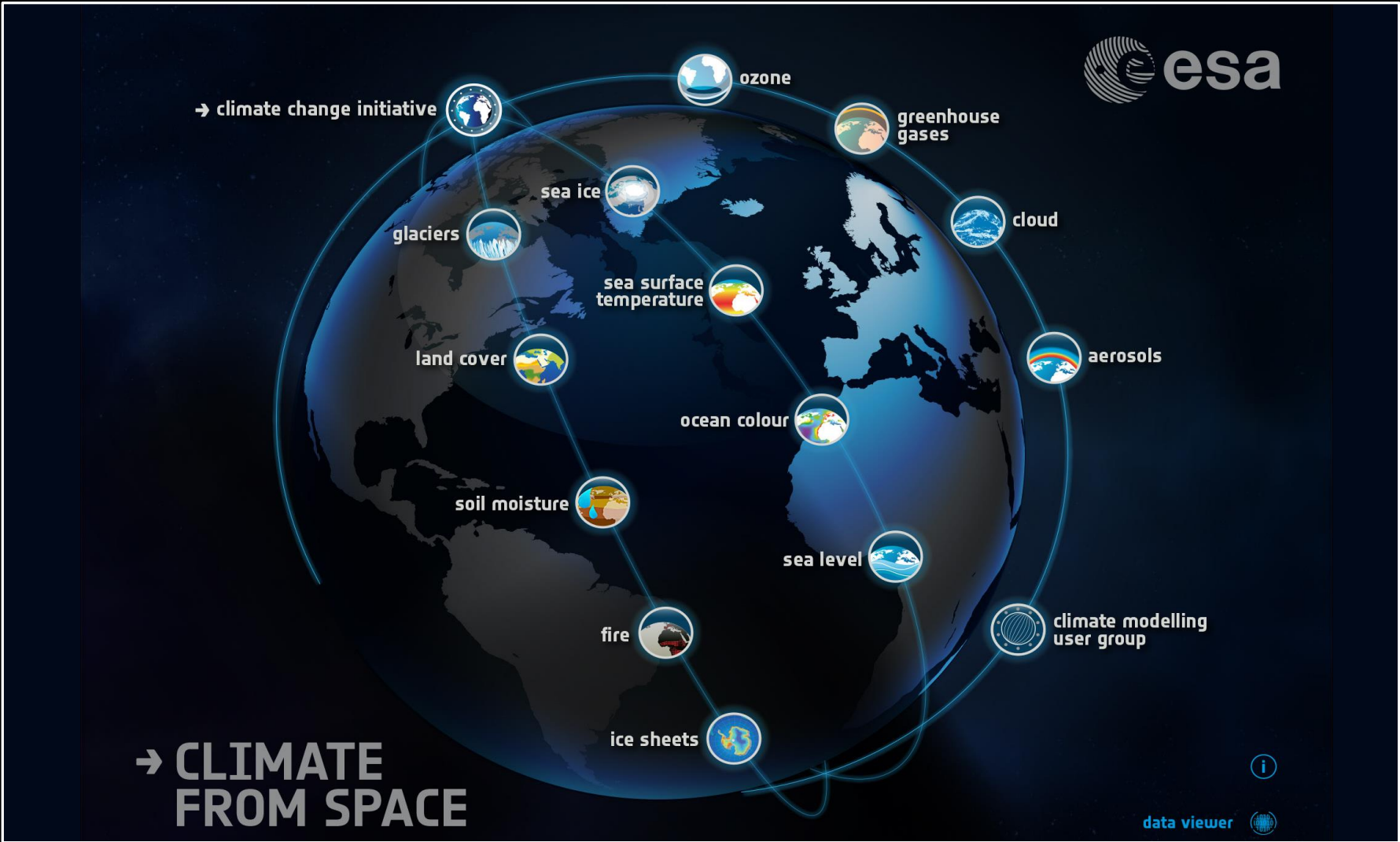


Photonics technologies for Climate Change Monitoring from Space

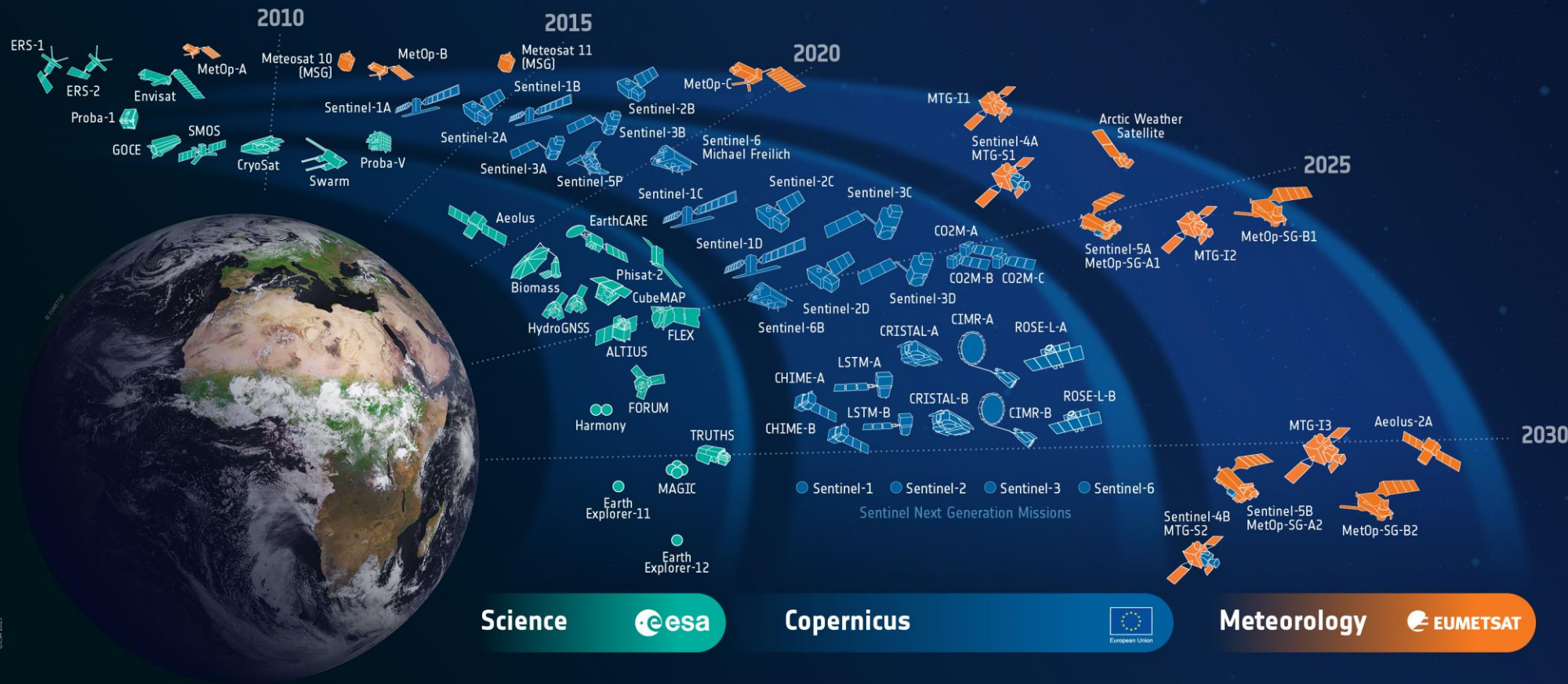
Arnaud Hélière, European Space Agency

Head of the Optical Instruments section, Directorate of Earth Observation Programmes

EPIC online event on photonics for climate change monitoring- 24 April 2023



ESA-Developed Earth Observation Satellites



Satellites
Heritage 04
Operational 15
Developing 41
Preparing 22
Total 82
+ Third Party Missions

EarthCARE: Earth Cloud, Aerosol mission



- Global observations of clouds, aerosols and radiation
- Collaboration with JAXA
- Launch date 2024

- Payload:

- Atmospheric UV backscatter Lidar
- Doppler Cloud Profiling Radar (JAXA)
- Multispectral Imager
- Broadband Radiometer

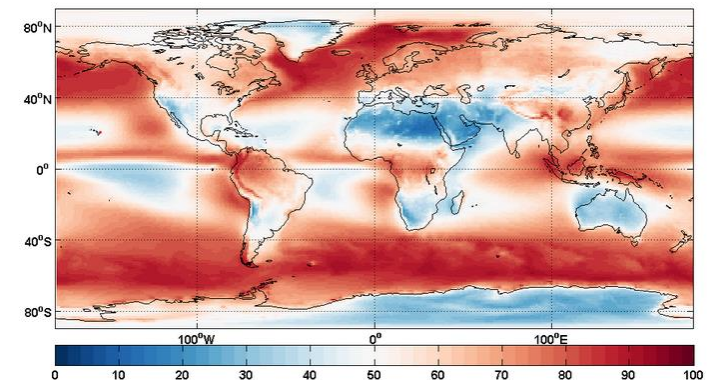
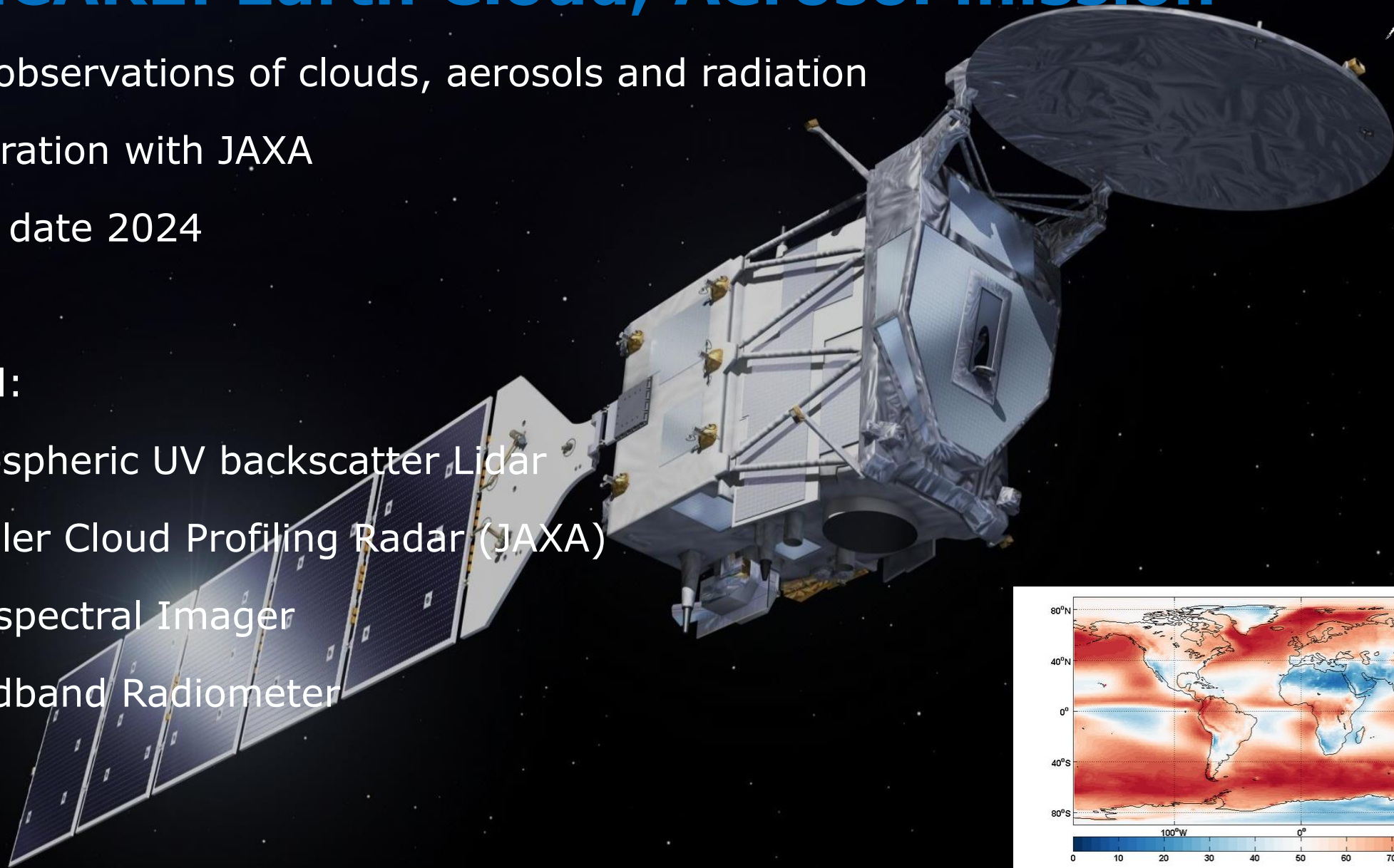
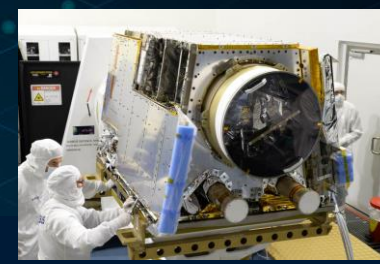


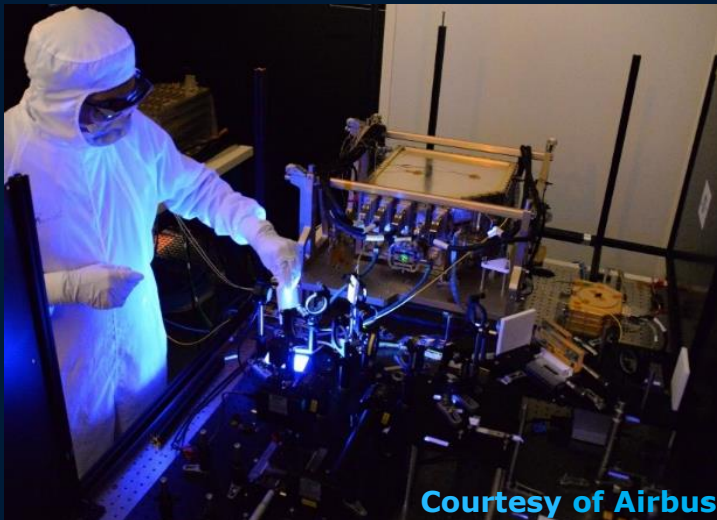
Figure: Climatological mean total cloud fraction averaged over 26-year period (1984-2009) from Climate Monitoring Satellite Application Facility (CM SAF) Cloud, Albedo (CLARA-A2). The CM SAF project is a part of the ground segment of the European organization for the exploitation of meteorological satellites (EUMETSAT).

EarthCARE Lidar technologies

- Diode-pumped Nd:YAG laser (1064 nm), with frequency tripling stage to generate the third harmonic of 355 nm
- Frequency stabilisation with injection seeding through optically fibered reference laser path.
- High spectral resolution filter centred on the laser wavelength: Fabry-Perot etalon
- Separation of the Rayleigh and Mie channels by polarizers
- Quasi photon counting memory CCD

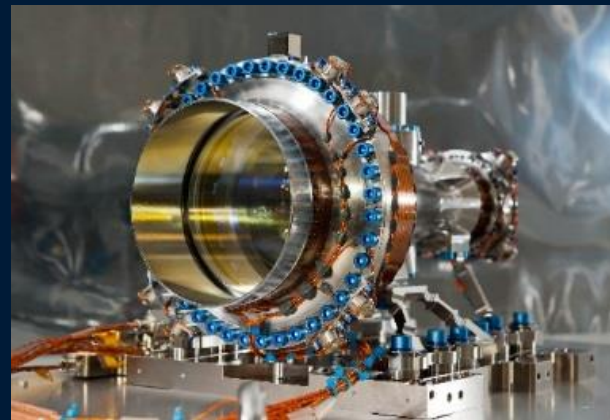


Laser main requirements	
Pulse energy	38 mJ UV
PRF	51 Hz
Divergence	<200 μ rad
Linewidth	< 50 MHz
Frequency stability	< 50 MHz over 1 month
Total number of shots	>5 Gshots



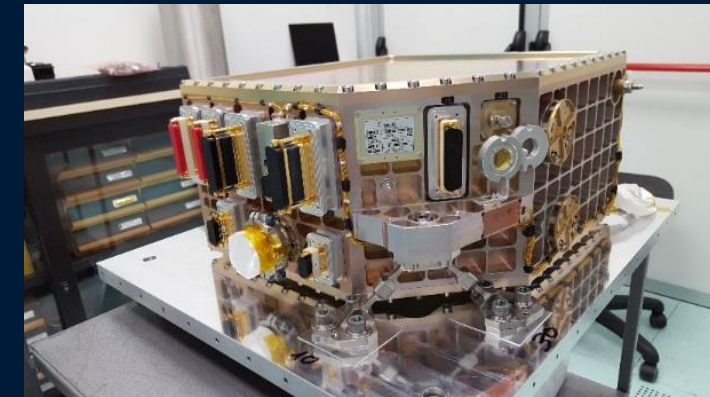
Courtesy of Airbus DS

Beam Expander



Courtesy of SODERN

Power Laser Head



Courtesy of Leonardo

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Aeolus : Wind Lidar mission



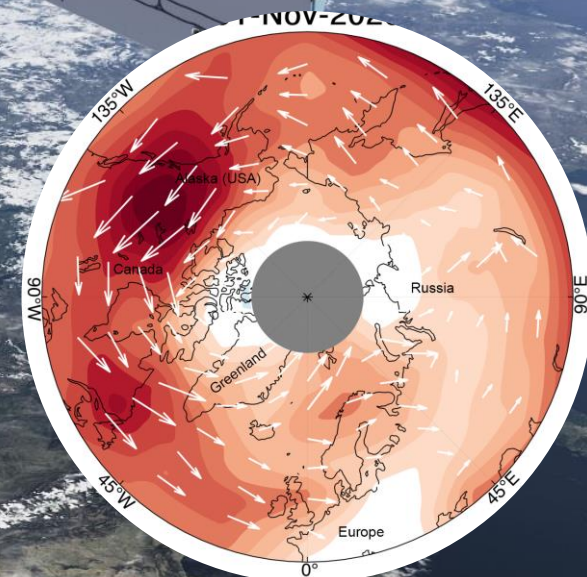
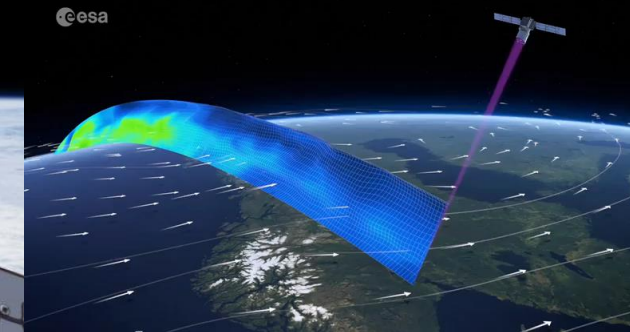
Close to 5 years of successful operation

Objectives

- To improve the quality of weather forecasts;
- To advance our understanding of atmospheric dynamics and climate processes;
- Demonstrate space-based Doppler Wind LIDARs
- Observation means:
- Provide global measurements of horizontal wind profiles in the troposphere and lower stratosphere

Payload

- ALADIN: Direct detection UV Doppler lidar



- EPIC online event on photonics for climate change monitoring - 24 April 2023

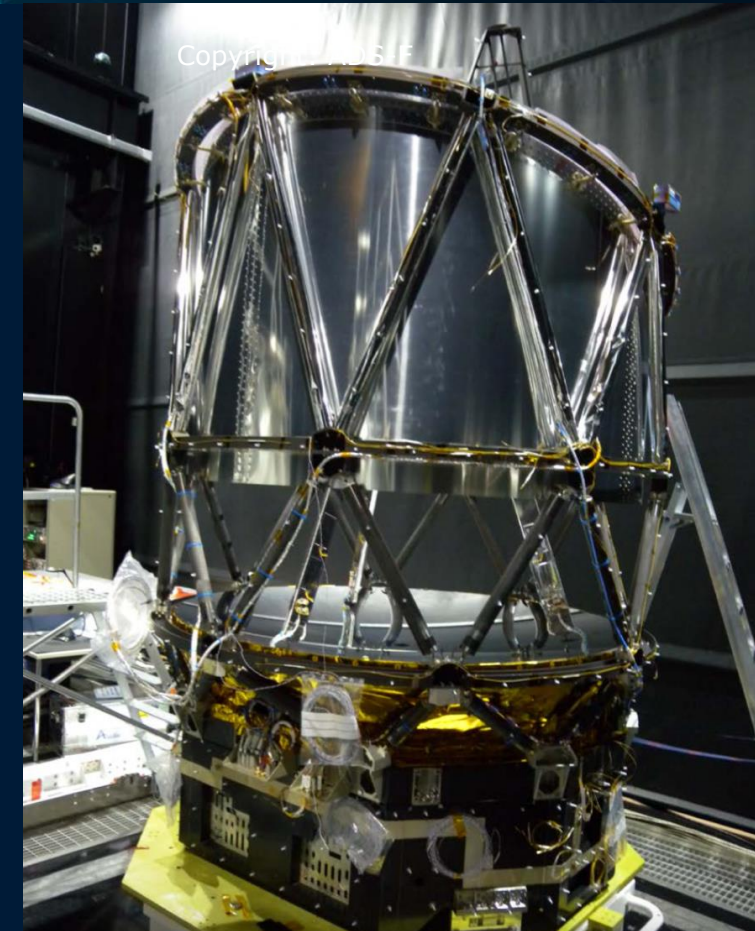


→ THE EUROPEAN SPACE AGENCY

AEOLUS : ALADIN Instrument and technologies



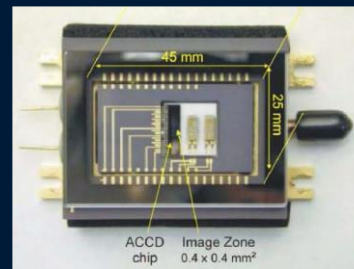
- ❑ Mono-static concept, telescope : 1.5m diameter
- ❑ 2 receiver channels based on HR interferometers:
 - Mie receiver (Fizeau) to determine winds from aerosol & cloud backscatter.
 - Rayleigh receiver (Fabry-Perot etalon) to determine winds from molecular backscatter
- ❑ High energy UV laser : up to 100mJ @355nm, PRF: 50Hz
- ❑ Detection using 2 Accumulation CCD's (back illuminated thinned CCD's)



Preparation for an operational Aeolus-2 mission are on-going



Courtesy of TAS-CH



Courtesy of Teledyne e2v

Courtesy of Airbus DS

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→ THE EUROPEAN SPACE AGENCY

Copernicus: European leadership in EO



Sent-1A/B



Sent-2A/B



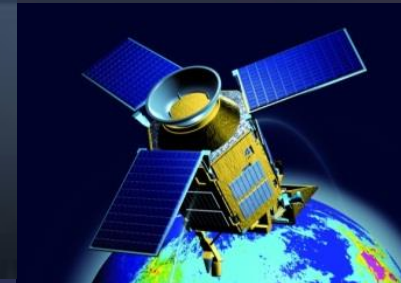
Sent-3A/B



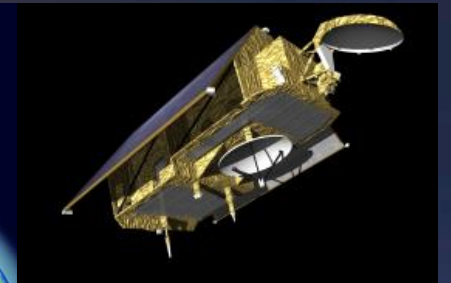
Sent-4A/B



Sent-5/5P

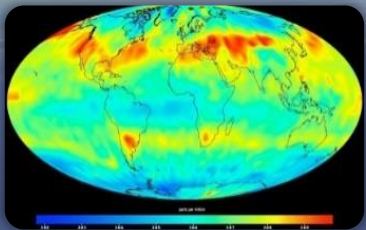


Sent-6A/B



- European space flagship programme, led by the EU, for global monitoring of the environment
- Missions include Sentinels and contributing missions (from national Agencies and companies)

CO2M



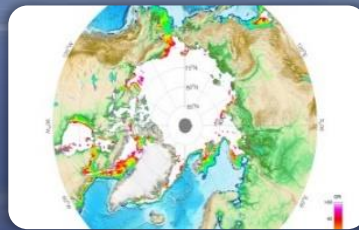
Anthropogenic
CO₂ Monitoring

CRISTAL



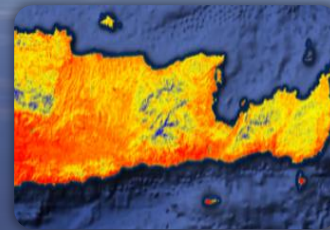
Polar Ice & Snow
Topography

CIMR



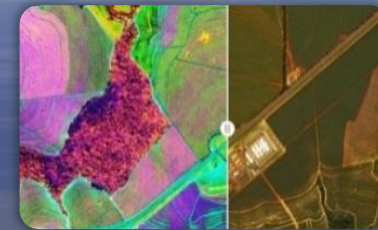
Passive Microwave
Radiometer

LSTM



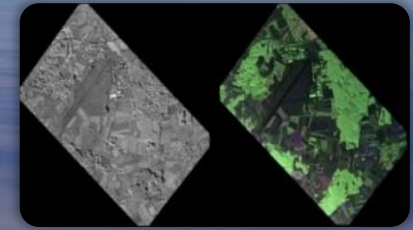
Land Surface
Temperature Mission

CHIME



Hyperspectral
Imaging Mission

ROSE-L



L-band SAR Mission



Sentinel-3: Global Land and Ocean Mission



Mission Objectives

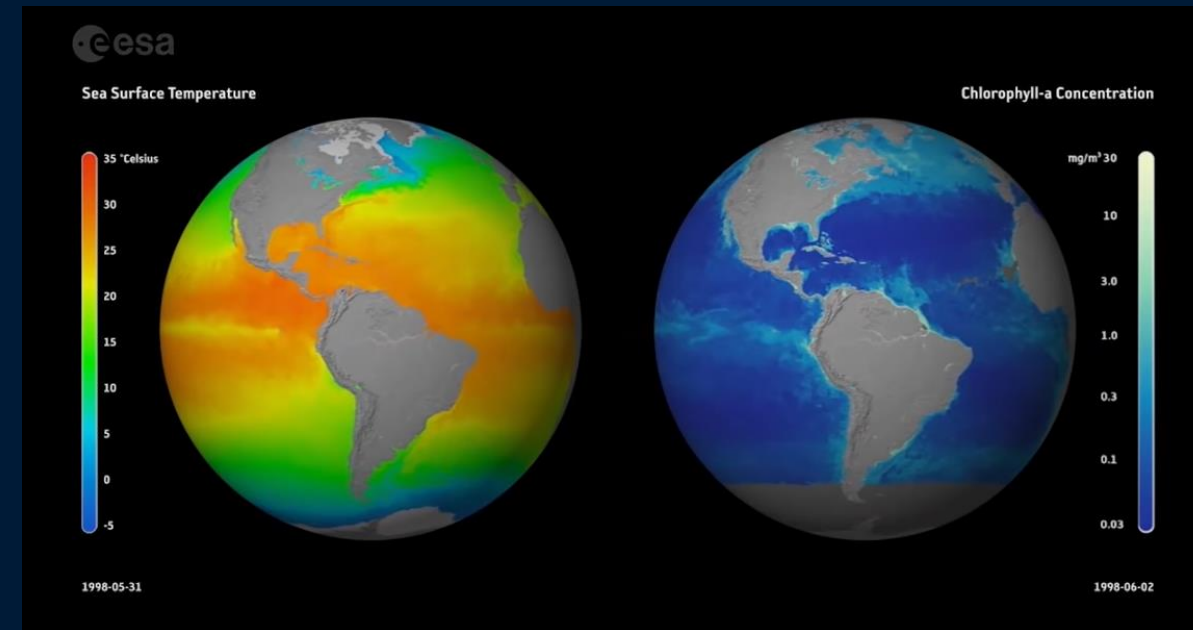
- Sea and land colour data
- Sea and land surface temperatures
- Sea-surface and land-ice topography
- High-resolution altimetry for synthetic aperture processing
- Land synergy products from optical instrument data

Optical Mission Payload

- Ocean and Land Colour Instrument (OLCI)
- Sea and Land Surface Temperature Radiometer (SLSTR)

Topography Mission Payload

- Synthetic Aperture Radar Altimeter (SRAL)
- Microwave Radiometer
- GNSS, DORIS, LRR

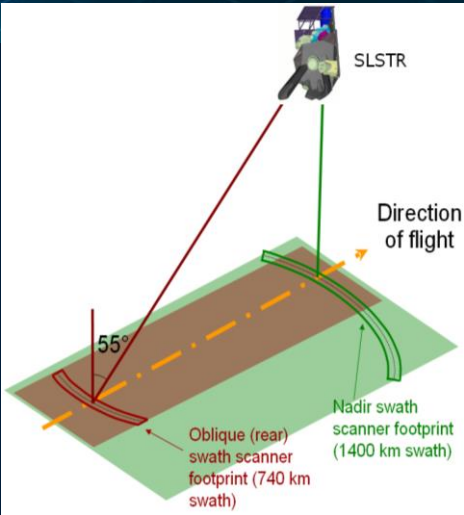


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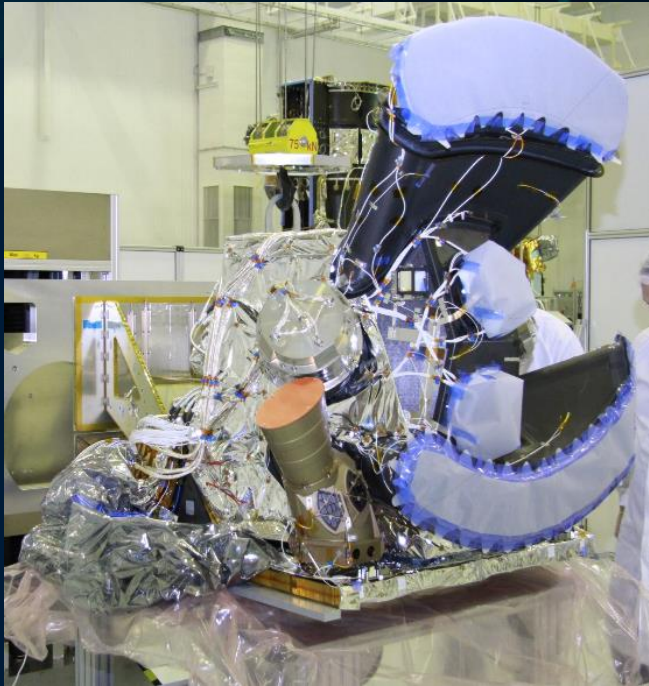
Sea and Land Surface Temperature Radiometer



- Global coverage of Sea Surface skin Temperature (SST_{skin}) with zero bias and uncertainty of $\pm 0.3K$ (1σ)
- Stirling cooler
- Dichroic filters
- Two-points calibration on board blackbody and sun diffuser (PTFE, Zenith)
- CMOS VIS detectors @ 260K
- MCT TIR detectors @ 85K



Swath width	Nadir view	1400 km
	Oblique view	740 km
Spectral channels (μm)	VIS	0.555-0.659-0.865
	SWIR	1.375-1.61-2.25
	MWIR/TIR	3.74-10.85-12.0
	Fire	3.74-10.85
SSD		0.5 km VIS-SWIR
		1.0 km IR-Fire
Radiometric resolution	VIS	SNR>20
	SWIR	SNR>20
	MWIR	NEDT < 80 mK
	TIR	NEDT < 50 mK
	Fire-1	NEDT < 1 K
	Fire-2	NEDT < 0.5 K



Courtesy of LEONARDO

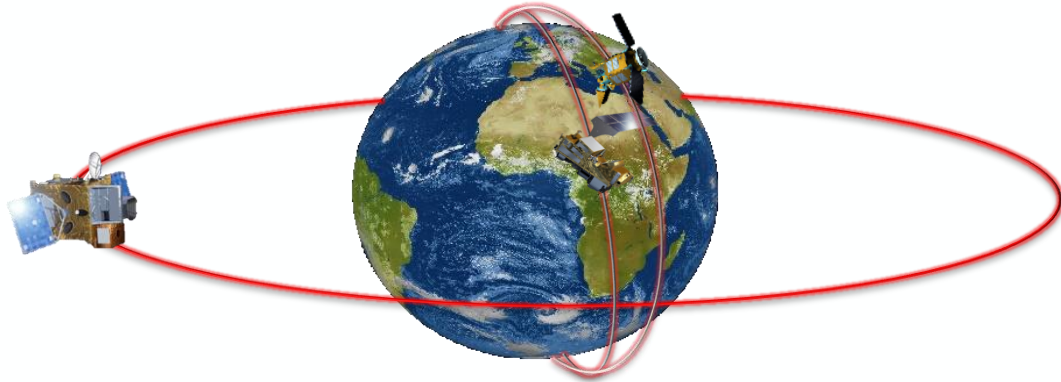


Courtesy of AIM



Courtesy of ABSL

The Sentinel Missions for Copernicus Atmosphere Service



Low Earth Orbit (LEO)

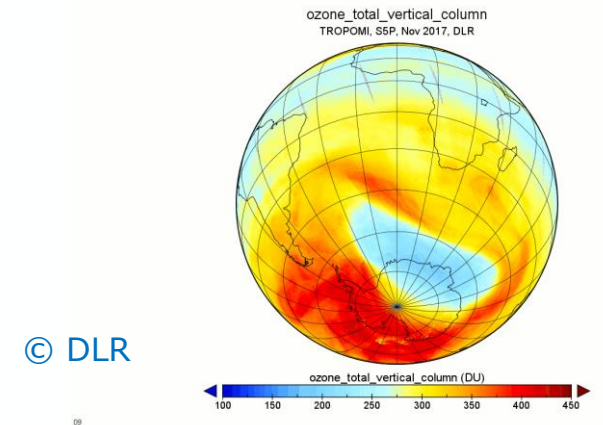
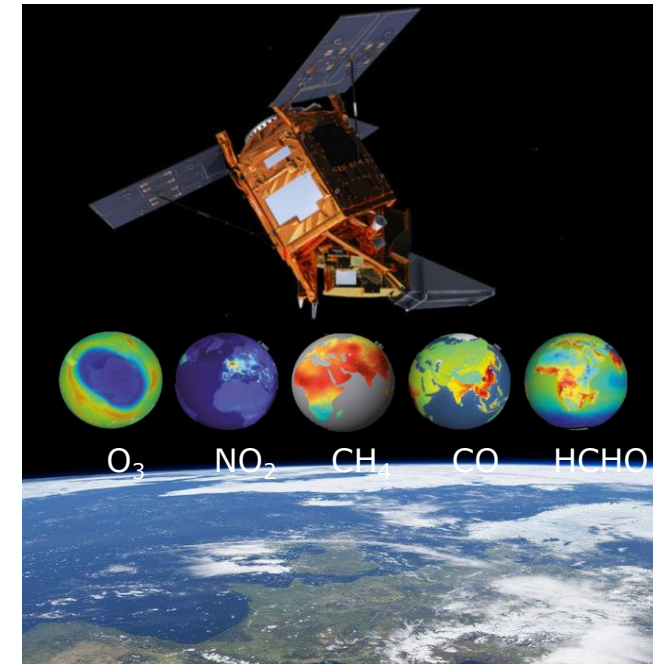
- Daily revisit time **global coverage**
- Climate, air quality, ozone & UV
- Tropospheric & stratospheric composition

→ Sentinel-5

UVNS spectrometer embarked on the EUMETSAT MetOp-SG platforms

→ Sentinel-5 Precursor

Single-satellite carrying the TROPOMI UVNS spectrometer as a precursor to sentinel-5



GEOstationary (GEO)

- Hourly revisit time over **Europe**
- Mainly air quality
- Diurnal cycle of tropospheric composition

→ Sentinel-4

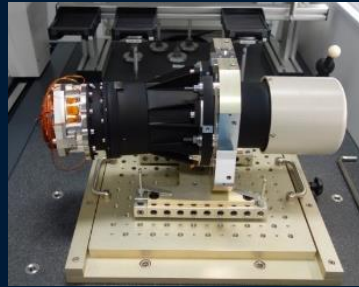
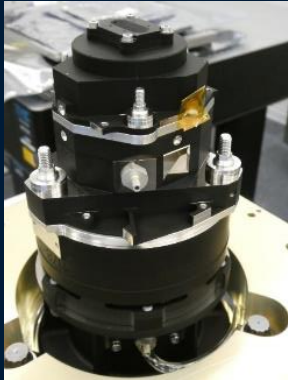
UV-visible-NIR spectrometer embarked on the EUMETSAT MTG-S platforms (synergy with other sensors)

Sentinel- 4: Spectrometer targeting air quality (O3, NO2, SO2, HCHO and aerosols)

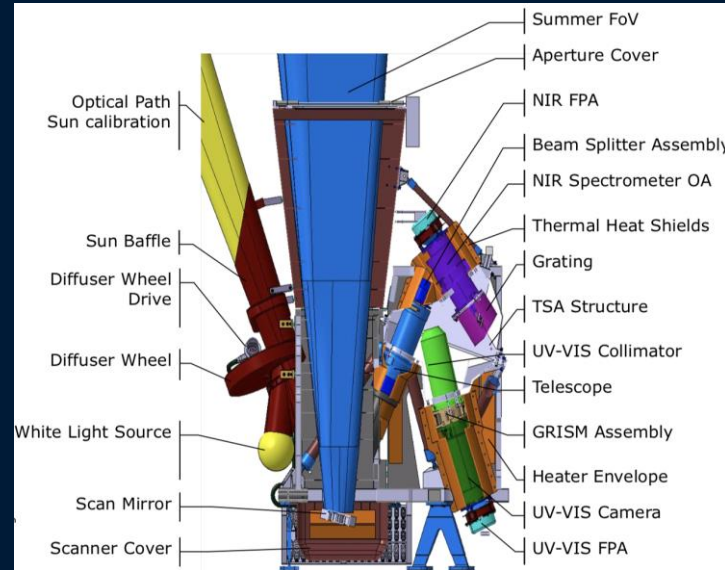


UV-Visible and NIR infrared spectrometer- 8km spatial resolution- 60 minutes repeat cycle

FM Telescope and UVVIS spectrometer



Jena-Optronik (DE)
courtesy

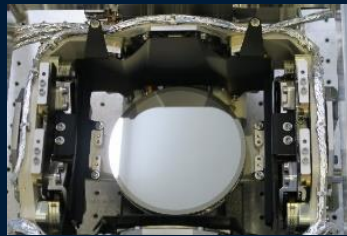


Sentinel 4 UVN PFM instrument



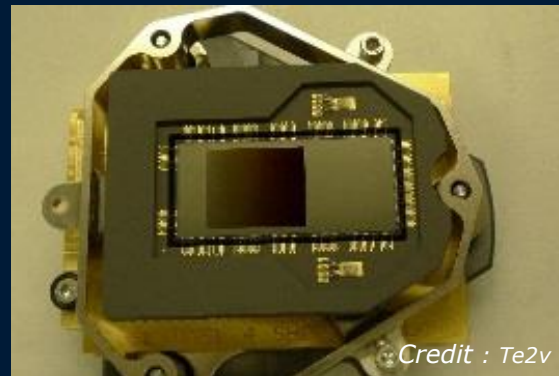
Airbus DS (DE) courtesy

2-axis FM scanning mechanism and scan mirror



Credit : RUAG

FM UVVIS Silicon CCD

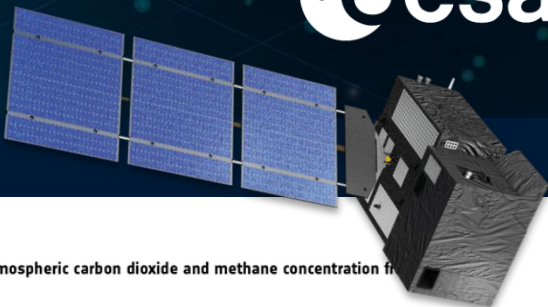


Credit : Te2v

High-performance onboard calibration sources (solar diffusers, white light source, LEDs)

CO2M – Europe’s first operational CO2 mission

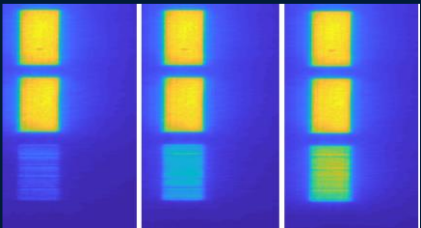
Planned to be operational from 2025/26



Telescope	Common telescope with polarisation scrambler and entrance slit homogeniser
Collimator	One reflective collimator, common for all bands
Band separation	3 Dichroic plates split used in collimated beam
Diffraction grating	4 Prism-Grating-Prism assemblies
Imagers	Glass (VIS/NIR) and silicon (SWIR-1/SWIR-2); band-pass filters
Detectors	Mercury-Cadmium-Telluride CMOS detectors in SWIR; Si CMOS in VIS-NIR

Key technologies

Fiber-based entrance slit made of stacked rectangular multi-mode fibers (TASiCH/Optec)



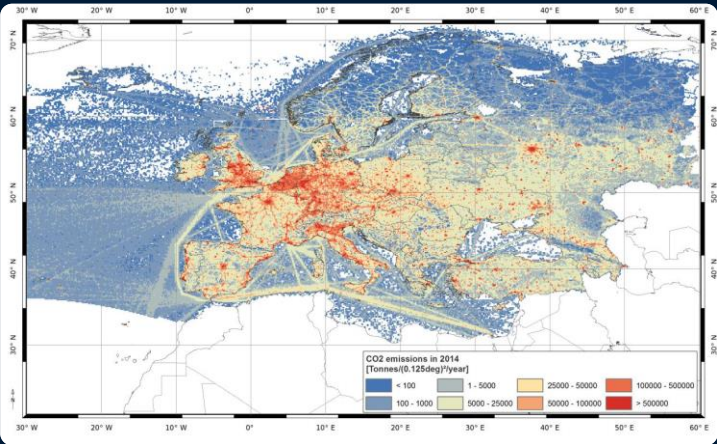
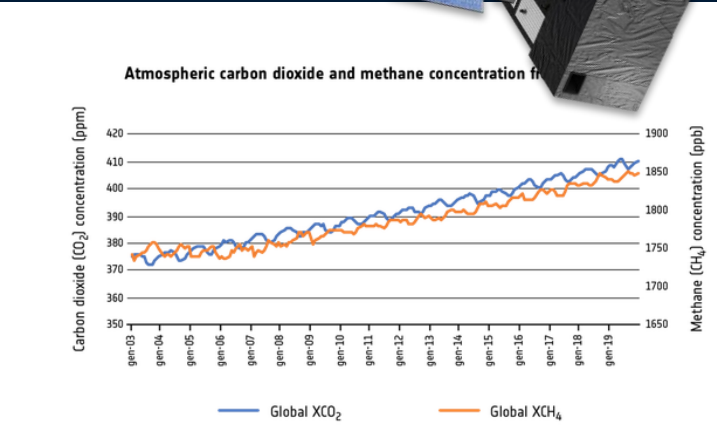
Credits:
Teledyne E2V



Credits: IOF

Diffraction gratings based on Prism-Grating-Prism assemblies (Fraunhofer IOF for NIR & SWIR)

CMOS (Teledyne E2V) and MCT (Lynred) detectors



CO2 or Methane Monitoring – Lidar missions

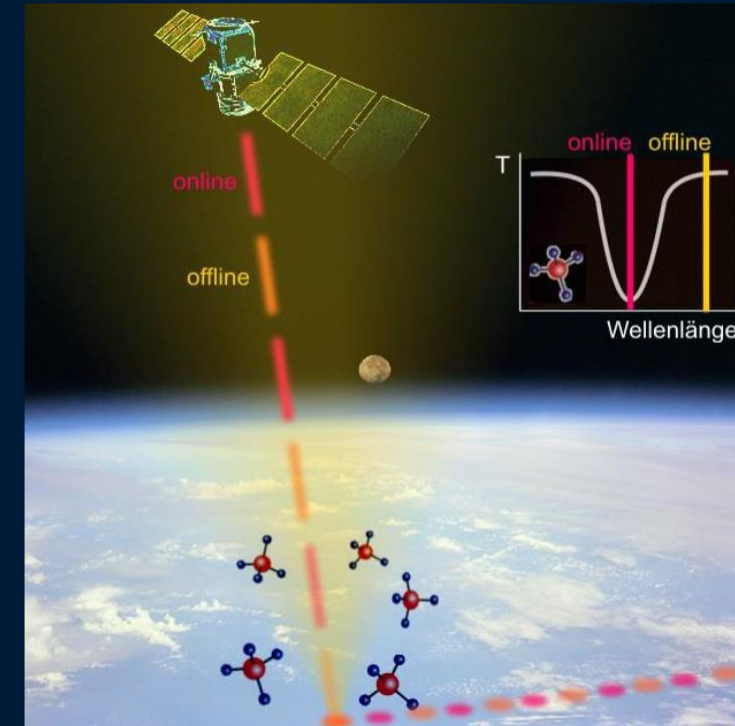
Differential Absorption Lidars are also able to provide column integrated CO2 or CH4 measurements

This is being implemented through MERLIN space mission by Germany/France

ESA studied A-SCOPE mission for CO2 measurements with a DIAL instrument

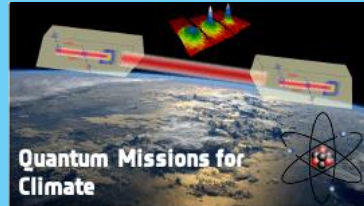
Key photonic technologies were developed for:

- **Laser source at 1.6 or 2 micron (OPO laser design or fibred lasers)**
- **Frequency stabilization: involving technologies such as frequency combs**
- **Power monitoring reference**
- **Fibred receivers**
- **MCT APD's are being also developed in Europe**



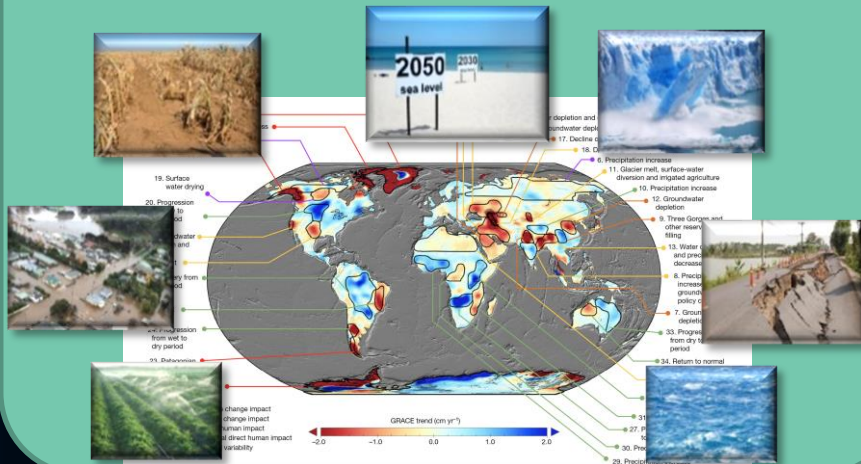
Quantum Missions for Climate

monitor climate changes
with constellation of
enhanced quantum sensors



to provide, enhance and enable new
Essential Climate Variables for a
more sustainable Earth

monitor and prevent in time major
hazards due to climate change

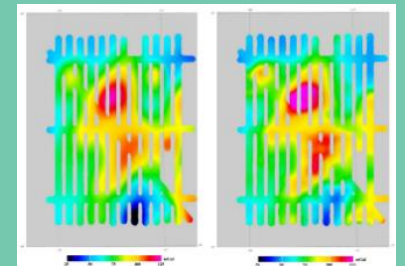
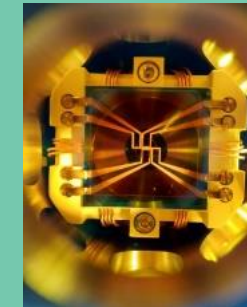
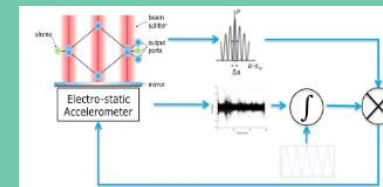
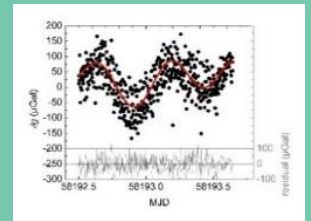
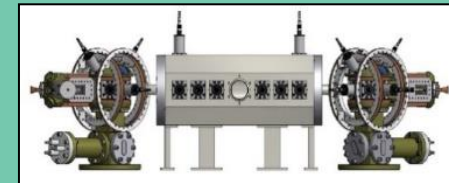


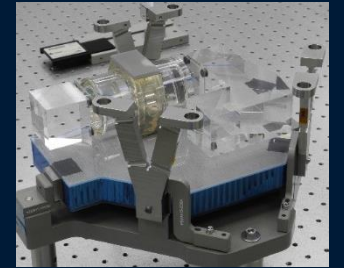
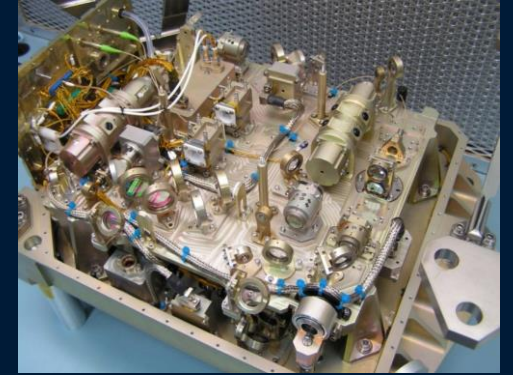
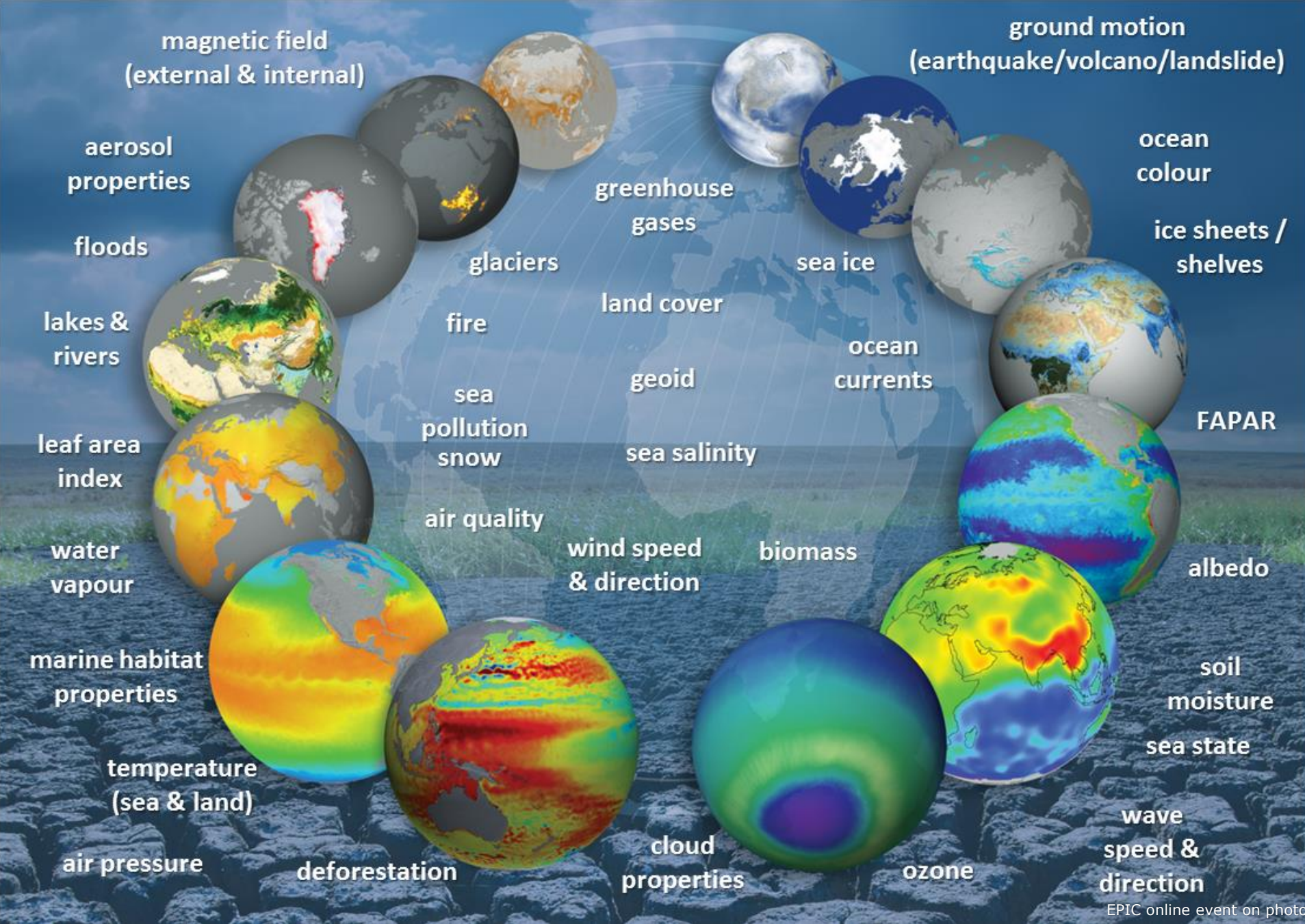
ECVs

User needs

Opening new
application
and services

Enter Quantum Technological Breakthrough
for new generation of enhanced sensors





www.esa.int

<https://climate.esa.int/>
arnaud.heliere@esa.int

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