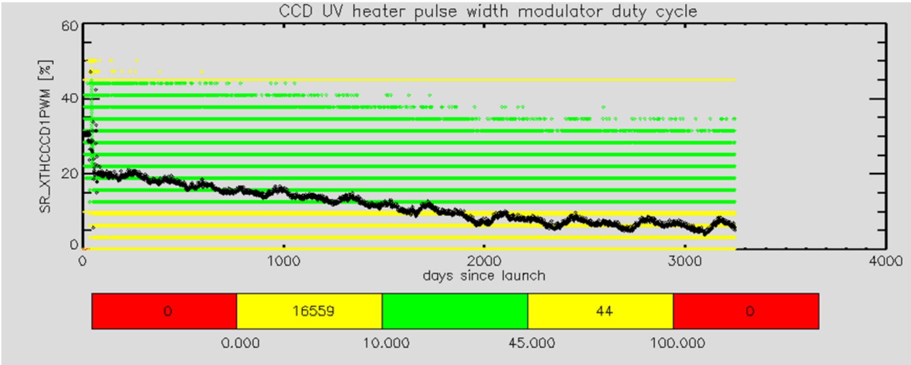
http://www.knmi.nl/omi/research/calibration/instrument_status_v3/index.html

# OMI inflight thermal behavior

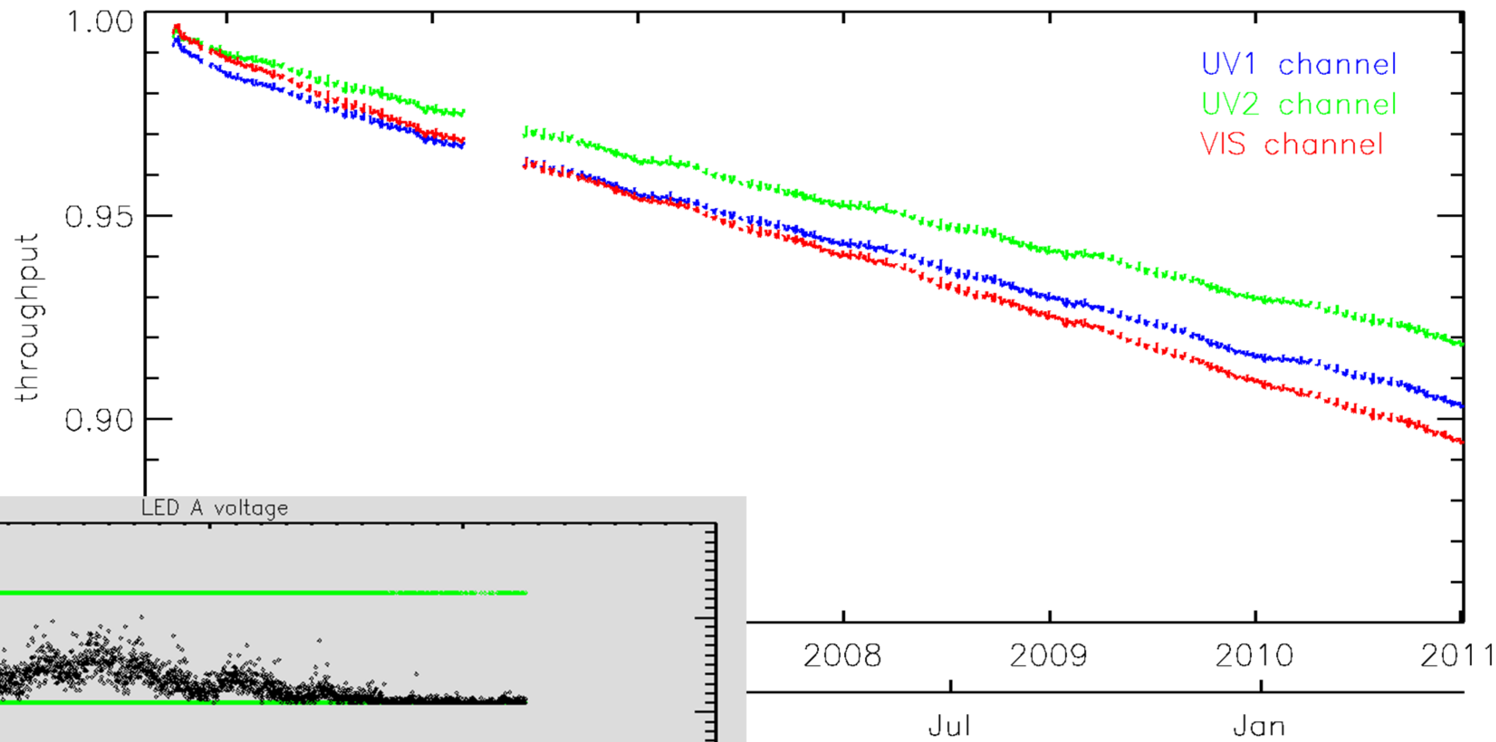


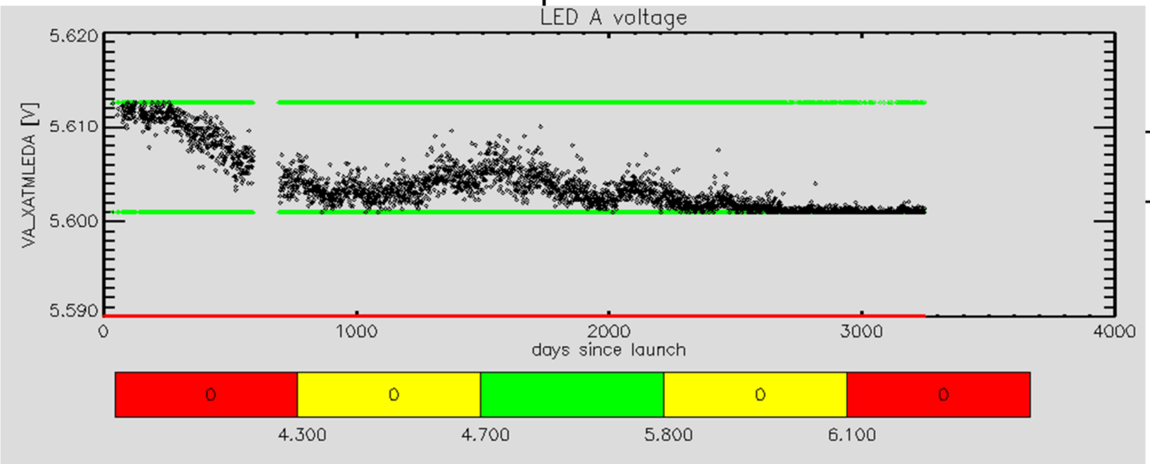



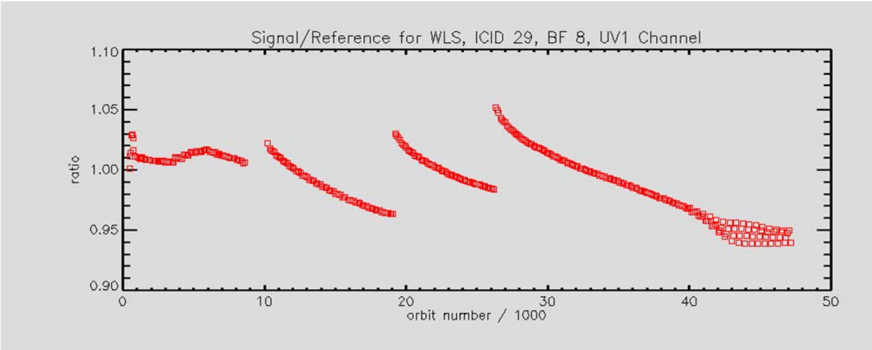



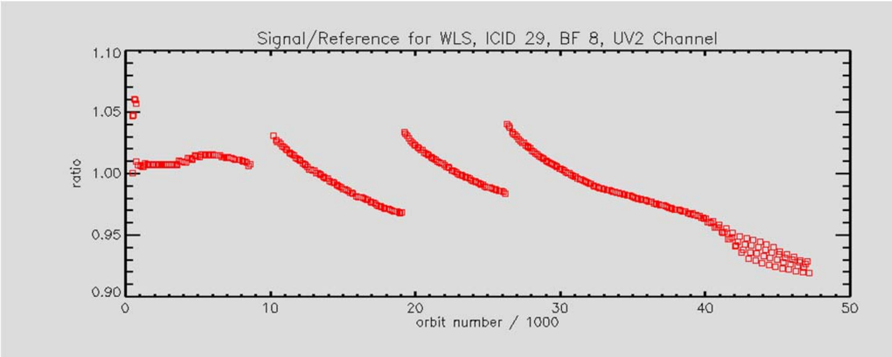
# OMI inflight calibration LED monitoring

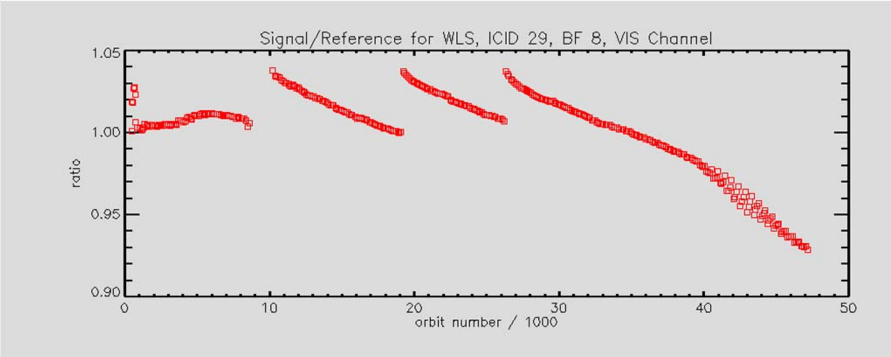


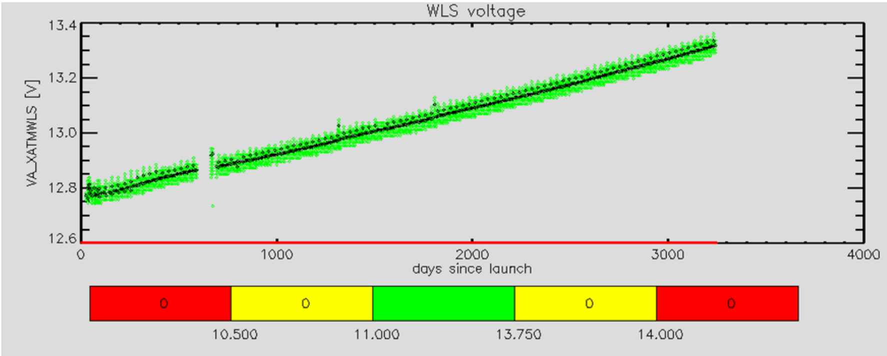



# OMI inflight calibration WLS monitoring



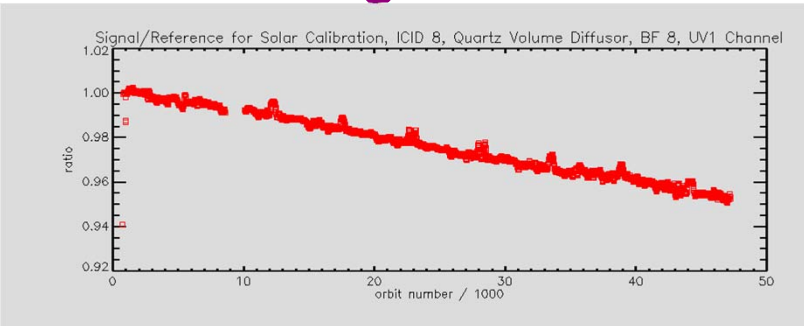



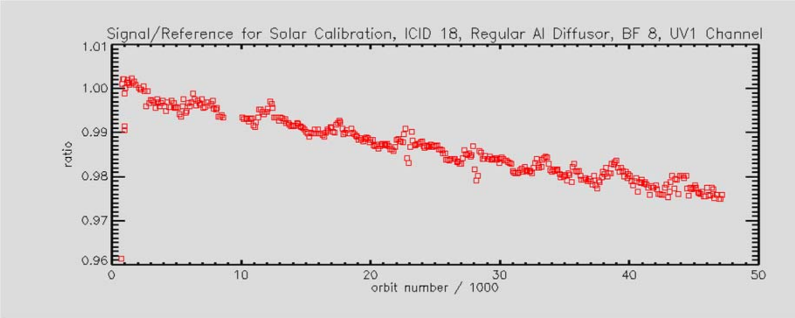



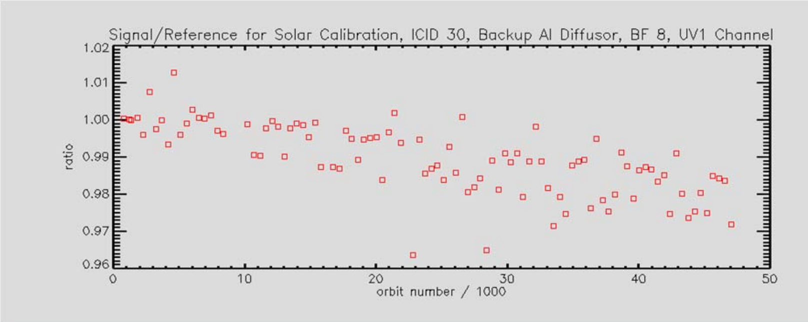




- WLS voltage increasing
- Current source
- Filament “necking”
- End of life?

# OMI inflight solar measurements



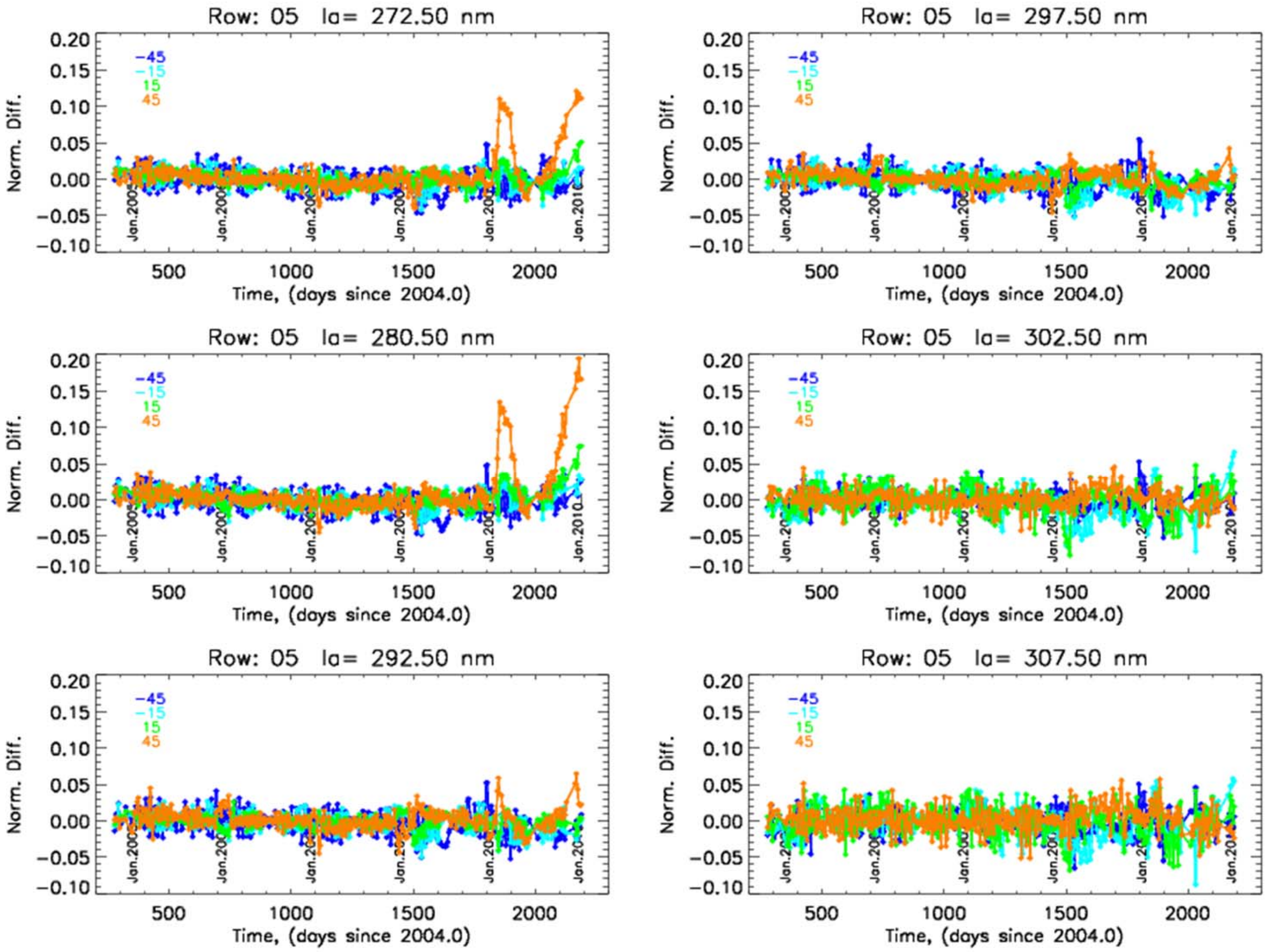




- QVD – daily
- ALU1 – weekly
- ALU2 – monthly
- remember onground ambient calibration
- QVD recalibrated after one year inflight
- assuming no degradation in first year
- difficult to compare OMI diffusers

| | UV1 | UV2 | VIS |
|---|---|---|---|
| QVD path | 0.955 | 0.973 | 0.980 |
| ALU1 path | 0.977 | 0.984 | 0.983 |
| ALU2 path | 0.980 | 0.985 | 0.984 |
| optical | -2.0 % | -1.5 % | -1.6 % |
| QVD | -2.5 % | -1.2 % | -0.4 % |

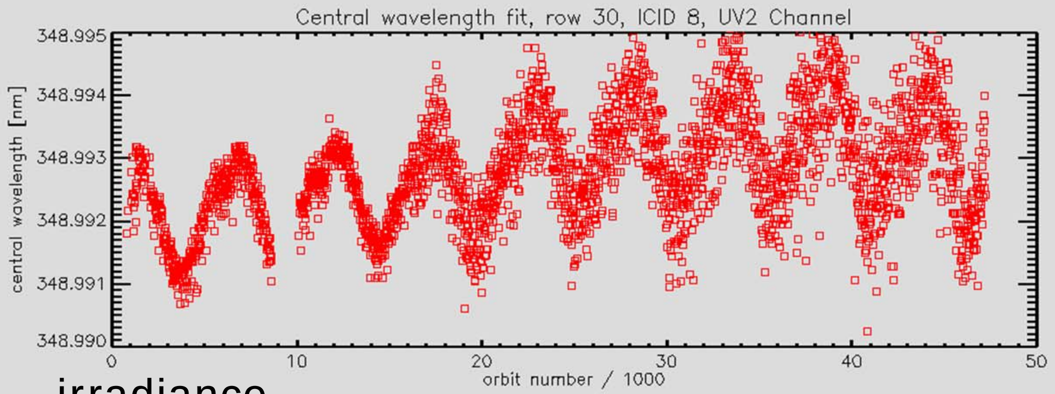
# OMI spectrometer degradation



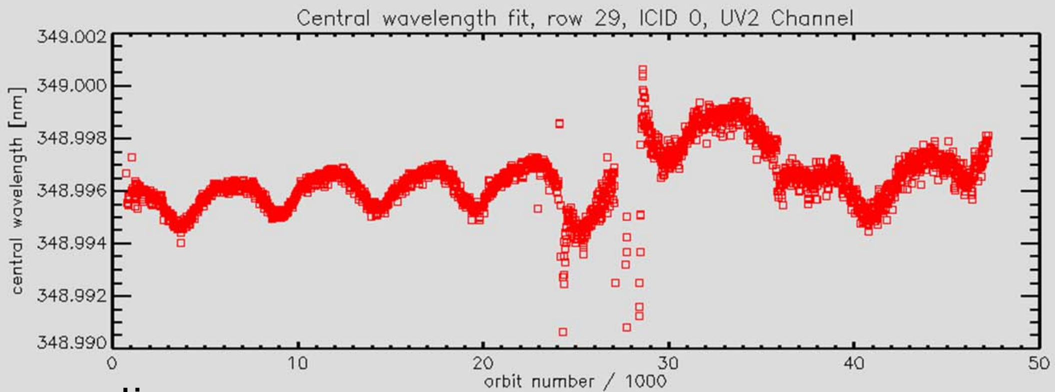

- UV1 trend
- No degradation spectrometer
- Folding mirror suspect

Sergey Marchenko & Glen Jaross

# OMI inflight spectral stability




irradiance

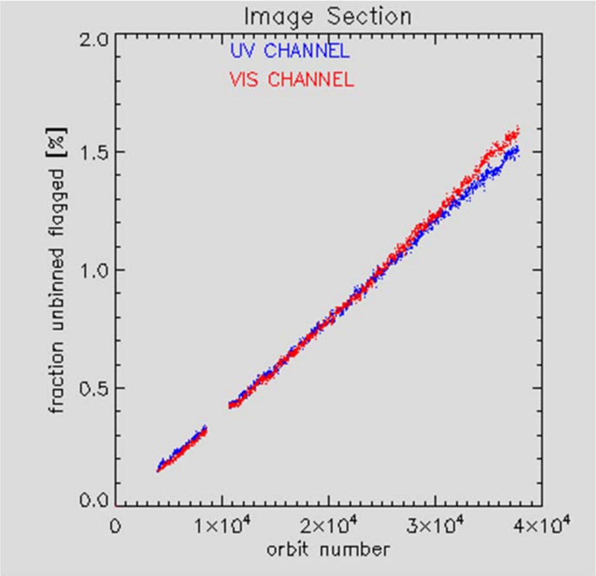


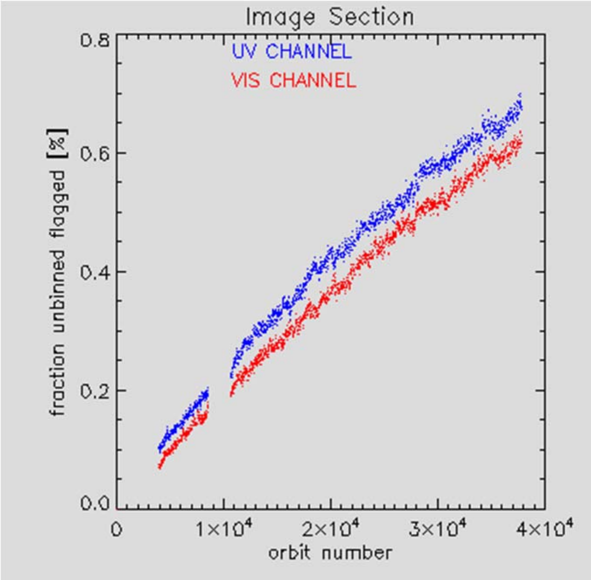

radiance

- spectral stability in general good
- folding mirror anomaly from 28/02/2006 and 11/06/2006
- row anomaly
- spectral calibration switched on in L01b processor

| | UV1 | UV2 | VIS |
|---|---|---|---|
| **trend** | **0.015 nm** | **0.001 nm** | **0.001 nm** |
| **seasonal** | **0.001 nm** | **0.001 nm** | **0.002 nm** |

# OMI inflight bad and dead pixels



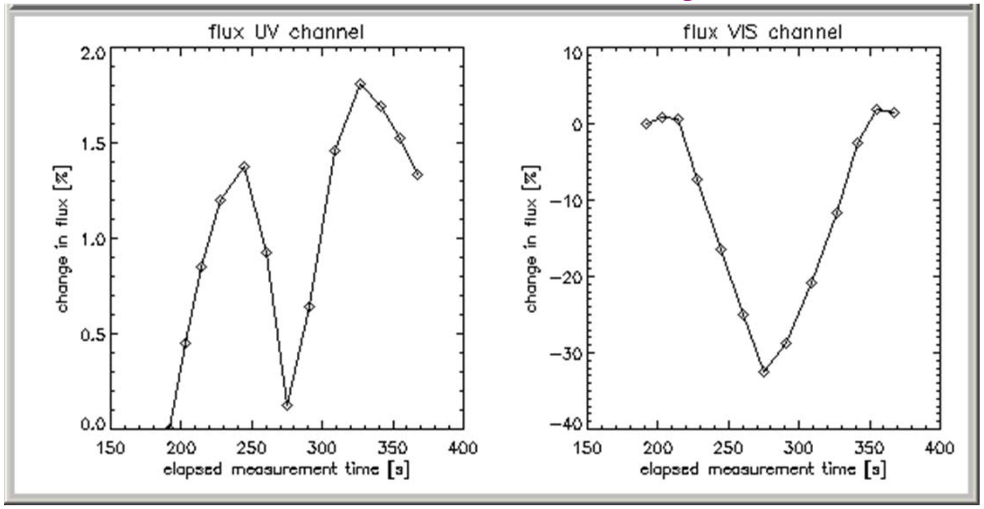

reduced performance pixels

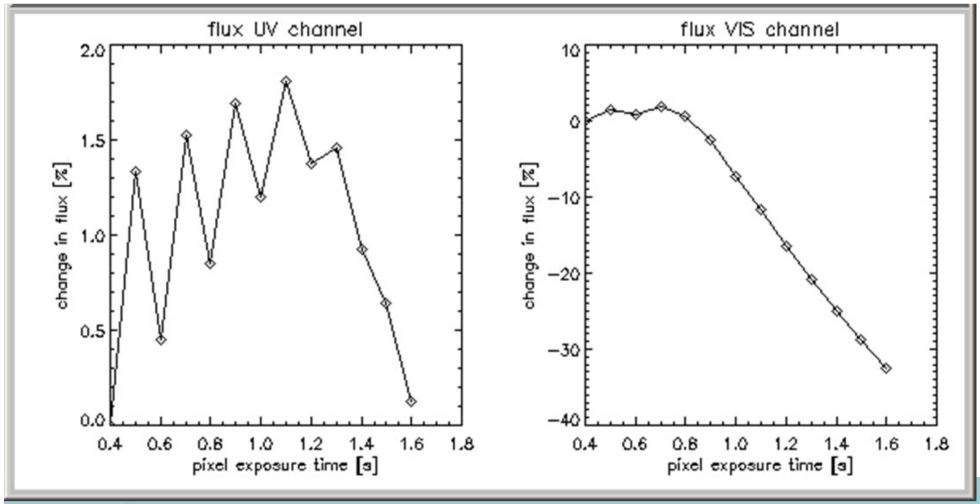
unusable pixels

- increased darkcurrent
- RTS
- reduced QE?

- lowered operational CCD temperature
- increased shielding ( 6 Kg aluminium)
- automatic daily updates of background images
- automatic updates of pixel quality maps

# OMI WLS stability

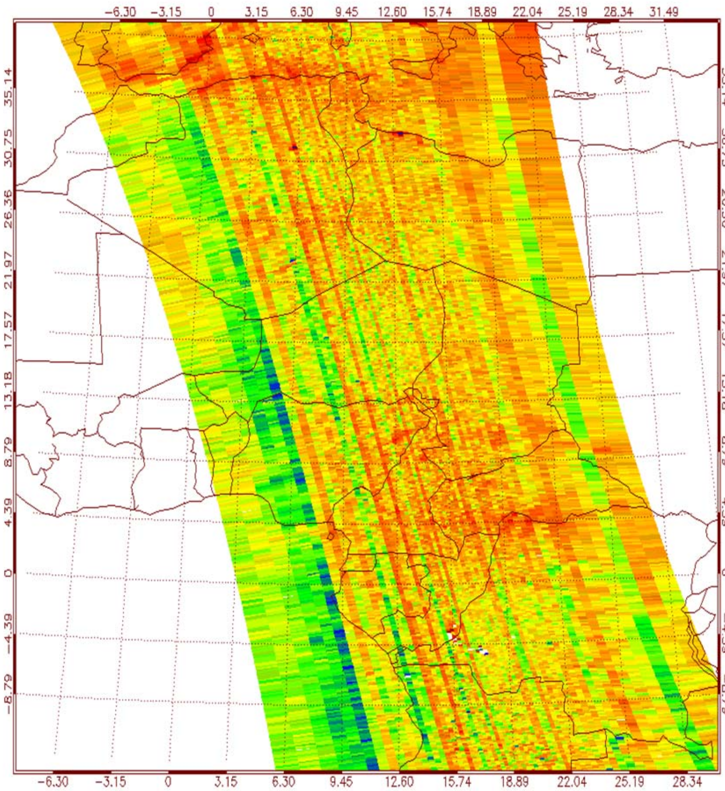


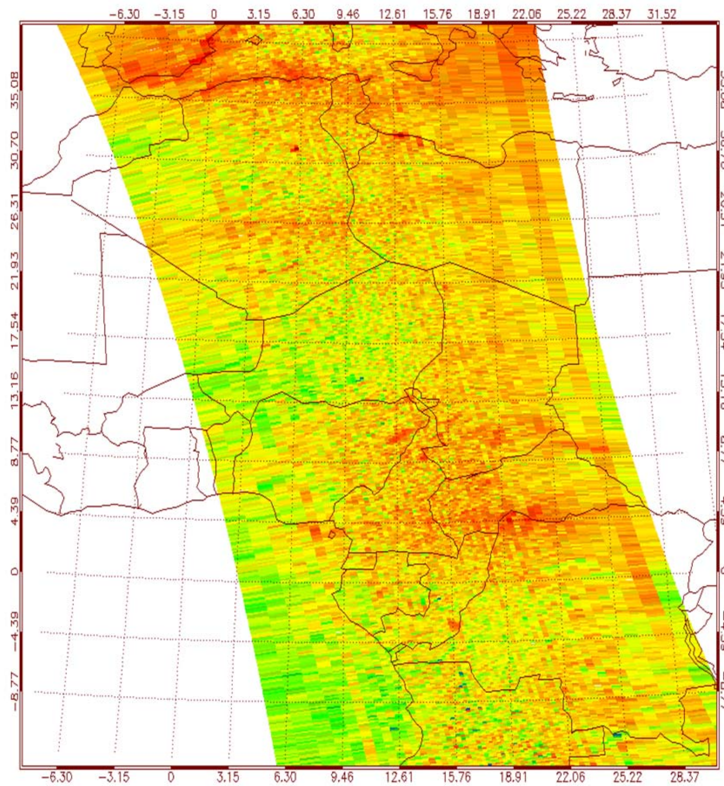




| sequence | Exposure time |
|---|---|
| 1 | 0.4 |
| 2 | 0.6 |
| 3 | 0.8 |
| 4 | 1.0 |
| 5 | 1.2 |
| 6 | 1.4 |
| 7 | 1.6 |
| 8 | 1.5 |
| 9 | 1.3 |
| 10 | 1.1 |
| 11 | 0.9 |
| 12 | 0.7 |
| 13 | 0.5 |

# OMI along track stripes

## Caused by random errors becoming systematic



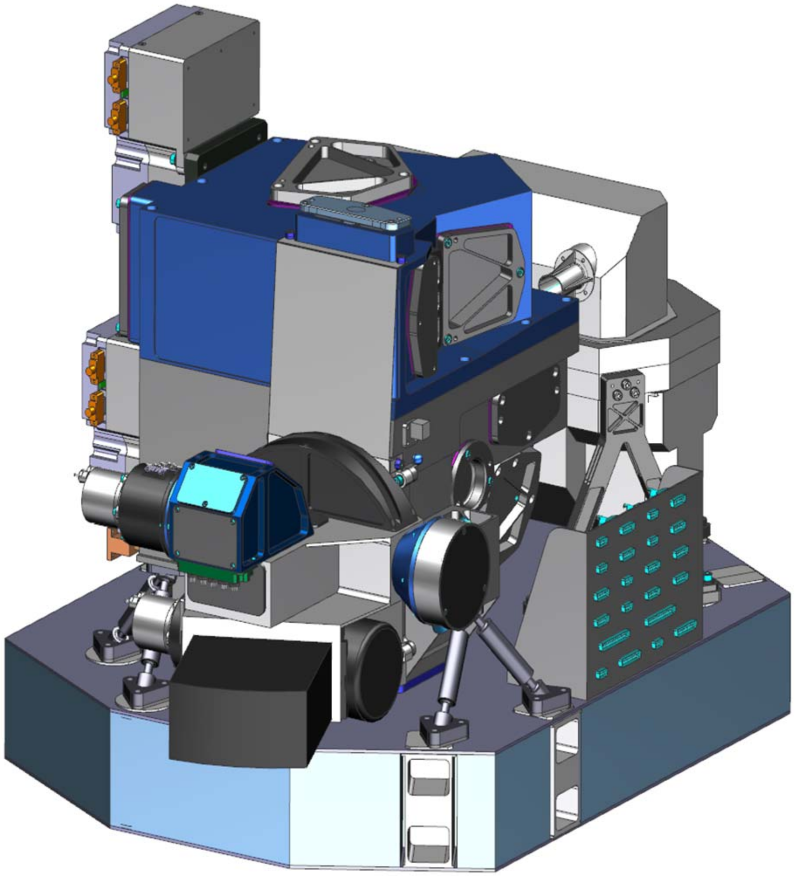
# OMI achievements

- OMI successfully demonstrates the use of 2-D detectors for nadir-viewing solar backscatter spectrometers.
- The optical degradation is the lowest of UV instruments launched.
- The wide angle telescope, the polarization scrambler and the QVD solar diffuser were all successful.
- Measurement of the instrument spectral response (slit) function was successfully performed and has preference over gas cell measurements.
- Effects of detector degradation (RTS effects) should be decreased by frequently updating dark current maps and lowering the detector temperature.
- Solar irradiance measurements and other calibration measurements should have a SNR much higher than the radiance data to avoid stripes in the data products

# OMI lessons learned

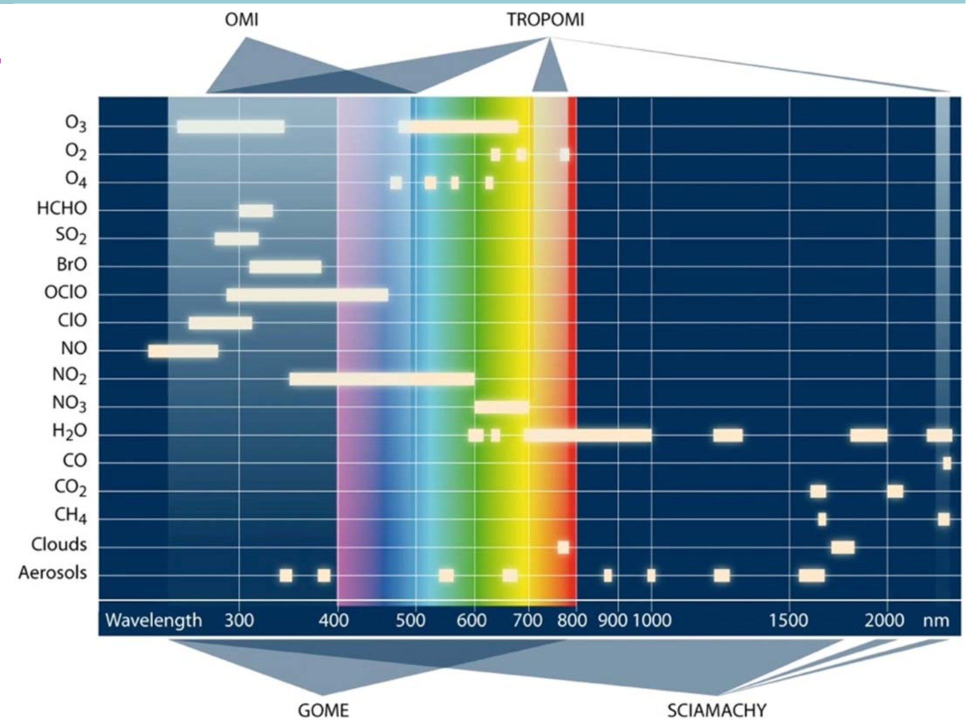
- use identical diffusers
- improve heater control for thermal stability
- Stabilize OBM thermally
- row anomaly attributed to MLI rupture
- room temperature calibration + delta = bad idea
- radiation damage to CCD's must be reckoned with
- trend monitoring and OPF updates using TMCF
- close interaction between operations, calibration and L2 scientists
- decontamination in early commissioning phase
- instrument heated during launch
- WLS not stable – long term – short term

# the TROPOMI program



| | |
|---|---|
| **Program management** | NSO / ESA |
| **Financed by** | NSO |
| **Prime contractor** | Dutch Space |
| **subcontractors** | TNO, various european subco's |
| **L01b data processor** | KNMI |
| **onground calibration** | KNMI (definition)<br>Dutch Space (execution) |
| **operations** | KNMI |
| **inflight calibration** | KNMI / SRON |

# the TROPOMI instrument


| detector | UV | | UVIS | | NIR | | SWIR | |
|---|---|---|---|---|---|---|---|---|
| type | CCD | | CCD | | CCD | | CMOS | |
| detector columns | 1024 | | 1024 | | 1024 | | 1024 | |
| detector rows | 1024 | | 1024 | | 1024 | | 256 | |
| band | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| detector binning factor | 16 | 4 | 4 | 4 | 4 | 4 | 1 | 1 |
| spatial pixels | 72 | 260 | 260 | 260 | 260 | 260 | 256 | 256 |
| spatial sampling [km] | 7 x 28 | 7 x 7 | 7 x 7 | 7 x 7 | 7 x 7 | 7 x 7 | 7 x 7 | 7 x 7 |
| spectral pixels | 385 | 385 | 470 | 470 | 512 | 512 | 512 | 512 |
| spectral range [nm] | 270 - 300 | 300 - 320 | 300 - 400 | 400 - 500 | 675 - 725 | 725 - 775 | 2305 - 2345 | 2345-2385 |
| spectral resolution [nm] | 1.0 | 0.5 | 0.55 | 0.55 | 0.5 | 0.5 | 0.25 | 0.25 |
| spectral sampling [nm] | 0.065 | 0.065 | 0.2 | 0.2 | 0.1 | 0.1 | 0.1 | 0.1 |
| minimum signal to noise | 100 | 100 -1000 | 1500 | 1500 | 500 | 100 - 500 | 100 | 100 |

# Lessons learned incorporated in TROPOMI (1)

- better heater control
- OBM thermal stabilized
- no MLI in front of primary mirror field of view [row anomaly]
- close interaction between operations, L01b, OCAL, ICAL calibration and L2 people
- CCD used in NIMO to prevent RTS due to radiation damage
- no ALU diffusers, 2 identical QVD diffusers
- WLS and LED in calibration unit [alternative for WLS]
- LED's for all detectors [better short term stability]
- Laser diodes for ISRF monitoring in SWIR [ice layer]
- operations baseline seasonal independent and  optimized for trend monitoring
- aluminum platform [water vapour]

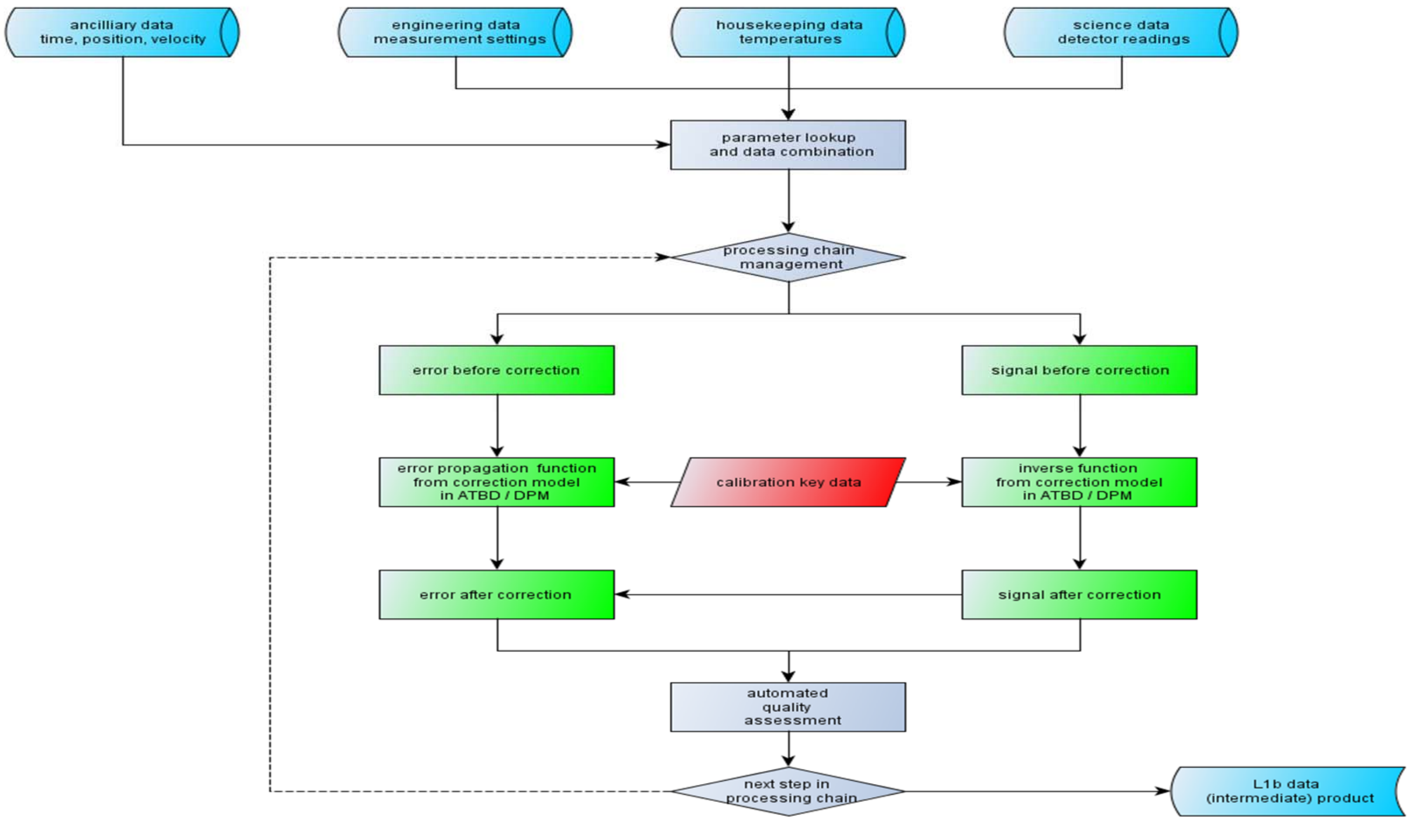
# Lessons learned incorporated in TROPOMI (2)

- verification of onground calibration
- validation of accuracy of calibration vs requirements
- tools to monitor the calibration process
- calibration rehearsal
- formal error propagation
- CKD errors not taken into account
- L01b data processor not used during OGC
- flight representative conditions
- calibration definition by PI institute, execution under industry responsibility
- One-team approach to l01b / onground calibration and inflight calibration
- 2 axis turn – tilt cradle in vacuum facility
- No vacuum breaks during calibration [only 1]

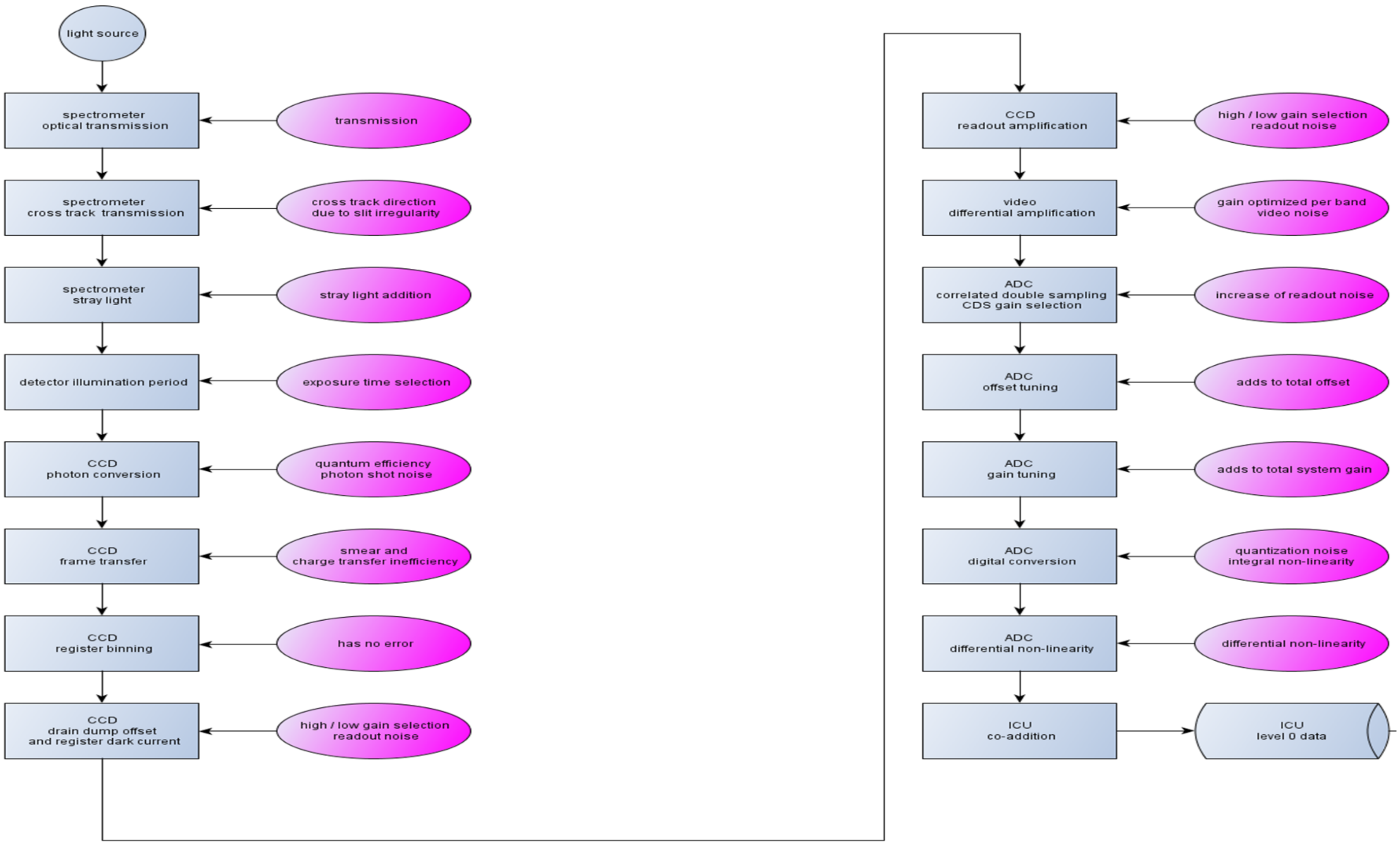
# TROPOMI calibration approach

- closed loop employment of L01b data processor
- formal error propagation
- include calibration errors in accuracy (signal, variance, noise)
- error propagation including CKD accuracy
- L01b algorithms and calibration algorithms developed together
- one-team approach
- install calibration board
- closed loop testing (end to end) for systematic and random errors
- verify calibration progress
- validate CKD accuracy

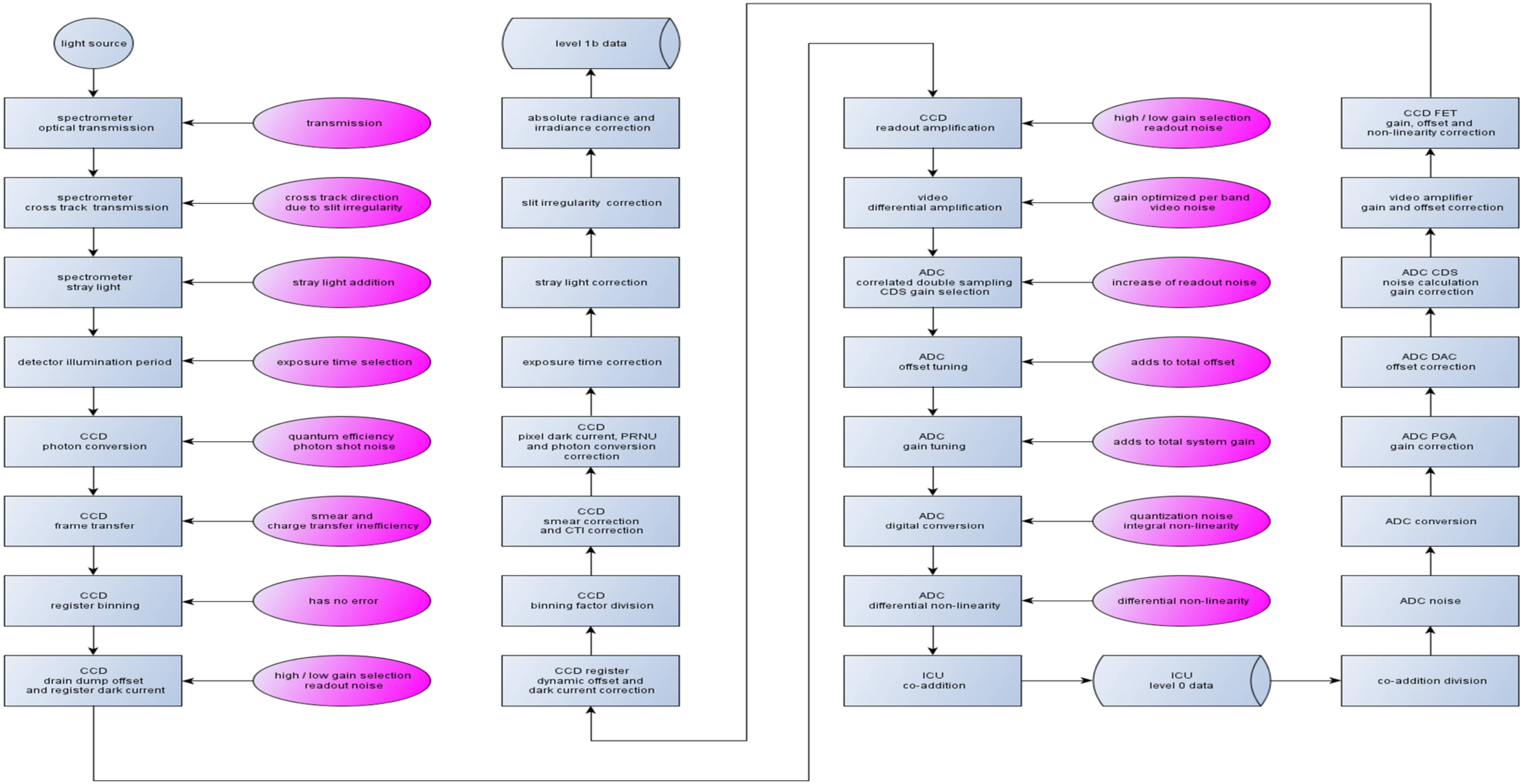
# L01b data processing and key data



# L01b forward processing flow



# L01b reverse processing flow

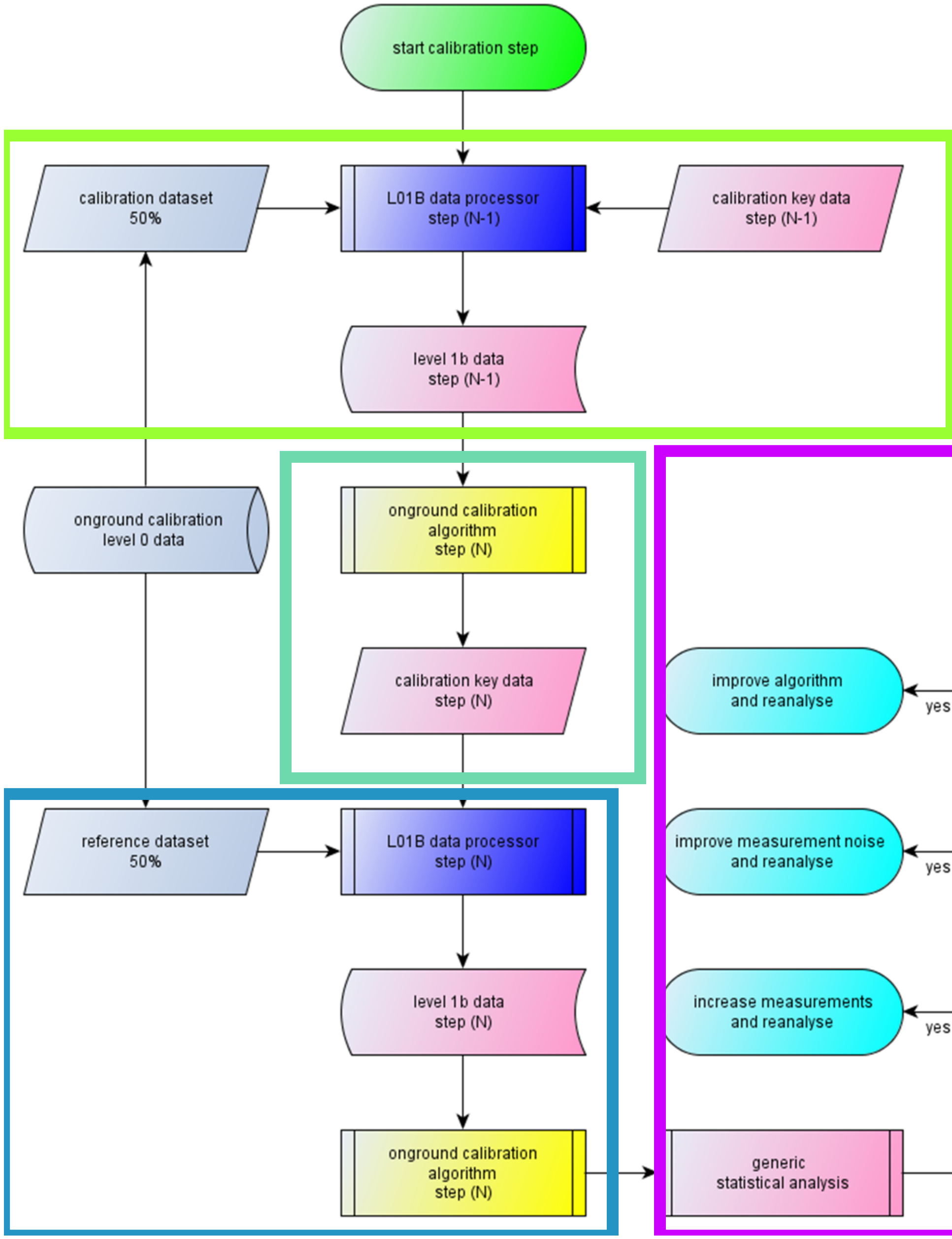


# Integral calibration, validation and verification

- Plan calibration in order of L01b reverse model order
- Preprocess calibration data with L01b production processor
- Correct all steps before the current step
- Include error propagation of noise and variance including the error in the calibration key data used
- Calculate the next key data
- Verify this key data with a separate test data set
- Use key data for postprocessing
- Check for systematic errors
- Check for error compliance

- Next step

# calibration validation

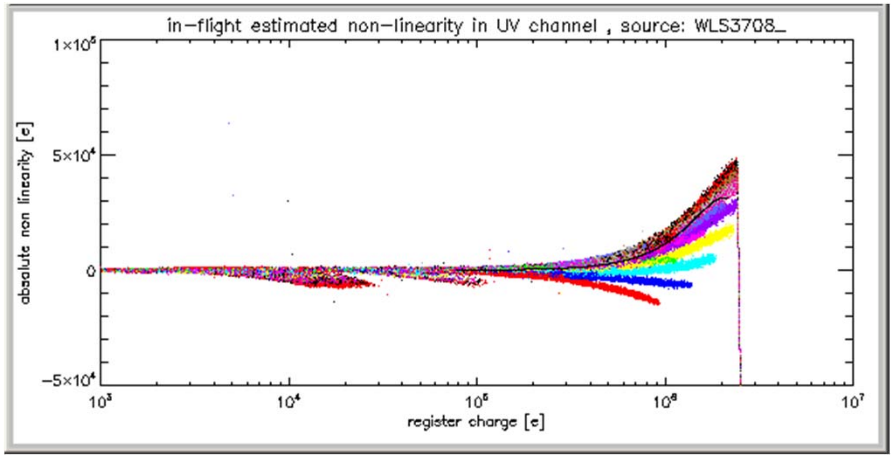



1. preprocessing
2. CKD derivation
3. verification / validation
4. problem resolving

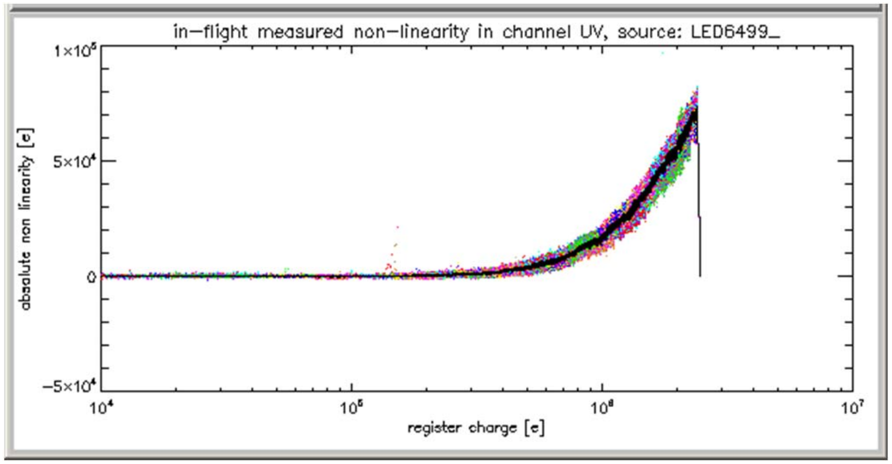
# TROPOMI calibration validation

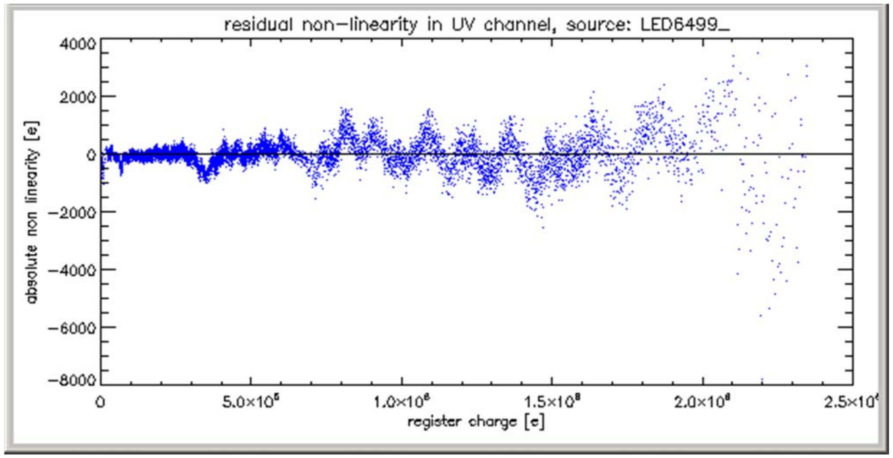
- first validate L01b reverse model software implementation (SValP)
- then validate consistency between L01b processor and real measurements made with instrument (on data)
- then validate noise and uncertainties against SRD requirements using error budgeting and propagation in L01b. (on data)
- also validate onground zenith sky measurements
- inflight validation of geolocation and solar irradiance

# OMI issues we try to avoid (nonlinearity)

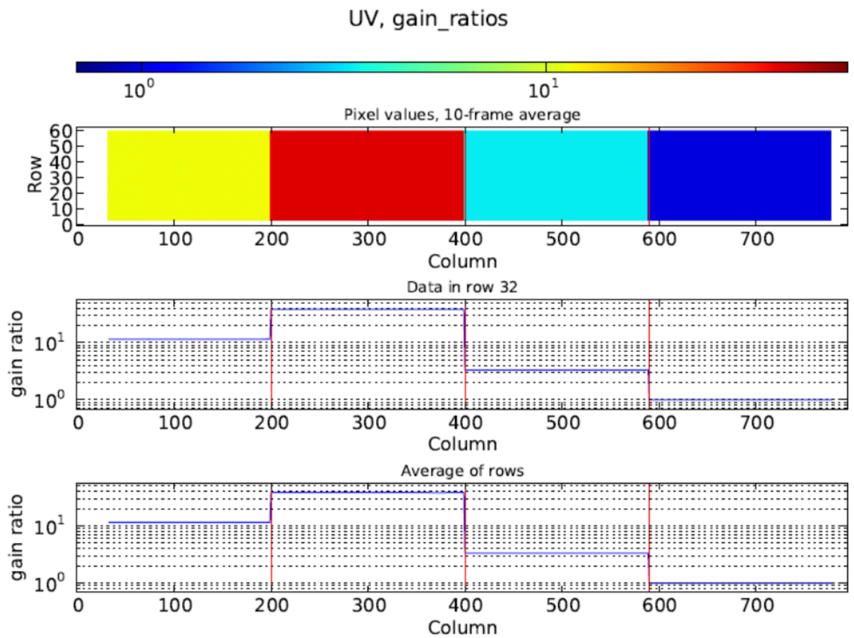



- nonlinearity very sensitive to drift
- residuals show errors in measurement setup
- residuals show systematic errors

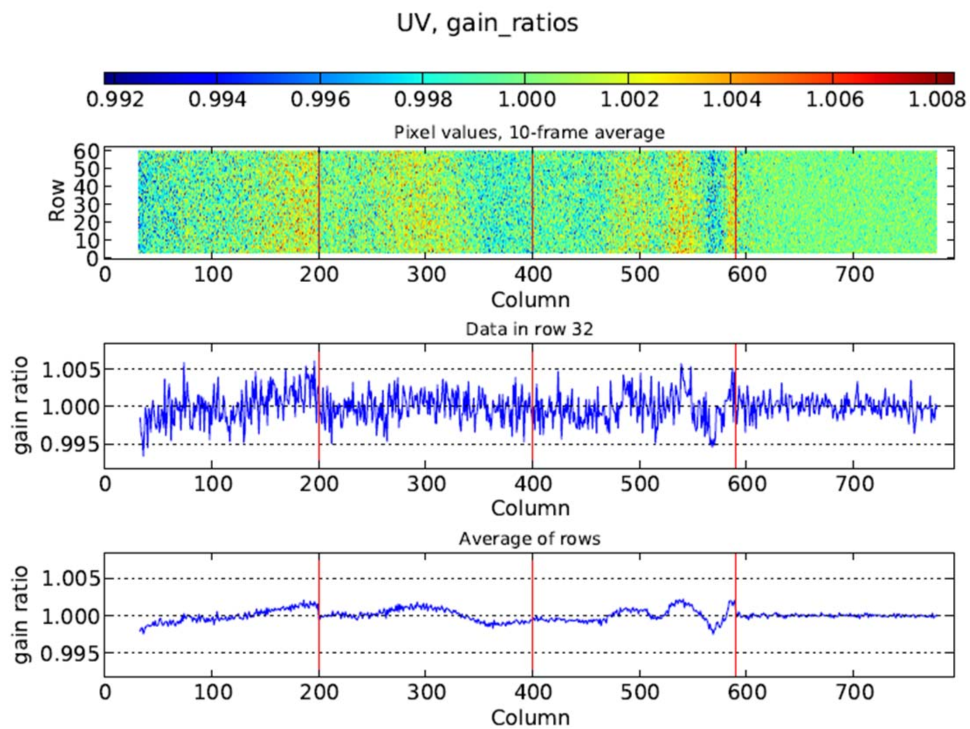


# OMI issue we try to avoid (gain)




- video chain gain switch in spectrum
- gain should be constant
- gain relative to default gain
- measurements with LED



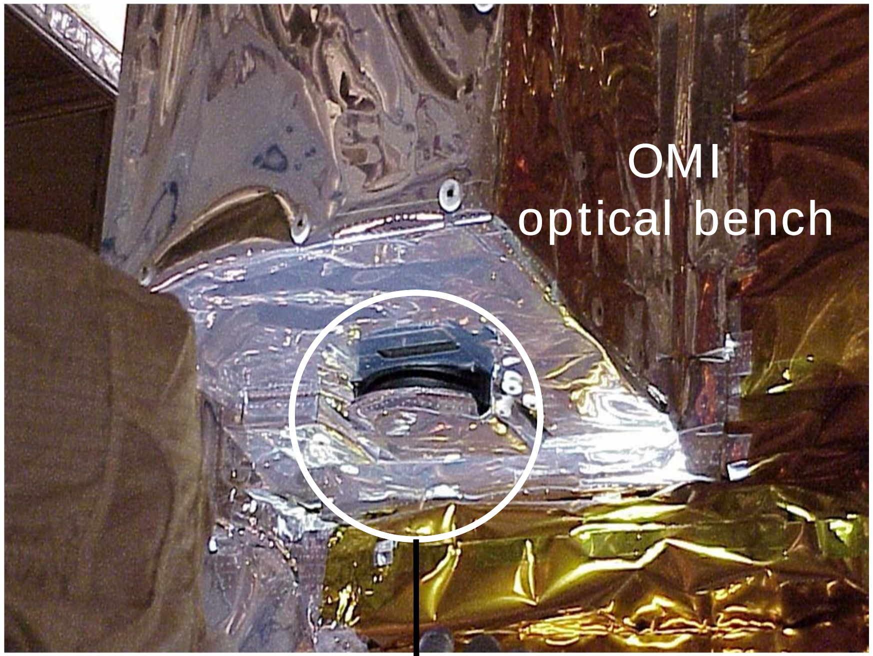

- measure gains
- derive key data
- correct for key data
- redo analysis

# TROPOMI challenges - conclusion

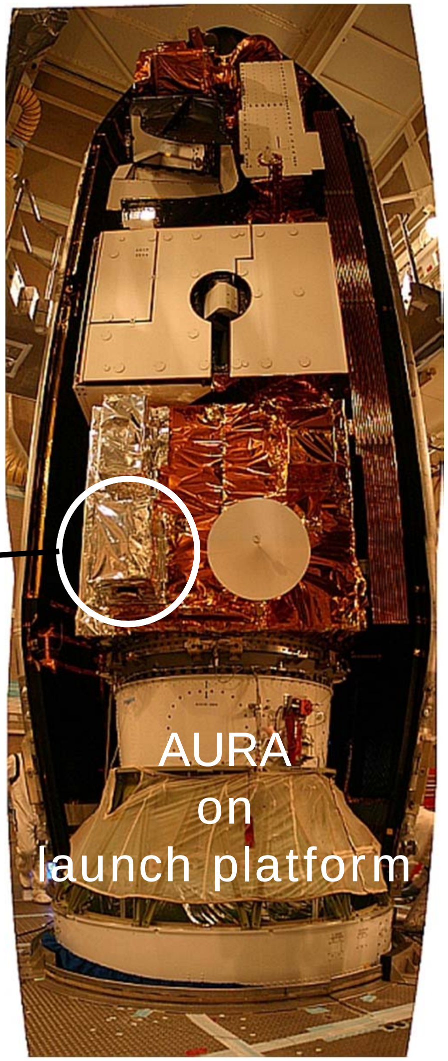
- Many lessons learned have been dealt with, but….
- challenging  straylight performance
- complex but versatile electronics UVN
- novel SWIR detector and module
- no QM / EM -> L01b reverse model difficult to define
- agile software approach needed to allow for late changes
- extensive planning and preparation for calibration needed
- large software effort
- onground calibration software must be developed beforehand
- 2 axis turn/tilt cradle available, but no translate function, very good knowledge of attitude needed.
- vacuum breaks unavoidable
- tight schedule

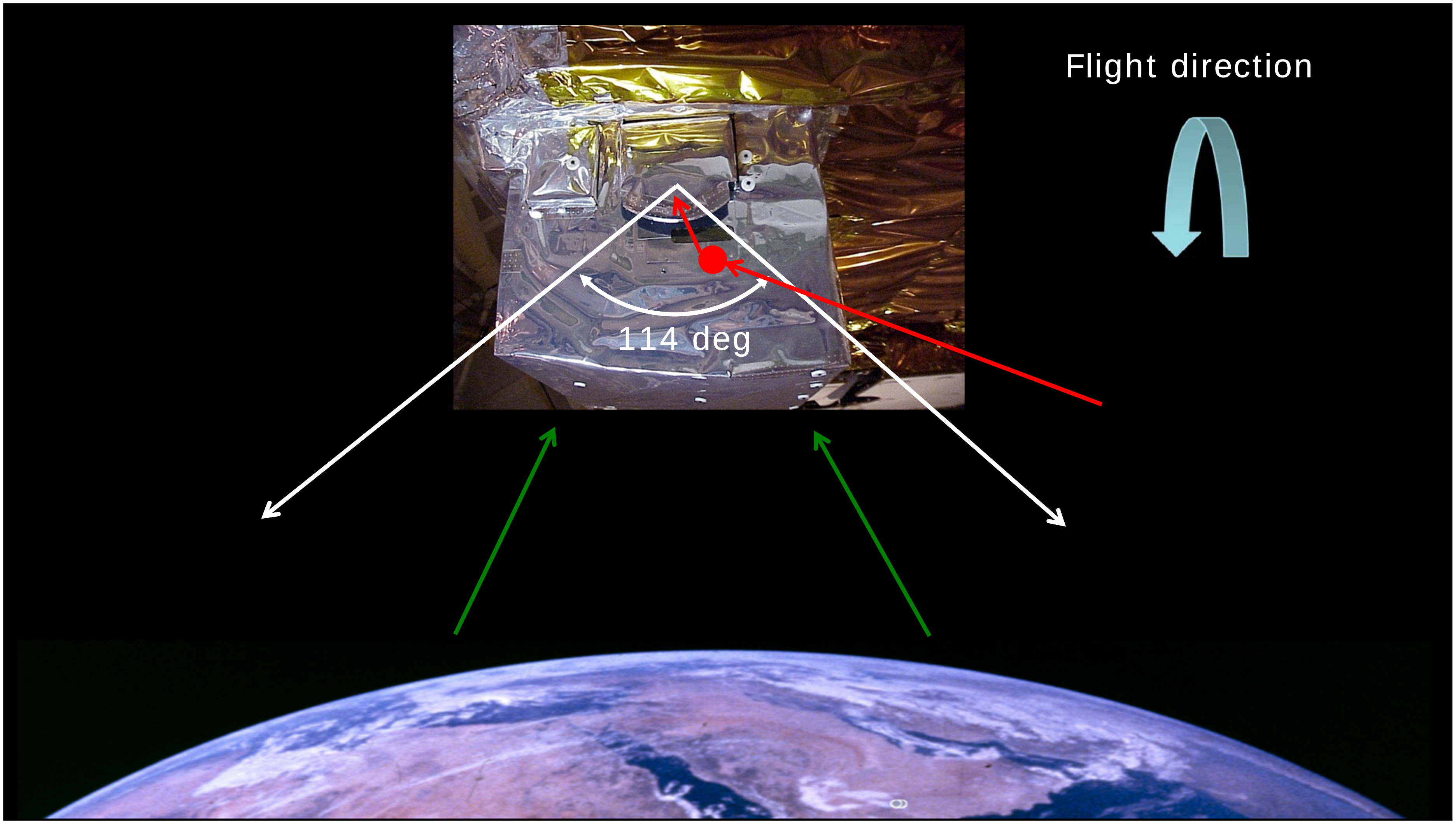
# Backup slides

# Possible cause of row anomaly




nadir port




Flight direction
114 deg

## INSTRUMENT

- Row anomaly behaviour changes on short-term as well as long-term timescales.
- Row anomaly is automatically monitored on a daily basis using L1b data.
- Using monitoring results, a Look-up Table is maintained which defines the ground pixels that need to be flagged for the row anomaly.
- About 40 % of the ground pixels is now impacted by the row anomaly.