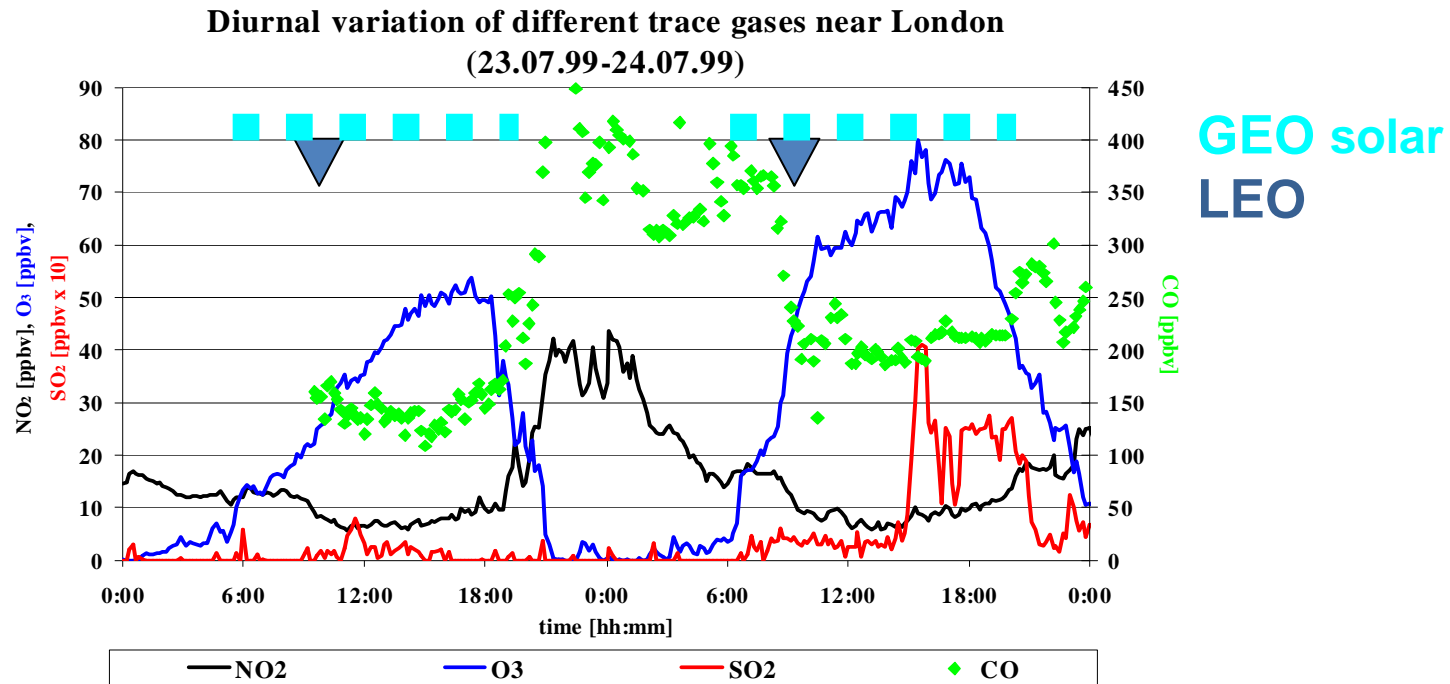


Hourly geostationary observations of key constituents to constrain air pollution and tropospheric chemistry at the urban scale: Sentinel-4 UVN on MTG

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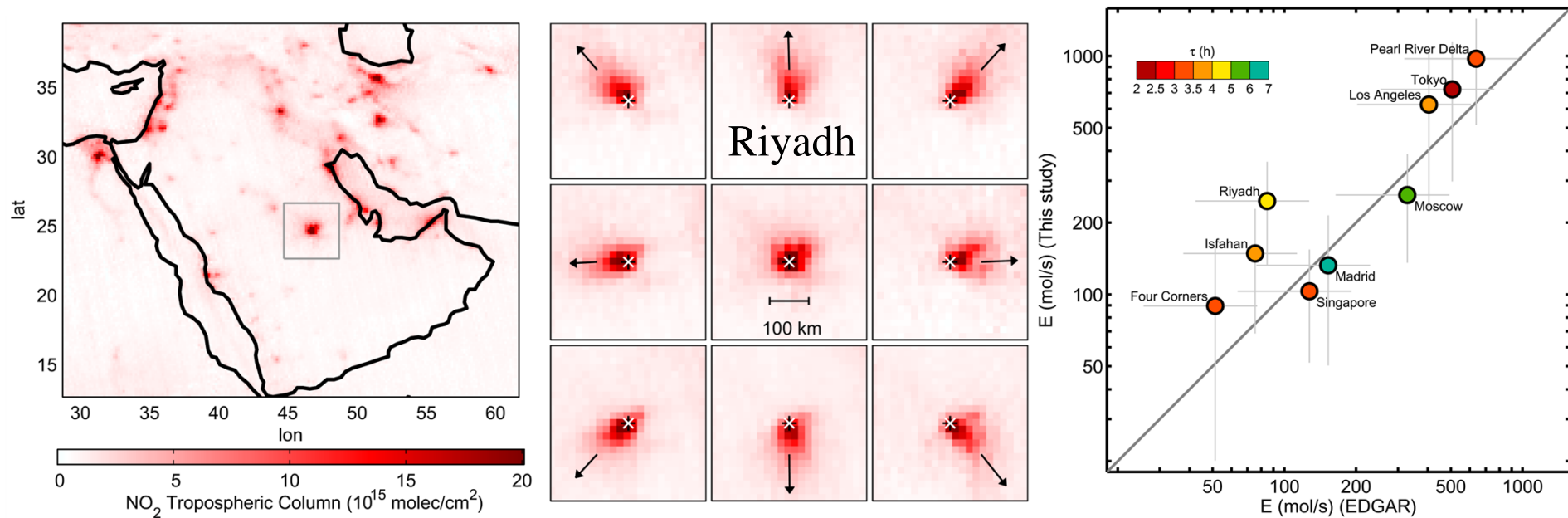
Sampling the diurnal variation



Hourly data of tropospheric composition in combination with modelling and data assimilation will allow

- to discriminate meteorology, photo-chemistry and emission
- to improve emission estimates
- to get deeper insight into processes

Monitoring City Emissions



Beirle et al., Science, 2011

- Mean NO₂ TVCD for the Middle East (OMI 2005-2009, cloud-free, calm)
- Approach currently limited to large and well spatially isolated cities due to spatial resolution of used sensor (13 x 24 km², OMI)
- with 8 x 8 km spatial resolution and hourly measurements during day time, will allow to determine city emissions at least on a monthly basis and with a short response time (some month).

Some History: GeoSCIA -> S4 UVN

1997 IGAC Conference Toronto, first results on trop. NO₂, SO₂ from GOME/ERS-2 and inspiring discussion with Jack Fishman about the geostationary concepts

1998 GeoSCIA UV-VIS-NIR (to ESA)

2000 GeoSCIA++ UV-VIS-NIR-SWIR-TIR/Lightning (to ESA)

2002 GeoTROPE UV-VIS-NIR-SWIR-TIR (to ESA)

2003 GeoSCIA^{light} UV-VIS (-NIR) (to DLR)

2005 GeoTROPE^{Regional} UV-VIS-NIR + TIR (to ESA)

2005 MTG UVS (EUMETSAT Phase 0)

2007 GMES Sentinel 4 UVN (ESA Phase 0)

2008 Decision to fly S4 UVN on MTG

2008-10 Sentinel 4 UVN (ESA Phase A/B)

Since 2011 Sentinel 4 UVN Phase C/D

2019 Launch

Copernicus (exGMES) dedicated missions: Sentinels



Sentinel 1 – SAR imaging

All weather, day/night applications, interferometry
x 2 satellites, 693 km, SSO dawn-dusk orbit

2013 / 2015



Sentinel 2 – Multi-spectral imaging

Land applications: urban, forest, agriculture,..
Continuity of Landsat capabilities, SPOT etc
x 2 satellites, 786 km, SSO, LTDN 10:30 am

2013 / 2016



Sentinel 3 – Ocean and global land monitoring

Wide-swath ocean color, vegetation, sea/land
surface temperature, altimetry
x 2 satellites, 814 km, SSO, LTDN 10:00 am

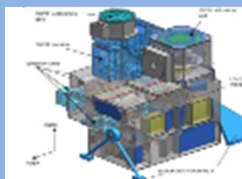
2013 / 2017



Sentinel 4 – Geostationary atmospheric

Atmospheric composition monitoring, trans-
boundary pollution, x 2 instruments on MTG series, 7 year each

2019



Sentinel 5 – Low-orbit atmospheric

Atmospheric composition monitoring. X 2-3 instruments on
METOP-SG series
(S5 Precursor launch in 2015, x 1 satellite, to fly with NPP)

2015/2020+



Sentinel spacecraft/instrument lifetime = 7 years, with consumables for 12

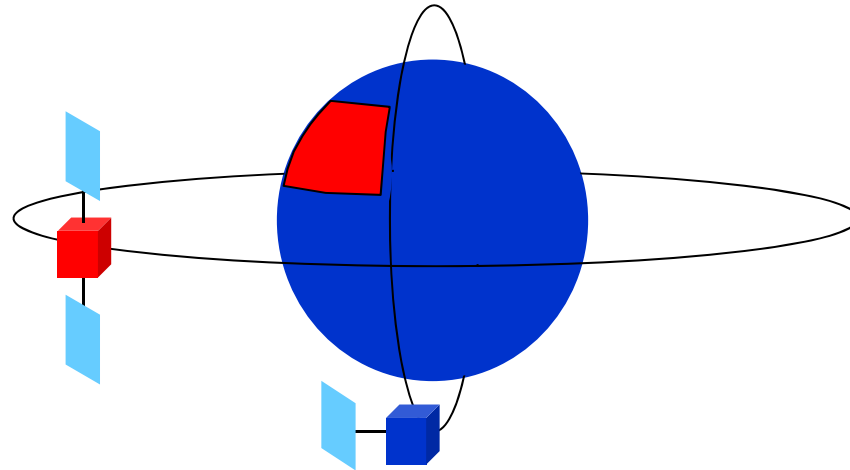


The GMES Sentinel 4 & 5

- The GMES (Global Monitoring of Environment and Security) Sentinel program is driven by **operational** user requirements
- GMES Sentinel 4, 5 and 5P focus on atmospheric chemistry
- S4 UVN serve requirements on tropospheric data with high temporal (< hour) and spatial (< 10 km SSP) resolution on **O₃, NO₂, HCHO, SO₂ and aerosol**.

| GMES Sentinel 4 on <i>EUMETSAT MTG</i> | Sentinel 5 <i>EUMETSAT Post-EPS</i> | Sentinel 5 Precursor |
|---|--|------------------------------------|
| Geostationary 0° E | Sun-synchronous similar to METOP | Sun-synchronous Early afternoon |
| 2019 2 x 7 years | 2020 | 2015 |
| UVN <i>IRS, LI, FCI</i> | UVNS <i>TIR, DPI, 3MI ...</i> | UVNS |

Constellation of Sentinels for Atmosphere Services



GEOstationary (GEO)

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

→ Sentinel-4

Low Earth Orbit (LEO)

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

→ Sentinel-5

→ Sentinel-5 Precursor

The MTG System

MTG-Sounder
InfraRed Sounder (IRS)
Sentinel-4/UVN (S4)



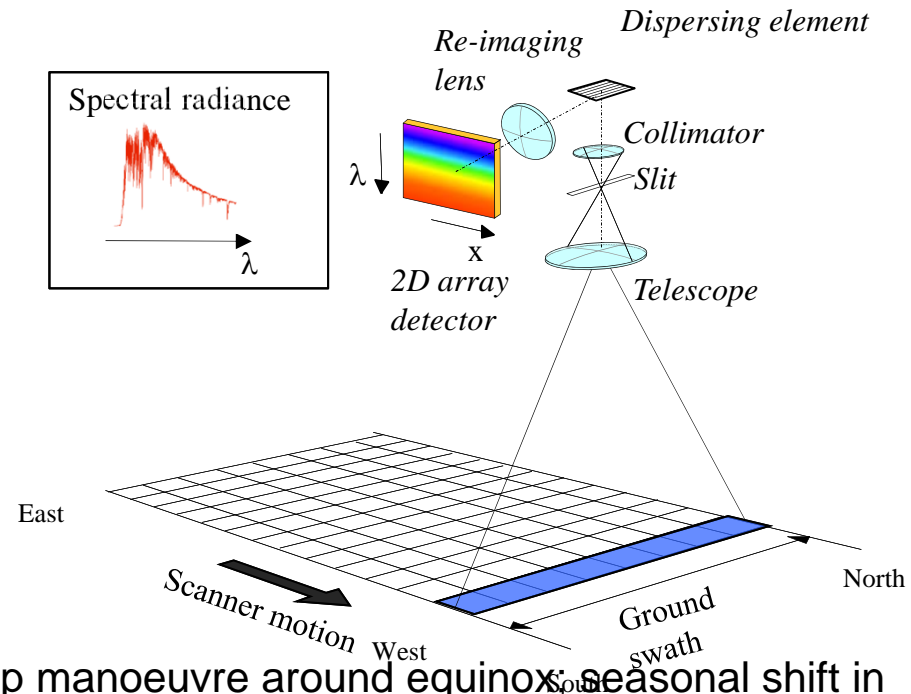
MTG-I
Flexible Combined Imager (FCI)
Lighting Imager (LI)



Sentinel-4/UVN Instrument Concept

Imaging Spectrometer in Geostationary Orbit

- Pushbroom in E/W direction
- N/S FOV: 4° , E/W FOR: 6.8°
- 8 km spatial resolution @ 45°N
- Coverage: Europe hourly
- 2 imaging grating spectrometers
- Cooled CCD detectors
- Scan mirror:
 - E/W scan
 - N/S for compensation of MTG yaw flip manoeuvre around equinox, seasonal shift in latitude (per steps of 5 deg up to 10 deg)
- High performance on board calibration sources (diffusers, lamp, LED)
- Instrument mass ~ 150 kg; power ~ 180 W; data rate ~ 25 Mbps



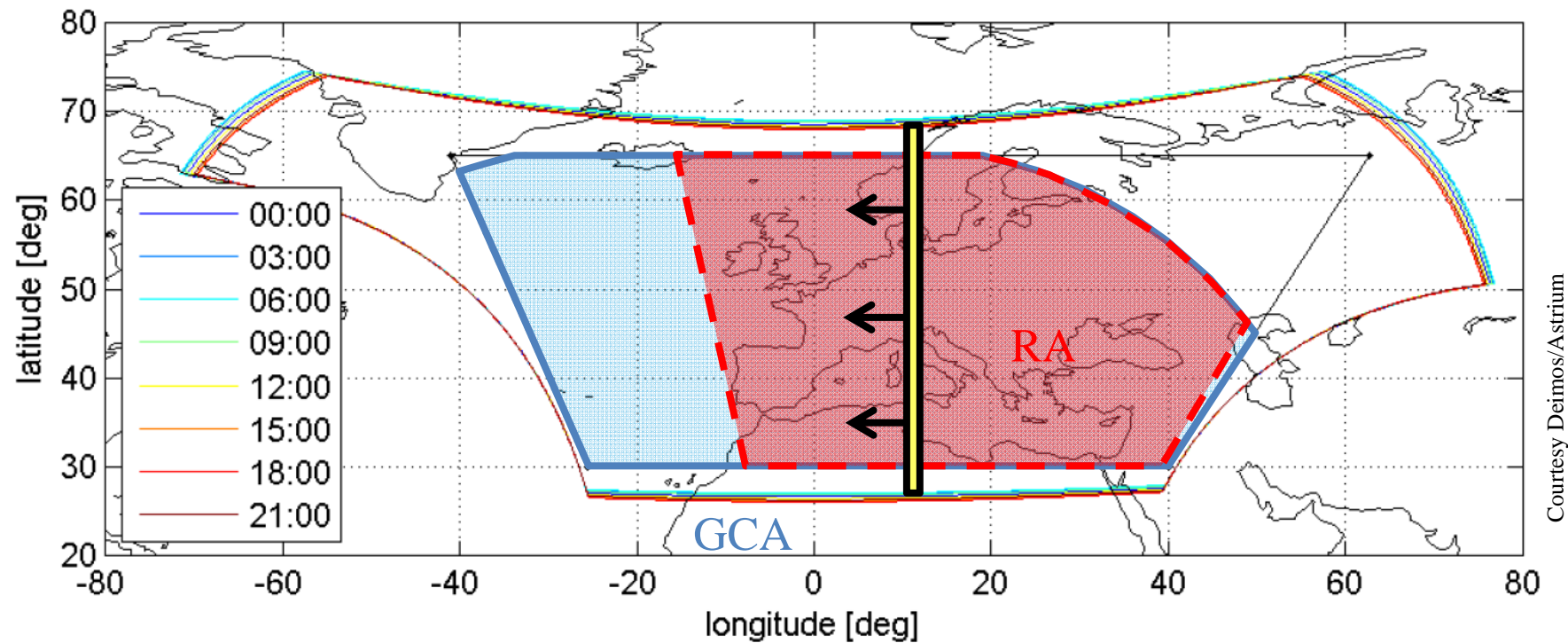
Sentinel-4/UVN Performance Requirements

| Band ID | Wavelength range [nm] | Species | Spectral resolution [nm] | Spectral sampling ratio | SNR @ 50°N, 15:00 UTC, Equinox, albedo 0.05 (UV-VIS) & 0.15 (NIR) (per spectral sample) |
|---------|-----------------------|--|--------------------------|-------------------------|---|
| UV | 305 - 400 | O ₃ , SO ₂ , HCHO, AAI, AOD, Ring | 0.5 | 3 | 200 - 1000 |
| VIS | 400 - 500 | NO ₂ , O ₄ , CHOCHO, AOD | 0.5 | 3 | 1400 |
| NIR | 750 - 775 | Cloud, Aerosol | 0.12 | 3 | 600 |

- Low sensitivity to polarisation (< 1%)
- Low level of spectral features (< 0.05%)
- High radiometric accuracy: < 3%
- High SNR

Sentinel-4/UVN Geometric Performance

- Geographical Coverage Area (GCA): Europe + part of Sahara
- Reference Area (RA): revisit time 1h

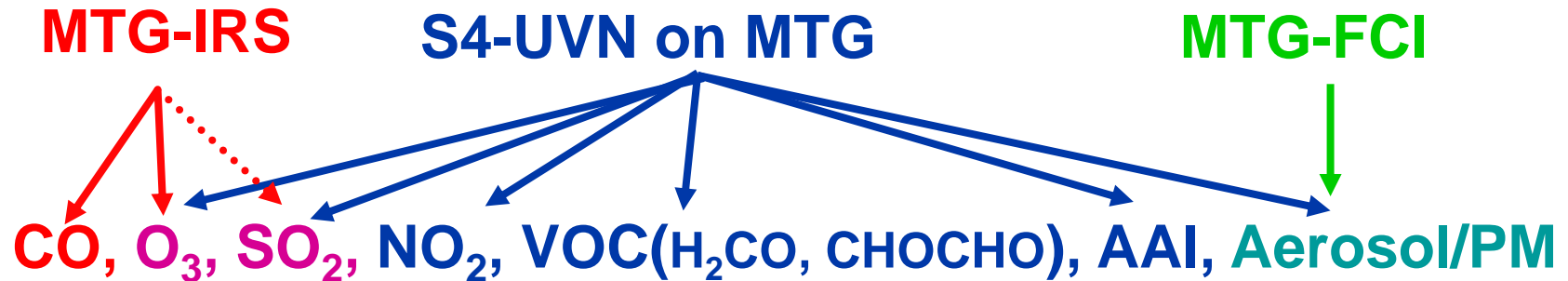


Sentinel-4 Level-2 Products

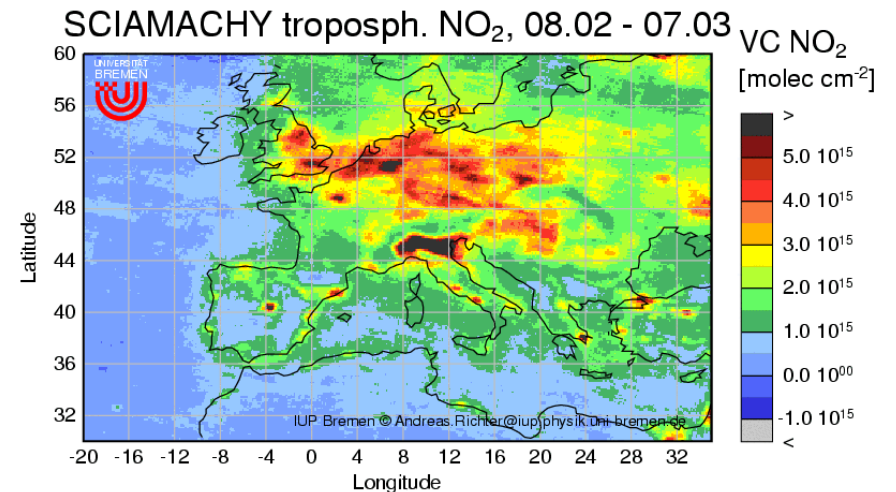
| Product | Application | | | Comment |
|---|-------------|---------|------------|---|
| | Air Quality | Climate | Surface UV | |
| O₃ total & trop. column | X | | X | |
| O₃ profile | X | | X | Synergy with infrared data from IRS |
| NO₂ total & trop. column | X | | | |
| SO₂ total column | X | | | Also for volcanic eruption monitoring |
| CHOCHO total column | X | | | By-product |
| CH₂O total column | X | | | |
| Aerosol extinction coeff. profile, column optical depth / type / index | X | X | | Also for volcanic eruption monitoring Also auxiliary for other S4 products Synergy with imager data from FCI |
| Cloud optical thickness, fraction, altitude | | | X | Mainly auxiliary for other S4 products Synergy with imager data from FCI |
| Surface reflectance daily map | | | X | Mainly auxiliary for other S4 products |

IRS-alone products (eg O₃, CO) assumed to be developed by EUMETSAT

S4 UVN Synergies on MTG for Tropospheric Chemistry and Air Pollution Applications



MTG-IRS, MTG-UVS/S4 UVN, and MTG-FCI and LI will provide unique and relevant data for tropospheric monitoring applications



Summary & Mission Implementation Status

- S-4 UVN - according to Phase A/B concepts and performance - is capable to provide important and unique data on trop. O₃, NO₂, SO₂, HCHO and aerosol relevant for European air pollution applications and research.
- Instrument Preliminary Design Review completed → Phase C/D
- L2 pre-development ongoing
 - aerosol profile retrieval from O₂ A-band (AEROPRO study with KNMI)
 - surface reflectance map from temporally aggregated S4 data (SURMACED study with BIRA, GC, LOA, IM)
- L2 processor development in preparation
- 1st launch with MTG-S1 in 2019, 2nd launch with MTG-S2 in 2026/27

Perspective 2019 onwards



TEMPO



Sentinel-4



GEMS

+ LEO (S5P/S5, OMPS etc.) for the global context

Geostationary AQ Constellation

| | GEMS | TEMPO | Sentinel-4 |
|-------------------------------|---------------------------------|----------------------------|-----------------------------|
| Spectral range(nm) | 300 – 500 nm | [290 – 690 nm] | 305-500 / 750-775 |
| Spectral resol(nm) | 0.6 (3 samples) | [0.6] | 0.5 / 0.12 |
| Spatial resol | 7 km NS x 8 km EW @ Seoul | [2.0 km NS x 4.5 km EW] | 8 km @ 45 N |
| Spatial coverage | 5 S – 45 N 75 E – 145 E | 30 N - 65 N 40 W – 60 E | 20 N – 60 N 30 W – 150 W |
| Obs. time | 30 min | [1 hour] | 1 hour |
| Detector @ T | CCD @ 278 K | [CCD @ 278 K] | CCD @ 230 K |
| Onboard calibration | Solar, cal light source | [Solar] | Solar, cal light source |
| Volume (m³) | 1.1 x 1.2 x 0.9 | [1 x 1.1 x 1] | ~1.1 x 1.2 x 0.9 |
| Mass (Kg) | 110 | [100] | 150 |
| Power (W) | 200 (on orbit) / 100 (transfer) | [100] | 180 |
| Data rate (Mbps) | 20 (up to 40) | [9] | 25 Mbps |

| | GEMS | TEMPO | Sentinel-4 |
|------------------|--|---|--|
| Operation | 2018-2027 | 2019-2021 | 2019-2035 |
| Products | O ₃ , NO ₂ , O ₄ , SO ₂ , HCHO, AI, AOD, SSA, Cloud | O ₃ ,(UV, Vis), NO ₂ , SO ₂ , H ₂ CO, H ₂ C ₂ O ₂ , AOD, AI, Cloud | O ₃ , SO ₂ , (BrO), HCHO, Ring , NO ₂ , O ₄ , (IO CHOCHO), AAI, AOD, Cloud |

Status 2013:

Phase A/B

Phase 0/A

Phase C/D

Conclusions

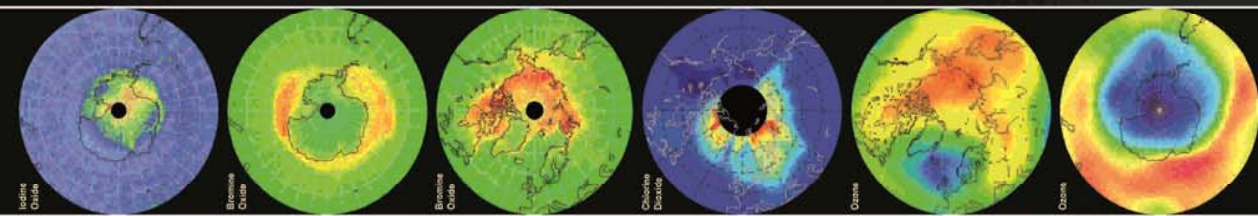
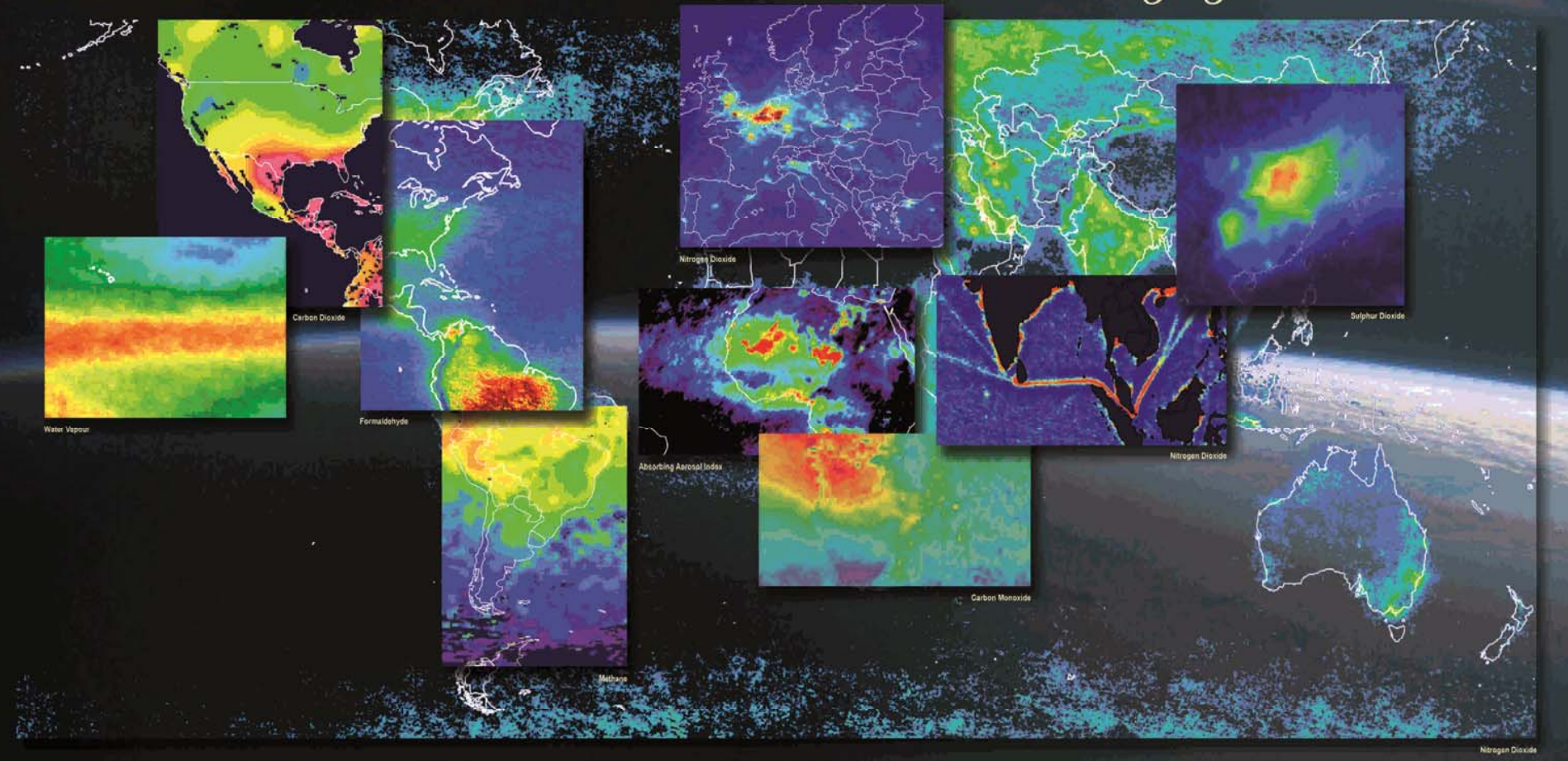
- Future geostationary observations will allow hourly observations with approx. 8 km spatial resolution for key components impacting air quality and tropospheric composition (exception: lower trop. CO)
- The operational LEO system (METOP SG, NPOES etc.) will make the global link
- On European side the system (MTG, METOP SG) is planned to be operated from 2019 – 2034 (~ 15 years)
- Main challenge:
 - funding of scientific activities to prepare community to make use of this unique data set (Level 2 retrieval, data assimilation etc.)
- Resolving the urban scale will require higher spatial resolution (1 - 2 km)
- Being prepared for the over next generation (2030+) of operational missions needs initiatives NOW! (CarbonSat, SCIA-ISS etc.)

SCIAMACHY



2002-2012

hunting light and shadows



Images: DLR, IUP-IFE University of Bremen, SRON, KNMI, IASG-BIRA, MPI for Chemistry, ESA, NASA

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- http://esamultimedia.esa.int/docs/S4-Data_Sheet.pdf