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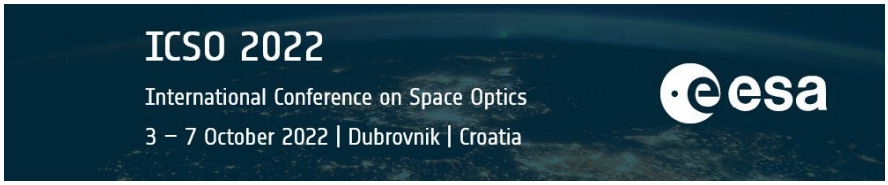

The Copernicus CO2M payload for monitoring anthropogenic carbon dioxide emissions

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The Copernicus CO2M payload for monitoring anthropogenic carbon dioxide emissions

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ABSTRACT

Thales Alenia Space has been selected to design and provide the payloads of the European Copernicus CO2M mission, whose main aim is to provide monitoring of the anthropogenic carbon dioxide emissions from space.

Each payload is composed of :

- The CO2 instrument, which is the instrument dedicated to measuring atmospheric CO2 and CH4. This dispersive instrument measures the spectral radiance in three bands (747-773, 1590-1675 and 1990-2095nm), used as inputs to the inverse models for determining total column concentrations for atmospheric CO2 and CH4. The instrument is designed for high spatial resolution, high spectral resolution, and high thermal and mechanical stabilities.
- The CO2 instrument embeds an imaging spectrometer in the VIS 405-490nm band dedicated to measuring atmospheric NO2 content, permitting native nominal co-registration and optimized relative radiometric performances with the CO2 bands. This translates into an accurate tracing of anthropogenic CO2 plumes from power plants and cities while limiting the additional hardware and qualification procedures
- This combined CO2 and NO2 instrument is the core of the payload, and two additional instruments of limited mass and volumes are embarked: a multi-angle polarimeter dedicated to aerosols measurement (MAP) to better account for cloud and aerosols scattering effects, and a cloud imager (CLIM) with high spatial resolution to accurately filter the data for cloud-contaminated samples.

This article presents the payload design and development status.

Keywords: Copernicus program, CO2M, imaging spectrometers, anthropogenic carbon dioxide, greenhouse gas emissions

1. INTRODUCTION

The OHB & Thales Alenia Space consortium has been selected for the implementation of the ESA Copernicus anthropogenic CO2 monitoring (CO2M) mission, with OHB system as system and platform prime contractor, and Thales Alenia Space as payload prime contractor. The system will consist of minimum 2 identical satellites in LEO imaging along the satellite track on the sun-illuminated part of the orbit with a swath width >250 km, designed for a minimum duration of operation of 7 years. Each satellite will continuously provide measurements of CO2, CH4, NO2, as well as aerosols & cloud imaging capability permitting to support the XCO2[1] and XCH4 retrieval. XCO2 and XCH4 observations will be provided at a spatial resolution < 4km2, with precision (<0.7 ppm) and accuracy (bias <0.5 ppm) required to resolve the small atmospheric gradients in XCO2 originating from anthropogenic activities.

[1] The X in e.g. XCO2 denotes the concentration in terms of column-averaged dry air mole fraction

Thales Alenia Space is the prime contractor for the complete payload, with Thales Alenia Space in France being in charge of the CO2 instrument, Thales Alenia Space in the United Kingdom being in charge of the Multi-Angle Polarimeter (MAP) instrument dedicated to aerosols measurements, and OIP being in charge of the cloud imager.

2. PAYLOAD AND CO2 INSTRUMENT

The **payload** is composed of :

- The CO2 instrument, which is the instrument dedicated to measuring atmospheric CO2 and CH4. The instrument measures the spectral radiance in the NIR (747-773nm), SWIR-1 (1590-1675nm) and SWIR-2 (1990-2095nm) bands, used as inputs to the inverse models for determining total column concentrations for atmospheric CO2 and CH4. The instrument is designed for high spatial resolution, high spectral resolution, and high thermal and mechanical stabilities
- The CO2 instrument embeds an imaging spectrometer in the VIS band dedicated to measuring atmospheric NO2 content, permitting native nominal co-registration and optimized relative radiometric performances with the CO2 bands. This translates into an accurate tracing of anthropogenic CO2 plumes from power plants and cities while limiting the additional hardware and qualification procedures
- This combined CO2 and NO2 instrument is the core of the payload, and two additional instruments of limited mass and volumes are embarked:
  - a multi-angle polarimeter dedicated to aerosols measurement (MAP) to better account for cloud and aerosols scattering effects
  - and a cloud imager (CLIM) with high spatial resolution to accurately filter the data for cloud-contaminated cases

The combined measurements performed by the payload will be used to improve the determination accuracy of the atmospheric greenhouse gas contents. The main requirements driving the instruments designs are summarized hereafter:

- CO2 instrument (CO2I), that provides also O2 and CH4 measurements:
  - Three spectral channels: NIR (747-773nm), SWIR-1 (1590-1675nm) and SWIR-2 (1990-2095nm) bands;
  - Very high spectral resolution (≤0.12 to 0.35 nm as a function of the bands);
  - 4 km² pixel on ground;
  - Swath ≥ 250km;
  - Driving requirements: SNR, radiometric dynamic range, spatial co-registration, ISRF knowledge, and relative spectral radiometric accuracy incl. in particular the impacts of straylight and sensitivity to polarization
- NO2 band, embedded in the CO2 instrument:
  - 1 VIS (405-490nm) spectral band;
  - ≤0.6 nm spectral resolution;
  - Driving requirement: SNR & radiometric dynamic range. Though not as stringent as for the CO2I, the embedment of the NO2 band in the CO2 instrument provides to the NO2 measurement a quasi-perfect co-registration with the CO2 & CH4 measurements as well as native access to the CO2I calibration capabilities
- MAP (Multi-angular Polarimeter)
  - Multi spectral (6 bands), multi-directional: 40 along track (ALT) directions, 3 polarisations to measure, with data co-registered at L2 with the CO2 instrument;
  - Driving requirements: DOLP accuracy performance, at least the CO2 instrument swath, +/-60° ALT coverage
- Cloud imager
  - Oversampled pixels, co-located with CO2;
  - 3 spectral channels: VIS (670 & 753nm) & SWIR (1.37 µm) with limited bandwidths (resp. 20, 9 and 15 nm)
  - Driving requirements : SNR, co-registration with CO2I

The **combined CO2 & NO2 instrument (CO2I)** is composed of :

- The Flight Calibration Unit (FCU), for radiometric and spectral on-board calibration using white lamp source, lasers and sun diffusers
- The entry telescope imaging earth on the slit and defining the swath. The first optical element of the telescope is a multi-Babinet pseudo depolarizer that ensures the extreme insensitivity of the CO2I instrument radiometry to

polarization. The telescope is mounted on an highly stable interface bench, together with the star trackers, the MAP optical unit and the CLIM optical unit, to ensure nominal registration of all these elements

- The spectrometer generating the measurements in the four spectral channels required for CO2I & NO2. The CO2I spectrometer is assembled on a very rigid and extremely stable optical bench based on SI3N4 ceramic and makes use of in particular the following assets: 2D slit homogenizer for native quasi perfect co-registration and ISRF robustness, collimator with highly efficient broadband coatings, high efficiency gratings, visible and SWIR detectors with high radiometric performances resp. from Teledyne E2V and Lynred. In particular the use of the SI3N4 participates to the stability of a driving optical performance: the ISRF stability
- The passive thermal guard to cool down and ensure an extremely stable temperature of the spectrometer, limiting the signal background in both SWIR channels
- The passive cryogenic radiator to cool the SWIR detectors down for optimal noise performances, with stability performances achieved for both nadir and sun-glint pointings
- The video electronic equipments to drive the focal planes and send the digitized signal to the platform mass memory

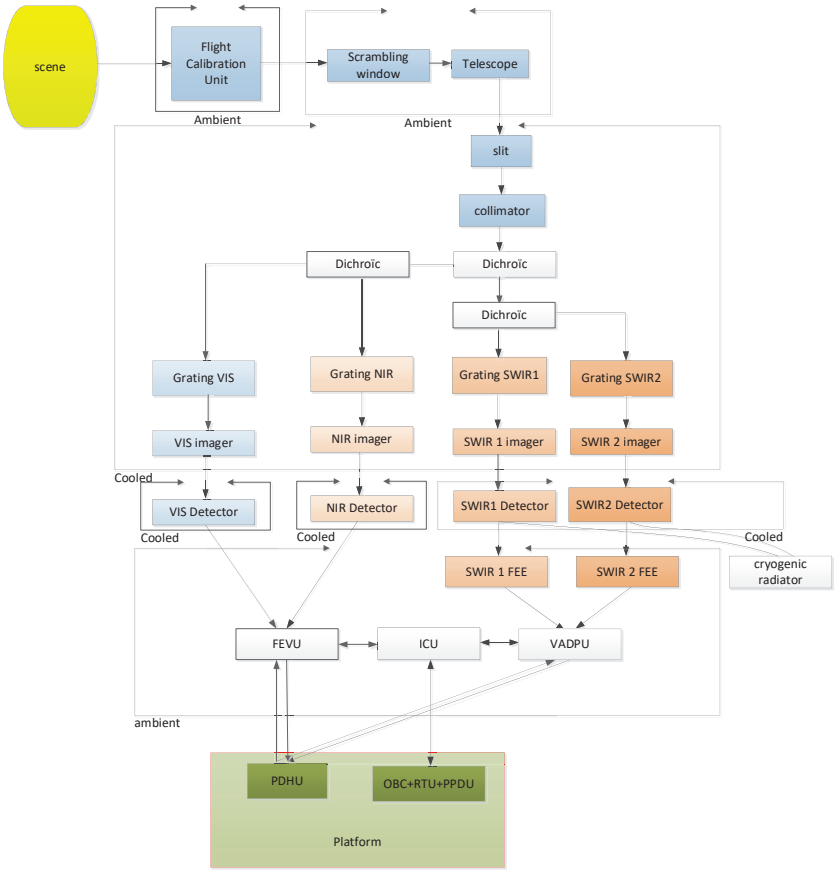


Figure 1. CO2I functional architecture, that includes the NO2 band. The core of the instrument is the spectrometer, that features a single slit and collimator for nominal co-registration, and dedicated gratings and imagers for nominal radiometric performances.

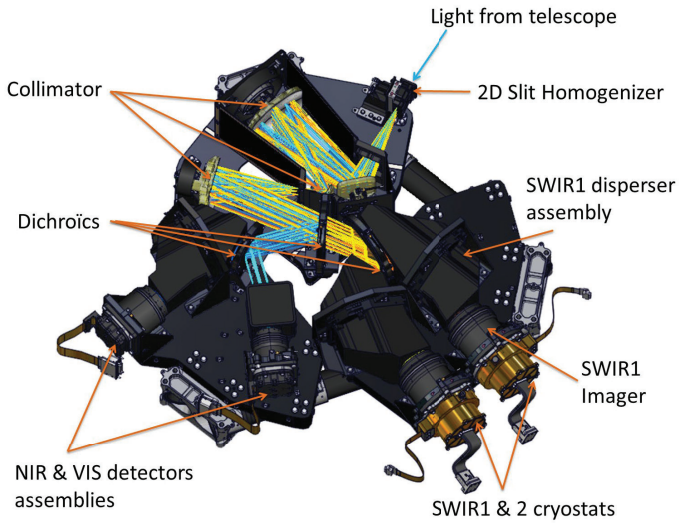


Figure 2. View of the CO2I spectrometer, that uses a 2D slit homogenizer and collimator common to all the bands to provide native quasi-perfect co-registration, dichroïcs to split the 4 bands into dedicated spectrometer bands with high efficient gratings, imagers with limited number of lenses to limit the straylight, and detectors. The spectrometer is assembled onto an optical bench whose rigidity and stability is ensured by the adequate use of Si3N4 ceramic.

The **MAP instrument**[2] is composed of :

- 4 identical, simple cameras, contained in a dedicated Optical Unit
- Each camera is a reflective telescope designed for minimum straylight, and a focal plane consisting of a stack of the detector TE2V CIS-120, a multi-spectral filter and a micropolarizers array
- Flight Calibration Units providing shutter position & radiometric calibration via sun diffusers to all the cameras are implemented
- A separate Electronics Unit optimized for thermal rejection, providing control and delivering binned & oversampled detector data to the mass memory

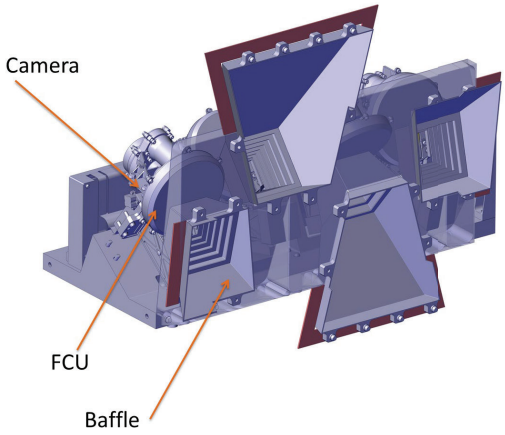
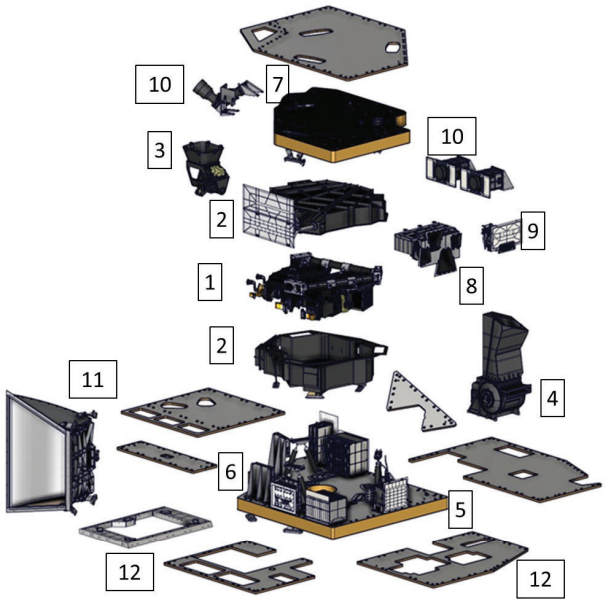


Figure 3. view of the MAP Optical Unit (covers and structure removed), showing the modular use of identical cameras to cover the specified along-track field of view.

[2] See more details in e.g. D.Spilling & A.Thales @ICSO 2020

The **CLIM instrument** is largely based on the heritage of the Proba-V instrument (ESA mission).

The whole CO2I integration, payload integration and qualification as well as the CO2I calibration will be performed in a single facility at Thales Alenia Space in France, in Cannes, and the final steps of the MAP, CLIM and star trackers integrations will also be also performed at the same place. The payload will then be transferred to OHB for integration on the platform.



1	CO2I spectrometer
2	Spectrometer thermal guard
3	CO2I telescope
4	CO2I Flight Calibration Unit
5	PL to PF interface panel (ISP)
6	Electronics
7	Interface Bench for LoS sensitive optics (USIB)
8	MAP Optical Unit
9	CLIM Optical Unit
10	Star Trackers
11	Passive SWIR FPAs cooler
12	Closing panels

Figure 4. Structuration of the payload, with the CO2I spectrometer at its core.

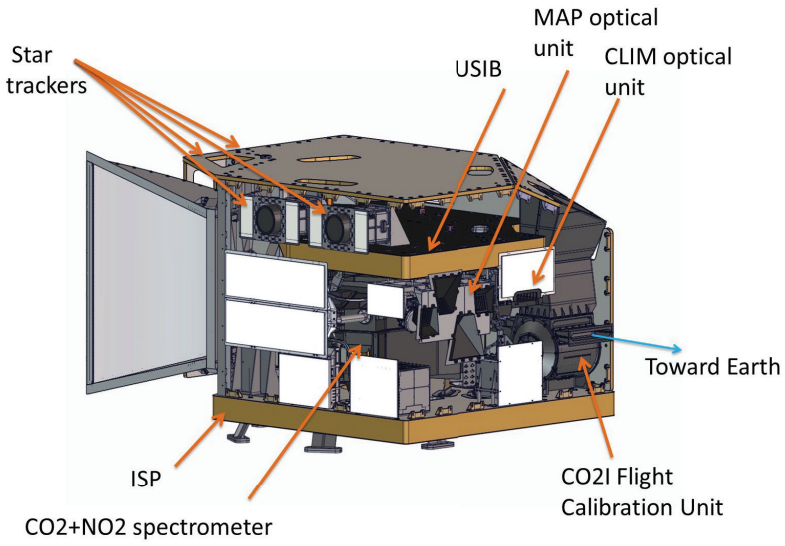


Figure 5. View of the CO2M payload w/o the MLIs (seen from the cold face side, earth toward the right).

3. DEVELOPMENT STATUS

The different equipments that will constitute the payload are currently between their respective PDRs and CDRs. The payload CDR is planned for 2023, as well as the start of both PFM and FM2 payload AITs.

For CO2I and MAP, in particular optical development models named Elegant BreadBoards (EBBs) are under implementation, permitting to secure the alignment procedures, optical GSEs, processing algorithms… For the CO2I, the EBB is a breadboard of the SWIR-1 band of the CO2 spectrometer, and has already provided excellent performances results especially on geometrical, spectral and straylight aspects, with good match to the expectations.

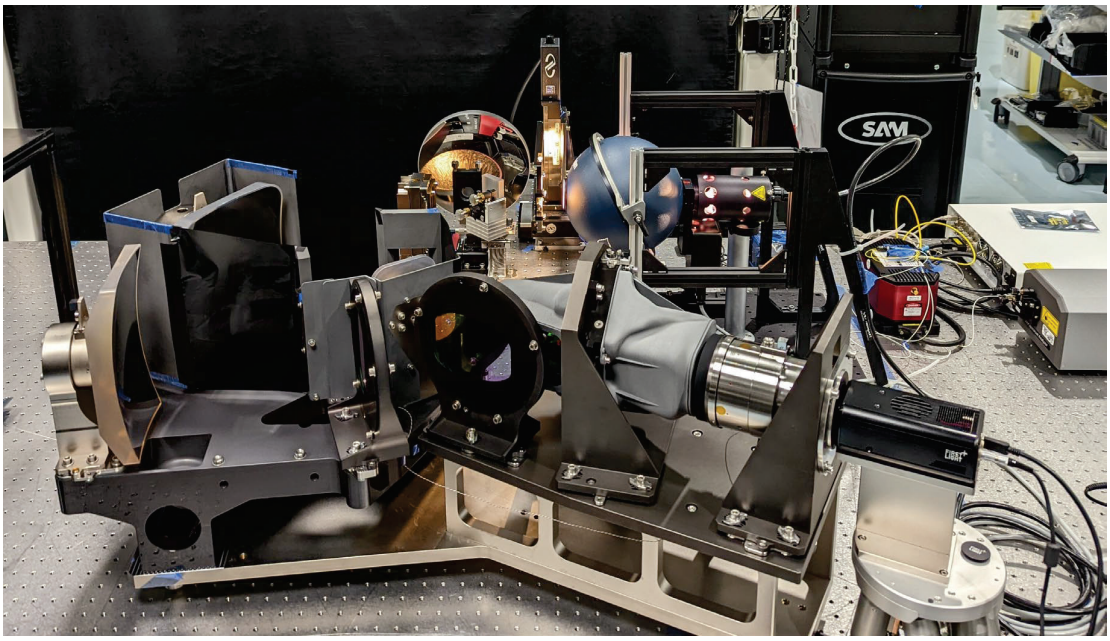


Figure 6. Partial view of the EBB. The collimator assembly can be seen on the left side, 2 of the 3 dichroïcs at the center, and the SWIR-1 assembly (disperser under its light grey baffles, imager in its barrel, GSE camera) on the right.

4. CONCLUSIONS

Thales Alenia Space has designed and is currently implementing the Copernicus CO2M payload, and in particular the CO2 instrument, which is the instrument dedicated to measuring anthropogenic XCO2, CH4 and NO2. The extremely demanding specifications in many performances areas (SNR, radiometric dynamic range, spatial co-registration, ISRF knowledge, relative spectral radiometric accuracy incl. in particular the impacts of straylight and sensitivity to polarization) have driven the concept and detailed definition of the instrument. In particular the implementation of the Elegant BreadBoards, which for the CO2 instrument is an optical breadboard model of the full SWIR-1 band spectrometer, permits to secure the performances, the AIT procedures and the processing aspects for the flight models. All the equipments developments are progressing, and the AIT of both the PFM and FM2 payloads is planned to start in 2023.