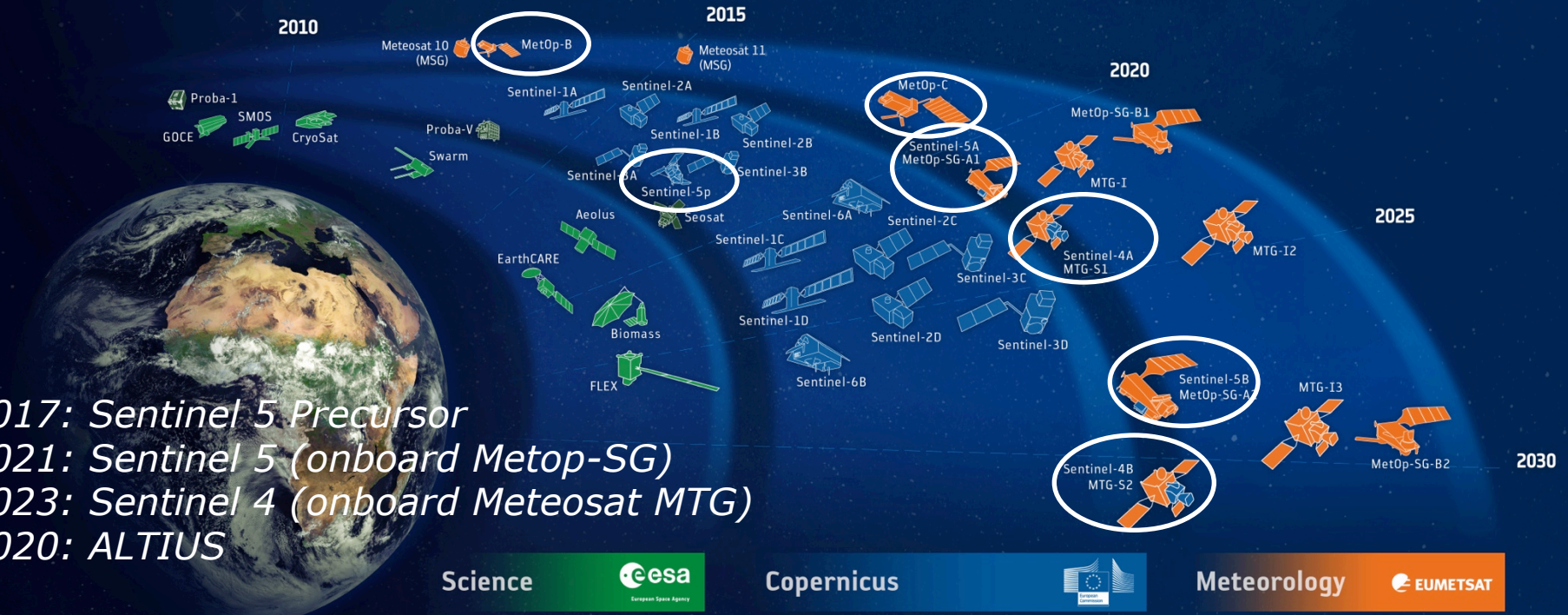
Contribution of the European Space Agency to Ozone Research and Monitoring

September 2017

ESA-developed Earth Observation Missions relevant to Ozone Monitoring

1995-2011: GOME onboard ERS-2
2002-2012: GOMOS, MIPAS, SCIAMACHI onboard Envisat
since 2006: GOME-2 onboard MetOp series



2017: Sentinel 5 Precursor
2021: Sentinel 5 (onboard Metop-SG)
2023: Sentinel 4 (onboard Meteosat MTG)
2020: ALTIUS

Science esa European Space Agency | Copernicus | Meteorology EUMETSAT

GOME and GOME-2

GOME: 1995 – 2011 onboard ERS-2 satellite

GOME-2: since 2006 onboard operational MetOp (EPS) satellite

Nadir-scanning UV-Vis spectrometer

Vertical resolution: 5 km (for O_3)

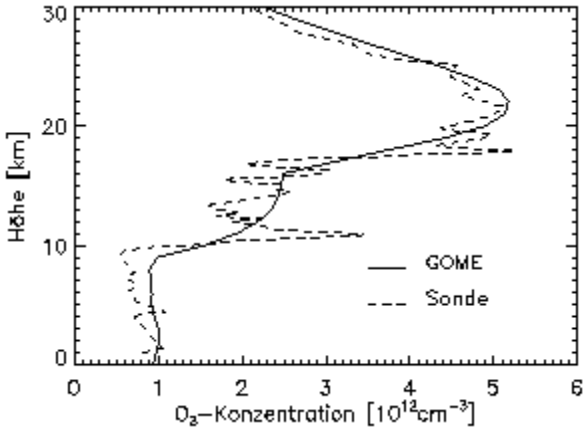
Horizontal res.: 40 x 40 km to 40 x 320 km

Swath Width: 120-960 km

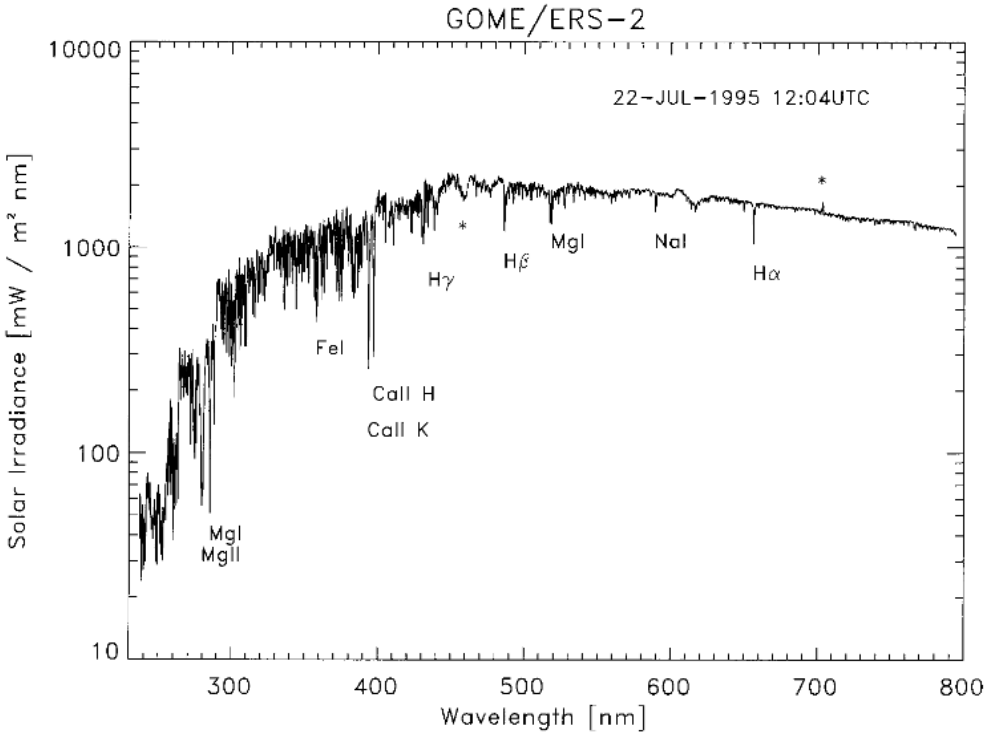
Waveband: 240 - 790 nm (res. 0.2-0.4nm)

GOME Data Products

- Total ozone column
- Ozone profiles
- NO_2, BrO, H_2O, SO_2, H_2CO, OClO

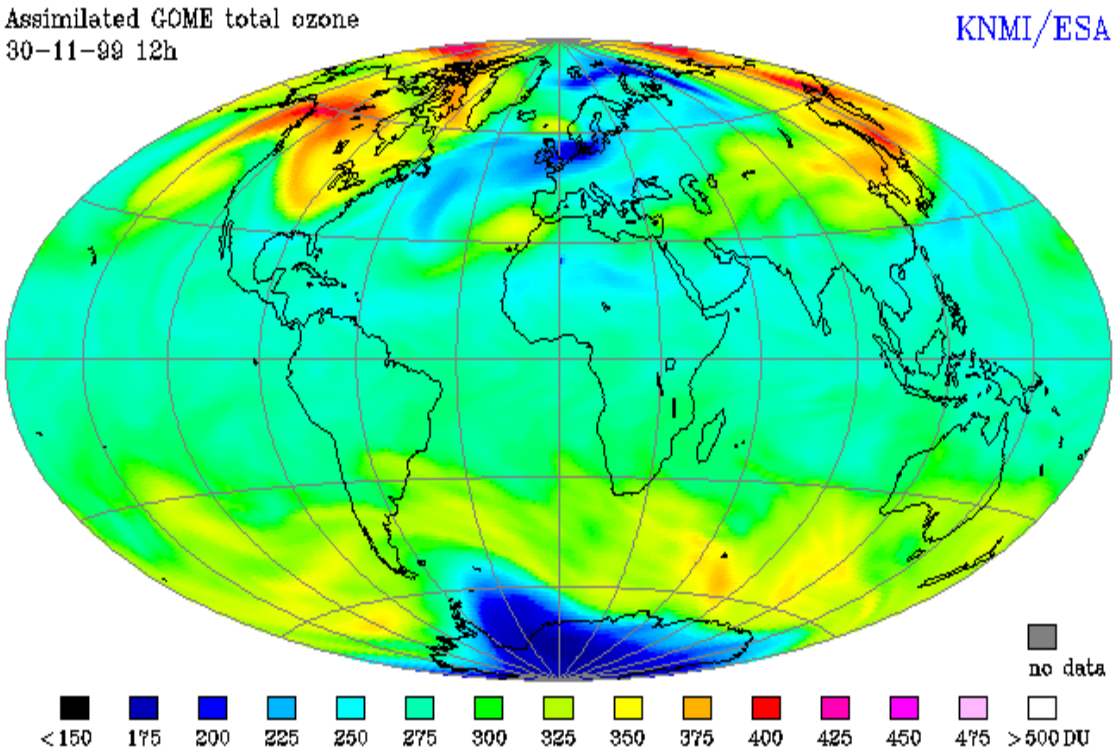


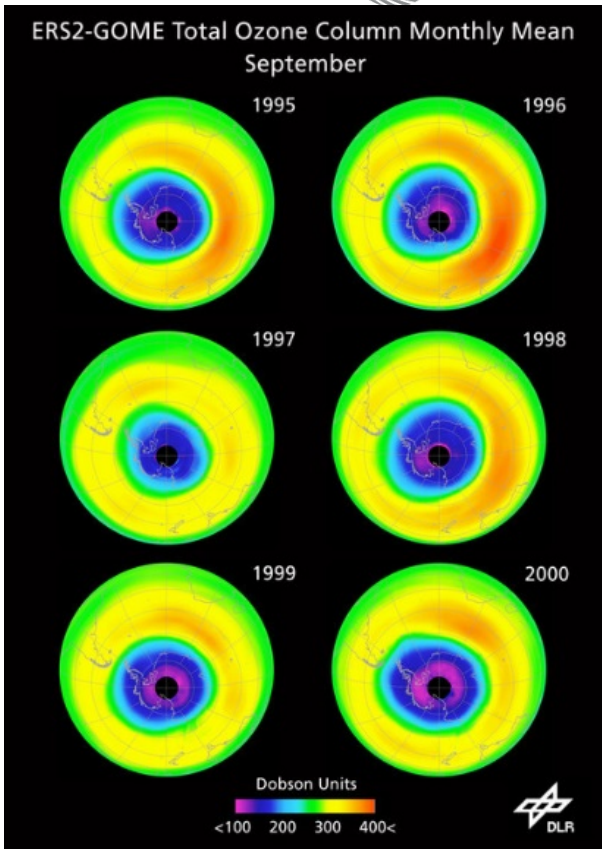
Retrieved O3 profile, 21 March 1997
Hohenpeißenberg, Germany
IUP, University of Bremen



GOME solar spectrum, 22 July 1995
Weber, M., J.P. Burrows and R.P. Cebula, GOME Solar UV/VIS Irradiance Measurements between 1995 and 1997 - First Results on Proxy Solar Activity Studies, Solar Physics 177, 63-77, 1998.

GOME Total Ozone Measurements





KNMI: O_3 assimilation in global chem.-transport model

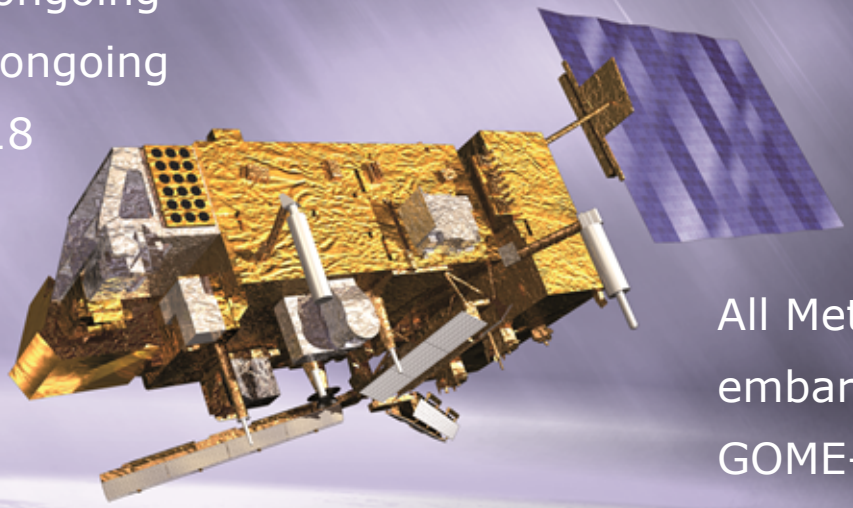
GOME-2 onboard MetOp / EPS

The MetOp satellites form the *EUMETSAT Polar System (EPS)* of operational meteorological satellites in Low Earth Polar Orbit

MetOp-A: 19 Oct 2006, ongoing

MetOp-B: 17 Sep 2012, ongoing

MetOp-C: launch 3Q 2018



All MetOp satellites embark the GOME-2 instrument

Envisat

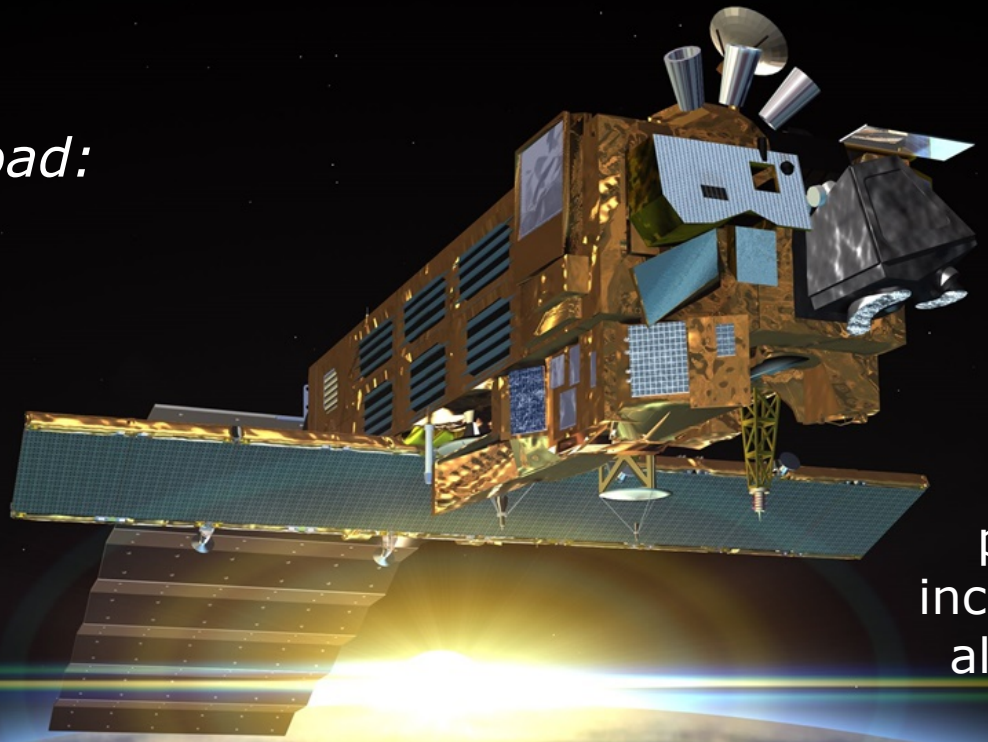
ESA's largest ever build Earth observation satellite
2002 – 2012

Atmospheric payload:

MIPAS:
IR spectrometer
limb sounding

GOMOS:
stellar occultation
limb sounding

SCIAMACHY:
imaging spectrometer, limb and nadir



Orbit
polar, sun sync
inclination: 98.5^{o}
altitude: 800km
10:00hrs DN

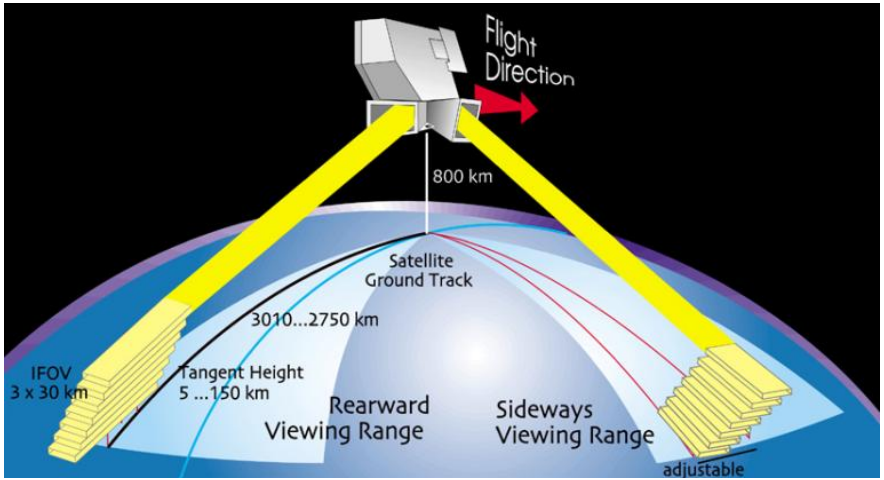
MIPAS

Michelson Interferometer for Passive Atmospheric Sounding

Mid-IR limb sounder: 4.15-14.4µm

Two viewing directions
Vert. range 5-150 km tangent height

Ozone and trace gases vertical profiles:
p, T, O_3, H_2O, CH_4, N_2O, HNO_3, NO_2



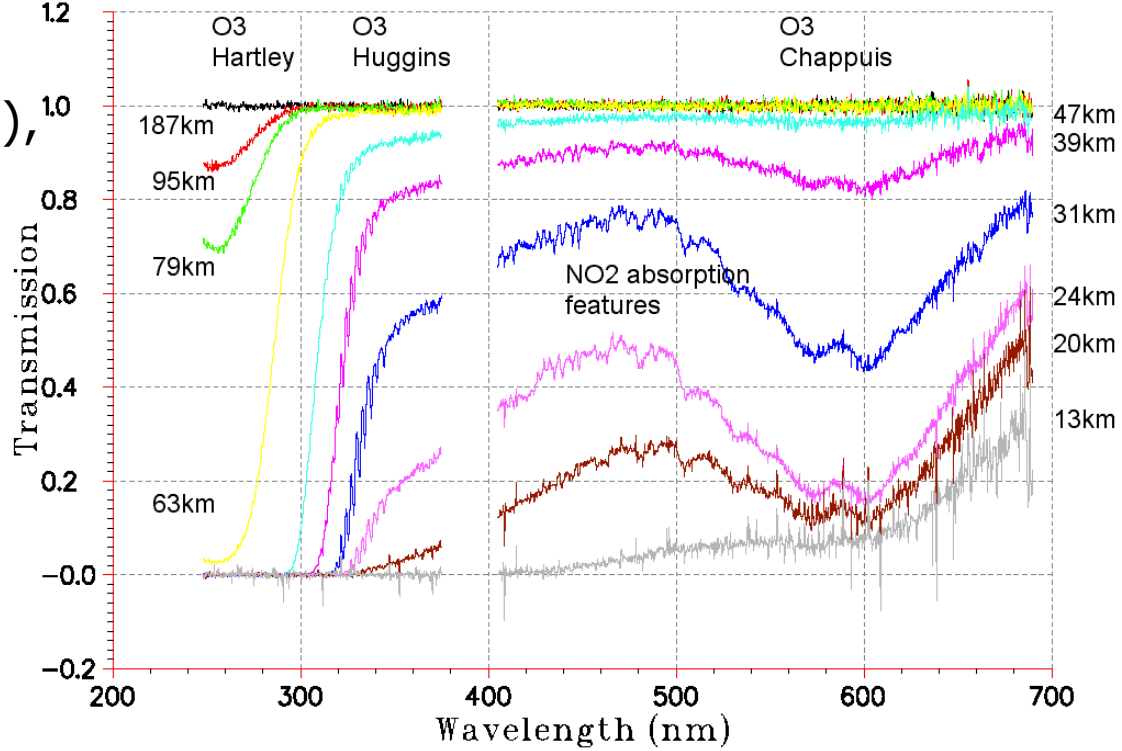
Footnote:
advanced limb sounder (IR & MW) PREMIER studied up to Phase A within Earth Explorer Programme, but not selected

GOMOS

Global Ozone Monitoring by Occultation of Stars

UV-vis (250-675nm),
Near-IR (756-773, 926-952nm),
Photometers (blue, red)

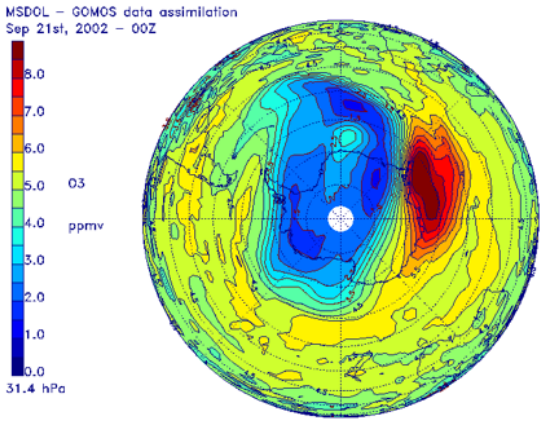
Measurements:
O_3, NO_2, NO_3, H_2O,
aerosol extinction,
O_2 (density, *T*)

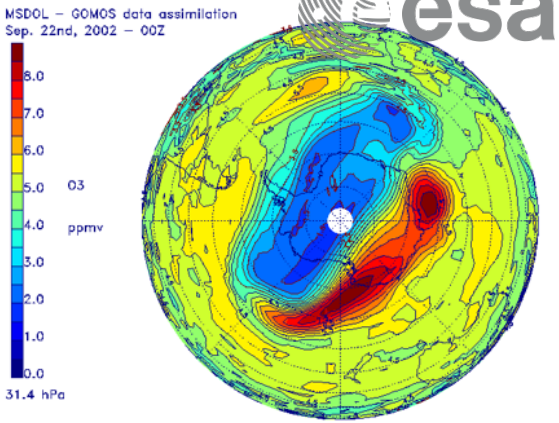


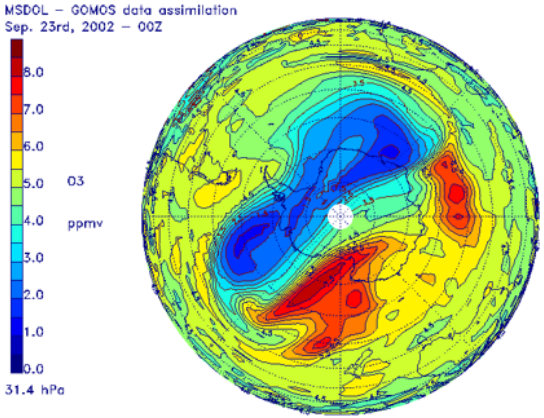
GOMOS

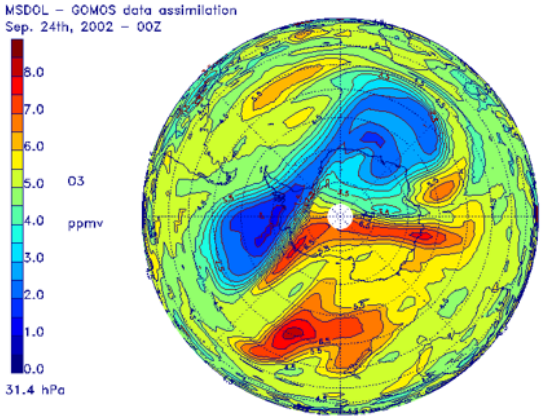
Daily ozone maps

here: 21-24 Sept 2002









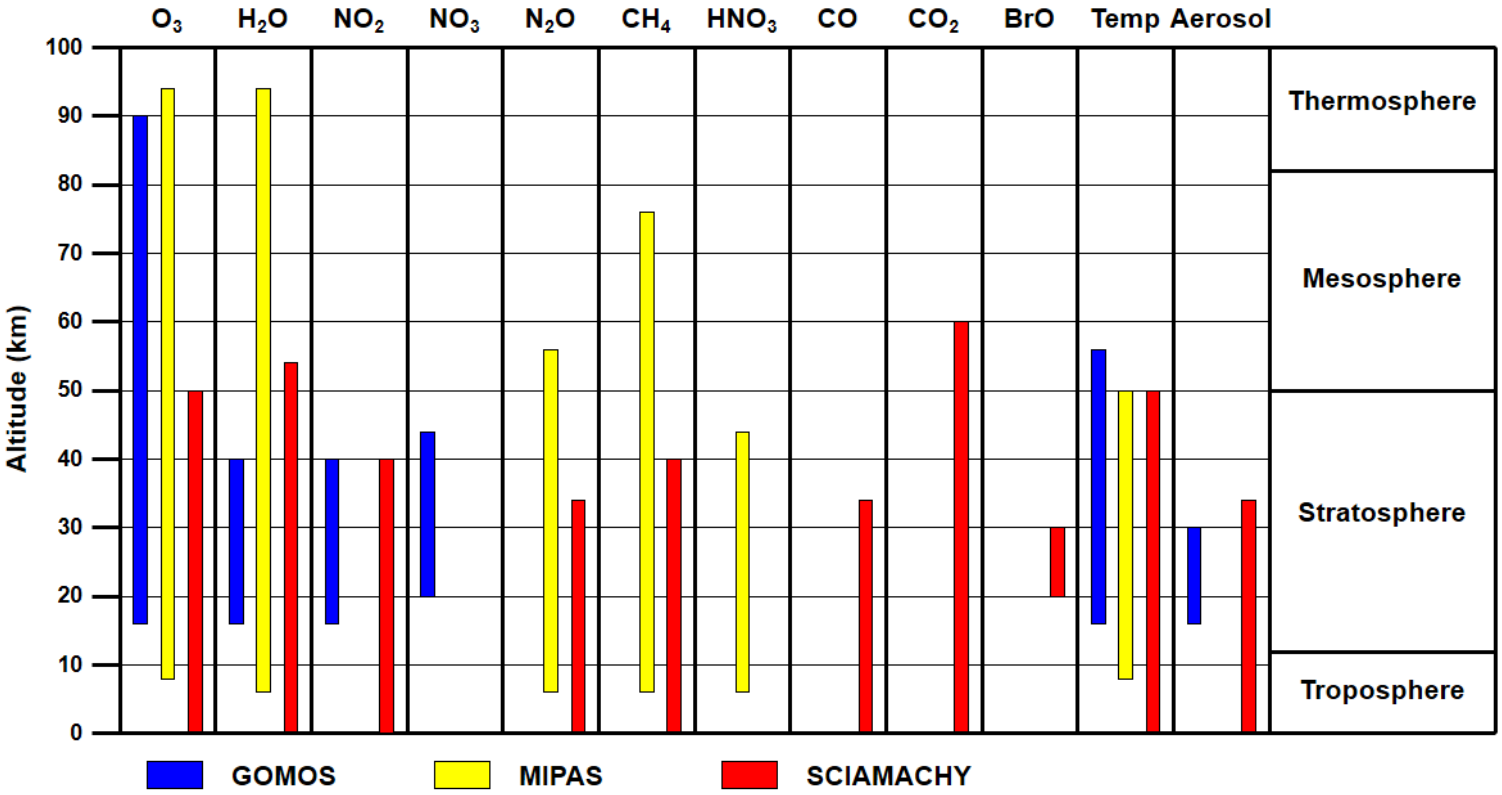
MSDOL Project
J.L. Bertaux *et al.*

SCIAMACHY

UV-visible and shortwave-IR scanning imaging absorption spectrometer, limb and nadir. Spectral ranges: 240-1750 nm contiguously, 1940-2040 nm, 2265-2380 nm; res. 0.2-1.5 nm

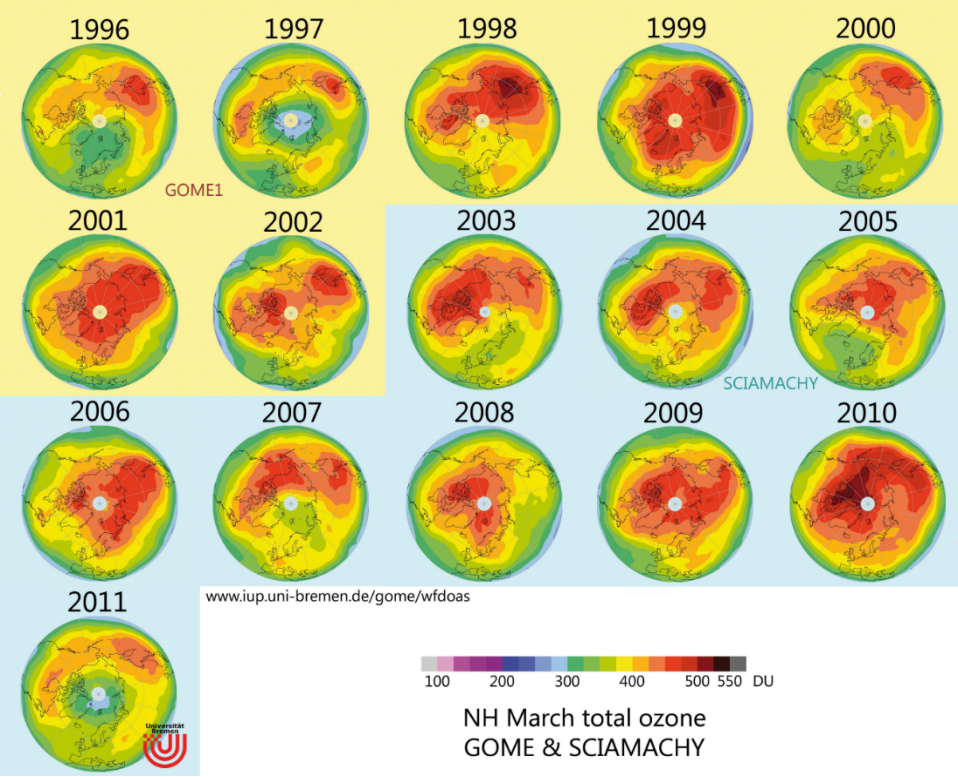
	Nadir			Limb		
	UV/Vis	**IR**	**UV/Vis/IR**	**UV/Vis**	**IR**	**UV/Vis/IR**
NRT	O_3, NO_2, SO_2, OClO, H_2CO	H_2O, CO, N_2O, CH_4	clouds, aerosols			
off-line	O_3, NO_2, SO_2, OClO, H_2CO, BrO		clouds, aerosols	O_3, NO_2, BrO	H_2O, CO, N_2O, CH_4, CO_2, p, T	aerosols

Constituents measured by MIPAS, GOMOS, SCIAMACHY

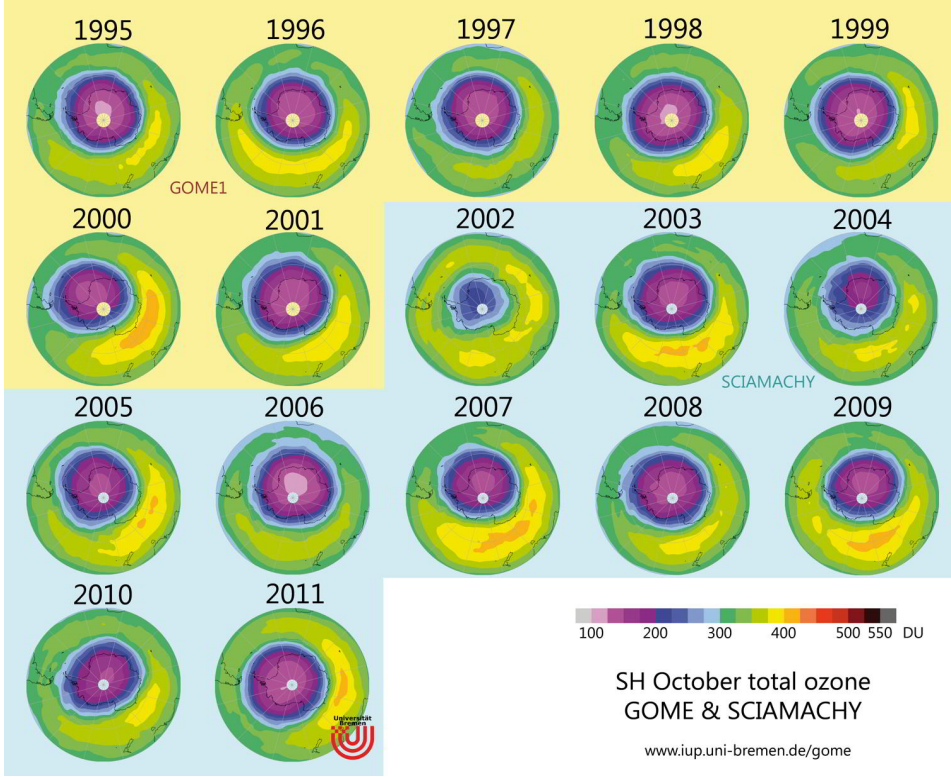


GOME-SCIAMACHY Ozone Record

Northern Hemisphere



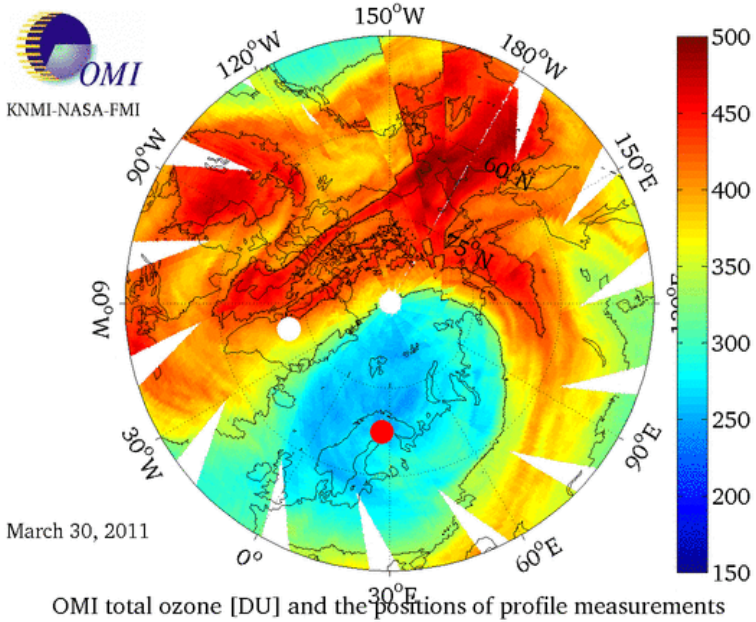
Southern Hemisphere



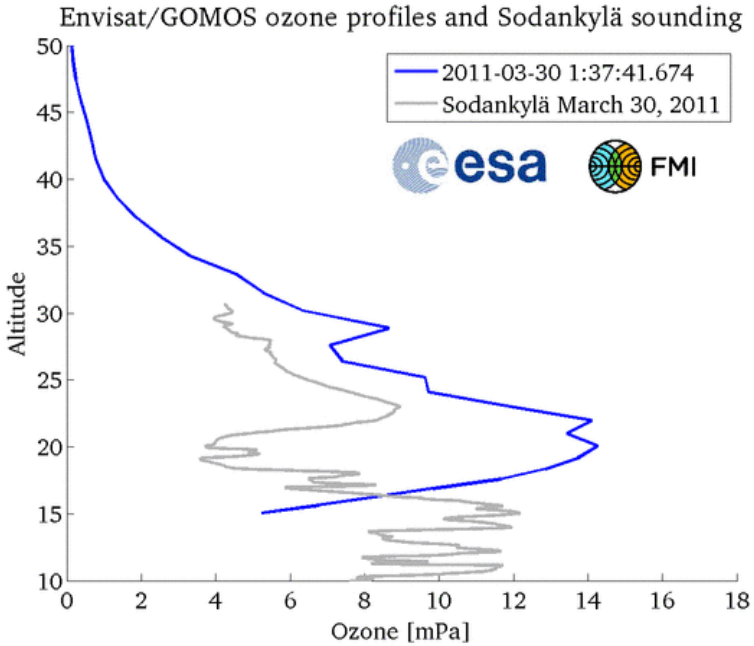
Credits: IUP, University Bremen

Example GOMOS: Arctic O_3 depletion in spring 2011

Exceptionally strong ozone depletion was observed in Arctic 2011. At the end of March GOMOS measured about 70% less ozone inside the polar vortex than outside the vortex at 20 km altitude.

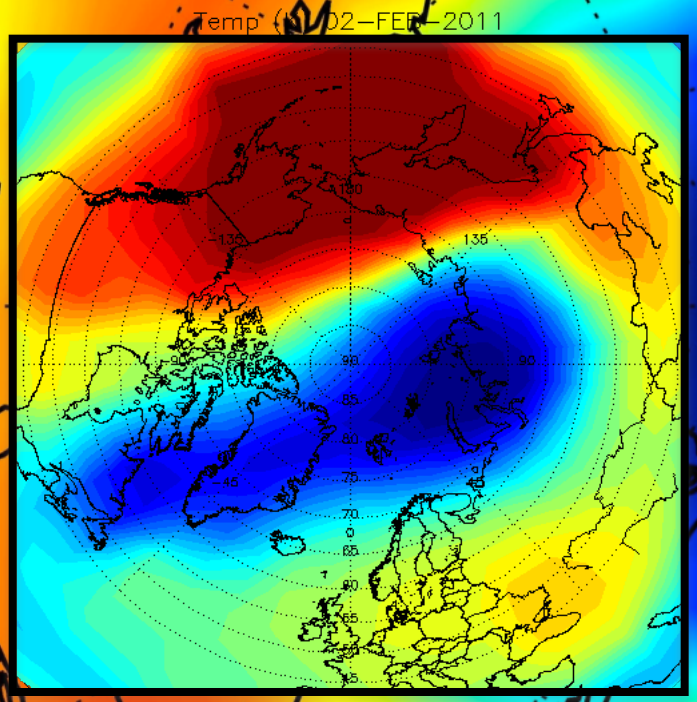


OMI total ozone [DU] and the positions of profile measurements

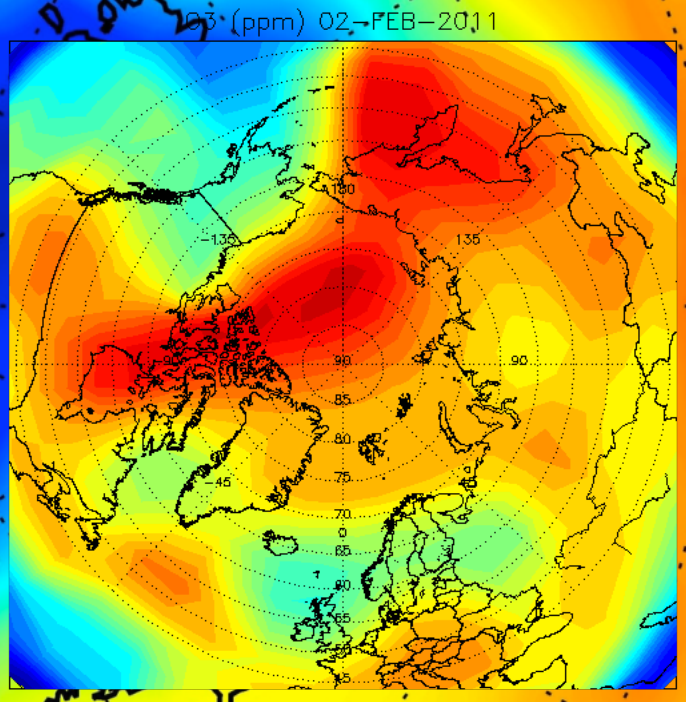


2011 Arctic Ozone hole observed by MIPAS
01 February – 01 May 2011

Temperature at 19 km



Ozone at 19 km

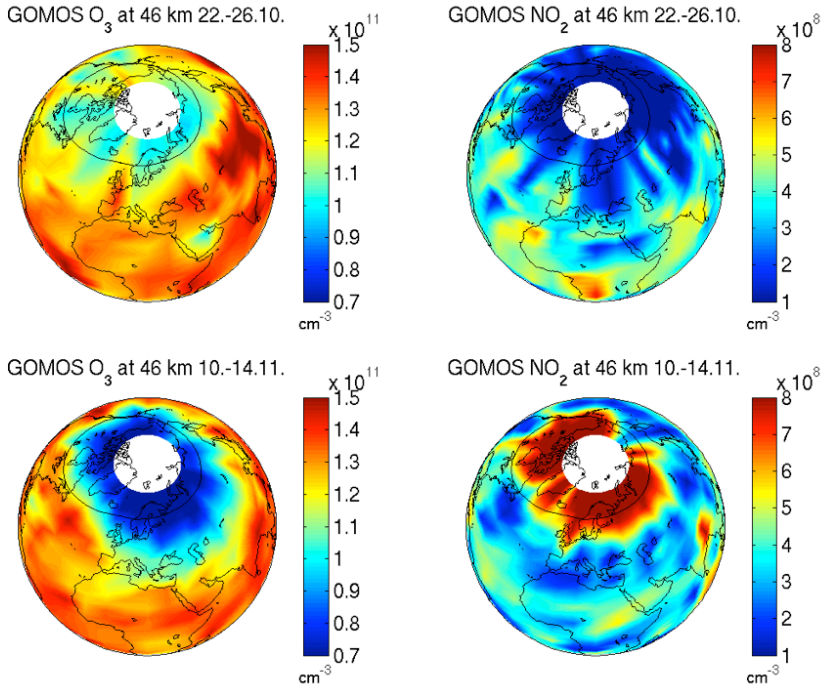


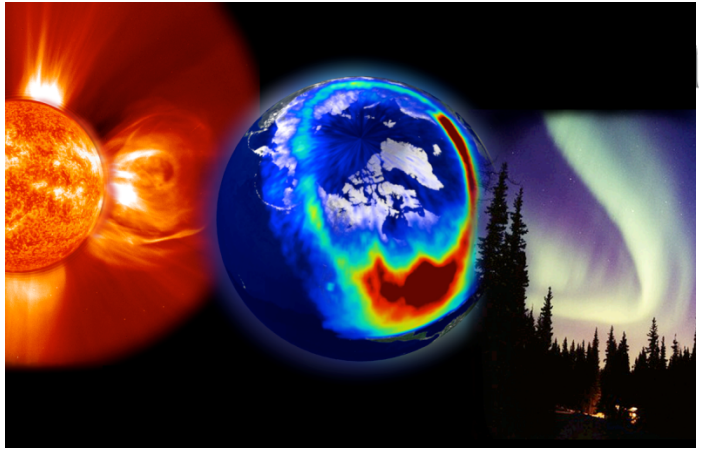
GOMOS observations were the first to show ozone loss from solar storms in the 2003 polar wintertime atmosphere:

Ozone ***NO2***

Before

After





Storms travel through the space and arrive at Earth causing beautiful displays of the Northern Lights in polar regions.

GOMOS observations show that solar particles penetrating to the polar atmosphere create massive amounts of NO_2, which leads to ozone loss in the atmosphere above the so-called ozone layer.

FMI

ESA Earth Observation Data Preservation/Exploitation

ERS/Envisat Phase F Activities: improve data products after Envisat end of life

EO Long Term Data Preservation Program:

- Preservation of ESA and Third Parties ESA managed missions on the long term, to ensure usability and accessibility

ESA Climate Change Initiative (CCI): Realise full potential of long-term global EO archives, as significant and timely contribution to the ECV databases required by the UNFCCC

- Several projects, including **Ozone CCI**
- CCI started in 2010 for 6 years (€M90), CCI+ to start in 2018
- Link to Copernicus Climate Chance Service (C3S)

http://cci.esa.int/

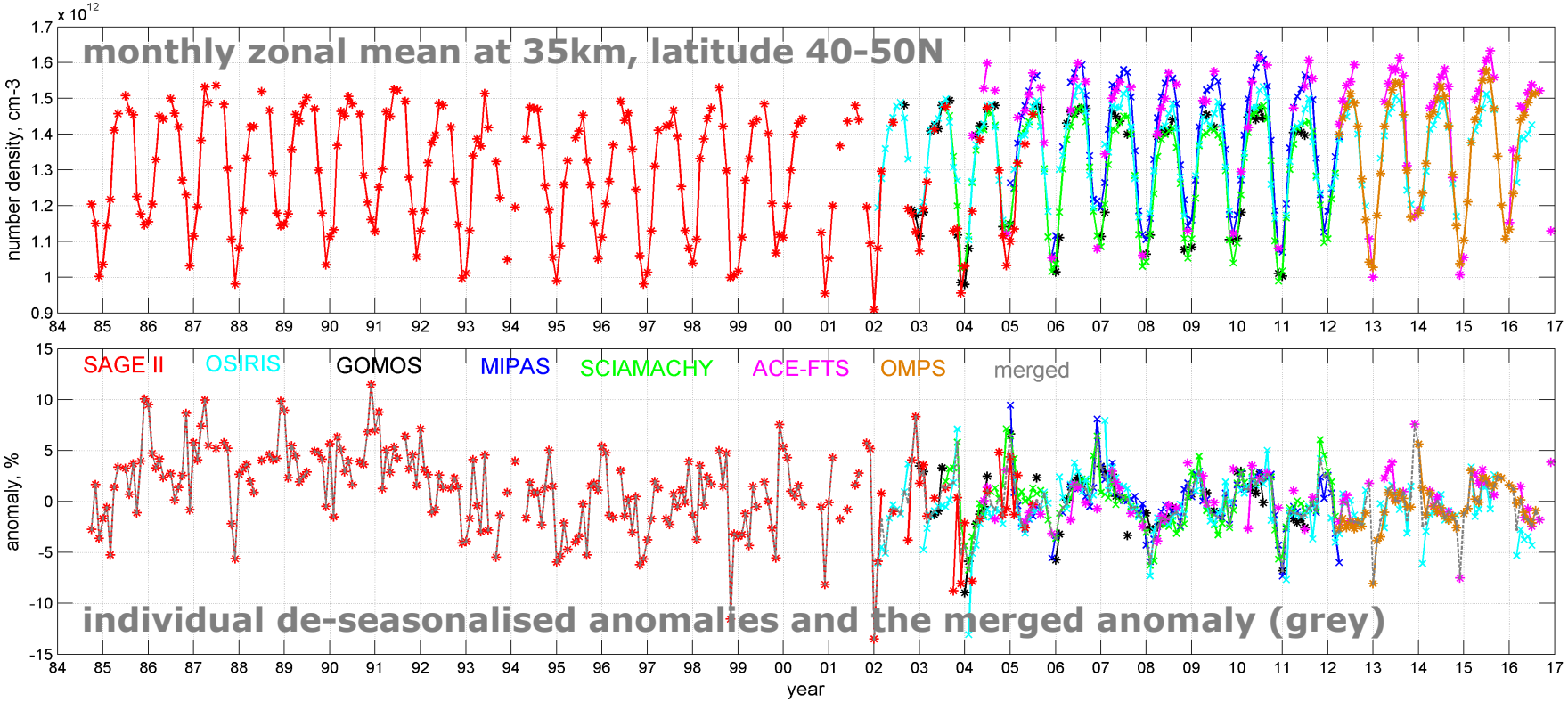
Ozone CCI

- **Total ozone**: Full reprocessing Level 2 using GODFIT multi-sensor prototype algorithm and monthly averages, using GOME, SCIAMACHI, GOME-2, OMI
- **Nadir ozone profiles**: monthly mean, assimilation: GOME, SCIAMACHI, GOME-2, IASI A/B
- **Limb ozone profiles**: individual profiles with common pressure grid and concentration units, monthly and zonal means from single instruments and merged: SCIAMACHY, GOMOS, MIPAS, OSIRIS, SMR, ACE, HALOE, MLS, OMPS, SAGE-II, SABER

http://esa-ozone-cci.org

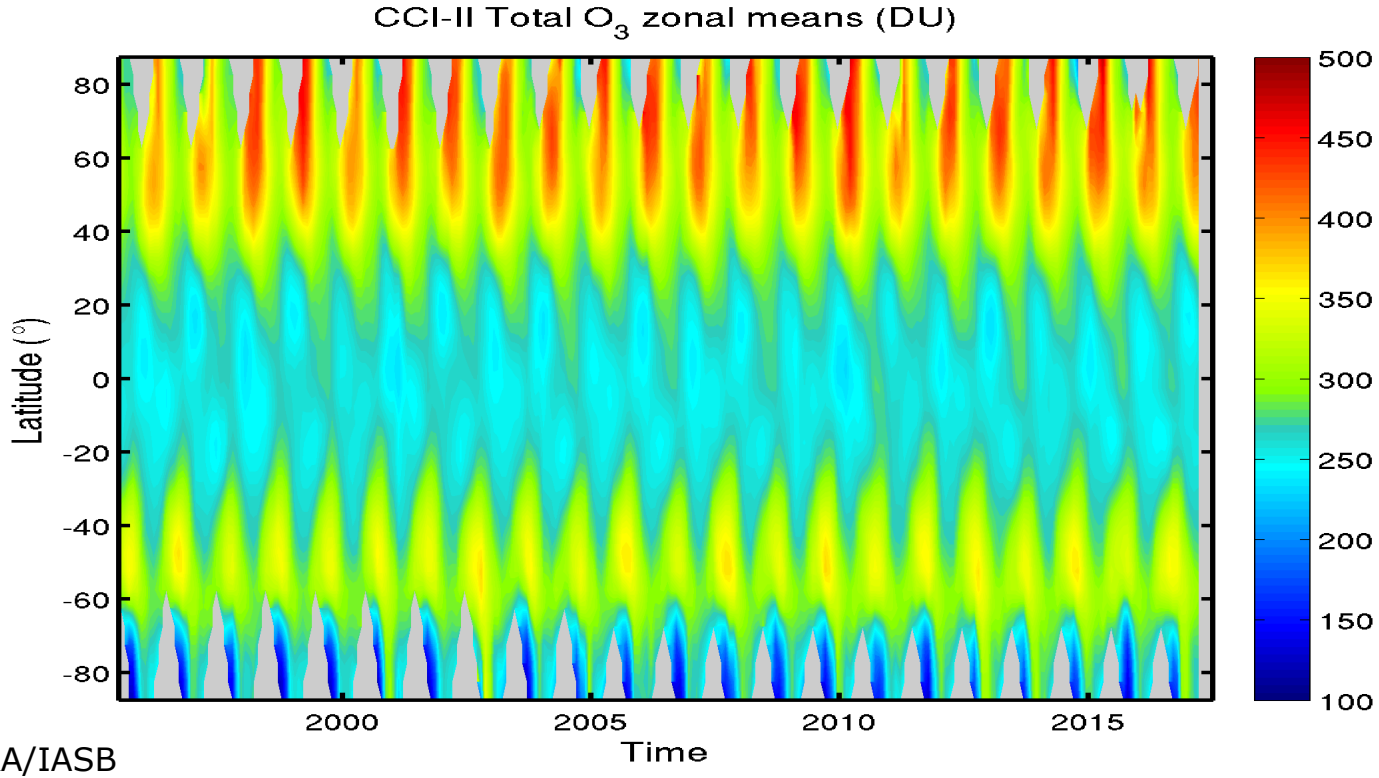
Ozone CCI (Example)

Limb ozone profiles: ongoing work, V. Soviefa, FMI



Ozone CCI (Example)

Combined GOME, SCIAMACHY, GOME-2, and OMI products



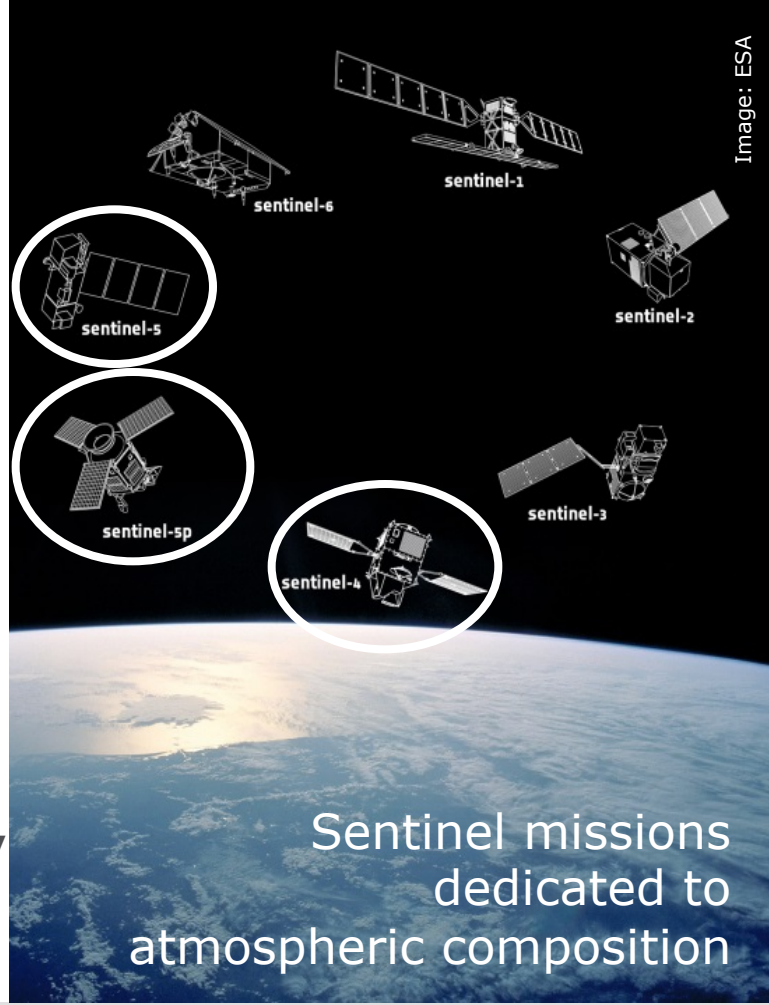
Credits: BIRA/IASB

Future Missions

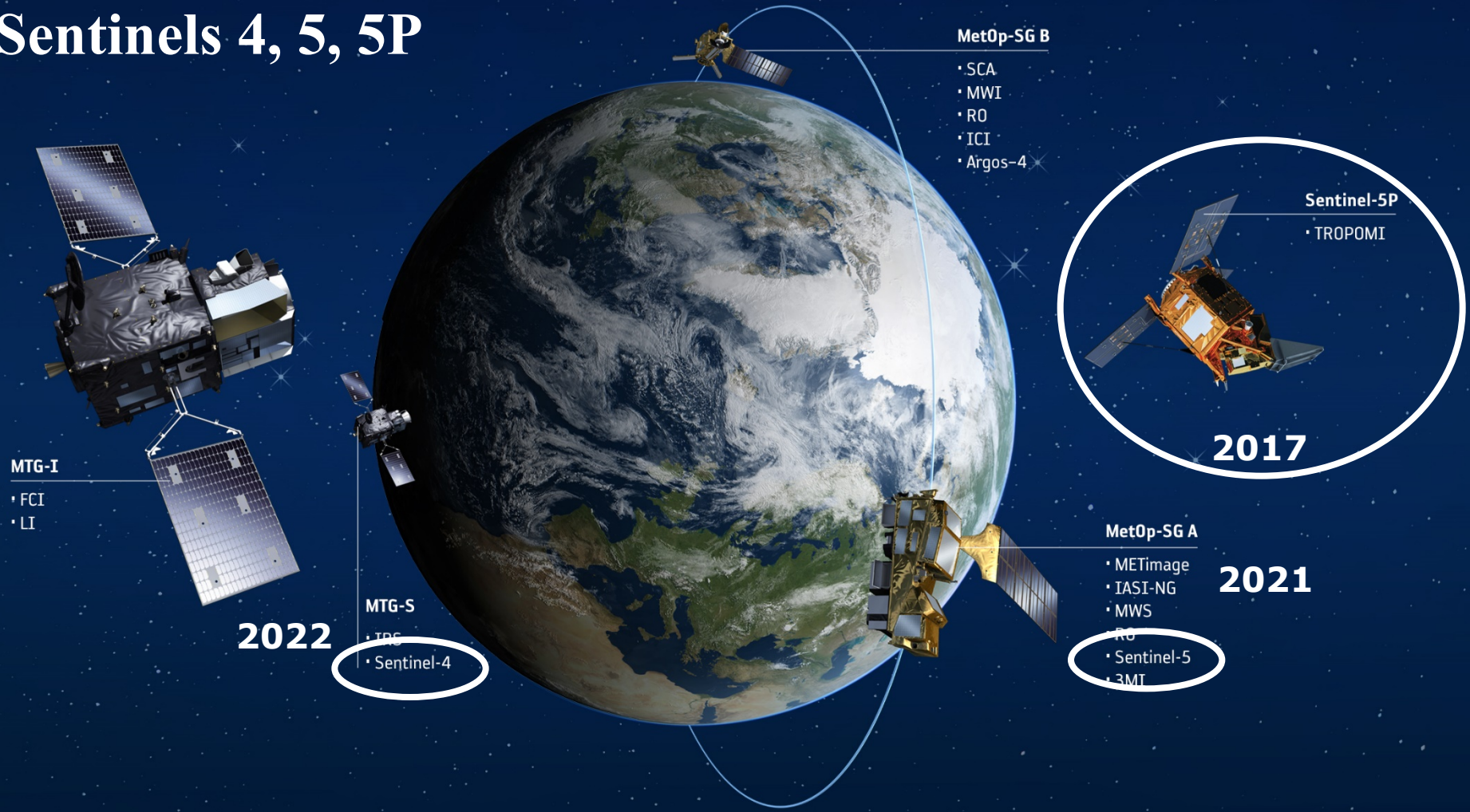
- Copernicus
  - Sentinel 5P
  - Sentinel 5
  - Sentinel 4
- ALTIUS
- PREMIER (candidate, not selected)

Future composition monitoring

- European system for monitoring land, marine, atmosphere, climate change, emergency management, security
- Observations from satellites, ground-based, air-borne sensors
- **Space Component:**
  Sentinel missions by European Space Agency
- For policymakers, public authorities, …, citizens



Sentinels 4, 5, 5P



Sentinel 5P

Orbit:

- early afternoon (13:30 asc.), sun-synch., polar (98.74), 824km

Payload: TROPOMI instrument

- UV-VIS-NIR-SWIR push-broom grating spectrometer
- Spectral range: 270-495 nm, 710-775 nm, 2305-2385 nm
- Spectral resolution: 0.25-0.55 nm
- Observation mode: nadir pointing, global daily coverage, 7x7 km^2 ground

Objectives: Air quality, Ozone and surface UV, Climate

- O_3, NO_2, SO_2, Formaldehyde, Aerosol, CO, CH_4, Clouds

Launch: October 2017

Sentinel 4 and 5

Sentinel 4

- onboard geostationary MTG
- short-lived species in troposphere
- Europe covered hourly
- air quality, climate, O_3 & UV, emissions:
- O_3, NO_2, SO_2, HCHO, CHOCHO, aerosol, cloud

- launch 2022

Sentinel 5

- onboard polar orbiting MetOp-SG
- short- and long-lived species in troposphere and stratosphere
- daily global coverage
- O_3, NO_2, SO_2, CO, CH4, HCHO, aerosol, cloud

- launch 2021

Evolution of footprint size

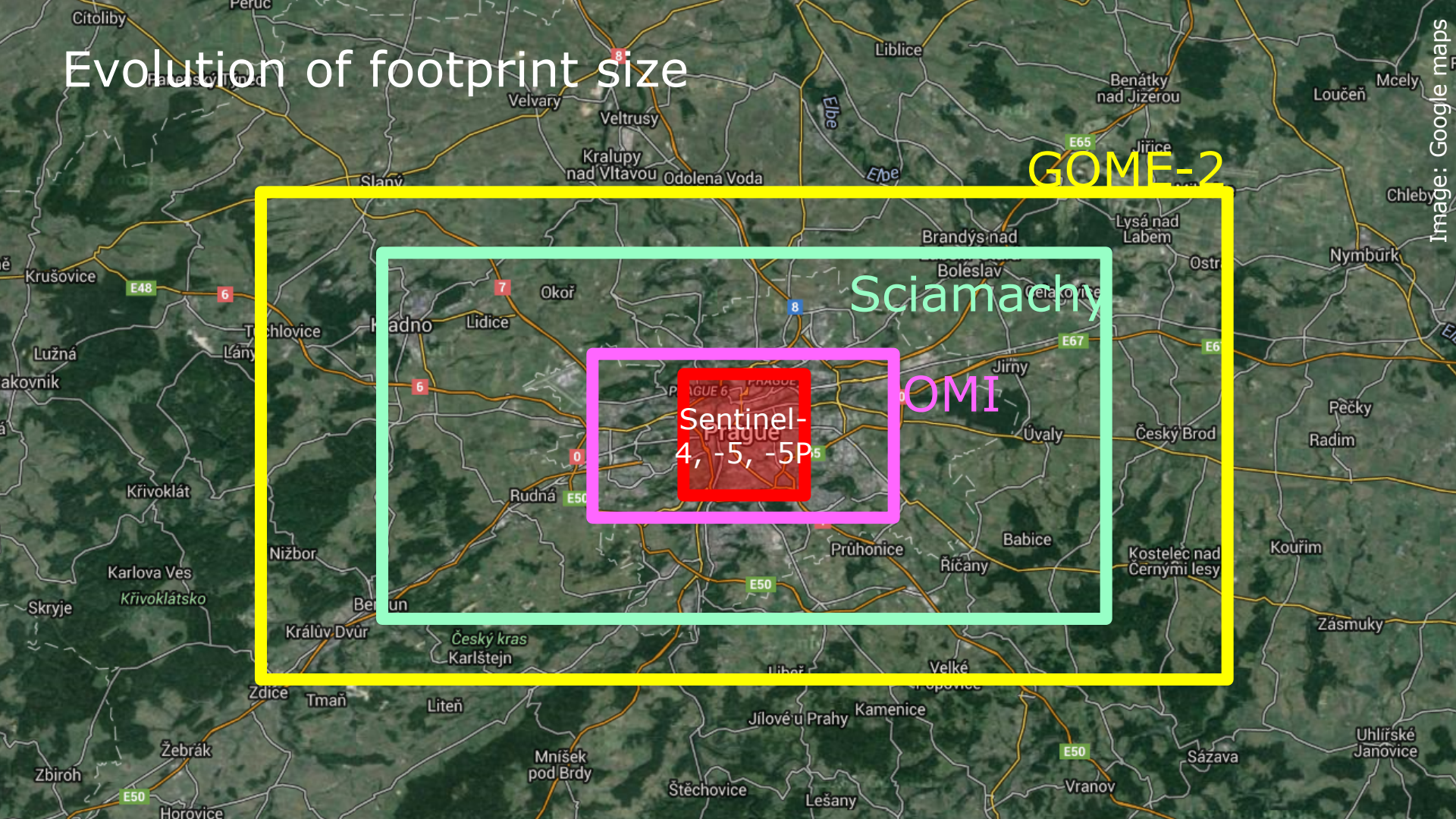


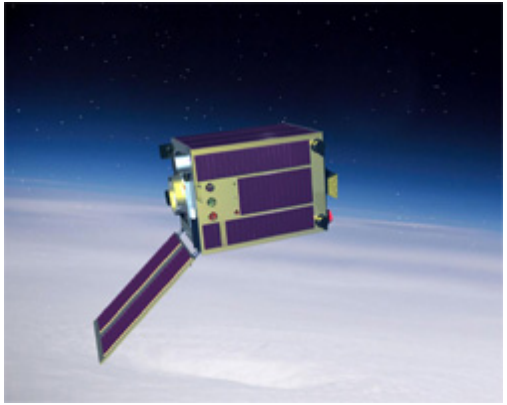
Image: Google maps

ALTIUS

Atmospheric Limb Tracker for the Investigation of the Upcoming Stratosphere

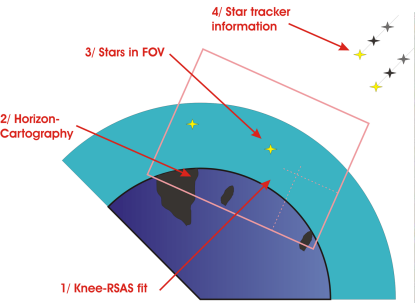
Selected for implementation as part of ESA's Earth Watch Programme

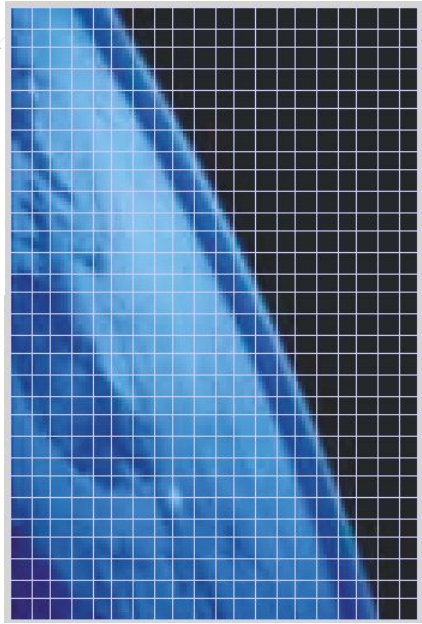
In co-operation with Belgium

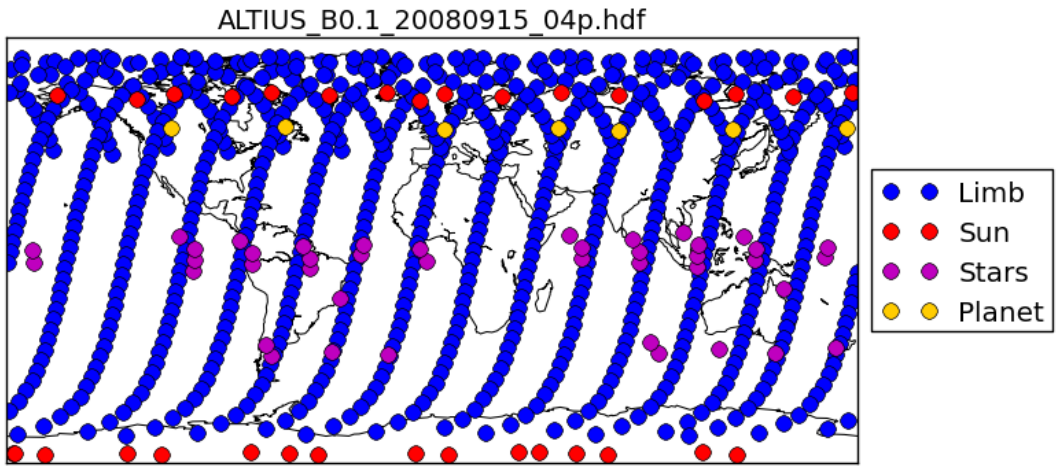


- UV-Vis-NIR spectro-imager onboard micro-sat (PROBA class), sun-synch. LEO, 3 days revisit
- Three spectral cameras (3 channels, 250 nm-1800 nm) with 2D detectors
- Limb scattering, solar and stellar occultation
  - → Operational NRT stratospheric ozone (profile) monitoring
  - → O_3, NO_2, H_2O, CH_4, aerosols, temperature, tomography, airglow,…

ALTIUS observational concept







Full 2-D limb imaging

Acousto-optical and FP filters

D. Fussen and team

PREMIER – Earth Explorer Mission Candidate

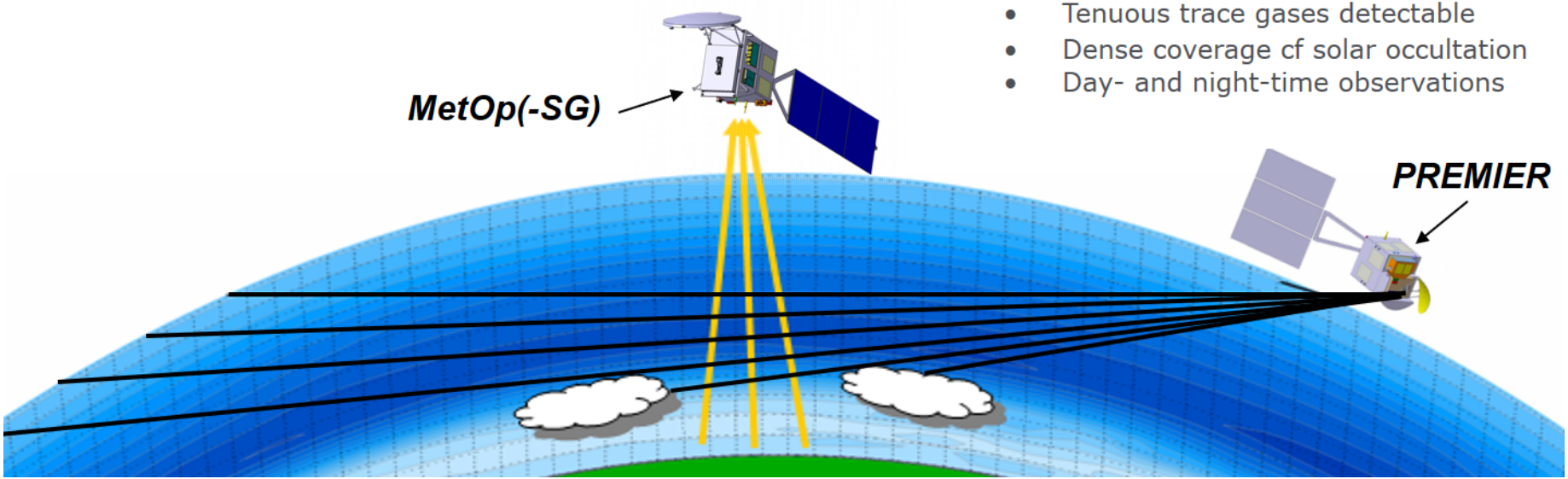
not selected for implementation

Nadir-sounding

- Near-surface layer seen between clouds but
- Little or no vertical resolution

Limb-emission sounding

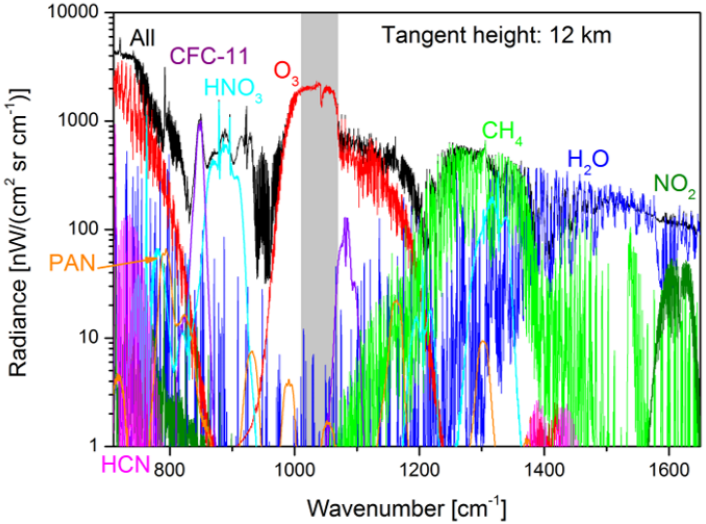
- High resolution vertical profiling
- Tenuous trace gases detectable
- Dense coverage cf solar occultation
- Day- and night-time observations

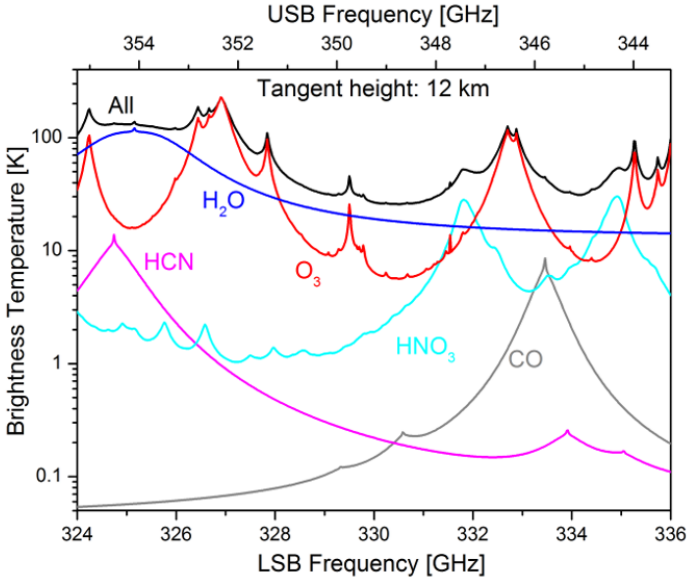


PREMIER – Earth Explorer Mission Candidate

not selected for implementation

IR and MM Limb-sounder, studied at Phase A, but de-selected in competition





Infra-Red Limb-Sounder (IRLS)

$\delta\nu$ = 0.25 cm^{-1} ("chemistry mode") *or*
$\delta\nu$ = 1.73 cm^{-1} ("dynamics mode")

Stratosphere-Troposphere Exchange And climate Monitor Radiometer (STEAMR)

δf = 25 MHz ($\delta\nu$ = 0.00083 cm^{-1})

Courtesy of M. Höpfner, D. Gerber

Presented by

Tobias Wehr

with contribution from

Thorsten Fehr

Claus Zehner

Ben Veihelmann

and many others

European Space Agency