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## ***TROPOMI, the Sentinel 5 precursor instrument for air quality and climate observations: status of the current design***

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# TROPOMI, the Sentinel 5 Precursor instrument for air quality and climate observations: status of the current design.

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**Abstract**—TROPOMI, the Tropospheric Monitoring Instrument, is a passive UV-VIS-NIR-SWIR trace gas spectrograph in the line of SCIAMACHY (2002) and OMI (2004), instruments with the Netherlands in a leading role. Both instruments are very successful and remained operational long after their nominal life time.

TROPOMI is the next step, scheduled for launch in 2015. It combines the broad wavelength range from SCIAMACHY from UV to SWIR and the broad viewing angle push-broom concept from OMI, which makes daily global coverage in combination with good spatial resolution possible. Using spectral bands from 270-500nm (UV-VIS) 675-775nm (NIR) and 2305-2385nm (SWIR) at moderate resolution (0.25 to 0.6nm) TROPOMI will measure O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub>, BrO, HCHO and H<sub>2</sub>O tropospheric columns from the UV-VIS-NIR wavelength range and CO and CH<sub>4</sub> tropospheric columns from the SWIR wavelength range. Cloud information will be derived primarily from the O<sub>2</sub>A band in the NIR. This will help, together with the aerosol information, in constraining the light path of backscattered solar radiation. Methane (CH<sub>4</sub>), CO<sub>2</sub> and Carbon monoxide (CO) are the key gases of the global carbon cycle. Of these, Methane is by far the least understood in terms of its sources and is most difficult to predict its future trend. Global space observations are needed to inform atmospheric models. The SWIR channel of TROPOMI is designed to achieve the spectral, spatial and SNR resolution required for this task.

TROPOMI will yield an improved accuracy of the tropospheric products compared to the instruments currently in orbit. TROPOMI will take a major step forward in spatial resolution and sensitivity. The nominal observations are at 7 x 7 km<sup>2</sup> at nadir and the signal-to-noises are sufficient for trace gas retrieval even at very low albedos (down to 2%). This spatial resolution allows observation of air quality at sub-city level and the high

signal-to-noises means that the instrument can perform useful measurements in the darkest conditions.

TROPOMI is currently in its detailed design phase. This paper gives an overview of the challenges and current performances. From unit level engineering models first results are becoming available. Early results are promising and this paper discusses some of these early H/W results.

TROPOMI is the single payload on the Sentinel-5 precursor mission which is a joint initiative of the European Community (EC) and of the European Space Agency (ESA). The 2015 launch intends to bridge the data stream from OMI / SCIAMACHY and the upcoming Sentinel 5 mission. The instrument is funded jointly by the Netherlands Space Office and by ESA. Dutch Space is the instrument prime contractor. SSTL in the UK is developing the SWIR module with a significant contribution from SRON. Dutch Space and TNO are working as an integrated team for the UVN module. KNMI and SRON are responsible for ensuring the scientific capabilities of the instrument.

**Index Terms**—Component, formatting, style, styling, insert. (key words)

## I. INTRODUCTION

TROPOMI is the most recent in a series of UV-VIS-NIR-SWIR sun backscatter hyper spectral instruments that measure the atmospheric composition. These instruments measure with or without polarization the combination of Earth and sun spectra. From their ratio – the reflectance spectra – absorptions taking place in the Earth atmosphere are derived. Concentrations of trace gases can be determined because these gases have very specific wavelength-dependent absorption features (see Fig.1). Other products, like aerosols, clouds and

surface properties, have broader absorption structures and can be derived after accurate radiometric calibration.

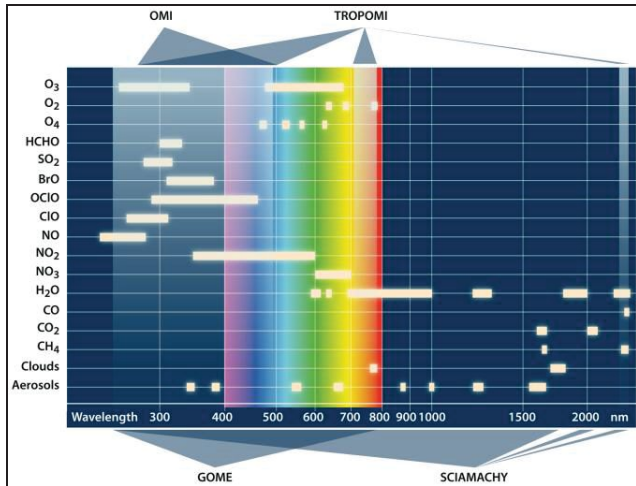


Fig. 1. Instrument spectral ranges in relation to the trace gas absorptions

Like OMI [1], TROPOMI will be a multichannel push-broom spectrometer in a sun-synchronous orbit, which results in daily coverage of nearly the entire globe. However, TROPOMI will be more sensitive than its predecessors, that is, the signal-to-noise ratio per ground pixel will be higher, and another notable change is a large improvement in ground resolution. OMI was already a big improvement in that sense to SCIAMACHY [2] and GOME [3] and TROPOMI takes this a big step further (Fig. 2. ). This will enable sub-city resolution.



Fig. 2. Comparison of spatial resolution of Schiamachy, GOME-2, OMI and TROPOMI (T).

After this introduction, this paper will first give a description of the TROPOMI instrument. Then an overview of the status of the instrument and its subsystems is given.

When reading this paper, please note that since TROPOMI and its subsystems are currently going through their critical design phase, some of what is described in this paper may have been changed by the time of the conference. The status described in this paper is that of August 2012.

THE INSTRUMENT DESIGN

The TROPOMI instrument [5] is an imaging spectrometer that consists of a UVN module, a SWIR module and an instrument control unit (ICU). The instrument is mounted on a telescope support structure (TSS) which in turn is mounted on the spacecraft (S/C) (Fig. 3. ). A passive thermal radiator is used to reject heat from the system.

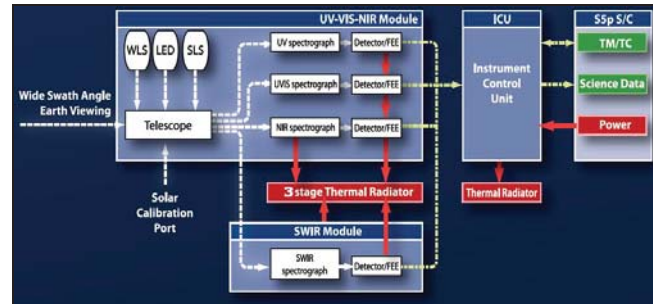


Fig. 3. TROPOMI functional diagram

The UVN module consists of the telescope – which is shared by the UVN and the SWIR – and the 3 UVN spectrometer channels (UV, UVIS and NIR) each equipped with individual detector units. The telescope has a very wide field-of-view of 108°. A polarisation scrambler is placed in the optical path to make the measurements insensitive to the polarisation state of the incoming light. The light from the telescope is separated in the flight direction by a reflective slit. This means that the UV and SWIR channels will see a slightly shifted part of the Earth than the UVIS and NIR channels (Fig. 4. ).

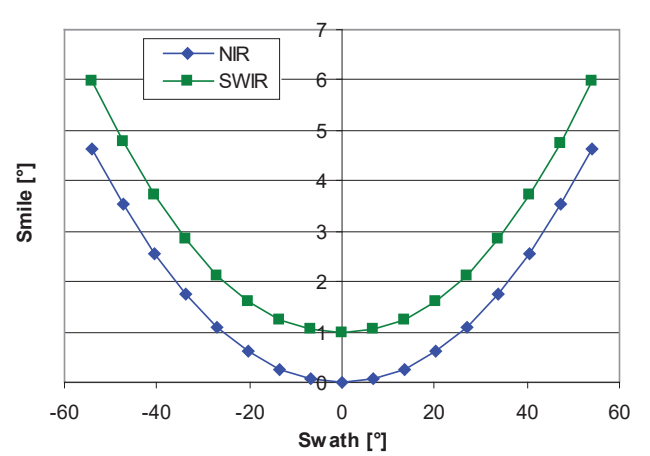


Fig. 4. Projection of the spectrometer slit on-ground. The so-called spatial smile is a.o. caused by off-axis mirrors in the telescope. The NIR (and UVIS) channel and SWIR (and UV1) channel have a FOV which is shifted by ~1 degree in the flight direction.

All detectors are optimized for the light that they will detect. The UVIS and NIR detectors have a graded anti-reflective coating, in order to reduce stray light and decrease interference effects in the Silicon. The detectors will be cooled to ~210K to reduce the dark current contribution and they will be thermally

isolated from the rest of the detector modules, which are kept at room temperature.

The SWIR module receives light via the telescope and an optics relay between the UVN optical bench and the SWIR. The SWIR consist of an optical bench and a detector module. The optical bench will be cooled to ~200K to reduce thermal self-emission and the detector will be cooled to ~140K to suppress dark current. The SWIR optical bench makes use of an immersed grating (Fig. 5. and [4]) which makes it possible to have a compact optical design.

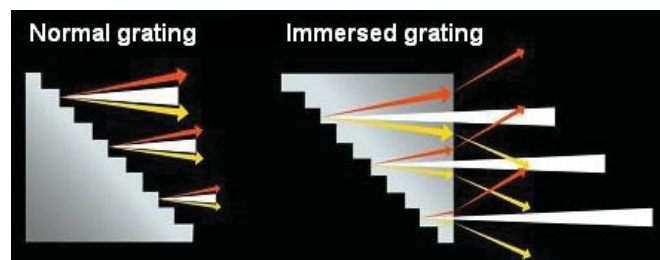


Fig. 5. Schematic difference between normal grating and the immersed grating as used for the SWIR

The instrument is controlled through the instrument control unit (ICU), which provides power to the subsystems and sends and receives tele-commands for operating the instrument. It also receives, processes and packetizes the science data that comes from the detector units.

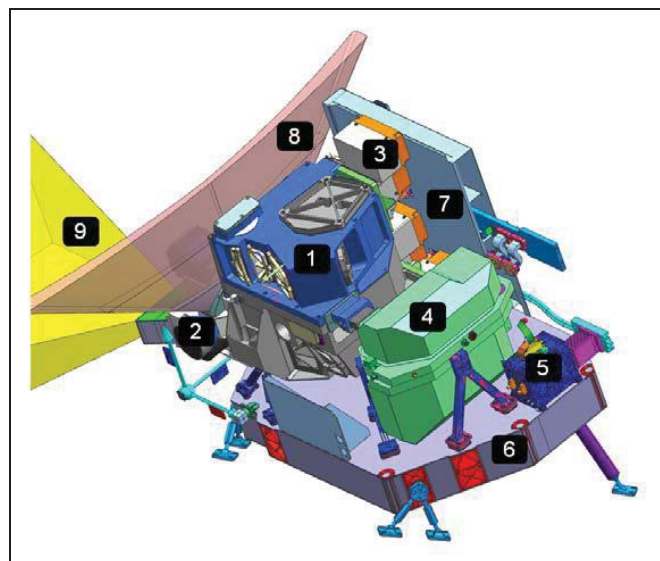


Fig. 6. Tropomi components located on the TSS: UVN Module (1), CU (2), UVN DEMs (3), SWIR Module (4), SWIR FEE (5), TSS (6), TBU (7), Nadir Field of View (8), Solar Field of View (9).

#### CALIBRATION UNIT (CU)

The calibration unit includes the following:

- Two sun diffusers; one for regular use, one as a backup

- A white light source (WLS); photo response non-uniformity (PRNU) calibration and on-ground health checks
- A LED to monitor the short term variation in the output of the WLS;
- For the SWIR channel, a number of laser diodes are placed in the CU, in order to be able to monitor the instrument spectral response function

Outside the Calibration unit, every detector will be illuminated by two LEDs after the grating in order to check the detector response and its linearity. Because the LED is located after the grating it will not be in a representative wavelength.

#### CURRENT STATUS OF THE UVN OPTICAL BENCH

The UVN optical bench is produced by TNO in the Netherlands. Gratings are critical items and procurement and expected performance are on schedule. Detailed optical design and tolerance analyses are being finalized and procurement of a number of optical elements is well underway. From FEM and breadboard test show that the scrambler design is sound and that the optical contacted wedge pairs can withstand the thermal survival loads.

#### CURRENT STATUS OF THE INSTRUMENT CONTROL UNIT

The ICU is produced by RSE (RUAG) in Sweden. After a successful preliminary design review (PDR) in February 2012, the unit is going through its critical design phase with an anticipated CDR in December 2012.

In June 2012 a successful early compatibility test between ICU and DEM and SWIR-FEE was held in Sweden, where for the first time the units were connected and shown to work together. The main objective of the test was to gain confidence in the digital interfaces between the units. The combined functional behaviour of the units as well as the robustness of the ASL and IDL links was tested.

#### CURRENT STATUS OF THE DETECTOR MODULES

The detector electronics module (DEM) is produced by RSSZ (RUAG) in Switzerland. The PDR was held at the end of 2011 and CDR is expected to be finished in September. At this moment manufacturing of the flight models will also be released. A number of critical topics have been investigated in the first half of 2012. One of the critical items is the thermal behaviour of the unit, in view of the large temperature difference between the detector and the surrounding electronics and housing. A redesign of the thermal link from the detector to the radiator was needed to limit the total amount of heat loss that can be rejected on system level. A mechanical test – mainly in order to see if the unit will withstand the launch loads – was performed twice and the most critical item – position stability of the detector – has been verified.

Currently the electronics design is undergoing its final scrutinizing tests where power consumption and conducted susceptibility are main points of interest.

#### CURRENT STATUS OF THE DETECTORS

The detectors for the UVN channels are frame transfer CCDs. They are specials produced by e2v in the UK. The detectors make use of metallized electrodes in order to minimize the frame transfer duration. Engineering models (EM) of the CCDs were delivered to RSSZ in the beginning of this year and on the detectors is integrated in the EM of the detector unit. Flight models of the CCDs are expected to be delivered in September and October 2012.

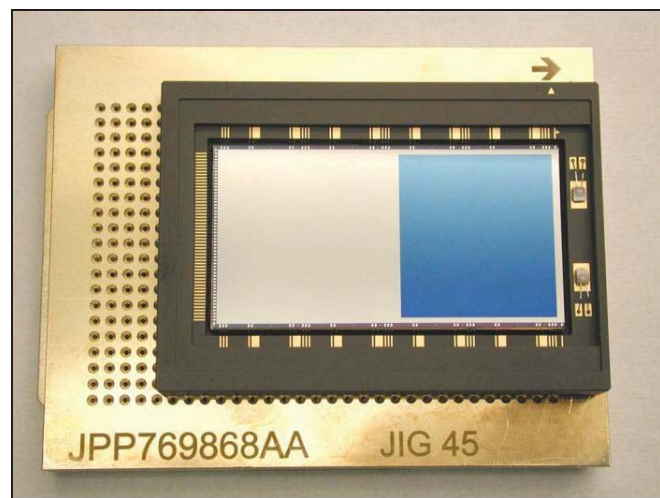


Fig. 7. Photograph on an Engineering Model of a TROPOMI CCD. The blue area on the left is the image area.

The SWIR detector is the Saturn detector produced by Sofradir in France. The SWIR detector is a HgCdTe CMOS device, hybridized to a silicon read-out circuit (ROIC). Flight devices are expected to be ready in September 2012.

#### CURRENT STATUS OF THE SWIR

The SWIR unit includes the SWIR optical bench and the detector unit. The detector unit contains the detector, the FEE and a detector assembly. The SWIR optical bench is produced by SSTL in the UK, and the FEE is produced by SRON in the Netherlands. The assembly of the detector unit is done by SSTL.

The SWIR had its PDR in March of 2012 and the CDR is scheduled for October 2012. A successful CDR for the SWIR detector FEE was held in April 2012. Production of the flight model for the FEE is now well underway.

#### CONCLUDING REMARKS

The development of TROPOMI and its subsystems is well underway. The design of its subsystems is in the process of being finalized. As expected many obstacles had to be overcome and it is expected that in the later integration, testing and calibration phases many challenges will have to be faced. For now, the TROPOMI program is progressing towards a world leading instrument that compared to previous instruments like OMI and SCIAMACHY continues to improve on clouds characterization and retrieve CH<sub>4</sub>, CO and H<sub>2</sub>O products.

TROPOMI steps beyond the SCIAMACHY and OMI by improving the spatial resolution (ground pixel) from OMI by a factor 8 towards 7 x 7 km<sup>2</sup> at nadir and from SCIAMACHY by a factor of about 100, depending on the SCIAMACHY operational mode. Next to this the sensitivity is improved by an order of magnitude to have useful data in the darkest conditions.

#### ACKNOWLEDGMENT

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