living planet symposium | BONN 23–27 May 2022

TAKING THE PULSE OF OUR PLANET FROM SPACE

EUMETSAT ECMWF EUSPA

ESA | JAXA earthcare

European Payload on EarthCARE

ESA's Earth, Clouds, Aerosols and Radiation Explorer

Presented by Kotska Wallace,
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26 May 2022

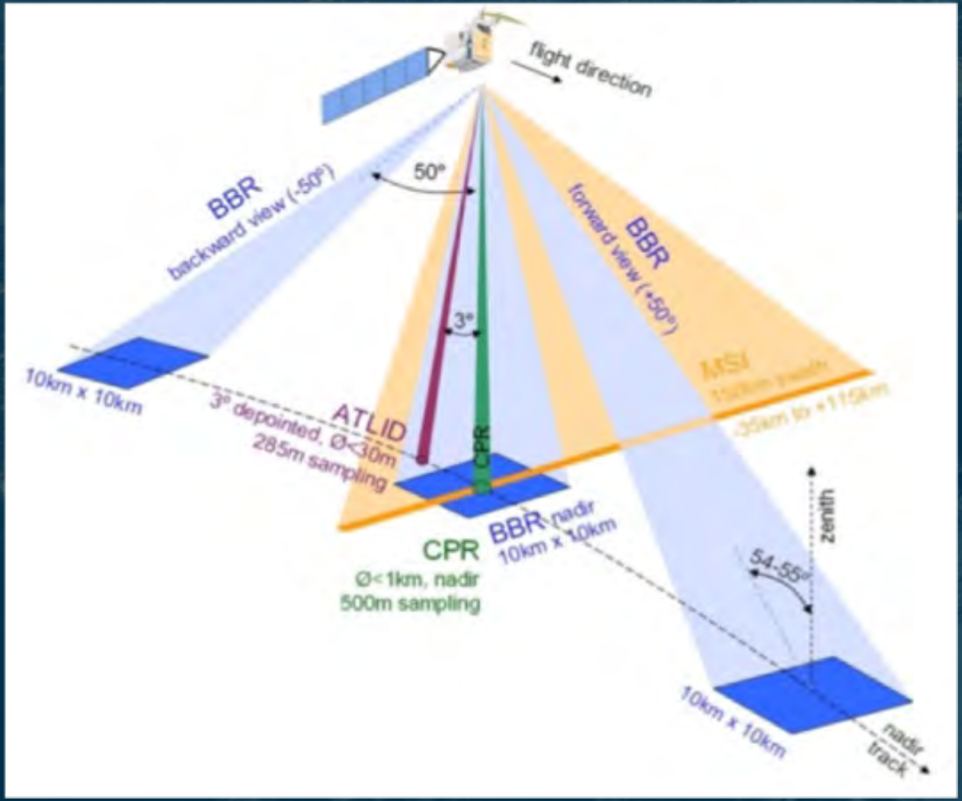
Table of contents

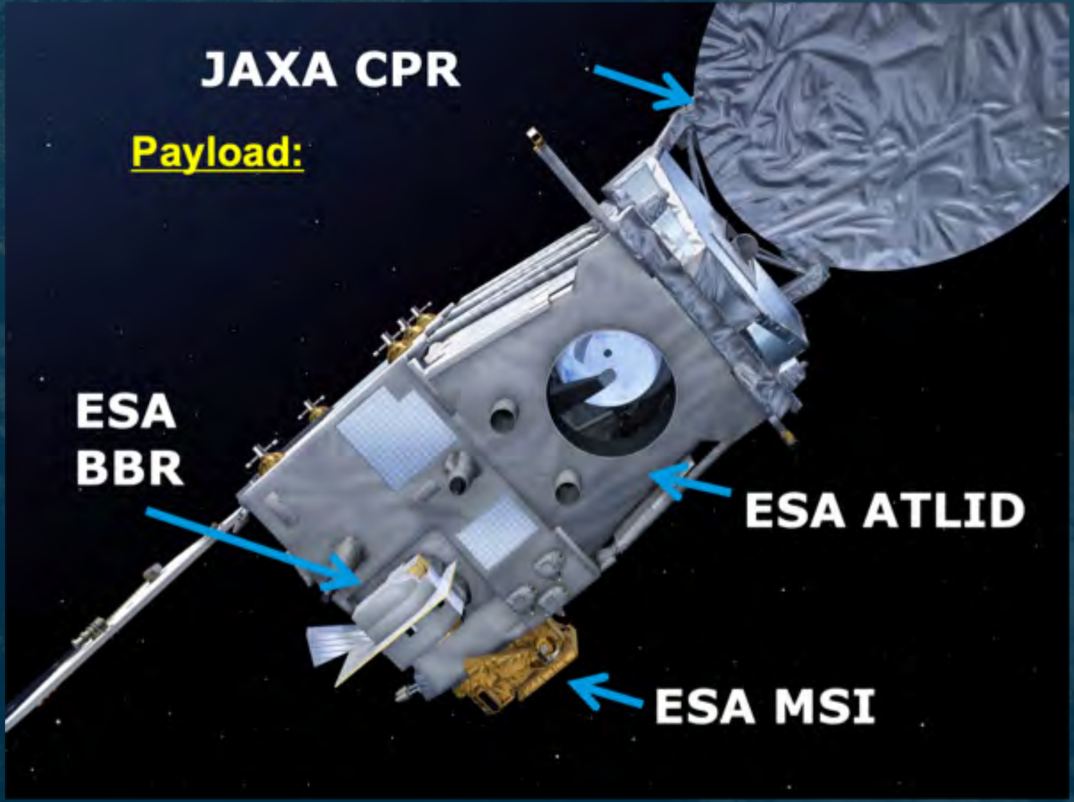
Instrument accommodation on the platform

Data synergy is crucial to EarthCARE mission!

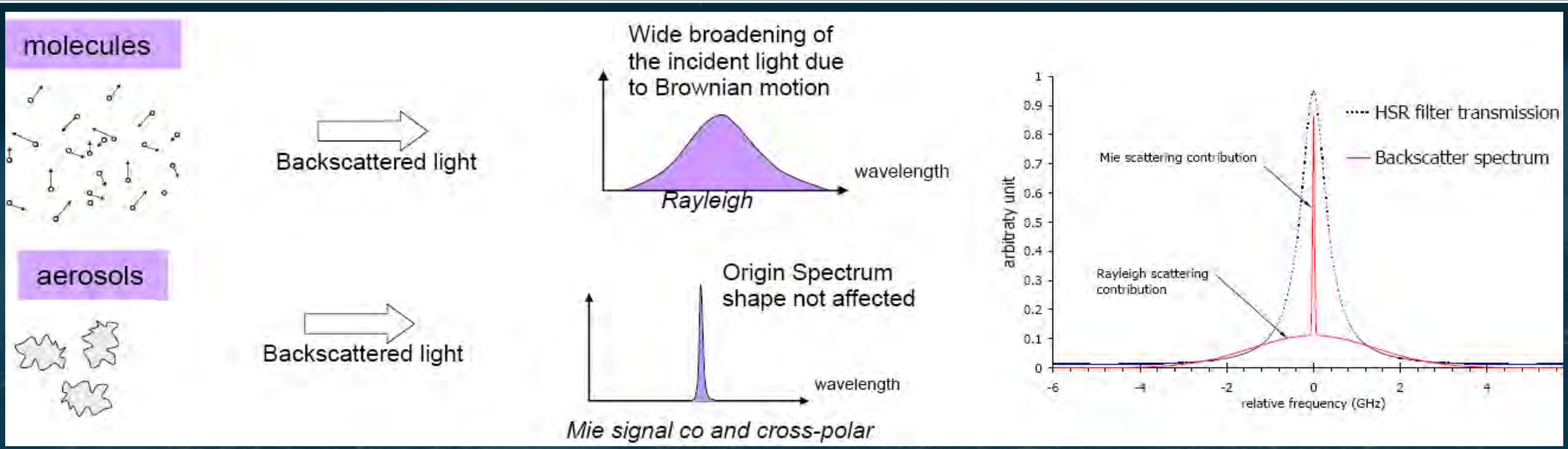
→ Single platform provides collocated scenes from active and passive instruments.

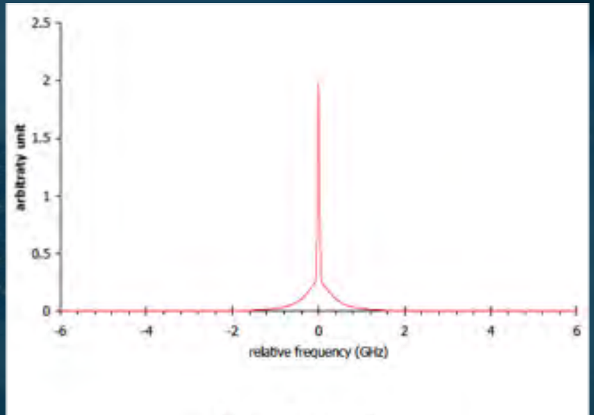
→ Direct measurements of the outgoing reflected solar & emitted thermal radiation, collocated with every cloud/aerosol scene, enable direct verification of the impact of clouds and aerosols on atmospheric heating rates and radiative fluxes.



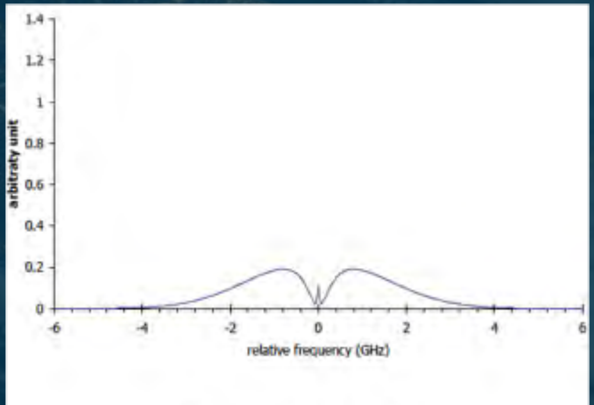


ATLID measurement





Mie channel



Rayleigh channel

Brownian motion of molecules induces broadening of incident spectrum, whereas scattering with aerosol particles does not:

- 3 channel receiver, providing signal profiles of:
  - Molecular backscatter (Rayleigh) signal.
  - Cloud and aerosol (Mie) backscatter co-polar signal (aerosol classification).
  - Cloud and aerosol (Mie) backscatter cross-polar signal, (aerosol classification).

ATLID observation need

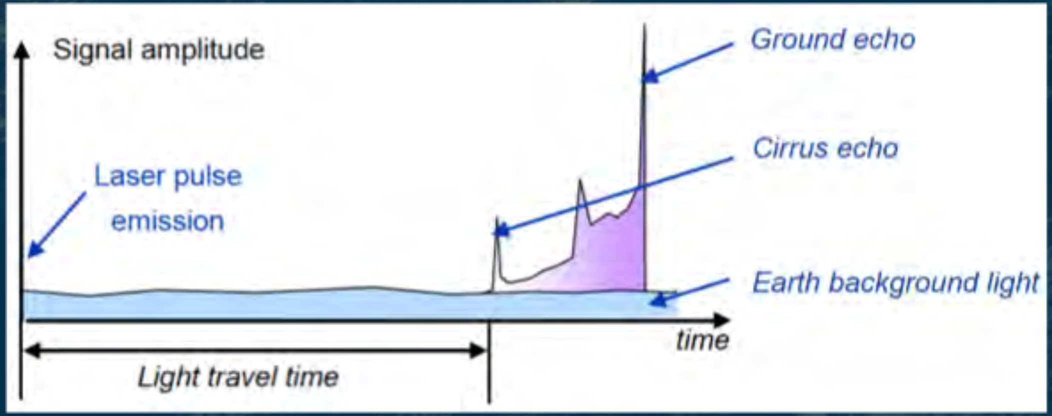
High Spectral Resolution, UV Lidar, λ = 355 nm, linearly polarised, 3º off nadir view.

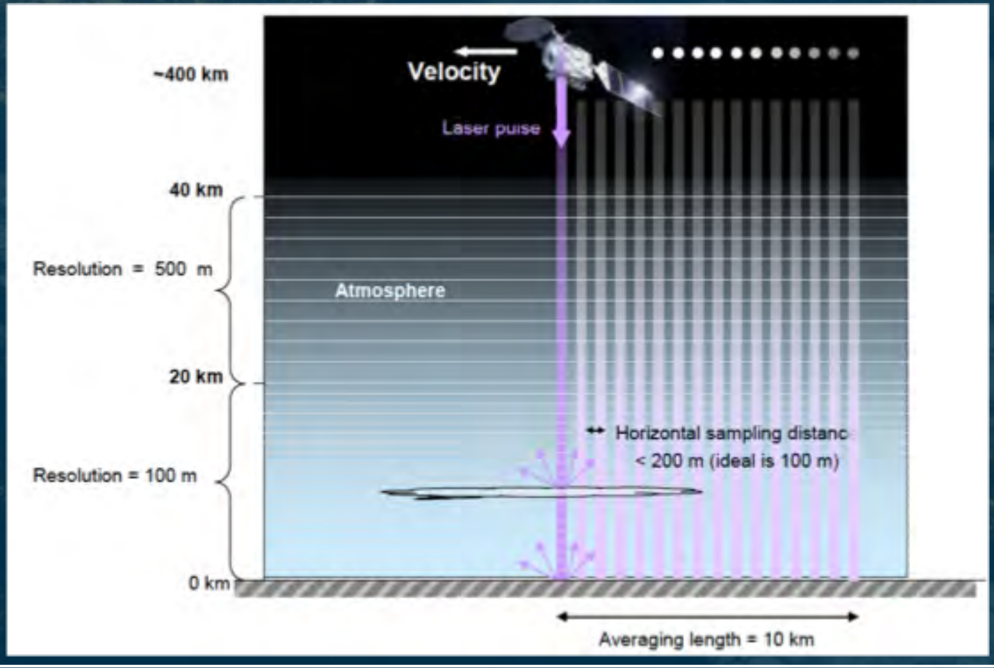
- Why UV? → Molecular scattering is high enough to measure more accurately backscatter extinction profiles and aerosols / thin clouds thickness.

ATLID will allow aerosol typing (e.g., smoke and dust) based on measured particle properties.

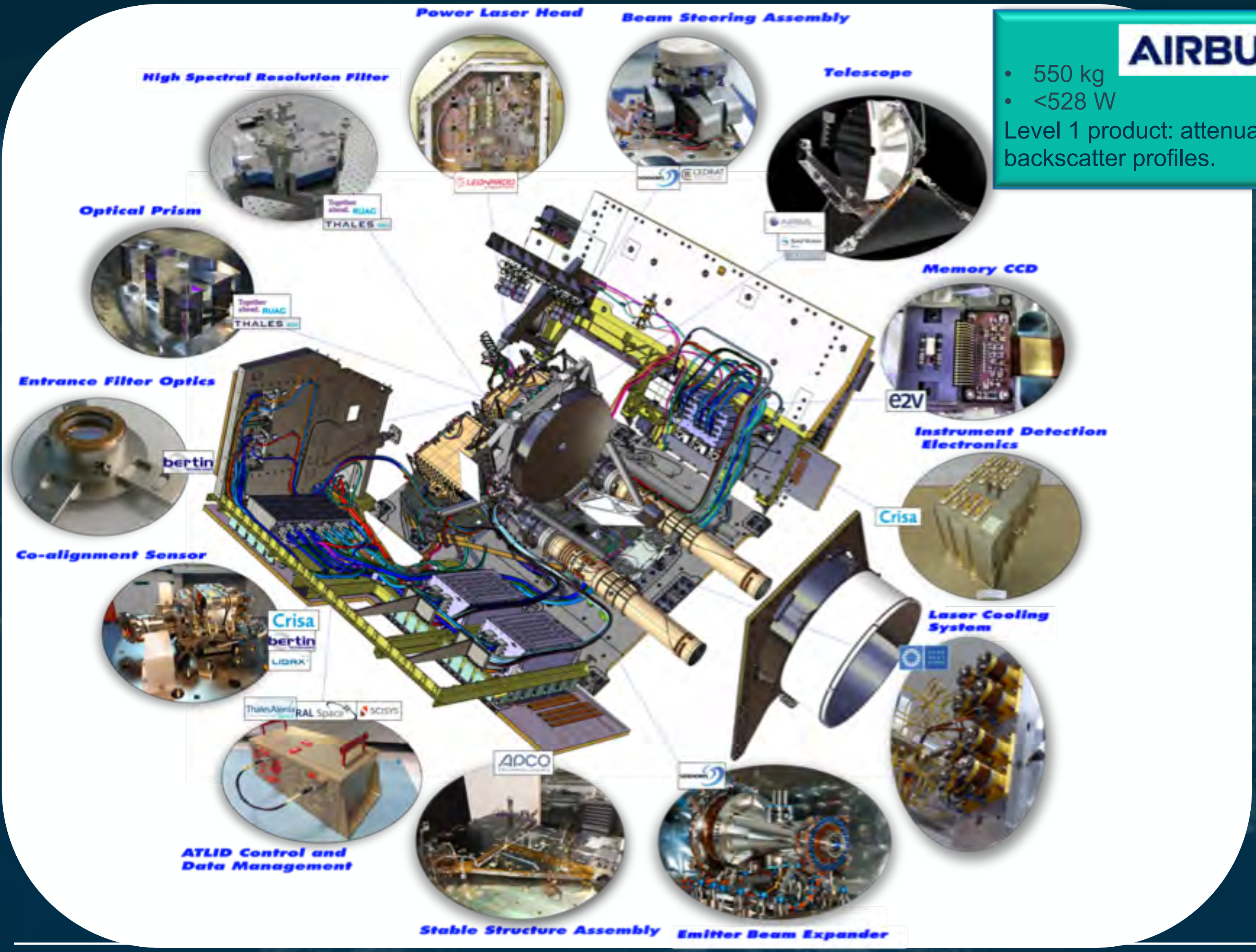
Along track sampling resolution of 285 m (2 shots integrated) and vertical resolution 100 m (altitude up to 20 km) and 500 m (altitudes 20 to 40 km)

- High resolution for structure analysis





ATLID instrument design

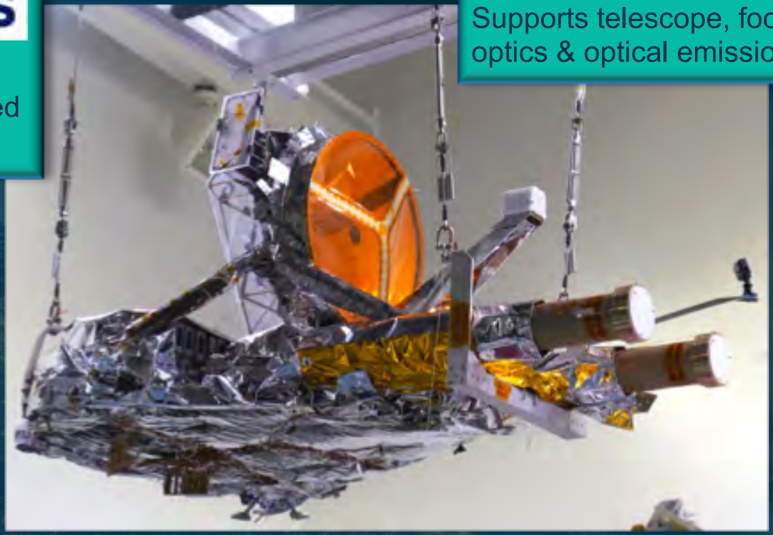


AIRBUS

- 550 kg
- <528 W

Level 1 product: attenuated backscatter profiles.

Stable Structure Assembly
Supports telescope, focal plane optics & optical emission chain.



Housing Structure Assembly
Encloses the SSA. Supports electronic units, their radiator, the detection chain and harness.

ATLID instrument design

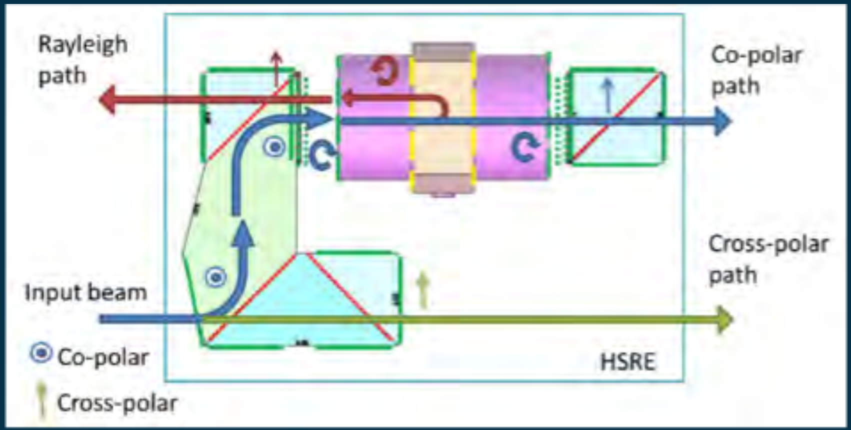
Transmitter Assembly (TxA)

- Emits <35 ns, 35 mJ laser pulses, 51 Hz repetition rate (corresponding to 140 m spatial resolution).
- Power Laser Head seeded by Reference Laser Head, with associated Transmitter Laser Electronics.
- PLH based on a diode-pumped Nd:YAG, frequency tripled to 355nm.
- Beam divergence 36 μrad after Emission Beam Expander.
- Co alignment sensor & electronics.

Bistatic lidar

Receiver Assembly (RxA)

- 620 mm SiC telescope collects backscattered signal.
- Field-stop delimits a 65 μrad field of view.
- Fabry-Perot etalon, tuned on backscattered flux central λ, reflects Rayleigh backscatter signal
- Mie co and cross polar channels defined by Polarising Beamsplitters.
- Fibre coupling to detection electronics Memory CCDs
- Small part of input signal diverted to Co Alignment Sensor



Laser Cooling System

- Honeycomb radiator on which are assembled the loop heat pipes condenser.
- Loop heat pipes link radiator to each PLH cold plate.

ATLID instrument design

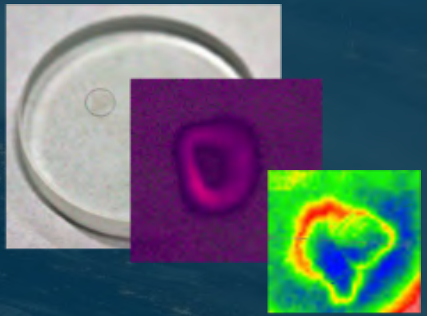
Model philosophy and heritage

- Protoflight model approach
  - Development models and breadboards (Laser Cooling System, TxA, Detector Fibre Assembly, …)
  - Life tests → Laser diodes

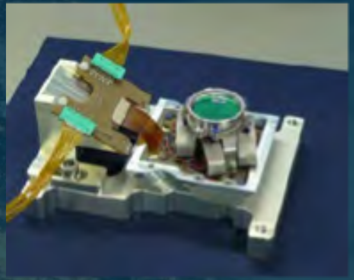
    → TxA 4 month life test

    → LIC tests on coatings

    → Loop heat pipes



- Significant TxA heritage from Aladin (AEOLUS), with change to bistatic configuration.
  - Full pressurization of emission path up to the emission beam expander, limits number of vacuum-exposed optical surfaces → reduced danger of Laser Induced Contamination (LIC).
  - Avoids cross contamination of emission and reception chain → reduced danger of LIC.
  - Co-alignment mechanism → allows to compensate misalignments on orbit.
  - Optimised design of Monitor Photo Diode units → minimises sensitivity to any internal misalignments.
  - Master Oscillator on rigid, isostatic mount and better thermomechanical decoupling from heat elements → impact of high heat dissipation components on alignment-sensitive items minimised.
  - CCD technology similar to Aladin, but different pixel architecture and timing → low risk of 'hot pixels'.



ATLID calibration and predicted performance

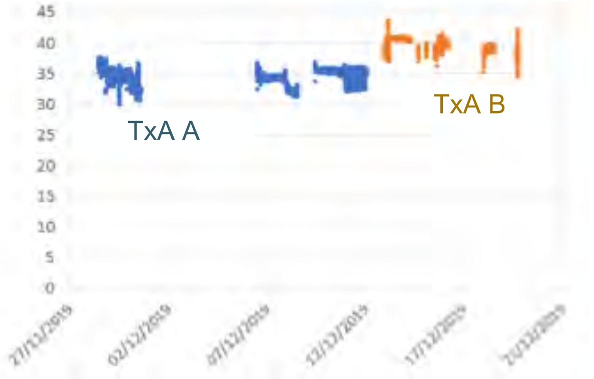
On ground characterisation has demonstrated excellent adherence to performance specification.

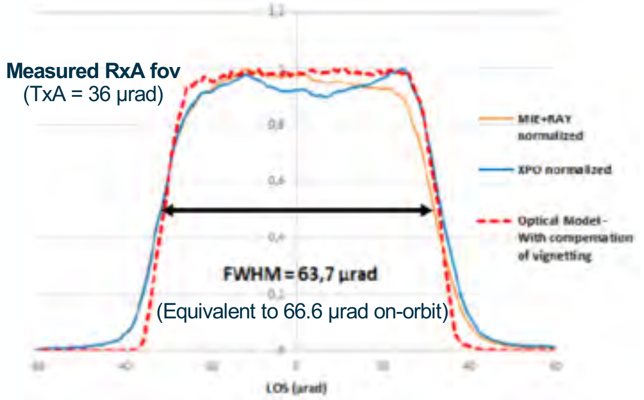
Detail at https://doi.org/10.3390/atmos12010076

Key on-orbit calibrations:

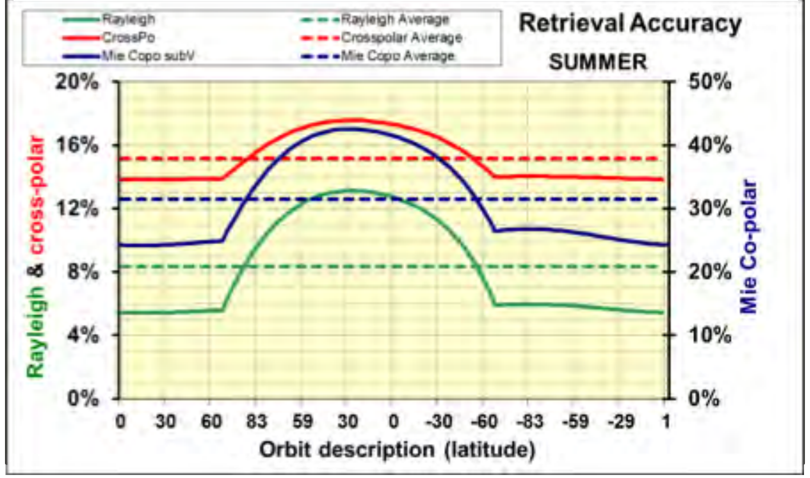
- Initial spectral calibration, TxA to RxA alignment.
- Dedicated instrument modes for weekly Fine Spectral Calibration, monthly co-alignment and Dark Current Calibration.
- Retrieved scenes (Earth background, atmosphere, ground & cloud echoes) to calibrate linearity, background, detector offsets, lidar constant, cross talks.

TxA pulse energy from internal laser monitor (mJ)





Sensitivity of Mie co-polar ($\beta = 8E^{-7}\ m^{-1}sr^{-1}$), cross-polar & Rayleigh derived signal accuracies, as a function of design case orbit position



Absolute backscatter retrieval accuracy (10 km altitude, 10 km horizontal integration, β = cloud backscatter coefficient)	Typical BOL	WC at EOL	Req.t
Mie co-polar on sub visible cirrus, $\beta=8\ E10^{-7}sr^{-1}\ m^{-1}$	31%	48%	48%
Mie cross-polar on cirrus with 10% depolaristion, $\beta=2.6\ E10^{-6}sr^{-1}m^{-1}$	19%	23%	45%
Rayleigh above cirrus 10 km	12%	17%	15%
Radiometric stability			
Rayleigh, Mie Cross	0.6%	1%	<5%
Mie Co	0.8%	3%	<2%

Absolute calibration accuracy	WCEOL	Req.t
Mie co-polar	11.1%	10%
Mie cross-polar	13.1%	15%
Rayleigh	6.6%	10%
Cross talk knowledge		
Spectral in Rayleigh channel	7.9%	<20%
Spectral in Mie co-polar channel	9.6%	<10%
Polarisation in Mie co- or cross-polar channel	1.2%	<1.0%

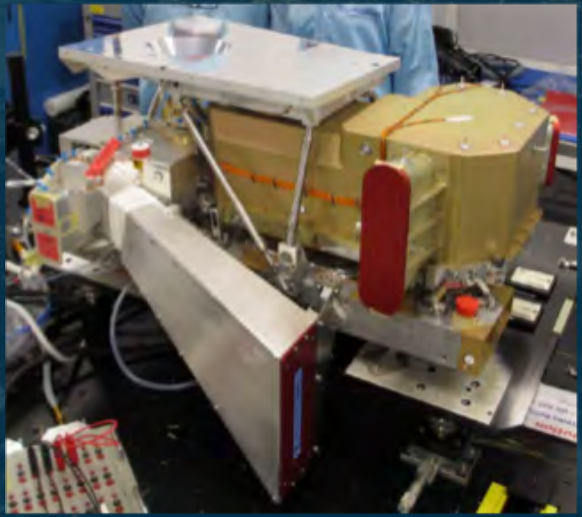
MSI observation need

Primary mission to provide contextual scene information to support retrievals of geophysical parameters by the active instruments.

- Provide information about horizontal structure of clouds.
- Secondary goal to provide measurements of aerosol properties and type, over sea.
- Scene identification to support calibration of the BBR instrument.

Key Performance Parameters.

- Spectral channels: 0.67μm, 0.86 μm, 1.65 μm, 2.2 μm, 8.8 μm, 10.8 μm, 12.0 μm
  - Bands consider existing systems (MSG SEVIRI, NPOESS AVHRR) for close link to temporally higher resolved satellite data.
- 150 km swath, tilted off-track to reduce sun-glint, -35 to 115 km.
- 500 m ground sampling distance.
- Pixel co-registration between channels 0.15



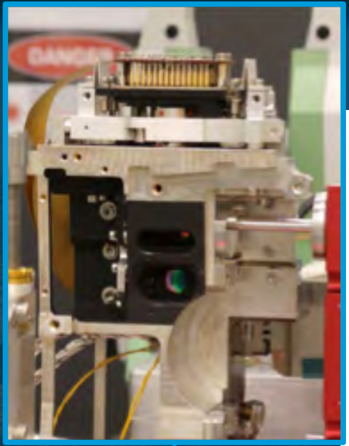
MSI instrument design

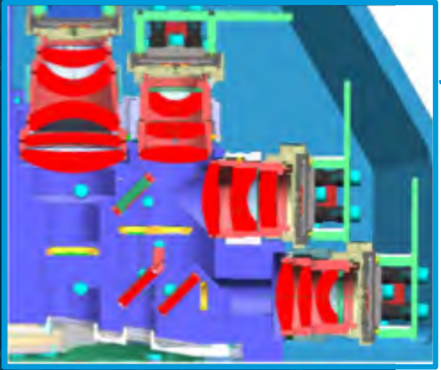
Two cameras share an optical bench:

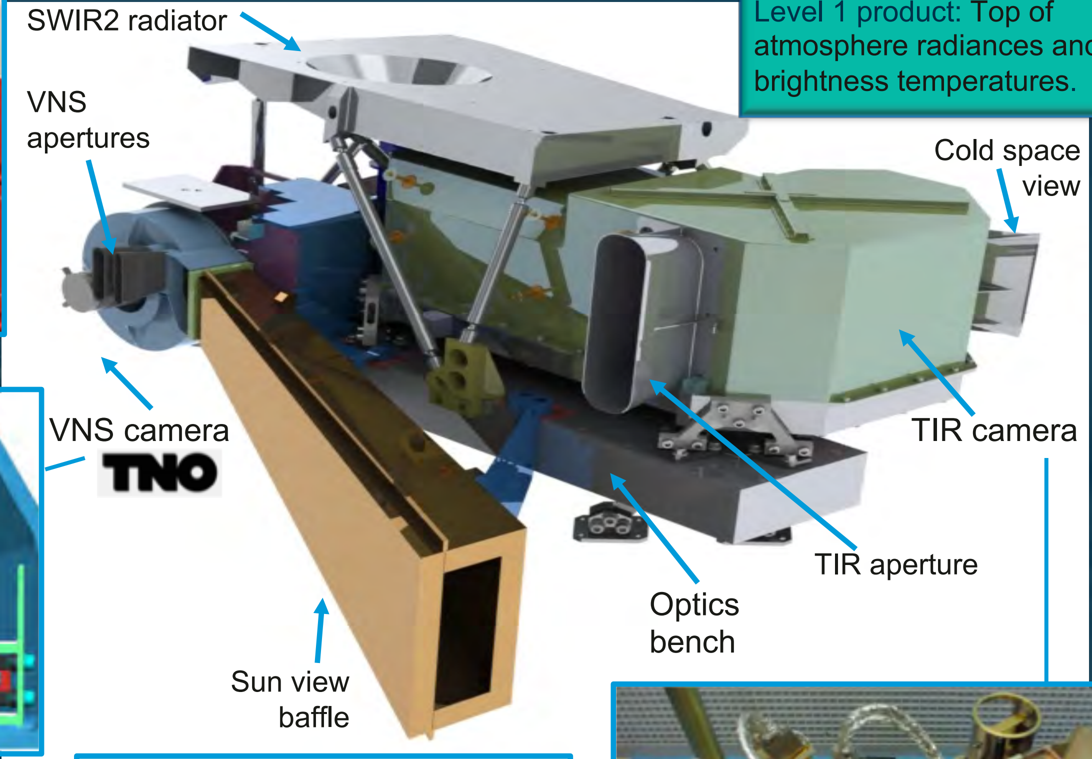
- Visible, Near IR, Short Wave IR (VNS) camera
  - Two apertures: SWIR-2 and Vis, NIR, SWIR-1.
  - Refractive Magnification Optics.
  - Band separation by dichroics and filters.
  - Photodiode Detector Arrays: Si and InGaAs.
  - 2-point in-flight calibration: diffuser & closed shutter.
- Thermal InfraRed (TIR) camera
  - Single aperture for 3 channels.
  - Band separation by dichroics and filters.
  - Refractive and reflective magnification optics.
  - Microbolometers 2D array in Time Delay Integration (TDI) mode.
  - 2 point in-flight calibration: blackbody & cold space view.

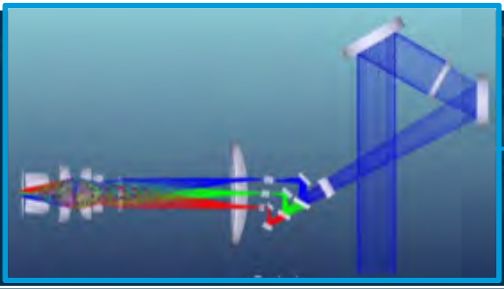
- 57 kg
- 60 W

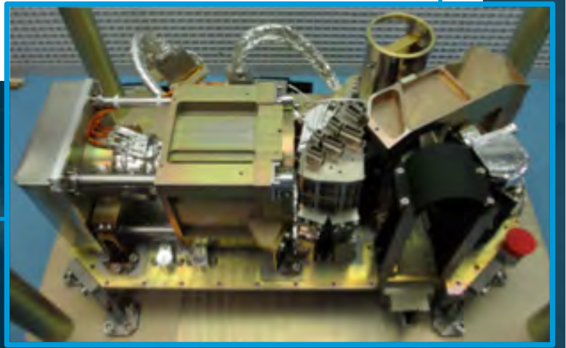
Level 1 product: Top of atmosphere radiances and brightness temperatures.







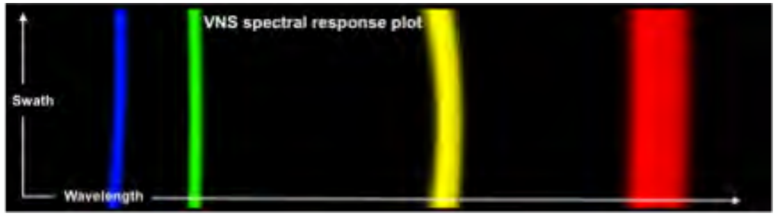


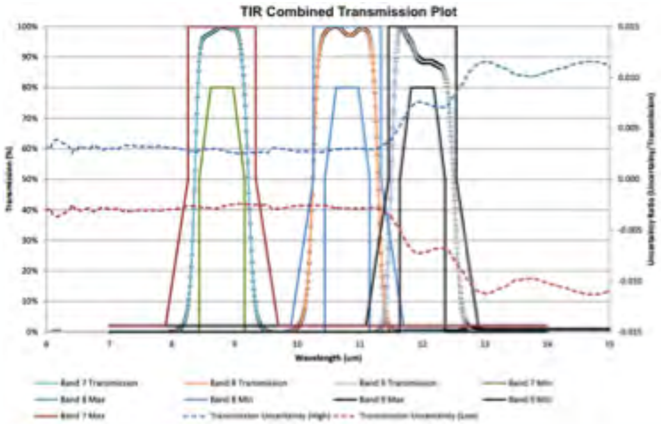


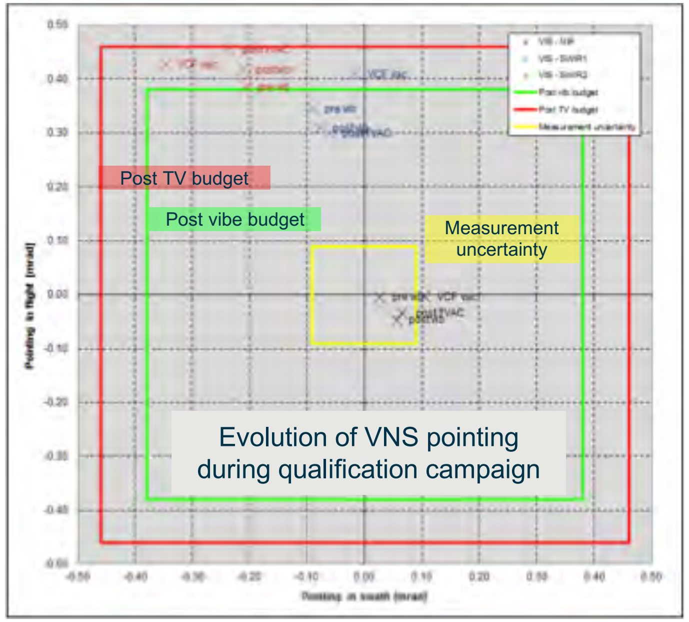
MSI calibration and predicted performance

Key on-orbit calibrations:

- VNS closed shutter, daily, for detector flat fields, image statistics.
- VNS diffusers for aging discrimination, daily set, monthly set.
- TIR blackbody and cold space views for detector noise, responsivity, detector flat fields and gain corrections.







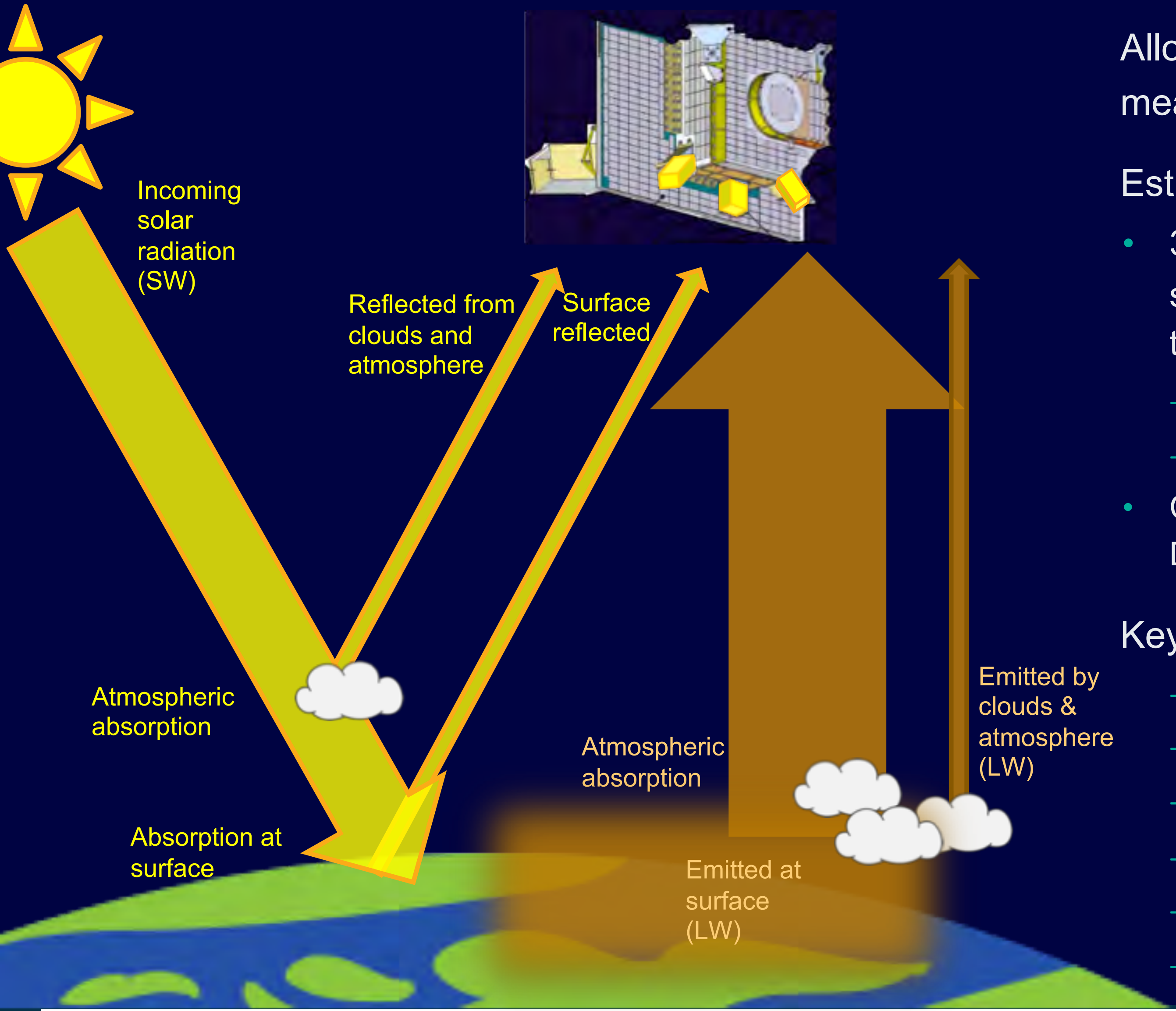
VNS Absolute Radiometric Accuracy (WC EOL)					Inter-channel Radiometric Accuracy (WC EOL)					
	VIS	NIR	SWIR-1	SWIR-2	VIS/NIR	VIS/SWIR1	VIS/SWIR2	NIR/SWIR1	NIR/SWIR2	SWIR1/SWIR2
Ref signal HIGH	2.20%	2.20%	2.20%	2.20%	1.40%	1.40%	1.40%	1.40%	1.40%	1.40%
Ref signal LOW	2.20%	2.20%	2.20%	2.20%	1.40%	1.40%	1.50%	1.40%	1.50%	1.50%
Spec. (goal)	10% (5%)				2%					

TIR Absolute Radiometric Accuracy (WC EOL)			
Scene temperature	Band 7	Band 8	Band 9
220 K	0.60	0.40	0.54
293 K	0.38	0.36	0.49
Spec.	1 K		

Straylight recovery - Edge response, HIGH to LOW signal							
	VIS	NIR	SWIR-1	SWIR-2	7	8	9
Across Track	C	C	C	2.1	2.55	2.34	C
Along Track	C	C	C	C	3	3	3
Spec. in SSD	2						

	SNR @high reference		**SNR @low reference**	
Band	Threshold	Measured	Goal	Measured
VIS	500	2560	75	203
NIR	500	1620	65	137
SWIR 1	250	1082	18	26
SWIR 2	250	5606	21	138
	NEDT @high reference (K)		**NEDT @low reference (K)**	
	Threshold (Goal)	Measured	Threshold (Goal)	Measured
TIR1	0.25 (0.1)	0.13	0.8 (0.6)	0.45
TIR2	0.25 (0.15)	0.10	0.8 (0.7)	0.25
TIR3	0.25 (0.15)	0.16	0.8 (0.8)	0.35

BBR observation need



Allow cross-check of radiation balance estimate calculated from measurements by the active instruments.

Estimate of outgoing solar reflected & thermal emitted fluxes.

- 3 views measure the Long Wave & Short Wave radiance from the same location, at different angles, pointing nadir, fore and aft along track.
  - Scene Integrated Energy matched for SW and LW channels.
  - Scene Integrated Energy matched for oblique and nadir views.
- Conversion to flux can be performed analytically using Angular Dependence Models.

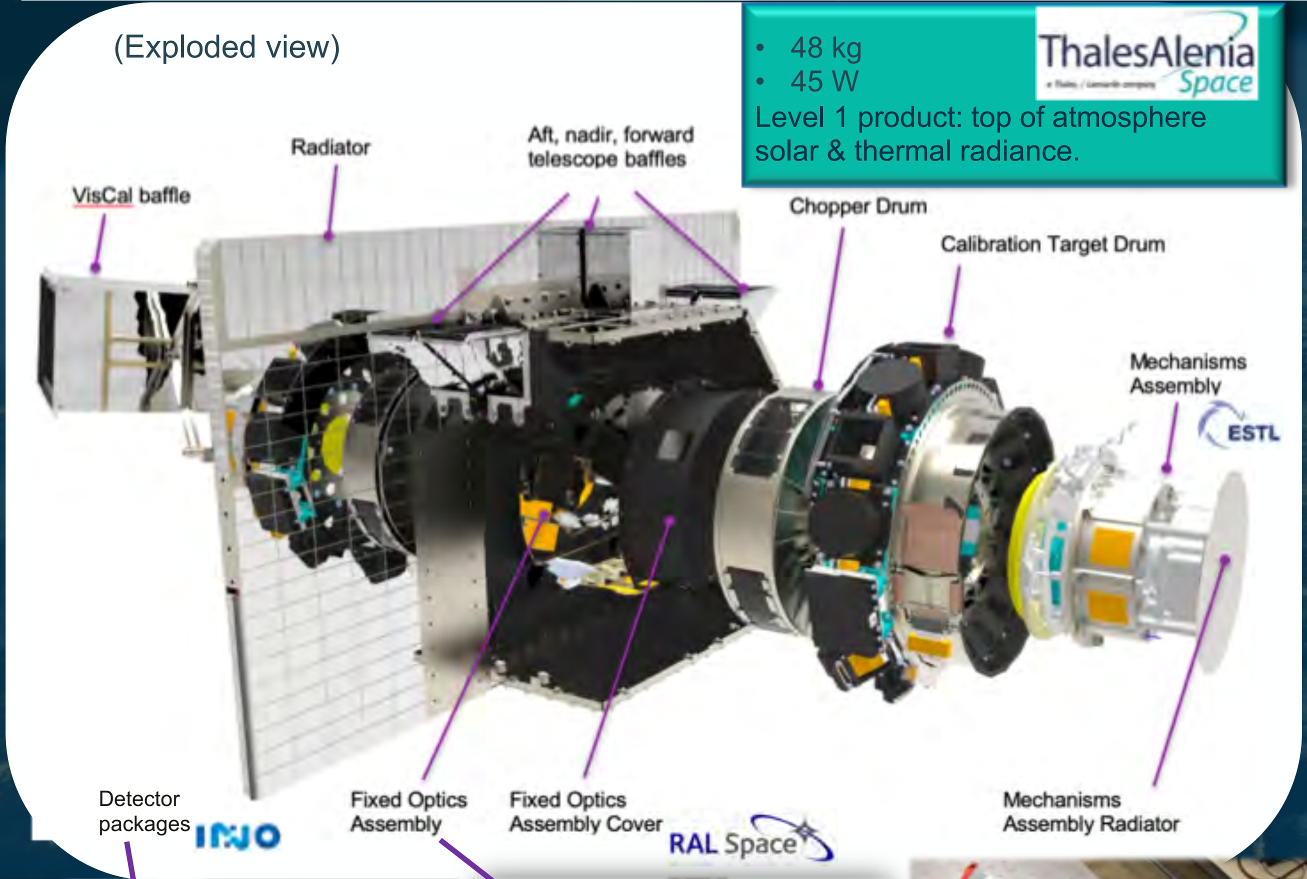
Key Performance parameters

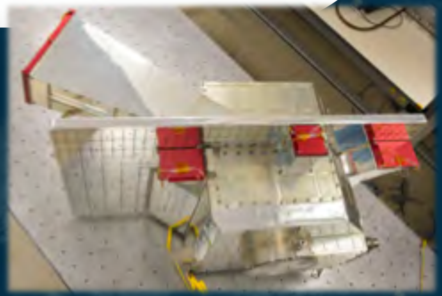
SW channel	0.25 to 4 µm, abs. accuracy 2.5 $Wm^{-2}sr^{-1}$
LW channel	4 to >50 µm, abs. accuracy 1.5 $Wm^{-2}sr^{-1}$
Angular sampling	+ 55°, nadir, - 55°
Spatial resolution	10 km x 10 km, or pixel level
Spatial sampling distance	1km
Dynamic range SW, TW	0-450 $Wm^{-2}sr^{-1}$, 0-550 $Wm^{-2}sr^{-1}$

BBR instrument design

- 48 kg
- 45 W

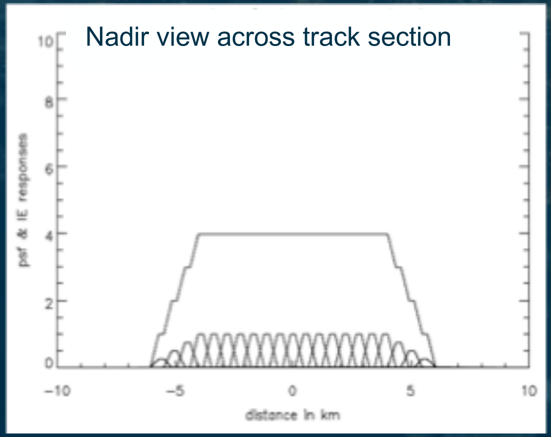
Level 1 product: top of atmosphere solar & thermal radiance.

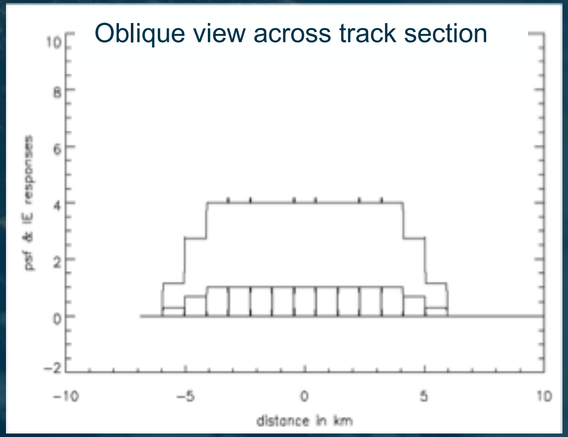




Push-broom motion of the fields of view from 3 fixed, single-mirror telescopes collects scenes along track

- Each with gold-black coated, microbolometer detector linear array.
- 10 km scenes synthesised on ground from individual pixel contributions to ensure Integrated Energy matching of scenes.
  - Product barycentres defined at 1km intervals along track.
  - Pixels falling within a 2D weighting function over the scene barycentre are weighted, according to their contribution to the scene PSF, and summed to the product radiance.





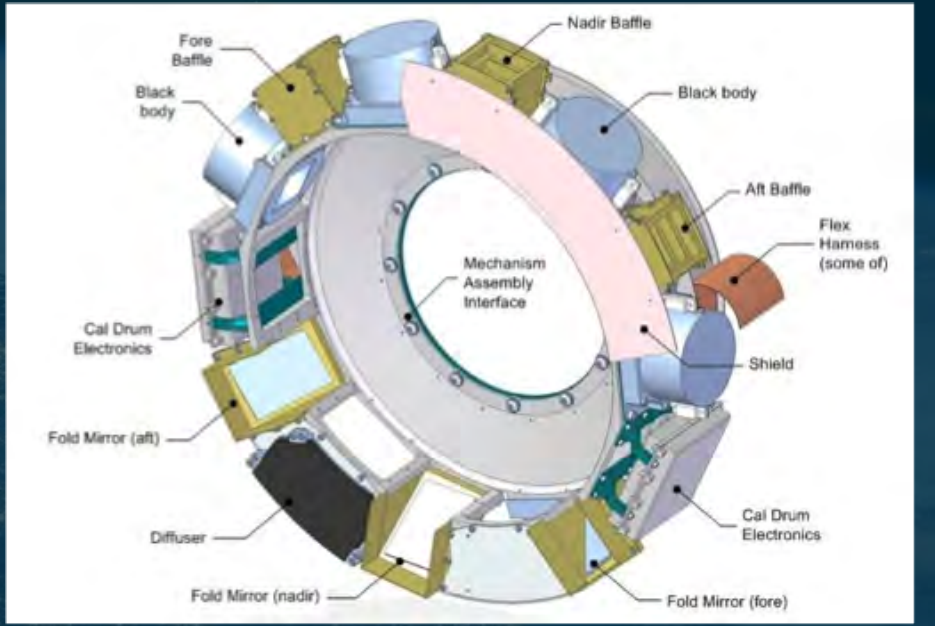
BBR instrument design

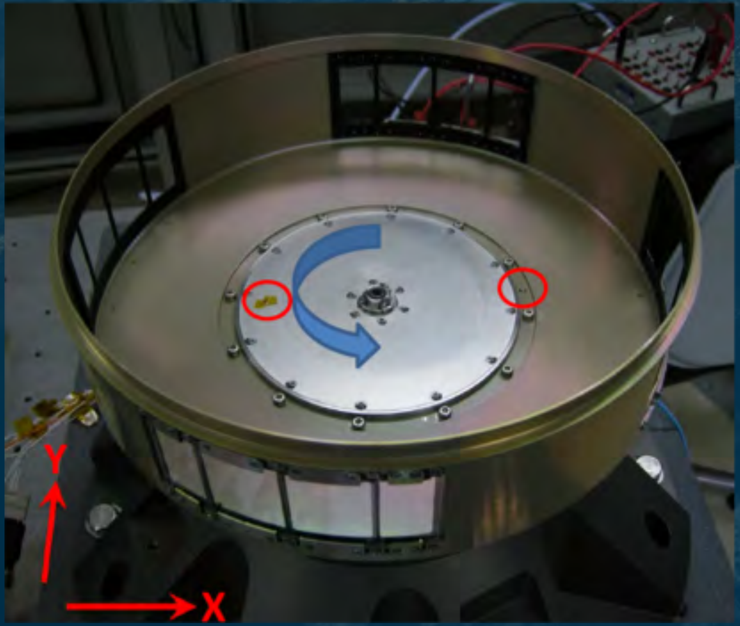
Chopper drum (CDM) rotates continuously: 261 rpm, 423 Mrev specification

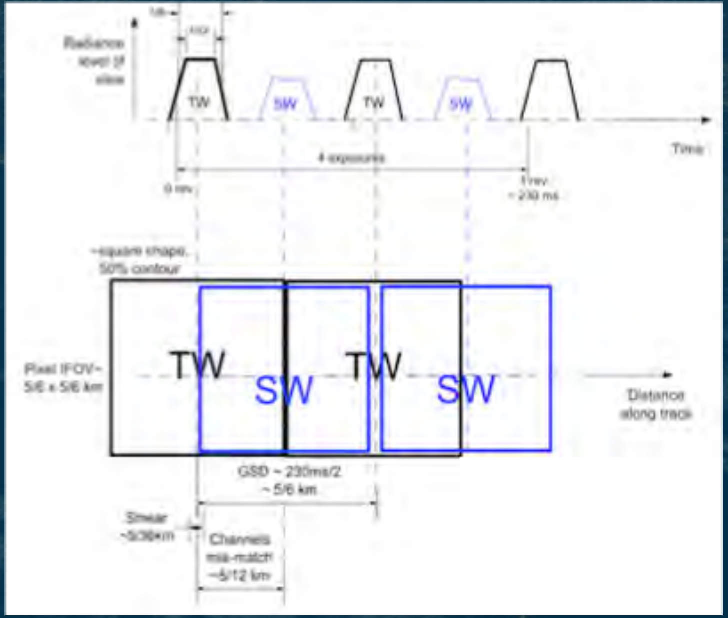
- Chops input signal between SW, constant background (drum wall) & TW view
- LW derived from subtraction of SW from TW channel, unfiltered from instrument spectral response using correlation with MSI data.

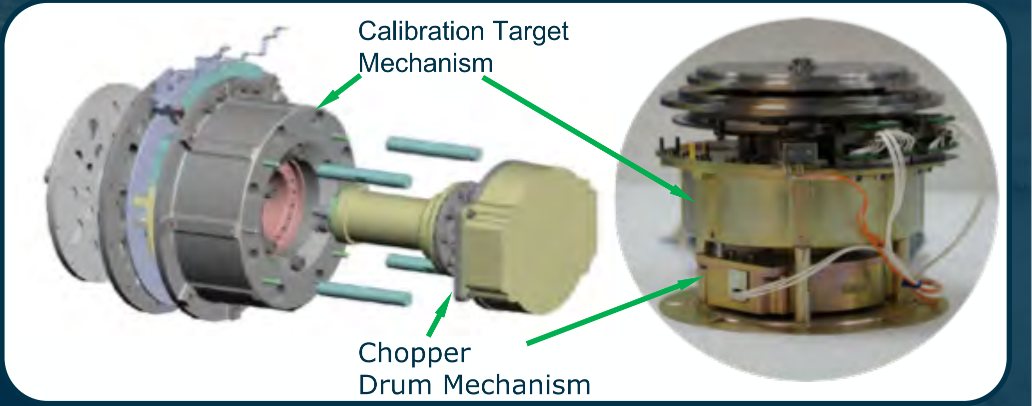
Calibration Target drum (CTM) periodically rotates into view:

- Hot or cold blackbody, every 88s, to calibrate LW gain & offset (in the ground processor)
- View to solar illuminated diffusor, every 2 months for 30 orbits, to monitor aging in the SW chain.







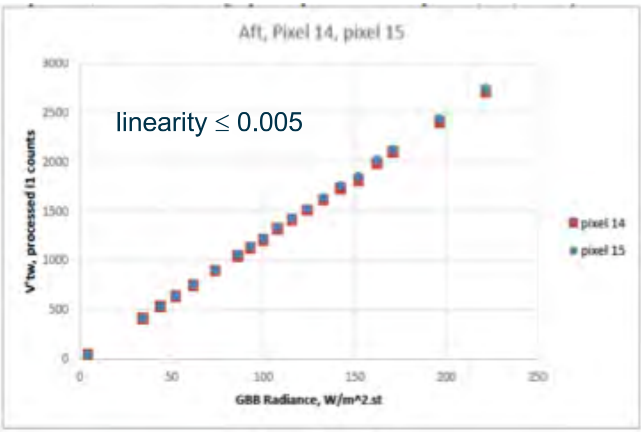


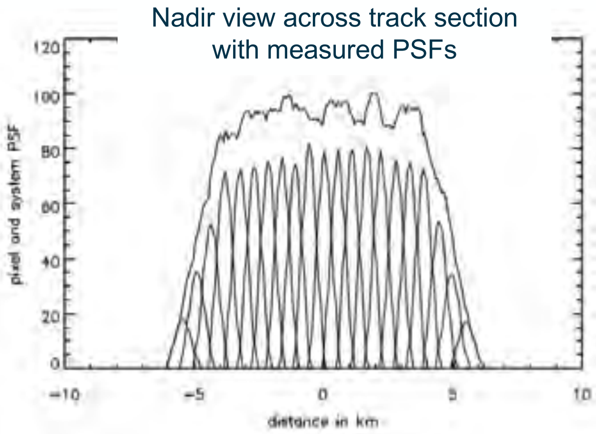
BBR on-ground calibration and predicted performance

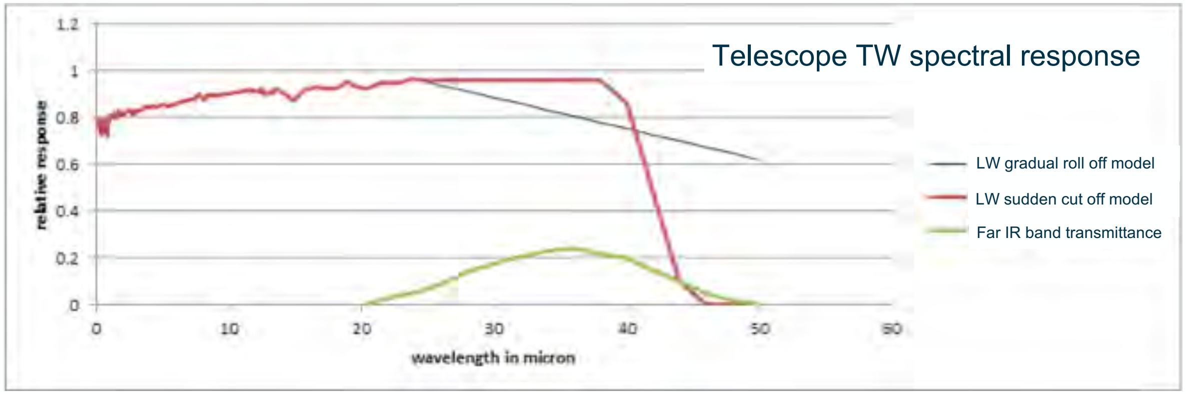
esa

Key on-orbit calibrations:

- Regular, 2-point calibration of the TW via view of the blackbodies.
- SW calibration data for in-flight reference and any update of calibration parameters.
  - In-flight reference to compare against Visible Calibration (VisCal) system on-ground reference of Monitor Photo-Diodes in telescope baffles.
- Half-yearly detector linearity check via continuous operation with swap of powers to hot and cold blackbodies







Radiometric error:	MaxSWRad scene				MinLWRad scene				MinSWRad scene				MaxLWRad scene			
	Nadir		Oblique		Nadir		Oblique		Nadir		Oblique		Nadir		Oblique	
Channel	SW	LW	SW	LW	SW	LW	SW	LW	SW	LW	SW	LW	SW	LW	SW	LW
Predicted error	3.17	0.56	3.29	0.59	2.16	0.54	2.24	0.57	0.56	0.37	0.59	0.41	0.75	0.64	0.78	0.67
Unfiltered	3.12	0.28	3.25	0.34	2.14	0.28	2.21	0.34	0.49	0.27	0.53	0.33	0.68	0.30	0.72	0.37
Spec. ($W/m^2/sr$)	2.50	1.50	2.50	1.50	2.50	1.50	2.50	1.50	2.50	1.50	2.50	1.50	2.50	1.50	2.50	1.50

Conclusions

EarthCARE payload is almost ready to deliver long anticipated, unique and crucial data, to address uncertainties in the influence of clouds and aerosols on the reflected solar and emitted thermal radiation.

- Cloud, aerosol and radiation interactions introduce the largest uncertainty in projections of the future climate and are critical to address to improve numerical weather prediction and climate modelling.
- EarthCARE instruments:
  - Systematically provide vertical profiles of clouds and aerosol, together with collocated measurement of the reflected solar & emitted thermal radiation.
  - Enable direct verification of the impact of clouds and aerosols on atmospheric heating rates and radiative fluxes.
- Instrument level qualifications are complete and they are demonstrated to meet well their performance specification. The satellite is about to start its qualification campaign to prepare for launch readiness in October 2023.

Acknowledgments

The significant contributions to the EarthCARE mission of the industrial teams working on the satellite and its payload are acknowledged. A big thank you to those teams in industry including the satellite prime, Airbus (Germany), and the instrument teams at Airbus (Toulouse), Leonardo (Italy), SSTL (UK), TNO (The Netherlands), TAS-UK, RAL Space (UK) and ESTL (UK).