



Copernicus Sentinel-4 and Sentinel-5

Status of Mission Implementation at ESA

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Acknowledgements: Sentinel-4 and Sentinel-5 project teams at ESA, industrial consortia led by Airbus, Sentinel-4 Level-2 consortium led by DLR, Sentinel-5 Level-2 consortium led by S&T

AC-VC#19, Brussels, Belgium, 24 – 27 October 2023

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Copernicus Missions for Atmospheric Composition

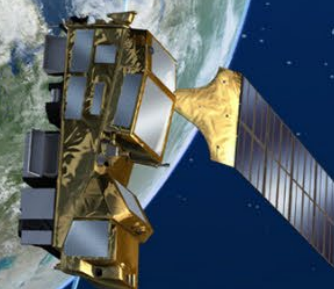
Image: ESA



Sentinel-4
on MTG-S



Sentinel-5 Precursor
TROPOMI



Sentinel-5
on MetOp-SG A

Focus	Short-lived species in troposphere
Driving Application	Air quality, ozone
Orbit	Geostationary
Coverage	Hourly over Europe + parts of Atlantic and North Africa

Short- and long-lived species in troposphere and stratosphere
Air quality, climate, ozone, ...
Low Earth orbit
Daily global

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Level-2 Products

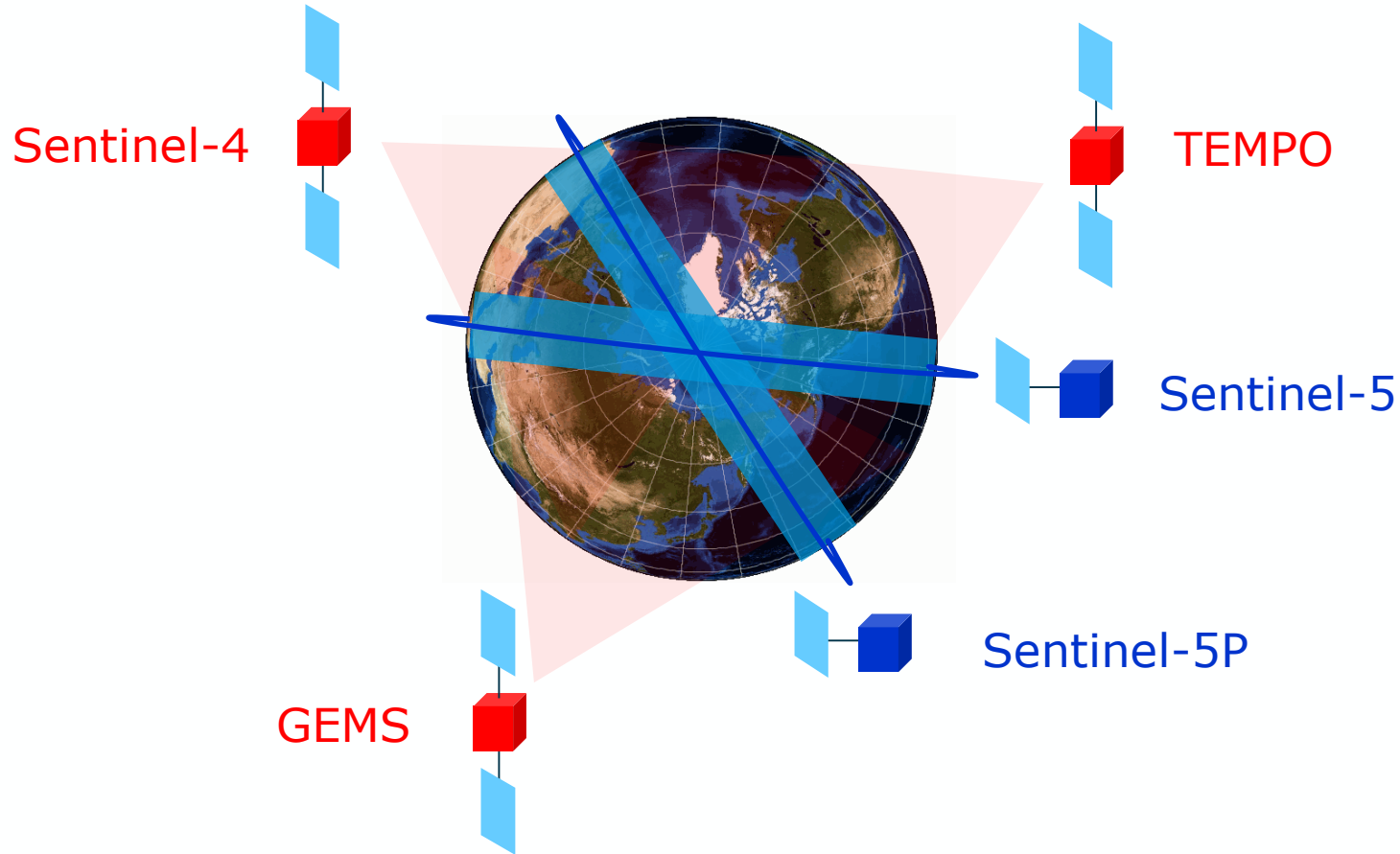


	S4	S5	S5P	Air Quality	Climate	Other
O₃	TOC & TRC	TOC & PRO	TOC & PRO	Toxic, lacrimatory	Warming agent, shortens CH ₄ lifetime	Controls downwelling UV, increases oxidising capacity, reduces plant growth
NO₂	TOC	TOC	TOC	Toxic, PM and HNO ₃ precursor	Aerosol precursor	Eutrophication and acidification of soil
SO₂	TOC	TOC, Layer height	TOC, Layer height	Toxic, PM and H ₂ SO ₄ precursor	Aerosol precursor	Volcanic events, acidification of soil
HCHO	TOC	TOC	TOC	Production of O ₃		Tracer for VOC oxidation
CHOCHO	TOC	TOC		Production of O ₃		Tracer for VOC oxidation
Aerosol	AOD*, Index, Layer height	AOD, Index, Layer height	Index, Layer height	Particulate Matter (PM)	Cooling agent	Volcanic, wildfire, dust events, Multi-phase chemistry
CH₄		TOC		Production of O ₃	Warming agent	Reduces oxidising capacity
CO		TOC		Toxic, Production of O ₃	Lengthens CH ₄ lifetime, CO ₂ precursor	Reduces oxidising capacity, Tracer for long-range transport
Cloud	Fraction, optical depth, height, regridded FCI	Fraction, optical depth, height, regridded MetImage	fraction, height			auxiliary
Surface	BRF*	LER	DLER			auxiliary
UV		Near surface downwelling				



Geostationary Air Quality Constellation

AC-VC whitepaper on
GeoAQ Validation Needs



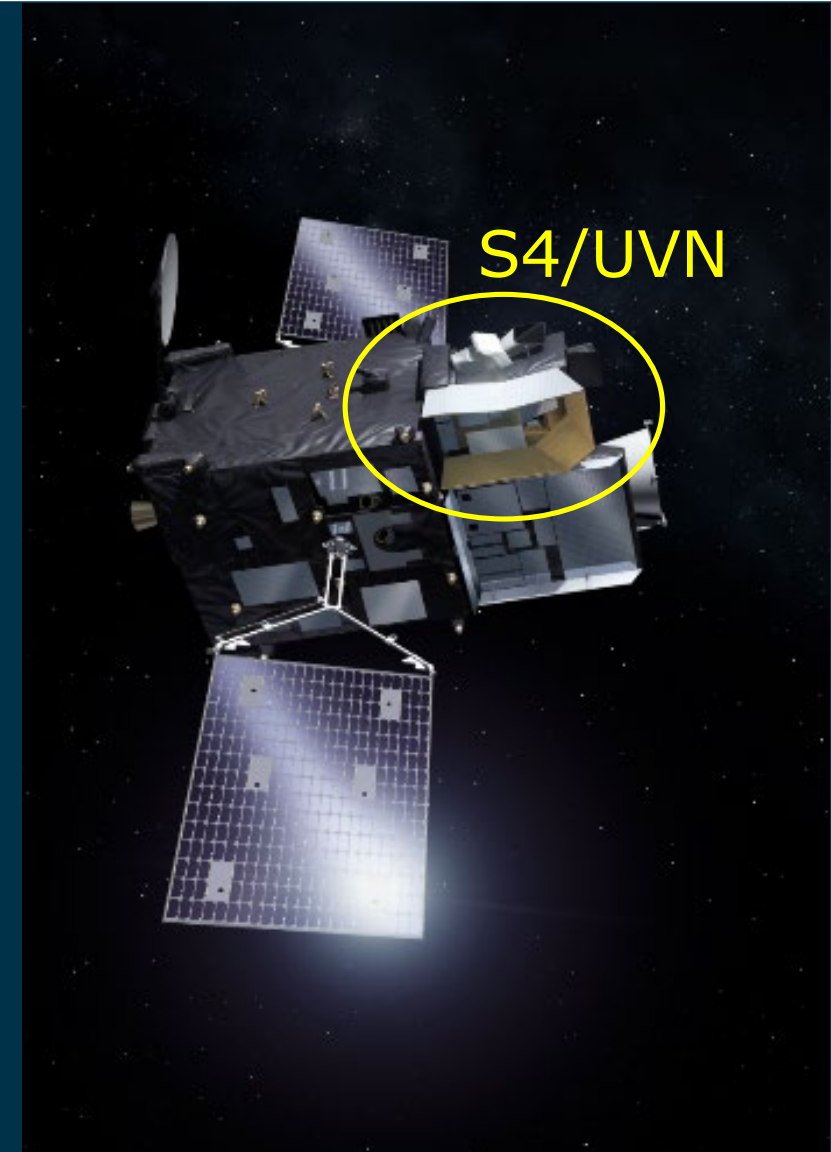
Consistency Targets		
O ₃	Total column	1%
	Stratospheric	5%
	Tropospheric	20%
NO ₂	total column	1×10 ¹⁵ molec/cm ²
	tropospheric	1×10 ¹⁵ molec/cm ²
SO ₂		1×10 ¹⁶ molec/cm ²
HCHO		1×10 ¹⁶ molec/cm ²
CHOCHO		4×10 ¹⁴ molec/cm ²
AOD		0.05 @ 440 nm
Earth radiance		2-5%
Solar irradiance		1-2%
Reflectance		2-5%

Copernicus Sentinel-4



For observing air quality over Europe with a fast revisit time
UV-Vis-NIR (UVN) Imaging Spectrometer

- Built under the responsibility of ESA
 - Instruments and Level-1b Prototype Processor (L1bPP) by Airbus
 - L1 Reference Processor (L1RP), for integration with the L2OP, by Huld
 - Level-2 Operational Processor (L2OP) by DLR
- Will be operated by EUMETSAT
- Geostationary → hourly coverage of Europe
- Two S4/UVN in sequence → mission lifetime of 15 years
- Embarked on Meteosat Third Generation Sounder S1 and S2
- Synergy with FCI and LI on MTG-I, IRS on MTG-S
- On-ground characterization & calibration campaign completed
- Proto Flight Model mounted on MTG-S1, FM2 integration ongoing
- L1bPP V2, L1RP V1, and L2OP V1 accepted
- Launch expected mid 2025



Spectral Range	305 – 400 nm	400 – 500 nm	750 – 775 nm
Spectral Resolution [nm] / Oversampling ratio	0.5 nm / 3	0.5 nm / 3	0.12 nm / 3
Signal to Noise Ratio of radiance (SZA~65°, albedo=0.05/0.05/0.15)	320 @ 310 nm	1800 @ 450 nm	600 (continuum)
Radiometric Accuracy	2 – 3%		
Polarisation Sensitivity	1%		
Spectral Features	0.1% < 315 nm, 0.05% > 315 nm	0.05%	0.5%
Revisit Time	hourly		
Coverage	Europe + part of Sahara and Atlantic		
Spatial Resolution / Sampling	8.9 × 11.7 km ² / 8 × 8 km ² (N/S×E/W @ 45°N)		

Copernicus Sentinel-4: PFM recent photos

S4 PFM



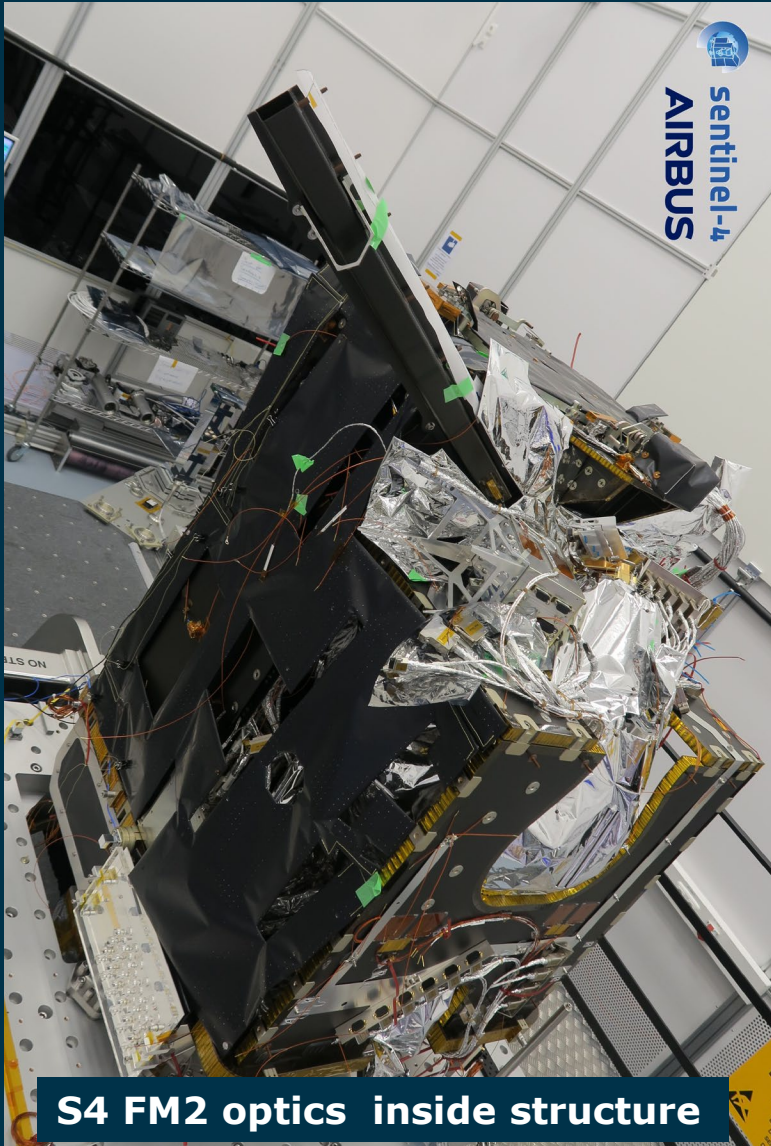
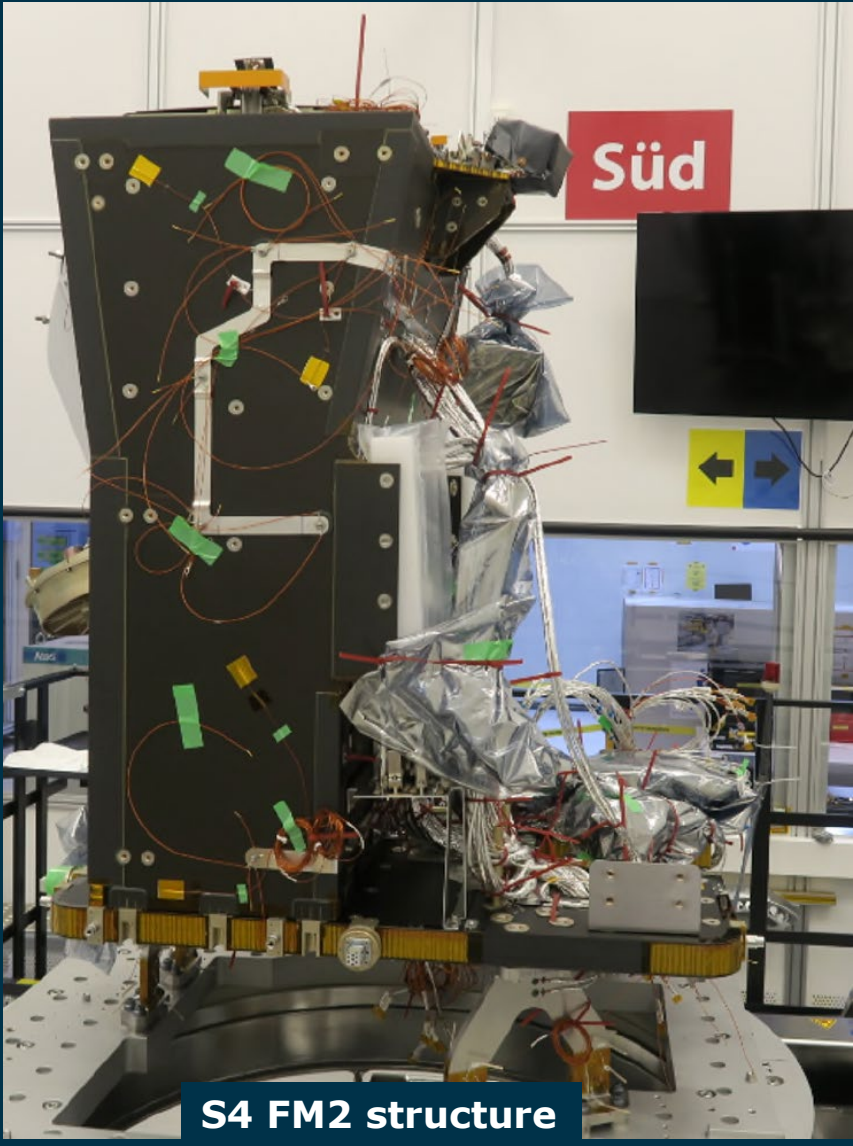
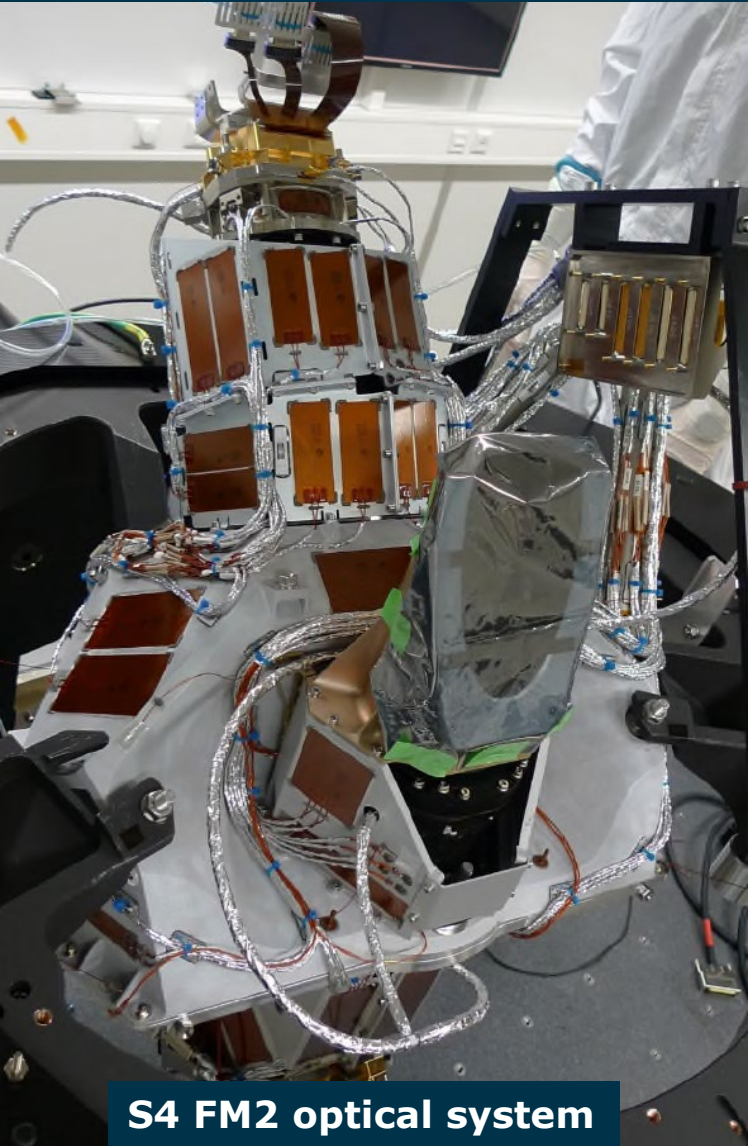
S4 PFM before integration on MTG-S1



S4 PFM integrated on MTG-S1



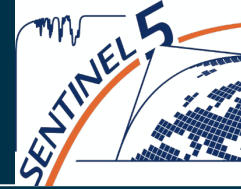
Copernicus Sentinel-4: FM2 recent photos



- L2OP development by a consortium lead by DLR
 - Algorithms verified by comparison with independent algorithms on synthetic and real data
 - Tested on large synthetic data set with variations of all driving conditions
 - Uncertainty budget established per product
 - Processor V1 acceptance completed
 - Testing on proxy data from geostationary GEMS and AMI
- Next steps
 - Processor V2 with input from on-ground C&C campaign
 - Processor V3 after instrument in-orbit verification
 - Integration in MTG L2 Processing Facility by EUMETSAT



Copernicus Sentinel-5

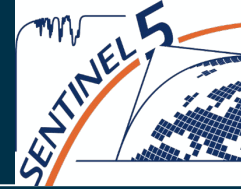


For observing the atmospheric composition with daily global coverage
UV-Vis-NIR-SWIR (UVNS) Imaging Spectrometer

- Built under the responsibility of ESA
 - Instruments and Level-1b Prototype Processor (L1bPP) by Airbus
 - L1bPP extensions, for integration with the L2PP, by Huld
 - Level-2 Prototype Processor (L2PP) by S&T
- Will be operated by EUMETSAT
- Low Earth Orbit ~9h30 local solar time
- Three S5/UVNS in sequence → mission lifetime 21 years
- Embarked on MetOp Second Generation A1, A2 and A3 satellites
- Synergy with MetImage, IASI-NG, and 3MI on MetOp-SG-A
- Proto-Flight Model integrated
- On-ground characterization & calibration started
- L1bPP V2 and L2PP V1 accepted
- Launch expected mid 2025



Copernicus Sentinel-5/UVNS



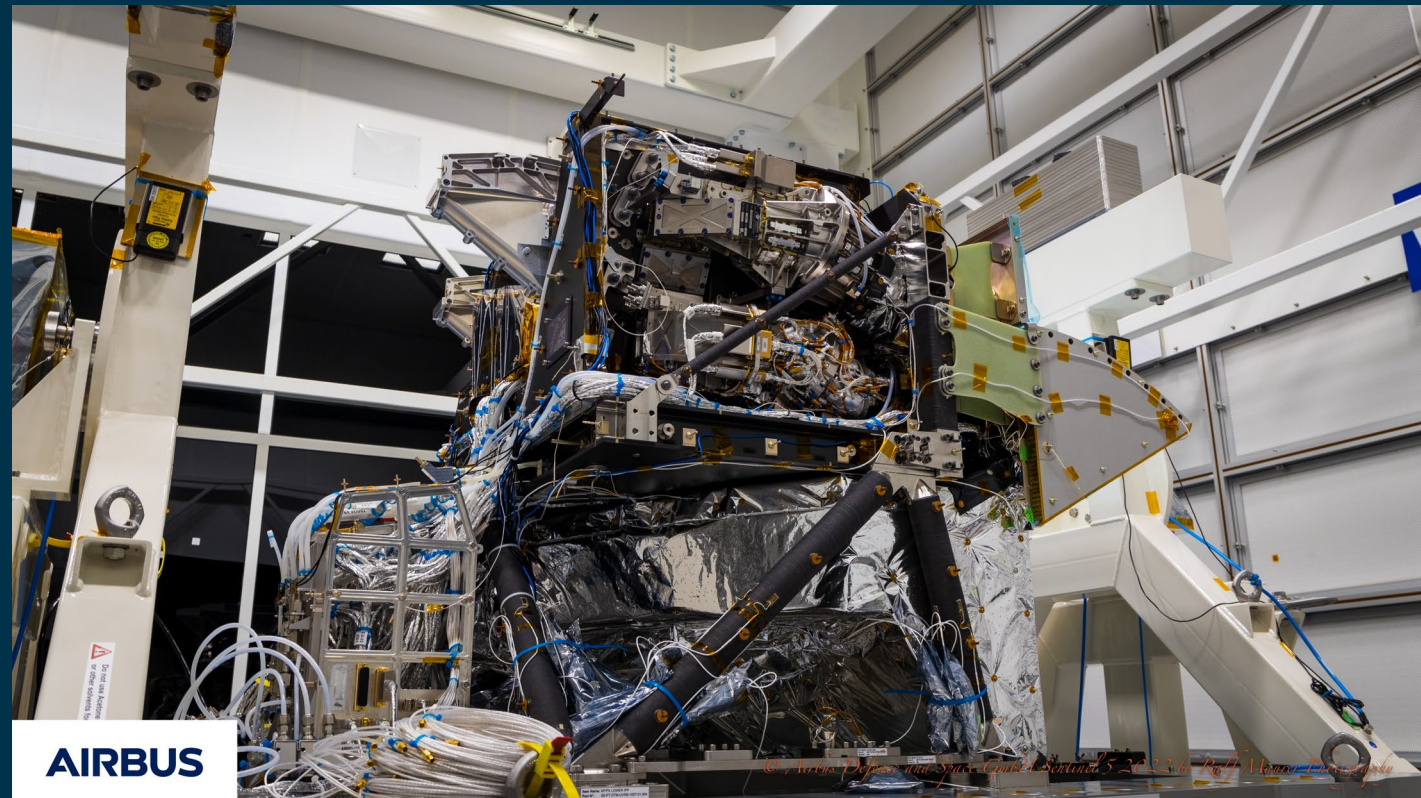
Spectral Range [nm]	270 – 310	300 – 500	685 – 710	755 – 773	1595 – 1675	2305 – 2385
Spectral Resolution [nm]	1	0.5	0.4	0.4	0.25	0.25
Spectral Oversampling	3	3	3	3	2.5	2.5
Signal to Noise of radiance (SZA=75/70°, alb=0.02/0.05 in UVN/SWIR)	100 @ 270 nm	1500 @ 420 nm	500 @ 710 nm	500 @ 755 nm	~220 (cont.)	~100 (cont.)
Radiometric Accuracy	3%	3%	3%	3%	6%	3.5%
Polarisation Sensitivity	0.5%	0.5%	0.5%	0.5 / 0.7%	20%	20%
Spectral Features	0.25% and L2 impact <50% of total uncertainty					
Revisit Time	Daily (more often at higher latitudes)					
Coverage	global					
Spatial Sampling	7.5 km @ nadir					

Copernicus Sentinel-5/UVNS



AIRBUS

© Airbus Defence and Space GmbH Sentinel 5 2022 by Ralf Maurer Photography



AIRBUS

S5 PFM prior to MLI closure

Images Airbus and RAL



12

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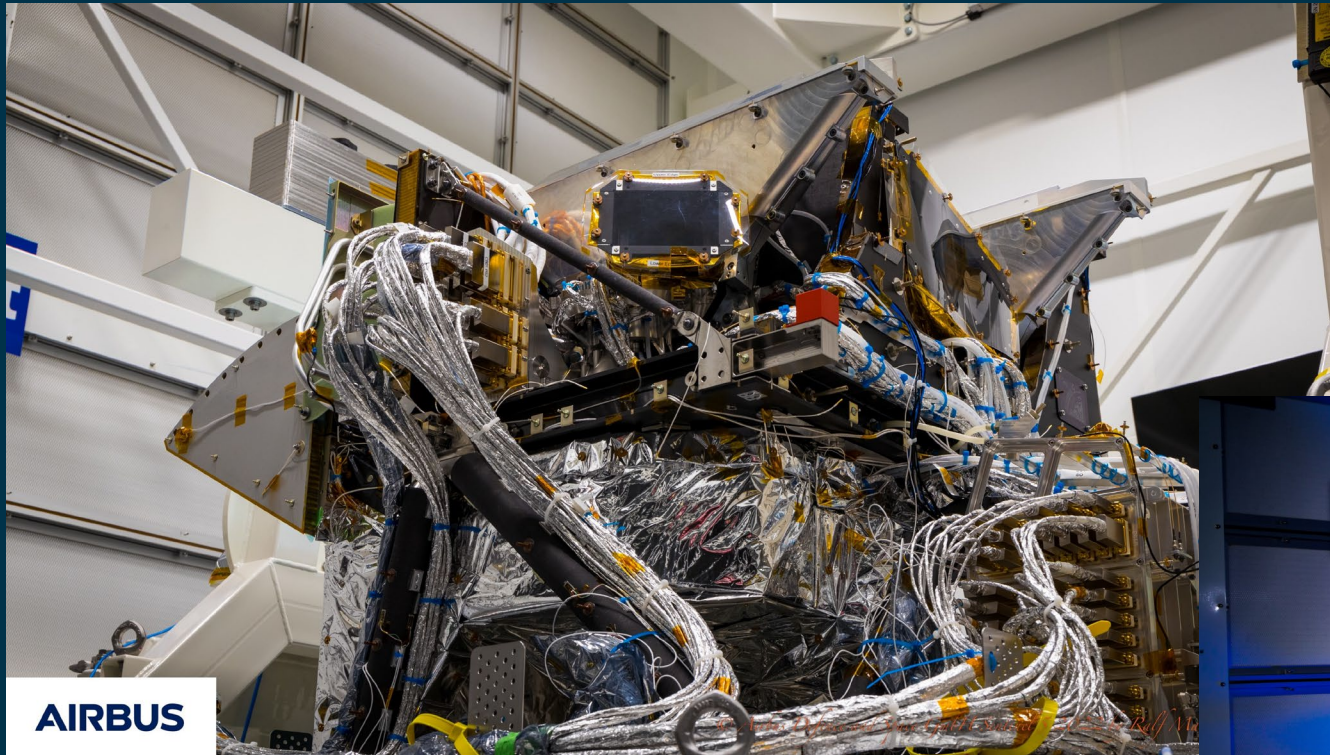


→ THE EUROPEAN SPACE AGENCY

Copernicus Sentinel-5/UVNS



Images Airbus and RAL



AIRBUS

S5 PFM prior to MLI closure



AIRBUS

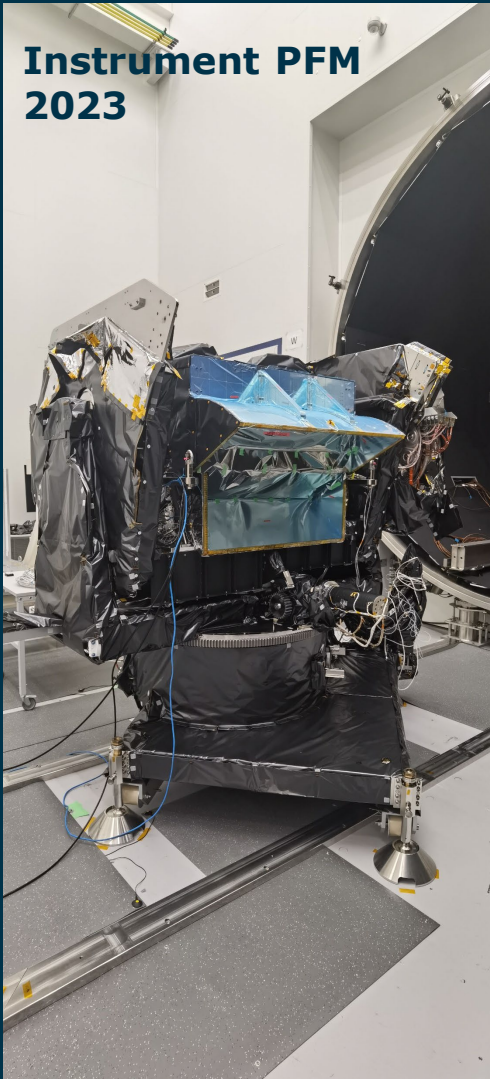
S5 PFM after MLI closure

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→ THE EUROPEAN SPACE AGENCY

Copernicus Sentinel-5/UVNS



Instrument PFM
2023



Sentinel 5 on MGSE
in front of TVAC



PFM in TVAC Chamber at RAL

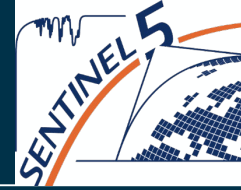
Images Airbus and RAL



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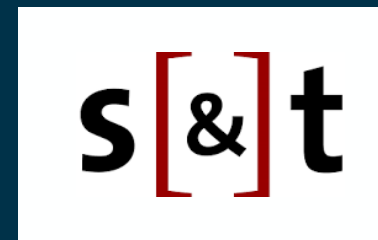
Copernicus Sentinel-5 Level-2



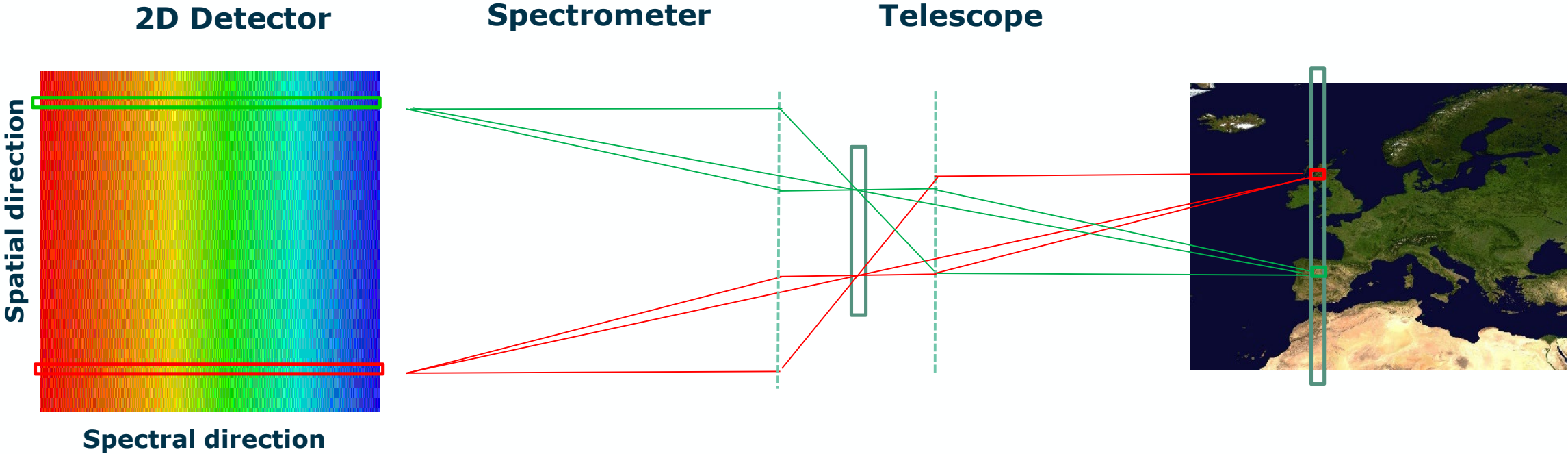
- Prototype Processor (L2PP) development lead by S&T
 - Algorithms verified by comparison with independent algorithms on synthetic and real data
 - Tested on large synthetic data set with variations of all driving conditions
 - Uncertainty budget established per product
 - Processor V1 delivered
- Next steps
 - Processor V2 after on-ground characterization and calibration of PFM
 - Processor V3 after instrument in-orbit verification
 - Operational Processor (L2OP) development and integration in EPS-SG ground segment by EUMETSAT



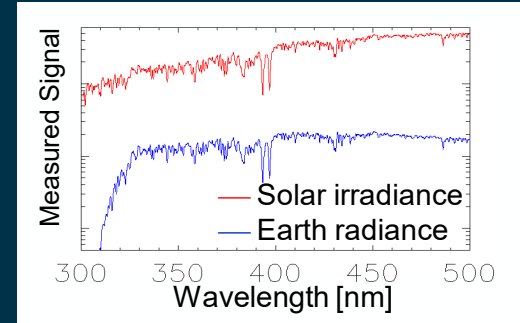
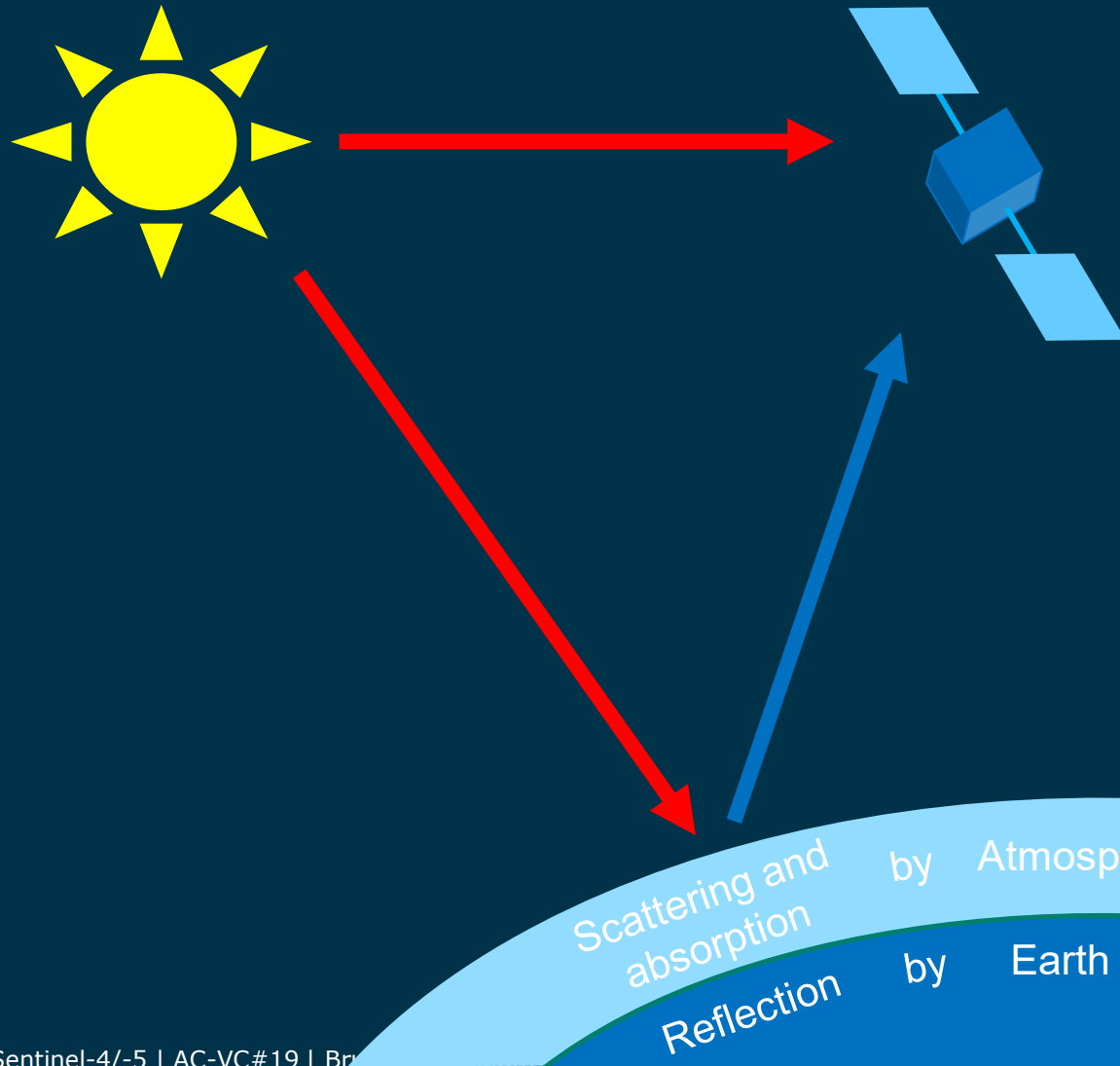
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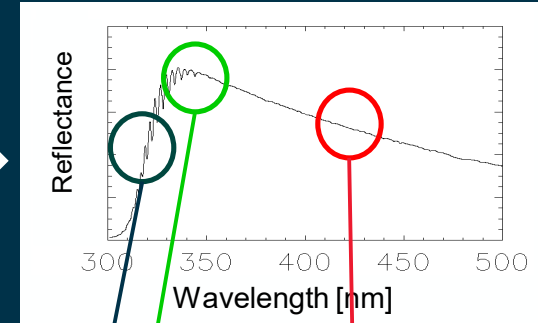
Observation Principle



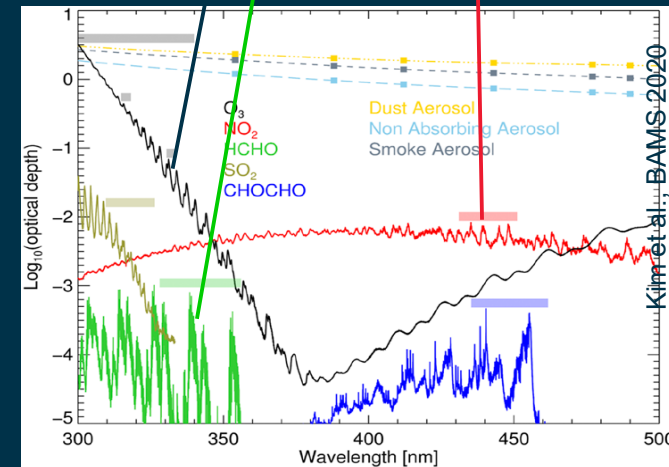
Observation Principle



ratio



Signatures of atmospheric trace gases and aerosol



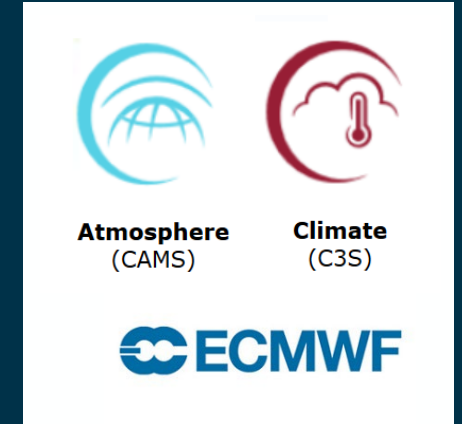
Copernicus Sentinel-4 and Sentinel-5 Data

- Free, full, and open access
 - Copernicus Sentinel Data Policy & EU Regulations
- Processed up to Level-2 in EUMETSAT's MTG and EPS-SG ground segments
- Dissemination of Level-2 products in near real-time via EUMETCast
- Access to Level-1b and Level-2 products via EUMETSAT Data Centre
- Cloud-based access to data and processing tools
 - Copernicus Data and Information Access Services (DIAS)
 - Enable users to build applications and process large datasets easily



Sentinel-4 and Sentinel-5 data will be used by

- Copernicus Atmosphere Monitoring Service (CAMS)
 - Monitor and forecast atmospheric composition
 - Provide input to local air quality services (e.g. mobile phone apps)
 - Monitor and forecast ozone and erythemal dose rates (UV index)
 - Support monitoring of compliance with European directives on air quality and emissions
 - Support policy makers to assess effectiveness of measures to reduce pollution
- Copernicus Climate Change Service (C3S)
 - Monitor WMO Essential Climate Variables: CH₄, O₃, aerosol, and precursors (NO₂, SO₂, HCHO, CO)
 - Detect and characterise ECV related emissions
 - Support policy makers to assess effectiveness of adaptation and mitigation measures
- Volcanic Ash Advisory Centres (VAAC)
 - support air traffic controllers
- Science community to
 - Study the atmosphere: composition trends, patterns, events, processes, ...
 - Improve atmospheric composition models
- ... and more



Approach to Calibration and Validation

- Sentinel-4 and Sentinel-5 Cal/Val Plan
 - Jointly prepared by ESA and EUMETSAT
 - Covers both Sentinel-4 and Sentinel-5
 - Formulates Cal/Val objectives and requirements
 - Sets frame for Announcement of Opportunity Call
- Announcement of Opportunity Call
 - Trigger & coordinate nationally funded Cal/Val activities, in particular campaigns
 - Jointly prepared by ESA and EUMETSAT
 - Released at ~1.5 years before launch
 - One combined Call for Sentinel-4 and Sentinel-5 (if launches are not too far apart)
- Level-2 Cal/Val Activities
 - Start once consolidated Level-1b becomes available
 - Bulk of activities after completion of Satellite In-Orbit Verification