

COPERNICUS MISSION FOR MONITORING ANTHROPOGENIC CARBON DIOXIDE FROM SPACE: PROGRESS OF CO2M PAYLOAD DEVELOPMENT

A. Dussaux (1); G. Bazalgette Courrèges-Lacoste (2), H. Ouslimani (2), J-M Gaucel (1), A. Liotard (1), C. Gaudin-Delrieu (1); D. Spilling (4); A. Grynagier (1); D. Miras (1); S. Lesschaeve (3), L. Verstraeten (3); G. De Roquefeuil (1); M. Silvestri (4), S. Strauss (4), J. Komadina (4), Y. Durand (2), A. Pasquet (2), A. Chanumolu (2), M. Casti (2), M. Caleno (2), Y. Meijer (2), J-P Fayret (1), V. Fernandez (2),

(1) Thales Alenia Space, 100 Boulevard du Midi, 06156 Cannes, France; (2) European Space Agency, Keplerlaan 1, 2200 AG Noordwijk ZH, The Netherlands; (3) OIP Sensor Systems, Oudenaarde, Belgium; (4) OHB System, Manfred-Fuchs-Platz 2-4, 28359 Bremen, Germany

ABSTRACT

The European Space Agency (ESA), in collaboration with the European Commission (EC) and EUMETSAT, is developing as part of the Copernicus Sentinel expansion programme, a space-borne observing system for quantification of the emissions of the main greenhouse gases: anthropogenic carbon dioxide (CO₂) and methane (CH₄). The anthropogenic CO₂ monitoring (CO2M) mission will be implemented as a constellation of three identical LEO satellites, to be operated over a period of at least 7 years and measuring CO₂ concentration in terms of column-averaged dry air mole fraction (denoted as XCO₂). Each satellite will continuously image XCO₂ along the satellite track on the sun-illuminated part of the orbit, with a swath width of 250 km. Observations will be provided at a spatial resolution better than 2 x 2 km², with high precision (<0.7 ppm) and accuracy (bias <0.5 ppm), which are required to resolve the small atmospheric gradients in XCO₂ originating from anthropogenic activities.

Starting by a summary of the main scientific drivers, this paper will provide an overview of the progress of the payload development. CO2M is now in phase D, with on-going manufacturing, integration and testing of the first two flight models (PFM and FM2) of the three instruments.

Keywords: CO2M, hyperspectral imager, GHG monitoring, Copernicus, Payload

1. INTRODUCTION

The Optical Payload is under the responsibility of Thales Alenia Space in Cannes, with OHB as satellite prime. The demanding mission requirements necessitate a payload composed of four instruments, which simultaneously perform co-located measurements [1][2]. The main instrument, called CO2I, consists of a push-broom imaging spectrometer which will perform co-located measurements of top-of-atmosphere radiances in the Near Infrared (NIR) and Short-Wave Infrared (SWIR) at high to moderate spectral resolution (NIR: 747- 773nm @0.1nm, SWIR-1: 1595-1675nm @0.3nm, SWIR-2: 1990-2095nm @0.35nm) for retrieving XCO₂ and XCH₄. These observations are complemented by a second instrument called NO2I in the same spectrometer acquiring measurements in the visible spectral range (405-490 nm @0.6nm), providing vertical column measurements of nitrogen dioxide (NO₂) that serve as a tracer to high temperature combustion of fossil-fuel and related emission plumes. High quality retrievals of XCO₂ will be ensured even in the presence of aerosol loading, thanks to co-located measurements of aerosol properties resulting from a third instrument called Multiple Angle Polarimeter (MAP). Polarimetric measurements are performed over 40 angular views and in six spectral channels in the range 410 nm to 865 nm. A fourth instrument is a three-band Cloud Imager (CLIM) that will provide the required capability

to detect small tropospheric clouds and cirrus cover with an accuracy of 1% to 5% and a sampling better than 400 m. Indeed, cloud contamination has a strong impact on the XCO₂ retrieval. Below is a schematic of the full optical payload of CO₂M (see figure 1).

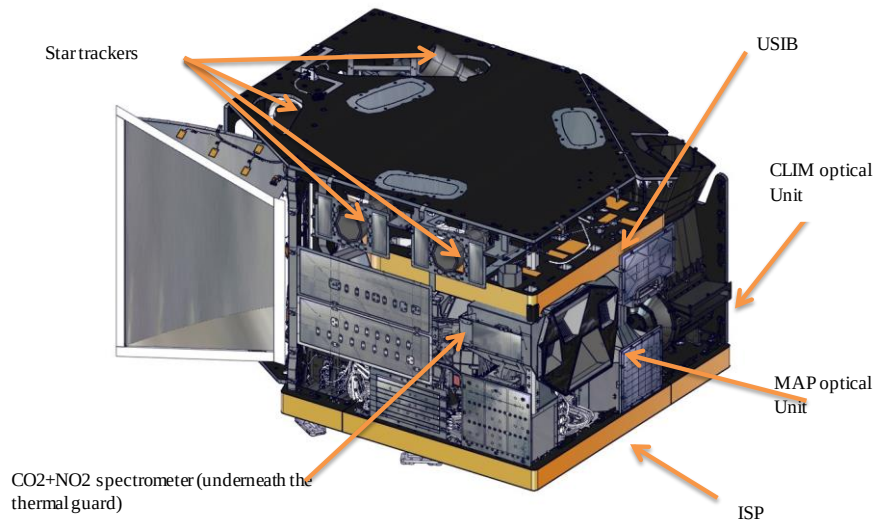


Figure 1. CO₂M optical Payload

The payload CDR has been achieved in 2024 [3], and the assembling integration and test of the three instrument is now ongoing for PFM and FM2.

2. CO₂M MAIN DRIVERS

The payload structure has been robustly designed and dimensioned to withstand stringent mechanical and thermo-elastic challenges such as sine vibrations, acoustic loads, shocks, thermal elastic distortions, interface flatness criteria, as well as handling and transportation stresses. It also complies with critical safety demands including fracture control and fail-safe protocols.

CO₂ Instrument

Heart of the CO₂ Instrument is the CO₂ NO₂ spectrometer. The CO₂ and NO₂ spectrometer has been engineered to meet rigorous performance requirements across multiple demanding conditions. It is seamlessly integrated with both the PL to PF interface bench and an ultra-stable interface bench, on which the optical assemblies are mounted. Optical bench rigidity is ensured by Si₃N₄ ceramic tubes, material also used on the collimator bench. All four spectral bands utilize a shared slit and collimator, while three dichroic elements effectively separate these bands, each featuring dedicated dispersers, imagers, and detection focal planes, ensuring optimized spectral performance (see figure 2).

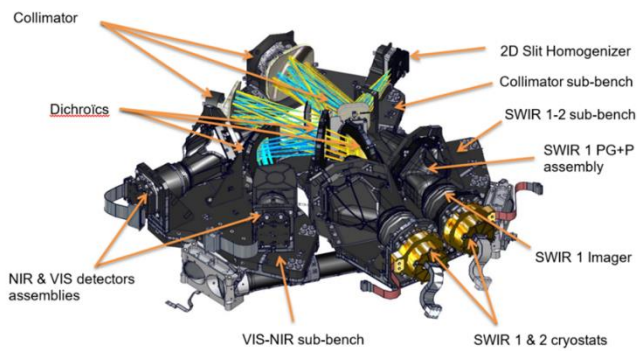


Figure 2. (left) schematic of the CO2I spectrometer assembly, (right) spectrometer bench during its assembling phase.

Some of the most stringent observation performance requirements are:

- High spectral resolution, and Instrument Spectral Response Function (ISRF) knowledge and robustness

In addition to the high mechanical stability, ISRF knowledge demands an extensive and precise characterization during the ground campaign. Moreover, the insensitivity to non-uniform scenes necessitates the use of a 2D slit homogenizer. This slit homogenizes the along-track and across-track input scenes thanks to the use of optical fibers.

- High spatial co-registration : here again, the 2D slit homogenizer allows separating all spatial samples thanks to the spacing between the fiber cores that are imaged at the detector focal planes. This provides a mean of high registration knowledge between the four instrument bands.
- Stringent requirement on radiometric accuracies necessitate to limit to the maximum all sources of bias in the acquisitions, which means for instance, cutting edge handling of the straylight (from the design phase, to the extensive calibration, and advanced correction algorithms). Use of high-performance polarization scrambler to cancel the instrument response dependency to the input scene polarization. Perfect knowledge of the video chain transfer function, and implementation of correction algorithm if necessary (see e.g. ref [4], and updated presentation at ICSO 2026).
- And indeed, high signal to noise ratio, which means if one wants to keep decent optical aperture and instrument size, using high transmission coatings, high performance gratings, dichroics etc...

CLIM and MAP Instruments

Cloud imager main drivers are the signal to noise ratio and improved spatial resolution (400 m), while multi-angle polarimeter instrument necessitates to combine in a compact form, multiple degrees of polarization, multiple spectral bands, and multiple viewing angles in the along track direction (up to $\pm 60^\circ$), with very demanding knowledge of the degree of linear polarization (see J. Ouaknin et al dedicated presentation at ICSO 2026).

3. ASSEMBLY, INTEGRATION AND TEST

Once fully assembled onto the Payload, the CO2 instrument spectrometer PFM has undergone its final alignment step with the shimming of the four focal planes so they are perfectly in focus. To achieve the precision needed at the 10 μm scale, the instrument must be aligned in the same conditions it will experience in space: a vacuum environment, with the spectrometer at 240K and SWIR detectors at 150K, see figure 3.

The campaign also took advantage of the space-simulated test environment to measure several key performance characteristics of the spectrometer. These included, in particular preliminary straylight measurements, spectral performance of the four bands, and video chain performances (see [5]).



Figure 3. CO2M's spectrometer being sealed within the vacuum chamber

During this major milestone, the testing phase also featured a thermal balance assessment of the spectrometer, enabling to verify that its thermal performance aligns with their expectations and providing valuable early data in the evaluation process.

Following the completion of this significant step, the instrument is now being returned to standard conditions to allow for the integration of its remaining elements to complete the payload: telescope and calibration unit of CO2I, then the two other instrument (cloud imager and multi-angle polarimeter).

Meanwhile, progress on the first satellite continues with the cloud imager having been finalized and delivered to Thales Alenia Space by OIP Sensor Systems. In parallel, the 4 multi-angle polarimeter PFM cameras integration is being finalized. The complete on-ground performance calibration tests of these cameras will be soon concluded at Thales Alenia Space France premises.

As preparations for the first satellite's instruments progress towards launch, the spectrometer for the second satellite is also making headway at the Cannes facility with FM2 spectrometer alignment process being performed in parallel of the PFM activities, see figure 4.



Figure 2. Both CO2M payloads (PFM and FM2) in the cleanroom

4. CONCLUSIONS

The paper has presented an overview of CO2M driving requirements and how the payload design is facing it. The status of the Copernicus CO2M mission payload development and the status of the three instruments CO2I/NO2I, MAP and CLIM has also been discussed. The Payload PFM has passed major milestones such as a complete integration and first measurements under flight conditions for the CO2I spectrometer, and the delivery of the first instrument, the cloud imager.

CO2M mission is crucial for enhancing our understanding of the global carbon cycle by providing precise, high-resolution measurements of atmospheric carbon dioxide. This mission will play a key role in monitoring greenhouse gas emissions, supporting climate change mitigation efforts, and informing international environmental policies.

ACKNOWLEDGEMENTS

This work has been done in the frame of the CO2M ESA project for which Thales Alenia Space is prime of the payload.

REFERENCES

- [1] Bernd Sierk, Valerie Fernandez, J.-L. Bézy, Y. Meijer, Y. Durand, G. Bazalgette Courrèges-Lacoste, C. Pachot, A. Löscher, H. Nett, K. Minoglou, L. Boucher, R. Windpassinger, A. Pasquet, D. Serre, F. te Hennepe, "The Copernicus CO2M mission for monitoring anthropogenic carbon dioxide emissions from space," Proc. SPIE 11852, International Conference on Space Optics — ICSO 2020, 118523M (11 June 2021); <https://doi.org/10.1117/12.2599613>
- [2] Yannig Durand, Gregory Bazalgette Courrèges-Lacoste, Charlotte Pachot, M. Martinez Fernandez, D. Sanchez Cabezudo, Valerie Fernandez, Stefan Lesschaeve, David Spilling, Antoine Dussaux, Denis Serre, Jonathon Komadina, Frank te Hennepe, Arnaud Pasquet, "Copernicus CO2M: status of the mission for monitoring anthropogenic carbon dioxide from space," Proc. SPIE 12777, International Conference on Space Optics — ICSO 2022, 127774I (2023); <https://doi.org/10.1117/12.2690839>
- [3] A. Dussaux, G. Bazalgette Courrèges-Lacoste, J.-M. Gaucel, et al. "Copernicus CO2M: the mission for monitoring anthropogenic carbon dioxide from space: status of the payload at the start of the AIT phase", Proc. SPIE 13699, International Conference on Space Optics — ICSO 2024, 1369916 (28 Jul 2025); <https://doi.org/10.1117/12.3072498>
- [4] Gaucel, J.-M.; Glandus, L.; Foulon, H.; Soman, M.; Sierk, B., "Persistence Characterisation and modelization for CO2M mission", ICSO. 2024, Volume 13699.
- [5] G. Bazalgette Courrèges-Lacoste, S. Ballion, J-M Gaucel, A. Liotard, A. Dussaux, A. H. Ouslimani, A. Pasquet, Y. Durand, A. Chanumolu, M. Casti, S. Strauss, G. Huber, J. Habets, Verification and Calibration of the payload Instruments of the CO2M Mission: CO2i Spectrometer TVAC Characterization, ICSO 2026