The 3MI Instrument onboard MetOp Second Generation

Living Planet Symposium 2022

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[2] Leonardo, Business Space, Firenze, Italy

[3] Airbus Defence and Space , Toulouse, France

[4] EUMETSAT, Darmstadt, Germany

Monitor Global Change

Aerosol

Volcano Sarychev Peak on Matua Island June 2009 from ISS

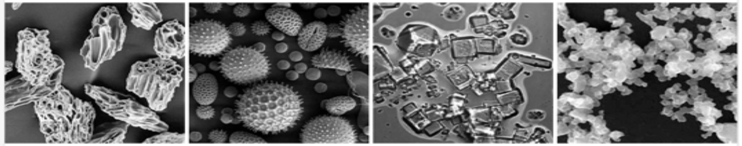
Wilde Fire producing CO from burning biomass

Nitrogen Oxides released by burned fossil fuels

Desert Storm over Sahara
Taken by A. Gerst ISS Blue Dot mission May 2014

Aerosol Composition

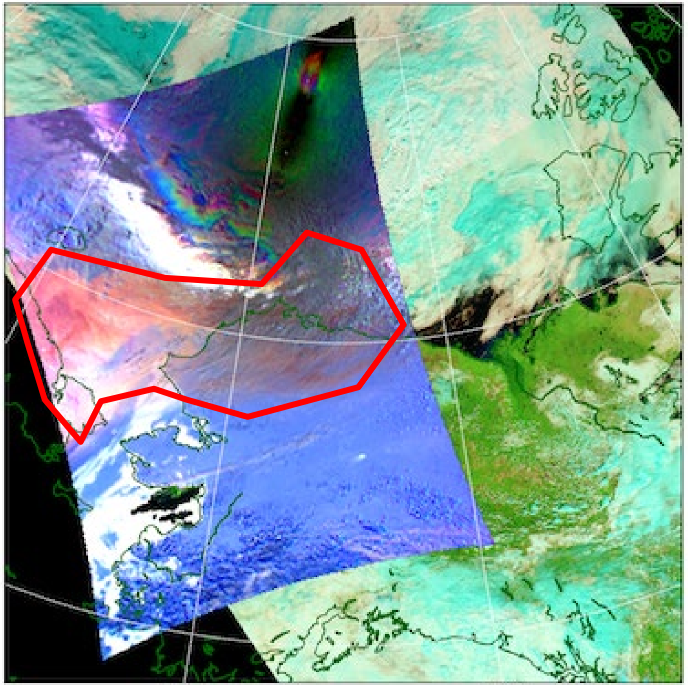
Volcanic ash | *Pollen* | *Sea salt* | *Soot*



Pollen

Monitor Global Change

Aerosol

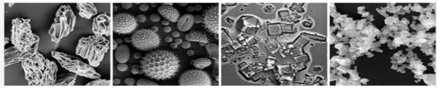
70°N
60°N

160°W 140°W

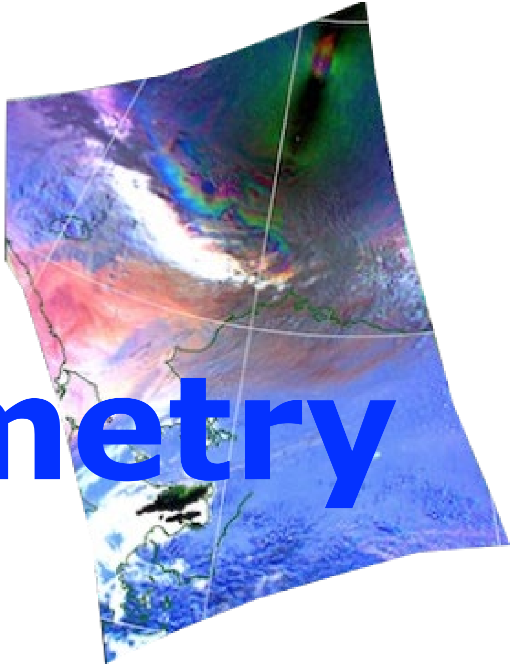
Polarization composite view from POLDER3/PARASOL (CNES mission)
Superimposed to MODIA/AQUA true color composite

Polarimetry

Aerosol Composition

Volcanic Ash | Pollen | Sea Salt | Soot





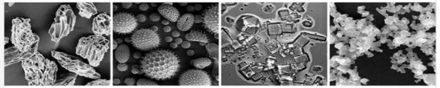
POLDER3/PARASOL (CNES mission)
(December 2004 - December 2013)

Polarimetry

Aerosol

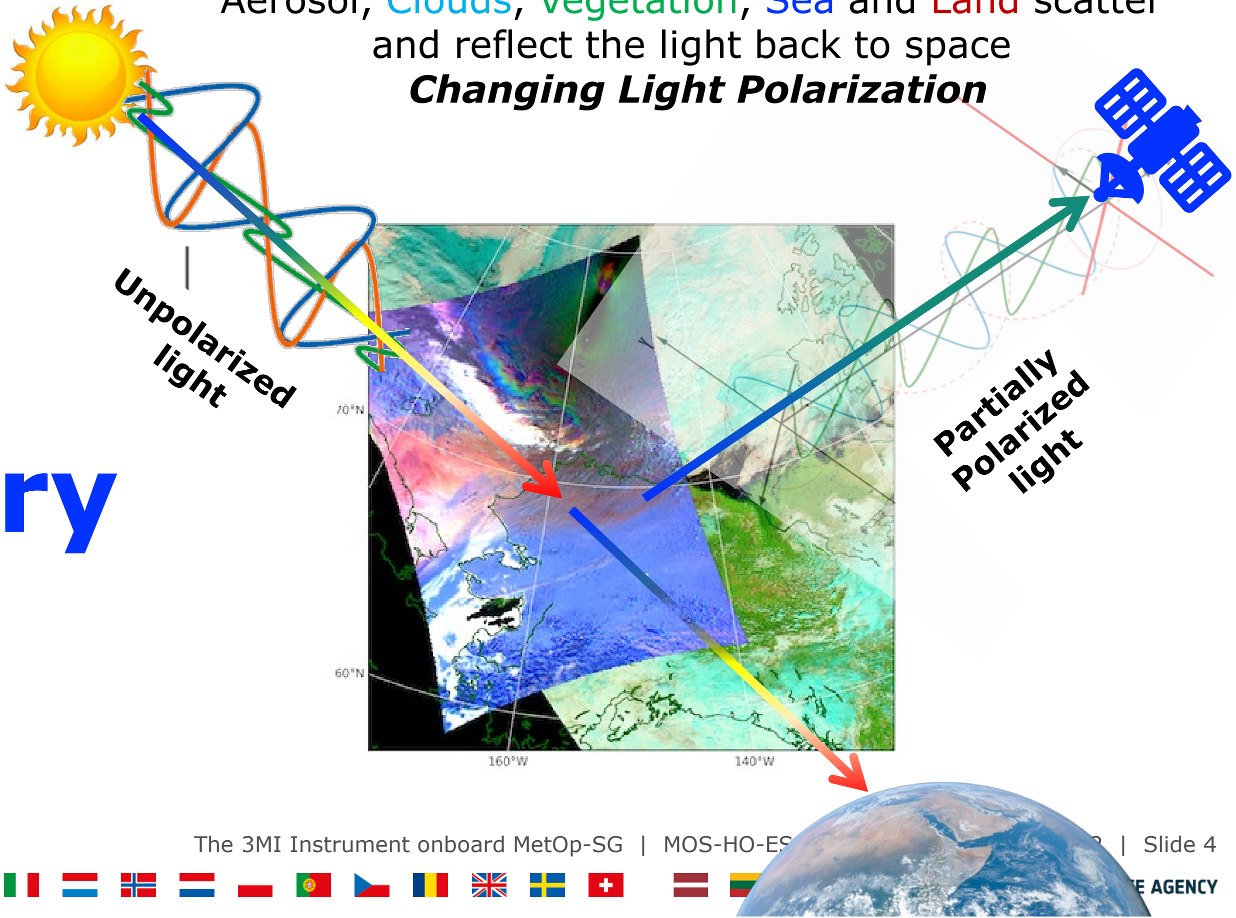
Polarimetry

Aerosol Composition



Aerosol, Clouds, Vegetation, Sea and Land scatter and reflect the light back to space

Changing Light Polarization



Polarimetry

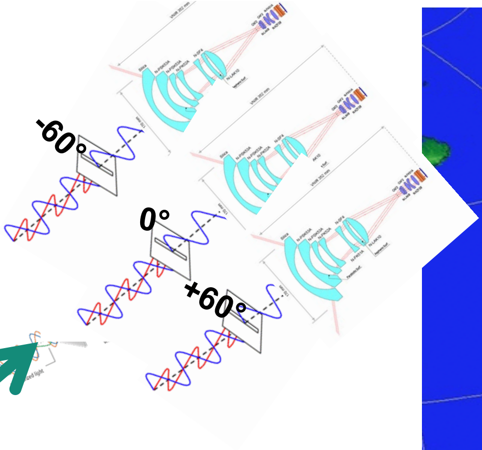
Polarimetry → Stockes Vector

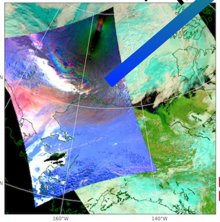
$$\begin{pmatrix} I_{k,\ell,p} \\ Q_{k,\ell,p} \\ U_{k,\ell,p} \end{pmatrix} = \frac{1}{G_k \, t_k \, A_k} M^{-1} \begin{pmatrix} X_{k,1,\ell,p} \\ X_{k,2,\ell,p} \\ X_{k,3,\ell,p} \end{pmatrix}_{Cor}$$

Channel K; Pixel l,p; Gain G; Integration Time I; Absolute Calibration A

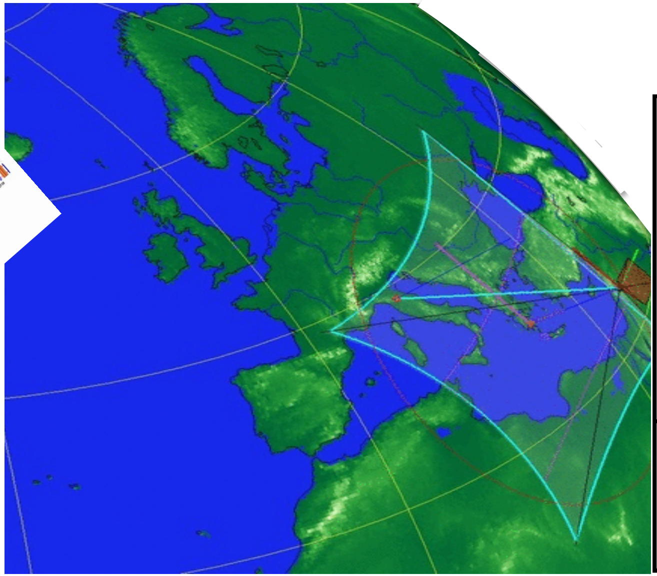
X digital counter for:
- Channel k
- Polarisation 1 (-60°), 2(0°) ,3(+60°)
- Pixel l,p

Multi Polarization





Multi View



Multi Channel

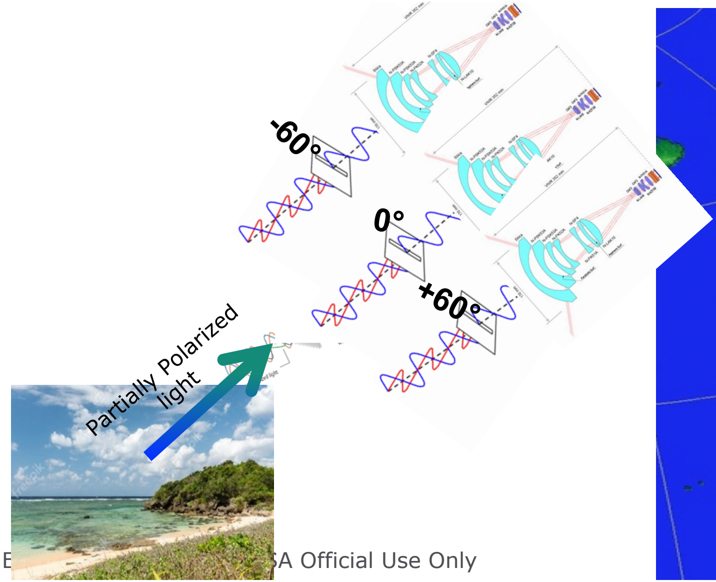
	Channel	Central Wavelength [µm]	Channel Spectral Width [µm]	Pol
VNIR	3MI-2	0.410	0.02	Y
VNIR	3MI-3	0.443	0.02	Y
VNIR	3MI-4	0.490	0.02	Y
VNIR	3MI-5	0.555	0.02	Y
VNIR	3MI-6	0.670	0.02	Y
VNIR	3MI -7	0.763	0.01	N
VNIR	3MI -8	0.765	0.04	N
VNIR	3MI -9	0.865	0.04	Y
VNIR	3MI-9a	0.910	0.02	N
SWIR	3MI -10	1.370	0.04	Y
SWIR	3MI -11	1.650	0.04	Y
SWIR	3MI -12	2.130	0.04	Y

Polarimetry and 3MI operative principles

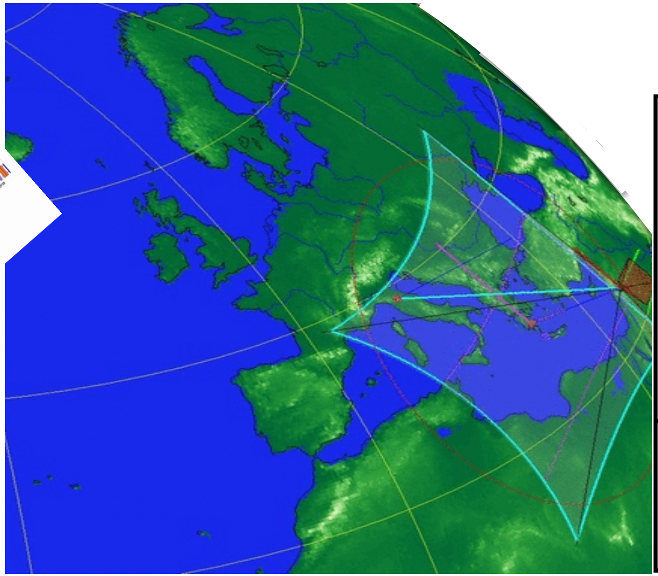
3MI dedicated to **Aerosol Characterisation** for:

- *Primary Objective*: Climate monitoring, Air quality monitoring and forecasting, NWP
- *Secondary Objective*: Cloud microphysics characterization and Surface BRDF/BPDF

Multi **P**olarization



Multi **V**iew



Multi **C**hannel

	Channel	Central Wavelength [µm]	Channel Spectral Width [µm]	Pol
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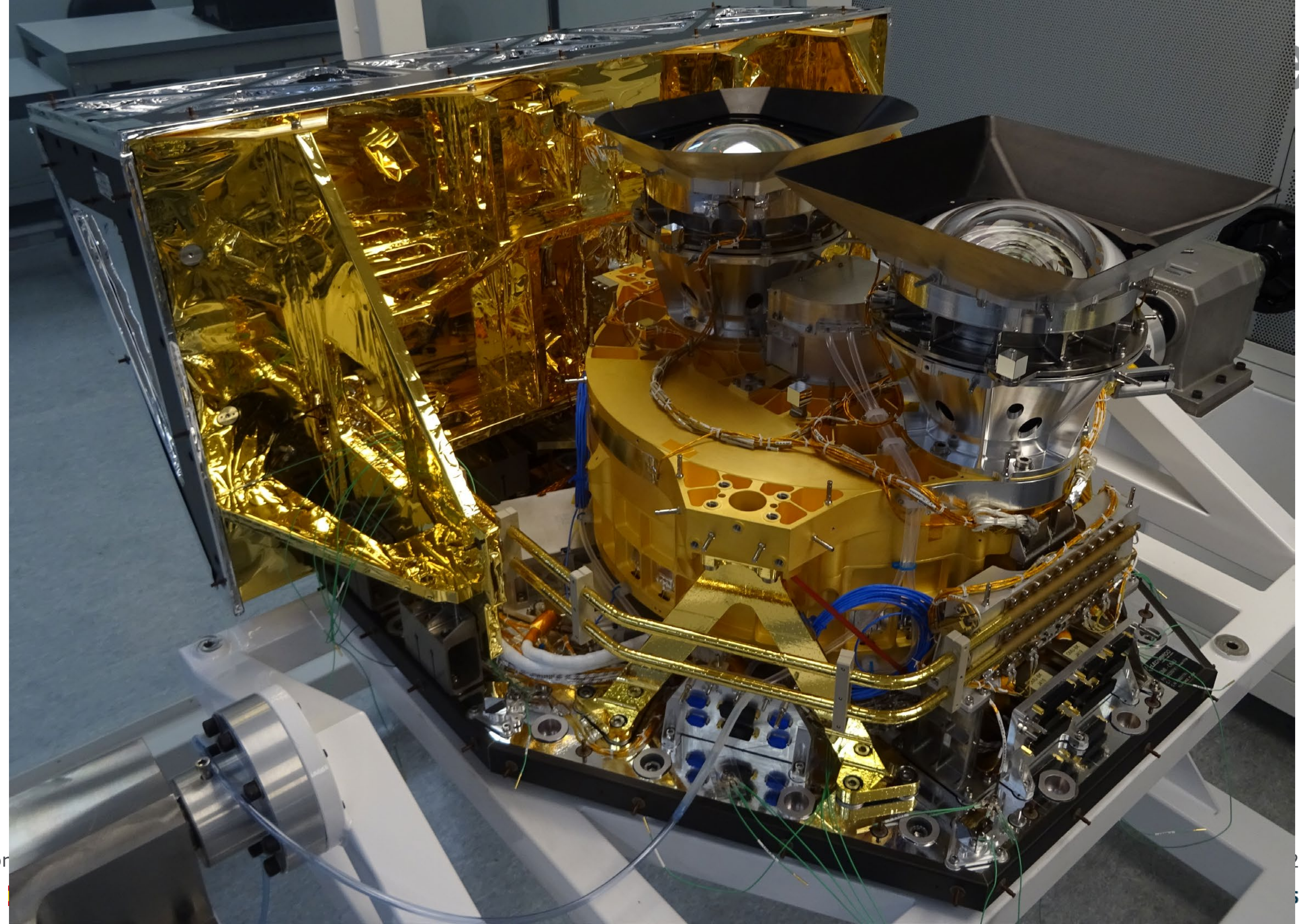
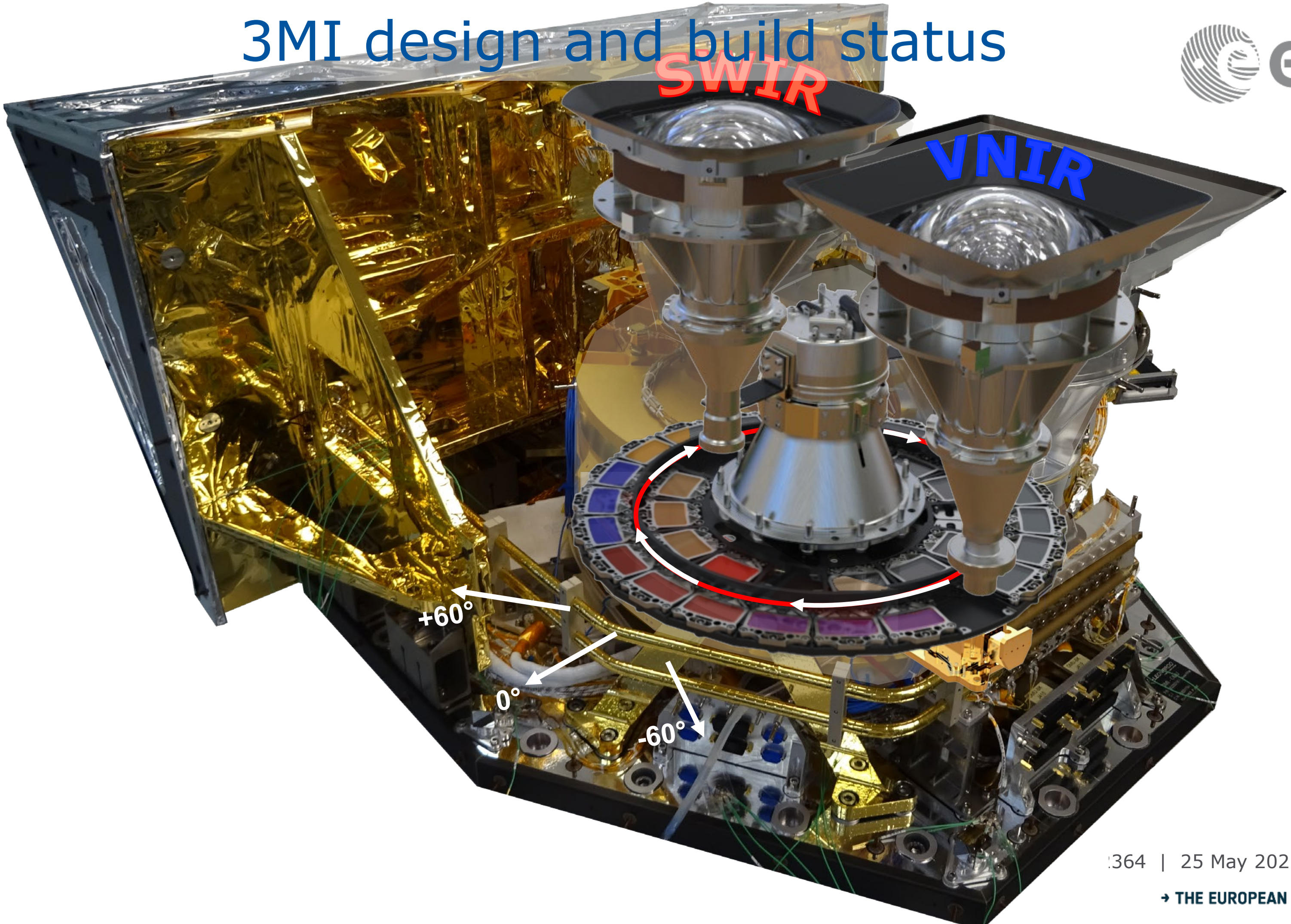
3MI

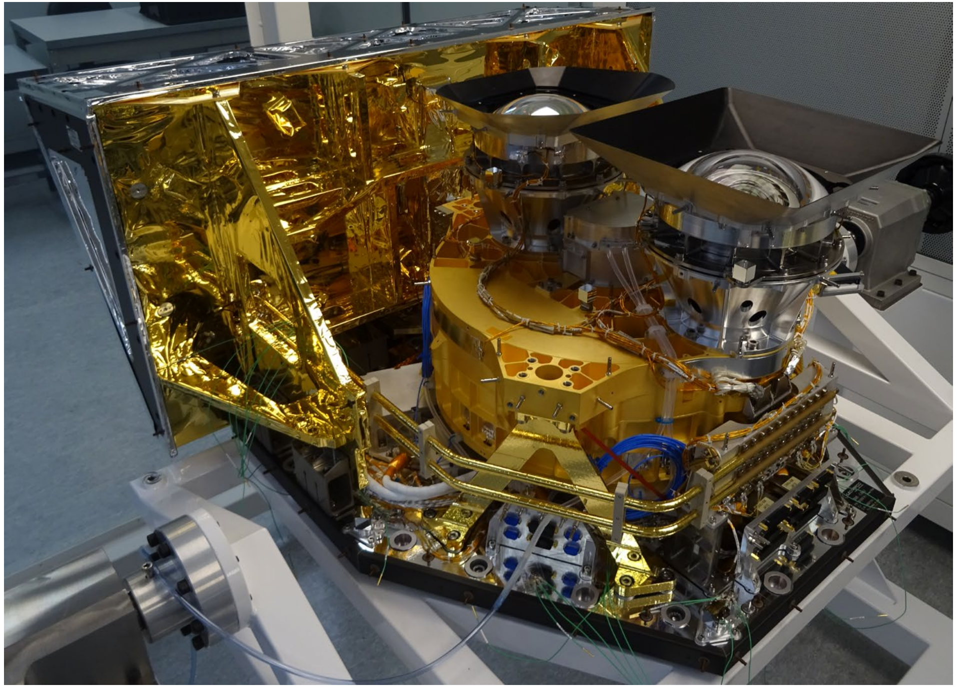


3MI design and build status



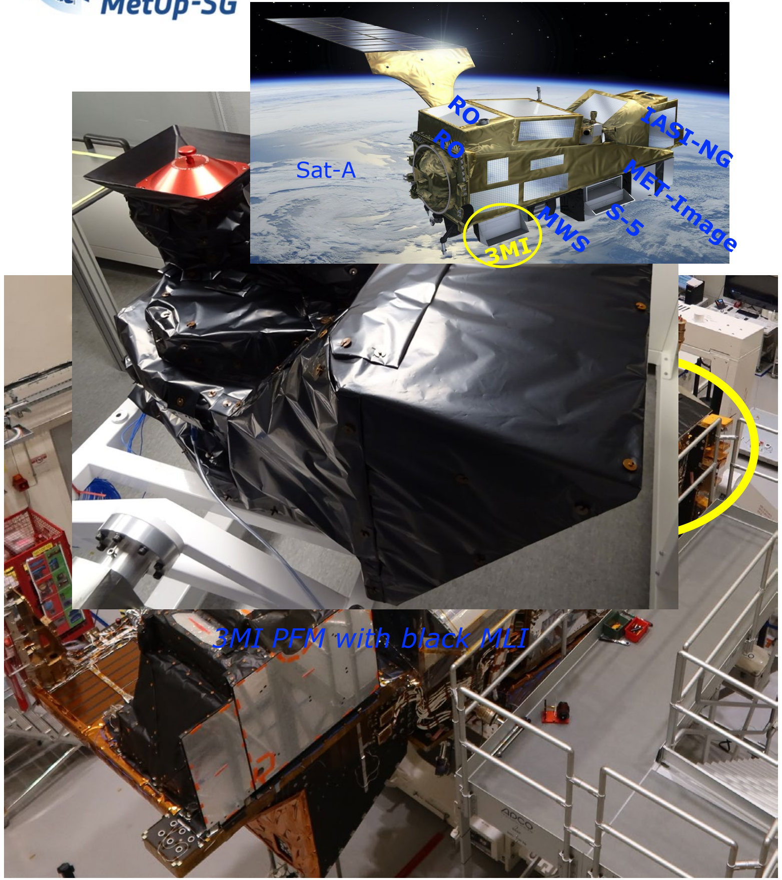
3MI design and build status

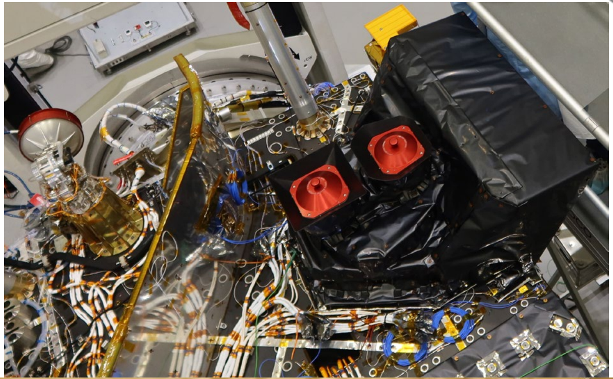
3MI PFM with black MLI

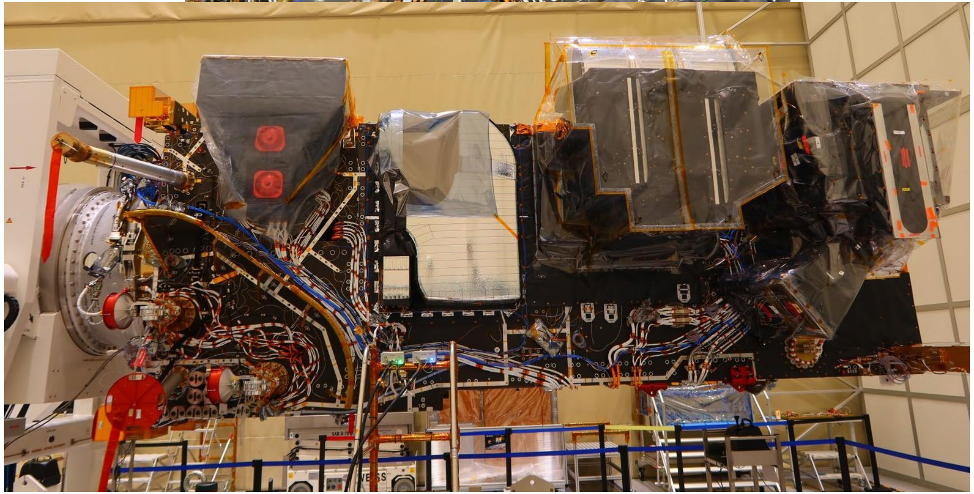


3MI PFM mounted on MGSE

3MI design and build status



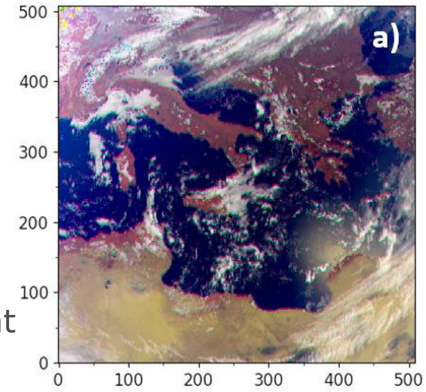




Instrument Performances

3MI is dedicated to **Aerosol Characterisation** for:

- *Primary Objective*: Climate monitoring, Air quality monitoring and forecasting, NWP
- *Secondary Objective*: Cloud microphysics characterization and Surface BRDF/BPDF

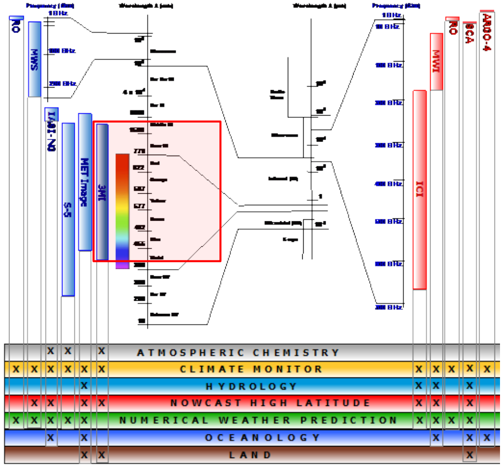


3MI does *not* have onboard calibration source therefore to reach 3MI's objectives:

- In-flight performances are based on the use of vicarious calibration, therefore on-ground calibration shall be achieved at the maximum possible accuracy
- Design and Performances stability for the 7.5 years of nominal mission is paramount

3MI *Design* and *On-Ground Calibration* shall guarantee:

- *Design* - Instrument short and long term stability:
  - Thermo-Mechanical
  - Radiometric Stability
  - Polarization Sensitivity & Orientation
- *On-Ground Calibration* - Instrument artefact correction:
  - Straylight (main challenge)
  - Linearity
  - Dark current and smearing
  - Flat field
  - Calibration database accuracy



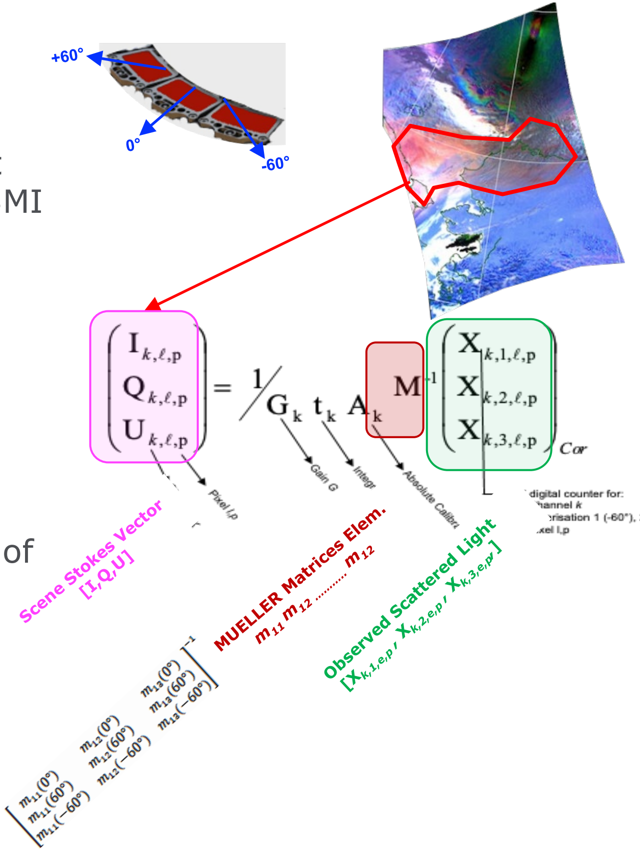
Instrument Performances

Polarization Sensitivity and Polarization Orientation

- To calculate **Scene Stokes Vector [I,Q,U]** it is necessary to perform at least three measurements with different polarization angles chosen for 3MI as **0°, -60° and +60°**

- To convert the **Observed Polarized Light [$X_{k,1,e,p}$, $X_{k,2,e,p}$, $X_{k,3,e,p}$]** to the Scene Stokes Vector [I,Q,U] the computation of the MUELLER matrix inversion is needed

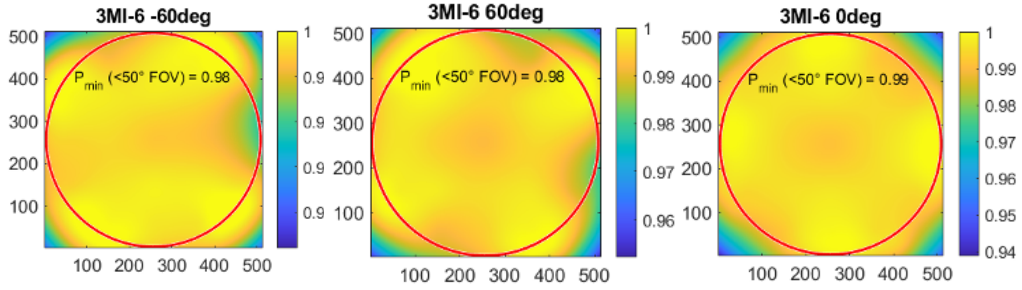
- To compute **MUELLER Matrices Element** requires a precise knowledge of absolute and relative polarization angles of each polarizer.

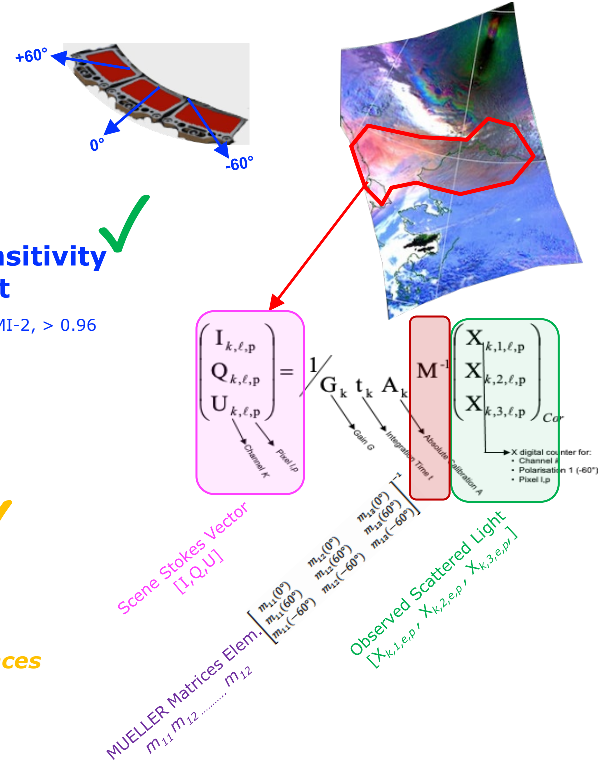


Instrument Performances

Polarization Sensitivity and Polarization Orientation

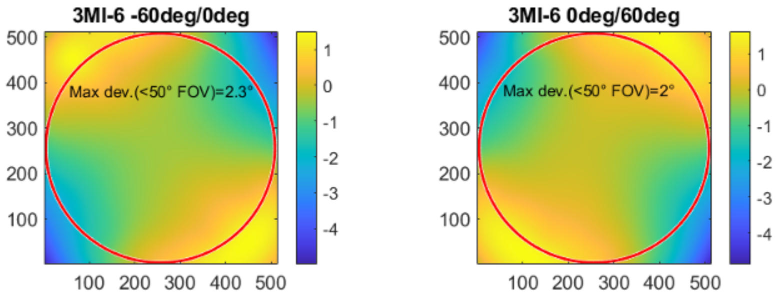
PFM Calibration campaign results





Polarization Sensitivity Compliant

Requirement: > 0.93 for 3MI-2, > 0.96

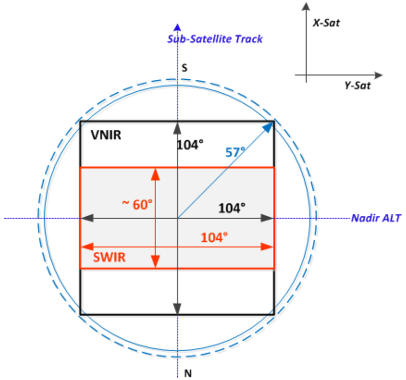


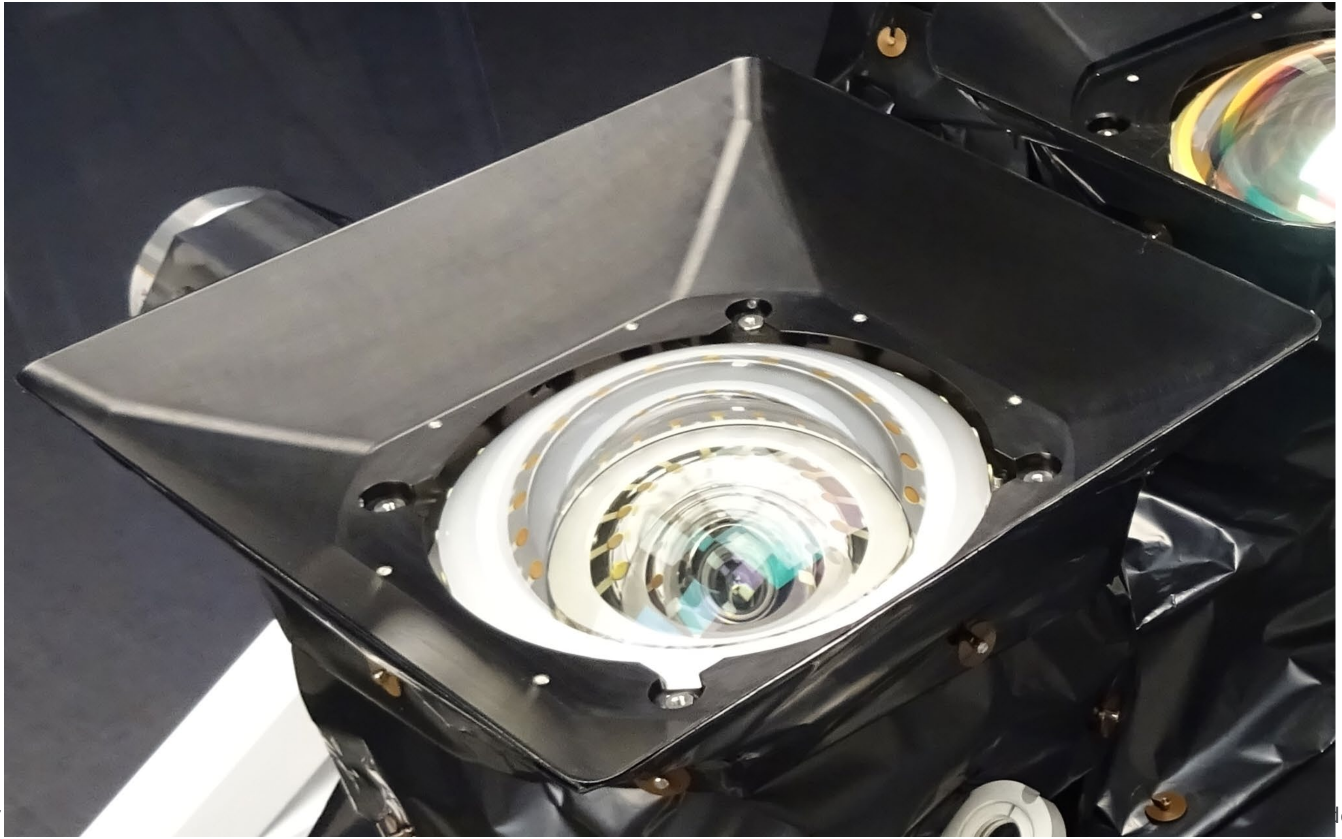
Relative Polar Orientation
Partially Compliant
No impact thanks to
Polar Orientation Knowledge Performances

Requirement: +/- 1 °

Instrument Performances

Straylight Characterization



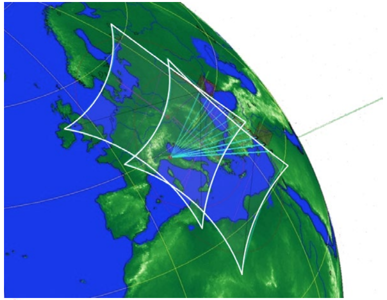


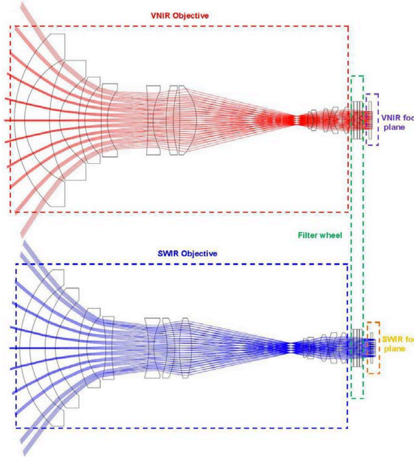
Instrument Performances

Straylight Characterization

Challenges:

- **3MI has a very large FoV VNIR ±50.30° SWIR ±31.15° x ±50.85°**
- Complex optical path with 7 lenses (2 aspheric) plus 5 in the focuser





- Straylight is corrected using the method of Spatial Point Source Transmittance (SPST) map
- An SPST map corresponds to the stray-light profile at detector level assuming a punctual field (point source) illumination of the instrument (i.e. collimated beam)

Full detail on SPST method and correction algorithm can be found in:
Stray-light calibration and correction for the MetOp-SG 3MI mission
L. Clermont, C. Michel, E. Mazy, C. Pachot, N. Daddi, C. Mastrandrea, Y. Stockman
SPIE 2018 proceeding volume paper 1070406

- Acquire SPST maps to compose a straylight correction database

To perfectly calibrate and correct straylight would be needed to calibrate 1 SPST map per each detector's pixels (field) per each of the 13 channels

- VNIR 512x512 = 262.144
- SWIR 256x512 = 131.072

= 30 sec x SPST x 33 filters slot = **2230 days**

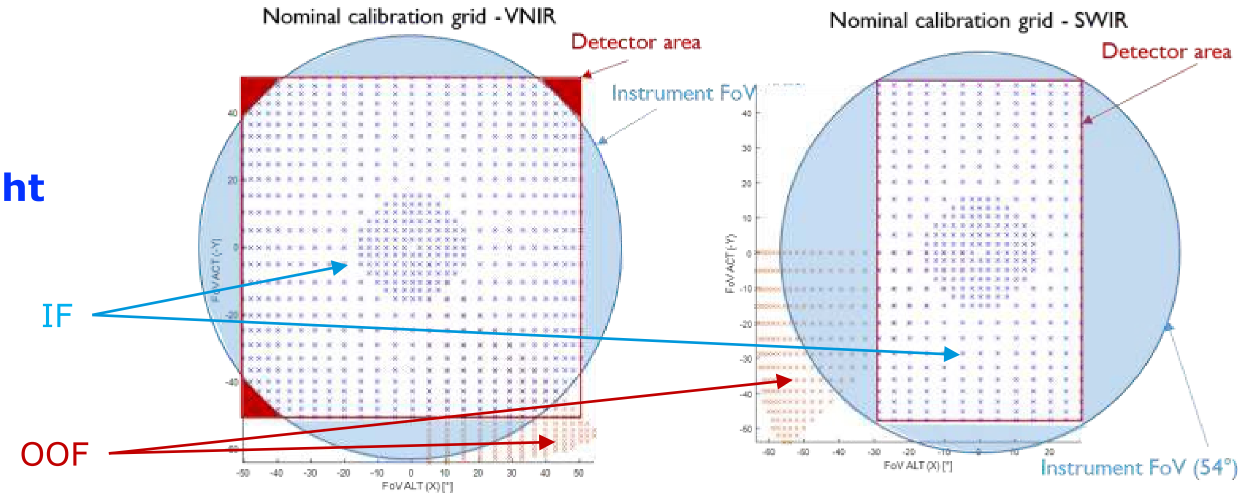
Impossible task due to measurement time and resulting size of correction database (PByte)

Instrument Performances

Straylight characterization

- Calibration Grid for SPST maps has been defined in order to interpolate calibrated SPST maps in the FOV dimension
- VNIR: 797 fields for In-field and 119 for OOF
- SWIR: 443 for In-field and 459 OOF

99% reduction of Stray Light characterisation time



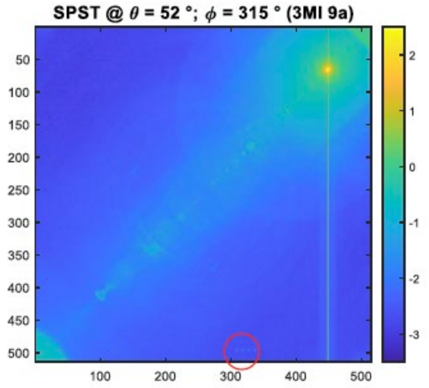
Instrument Performances

Straylight characterization

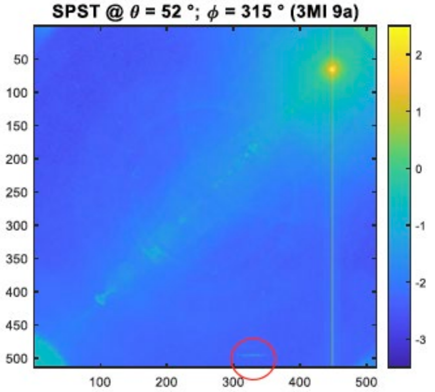
- With a *brutal force* method a scan of the first full lens per each of the Calibration Grid point would be needed
- "**S**tray-**L**ight **E**ntrance **P**upil" (SLEP) method has been developed
- The SLEP corresponds to the minimum area through which rays which are sent will result in straylight at the detector. This pupil is a function of wavelength and field of view

- The SLEP concept has been validated by 3MI EM measurements campaign and confirmed with PFM Calibration preliminary analysis
- No additional SL feature from 3MI have been detected performing measurements with the full spatial scan instead of the SLEP
- Full spatial scan would also introduce more noise as well as more SL from the OGSE

SLEP



Full Spatial Scan

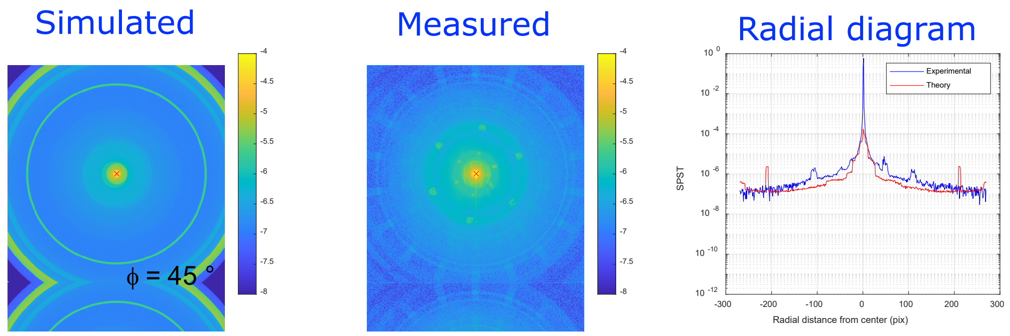


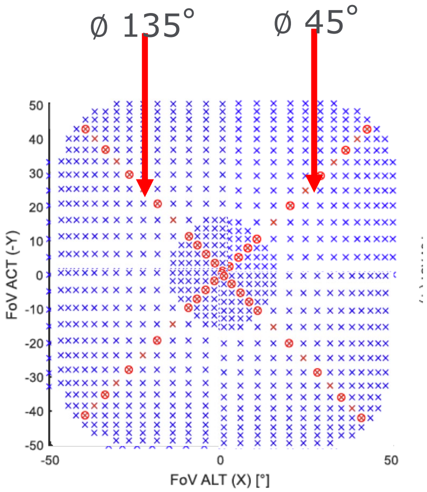
Instrument Performances

Straylight characterization

- Measurements at 910nm (3MI-9a channel) has demonstrated accurate measurements of the different SL features

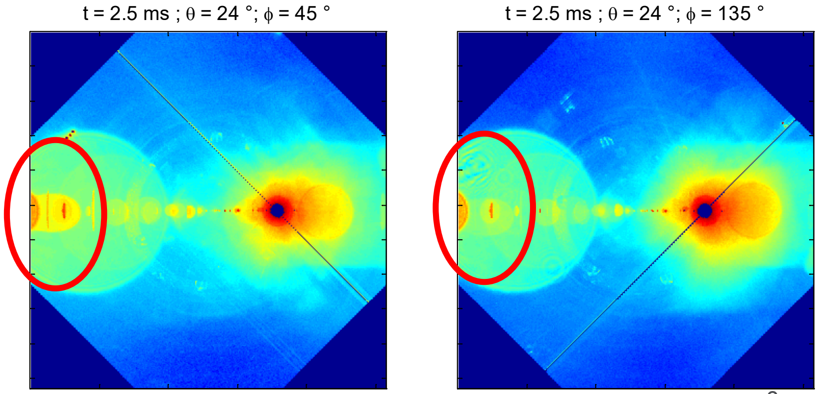
- Similarities with the theoretical maps have been obtained





- We tried to exploit revolution symmetry to calibrate *only* 1/4 of FoV

- Polarized ghosts power varies with the azimuth angle



Acquisition ø 45° Acquisition ø 135°

Conclusion

Key Innovations:

- 3MI is the first optical polarimeter to fly on an operational satellite
- First time with SWIR channels.
- Filter wheel system with 33 apertures.
- Extensive and novelty method for Straylight characterization

Chanel		λ Centre (nm)	Bandwidth (nm)	Polarization	Utilization
VNIR	3MI-2	410	20	-60°, 0°, +60°	Aerosol absorption, ash cloud
	3MI-3	443	20	-60°, 0°, +60°	Aerosol absorption, height indicators
	3MI-4	490	20	-60°, 0°, +60°	Aerosol, surface albedo, cloud reflectance, cloud optical depth
	3MI-5	555	20	-60°, 0°, +60°	Surface albedo
	3MI-6	670	20	-60°, 0°, +60°	Aerosol properties
	3MI-7	763	10	Non-polarize	Cloud and aerosol height
	3MI-8	765	40	Non-polarize	Cloud and aerosol height
	3MI-9	865	40	-60°, 0°, +60°	Vegetation, aerosol, clouds, surf. Features
	3MI-9a	910	20	Non-polarize	Water vapour, atmospheric correction
SWIR	3MI-10	1370	40	-60°, 0°, +60°	Cirrus clouds, water vapour imagery
	3MI-11	1650	40	-60°, 0°, +60°	Ground characterisation for aerosol inversion
	3MI-12	2130	40	-60°, 0°, +60°	Ground characterisation for aerosol inversion, clouds microphysics, vegetation, fire effects

Benefit:

- 3MI will provide a unique long-term of operational time series for atmosphere characterization for aerosol and clouds

3MI PFM Calibration has lasted for 85 days 24/7 for a total of 2040 hours of data acquisition in vacuum

Authors and Credits

Authors

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[1] ESA/ESTEC, Noordwijk, Netherlands

[2] Leonardo, Business Space, Florence, Italy

[3] Airbus Defence and Space , Toulouse, France

[4] EUMETSAT, Darmstadt, Germany

Images Credits

- Leonardo, Business Space, Florence (I) – Instrument and optics
- Airbus Defence and Space , Toulouse (F) – Satellite
- RUAG Space, Zurich (CH) – Filter Wheel Subsystem
- Sodern, Limeil-Brévannes (F) – VNIR and SWIR Focal Plan Array and Front End Electronics
- Invent, Braunschweig (D) – CFRP base plate
- AVIOTEC, Torino (I), - MLI
- Centre Spatial de Liège, Liège (B) – Calibration Facility and Straylight

The 3MI Instrument onboard MetOp Second Generation

Thank you for your attention

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