SSC22-VIII-05

GEI-SAT Constellation for Greenhouse Gases Detection and Quantification

Marcos Ubierna, Manuel Montesino, Eider Ocerin, Roberto Fabrizi
Satlantis Microsats S.L.
Edif. SEDE, Scientific Park, Campus UPV/EHU Bizkaia, 14D, 2ª planta, 48940 Leioa, Spain; +34 944 344 780
ubierna@satlantis.com

Tania Meixus
Enagás S.A.
Paseo de los Olmos, 19, 28005, Madrid, Spain; +34620770843
tmeixus@enagas.es

ABSTRACT

GEI-SAT constellation will embark SATLANTIS' solution for methane emissions detection and quantification. GEI-SAT pursues hot spot mapping of low emission levels of methane with a low-mass and low-cost very high-resolution multispectral SWIR camera onboard CubeSats & Microsats. The overall mission consists of: GEI-SAT Precursor, a 16U CubeSat (17.4 kg, ~150 kg/h detection threshold, 1.65 m resolution @VNIR and 13 m resolution @SWIR, up to 1700 nm) to be launched in Q1 2023; GEI-SAT Plus, a Microsat (92 kg, ~100 kg/h detection threshold, 0.8 m resolution @VNIR and ~7 m resolution @SWIR, up to 1700 nm) to be launched in Q4 2023; and another three Microsats with better detection threshold (92 kg, ~50 kg/h (TBC) detection threshold, 0.8 m resolution @VNIR and 9m resolution @SWIR, up to 2300 nm) to be launched in 2024-25. The Ground Segment will include the Mission Operations & Control Centre, the Ground Stations Network and the Data HUB. The methane absorption is obtained measuring the differential signal between SWIR images with different filters. The high spatial resolution that GEI-SAT provides in its SWIR channel, together with the geo-localization provided by very high resolution VNIR channel, will allow users to distinguish the exact location of methane emissions.

INTRODUCTION

Methane is the second most abundant greenhouse gas after CO2, with a global warming potential about 28 times that of CO2 over 100-year period. A quarter of today's global warming is estimated to be caused by anthropogenic methane emissions, where early action is key to decrease global average temperature.

The energy sector, with Oil & Gas at its head, is second only to agriculture in overall anthropogenic CH4 emissions. This includes methane leaks in gas assets, vents, incomplete combustion from flaring, among others. Projections estimate that natural gas will be key in the energetic transition for decades to come, presenting an opportunity for long term action.

According to MethaneSAT and EDF: "Detecting even low emission levels is critical, estimations show that roughly half of the methane being emitted from Oil & Gas infrastructure comes from smaller sources, which are largely unidentified".[1].

Methane emissions reduction is becoming a priority for Governments, Regulators & Environmental Agencies across the globe. More targeted environmental policies are being embraced, to bring agendas such as the Sustainable Development Goals for 2030, closer to reality. During the COP 26 held in November 2021 in Glasgow, the Global Methane Pledge (GMP) was launched which is a collective goal of reducing human-made methane emissions by at least 30% from 2020 levels by 2030. Today more than 110 countries have joined this Pledge.

Current methane emissions estimations have large uncertainties mainly due to the use of different methodologies and incomplete datasets that do not cover all relevant temporal and spatial scales, as well as errors present in detection and quantification processes. In this context, top-down/site-level monitoring using satellite data is emerging as a powerful and complementary tool, able to monitor emissions at different scales over long periods of time on a continuous basis.

Worldwide methane emissions mean economic losses in the tens of billions. Furthermore, methane emissions mitigation measures could be implemented in some cases at zero net cost, or even with benefits, getting into the circular economy. The financial sector is increasingly interested in evaluating sustainability and social impact of businesses. The ability to bring forth reliable measurements will allow for consistent reporting, transparency and trust.

GEI-SAT CONSTELLATION

SATLANTIS is a European leader in Earth Observation capabilities offering products and services over the whole value chain. SATLANTIS is a user-driven organization providing reliable and innovative End-to-End satellite solutions built around customizable High and Very High-Resolution optical payloads.

The core technology of the company around which the offer is built is iSIM (integrated Standard Imager for Microsatellites), a VHR optical payload relying on three key innovations: (i) the Ultra-High resolution algorithm developed and proprietary of SATLANTIS; (ii) the Multi-spectral capability without loss of spatial resolution independently of the number of bands; and (iii) the Agility to acquire images while the satellite observes both across and along its orbit thus allowing to continuously monitor non-linear structures on ground.

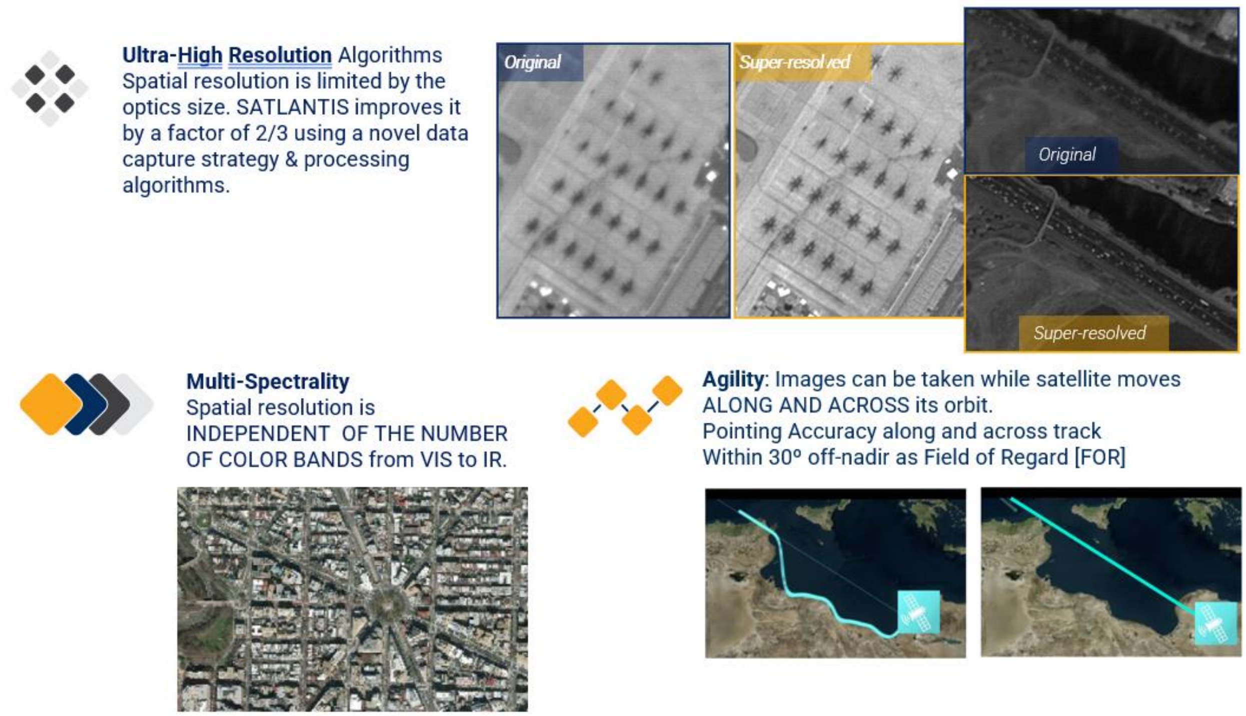


Figure 1: iSIM three key innovations

Among the various applications enabled by SATLANTIS technology, in recent years the company has been building a strong expertise in the environmental domain, especially in the detection of greenhouse gases like methane, in collaboration with strategic partners such as ENAGÁS, the main gas infrastructure operator in Spain. In the frame of this area of application, the company is developing, with the support of ENAGÁS, a constellation of four small-satellites, named GEI-SAT, that embarks SATLANTIS' innovative solution for methane emissions detection and quantification.

GEI-SAT pursues hot spot mapping of low emission levels of methane with a low-mass and low-cost very high-resolution multispectral SWIR camera onboard CubeSats & Microsats.

The overall mission consists of: GEI-SAT Precursor, a 16U CubeSat (17.4 kg, ~150 kg/h detection threshold, 1.65 m resolution @VNIR and 13 m resolution @SWIR resolution, up to 1700 nm) to be launched in Q1 2023; GEI-SAT Plus, a Microsat (92 kg, ~100 kg/h detection threshold, 0.8 m resolution @VNIR and ~7 m resolution @SWIR, up to 1700 nm), to be launched in Q4 2023; and another three Microsats expanding spectral capabilities, with similar resolution and better detection threshold (92 kg, ~50 kg/h (TBC) detection threshold, 0.8 m resolution @VNIR and 9m resolution @SWIR, up to 2300 nm), to be launched in 2024-25 (TBC).

The LEO constellation composed by a 16U CubeSat (with iSIM-90 SWIR camera) and four Microsats (including iSIM-90 and iSIM-170 and covering VNIR and SWIR) will employ robust and flight proven platforms compatible with small launchers. The operation lifetime will be of >4 years for the CubeSat, and >5 years for the Microsats.

The Ground Segment will include the Mission Operations & Control Centre, the Ground Stations Network (GSN) and the Data HUB.

THE "iSIM" CONCEPT: AN INNOVATIVE IMAGING PAYLOAD FOR EO

Overall Description of iSIM-90 SWIR

The "integrated Standard Imager for Microsatellites" (iSIM) is a state-of-the-art, high-resolution, multi-spectral, agile optical imager developed by SATLANTIS for the new generation of EO microsatellites constellations. The iSIM design combines class leading performance, via the utilization of cutting-edge technologies, standardized manufacturing procedures, significantly reduced build times and a new level of affordability. This combination approach will provide industries and government agencies with the ability to acquire and access unparalleled high-resolution data in real-time.

SATLANTIS has already developed two versions of this camera: iSIM-170, designed for the 50-100 kg microsatellite platforms, and iSIM-90 for the 12U-16U CubeSat platforms. And is currently developing a larger version, iSIM-300, with a resolution of less than 50 cm @500 km altitude.

iSIM-90 SWIR uses a modified Maksutov-Cassegrain optical design with a focal length of 775 mm and an effective aperture diameter of 77.5 mm. The imager is designed to provide diffraction-limited images between 450 and 1700nm over the entire 1.8º FOV in VNIR and SWIR spectral bands, with a spatial resolution of 1.65 m in VNIR (13 km swath @500 km altitude) and 13 m in SWIR (16.5 km swath @500 km altitude). The system relies on the technological integration of four key elements:

A diffraction-limited optical design of a binocular telescope, each consisting of just three optical elements with all spherical surfaces.

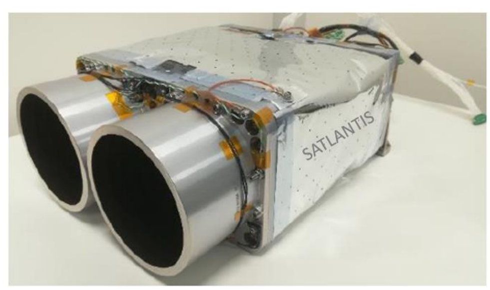
- A high precision, quasi-athermal, robust and light alloy structure supplemented with carbon fiber rods.
- A set of COTS 2D detector units, rugged to withstand vibration, thermal and radiation effects.
- A very high-performance, reconfigurable, on-board image processor (Figure 2).

Figure 2: Electronic Control System box, with "SPoCK" PCB (for image acquisition and processing) and "Smart Heater" PCB of the Thermal Control System (for thermal stabilization) inside

The iSIM-90 SWIR utilizes the certified core technologies already validated in space for iSIM-170 IOD, through developmental evolution and mission specific tailoring of these technologies. The following enhanced elements have been incorporated into this new generation of high-resolution imager:

- CubeSat-optimized mechanical structure.
- Improved thermomechanical design.
- Enhanced optical design and performance.
- Multispectral capability, with 5 filters in VNIR channel and 5 filters in SWIR channel.
- New generation of Electronic and Control Systems.
- New generation of VNIR detector proximity electronics.
- Implementation of SWIR detector.
- Implementation of platform communications protocol.

The fully iSIM-90 SWIR integrated camera is composed of the electronics (Figure 2) and the opto-mechanics (Figure 3).



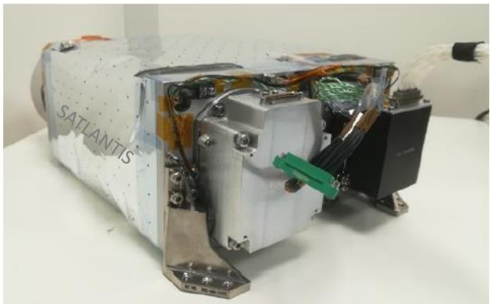


Figure 3: PM (Plane Model) opto-mechanics of iSIM-90 SWIR. The FM (Flight Model) will be slightly different, with a different VNIR detector

Flight heritage of iSIM-90

The iSIM-90 SWIR camera is based on three iSIM-90 VNIR cameras.

The first one is being demonstrated in CASPR mission, currently ongoing mission. The instrument FM was sent to NASA for final integration the 23rd of September 2020 and it was launched the 21st of December 2021 from Kennedy Space Center, Florida, onboard a SpaceX CRS-24. The commissioning already started and a report of in orbit operation will be ready along 2022. This will upgrade the iSIM-90 technology from TRL8 to TRL9.

The second iSIM-90 VNIR camera was launched in a CubeSat on 25th of May 2022 as part of the URDANETA mission from Kennedy Space Center, Florida, with the Transporter 5 mission onboard a SpaceX Falcon 9 rocket. It made its first communication with Earth and showed the nominal status of its subsystems.

The third iSIM-90 VNIR camera, as part of an ESA InCubed project, will be launched in December 2022 on an Ariane Vega-C in a mission named MANTIS.[2]. The Flight Model (FM) of iSIM-90 VNIR MANTIS camera was completed and successfully passed the environmental tests in June 2022.

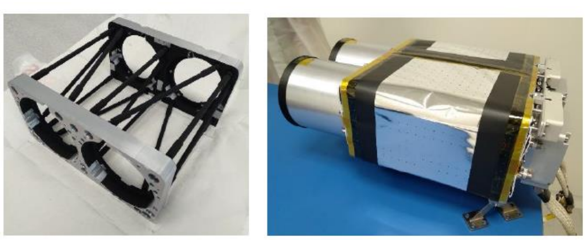


Figure 4: iSIM-90 VNIR camera for CASPR mission during integration at SATLANTIS

Figure 5: iSIM-90 VNIR camera for CASPR mission. Top: At SATLANTIS clean room. Bottom: At the ISS in the NASA modules

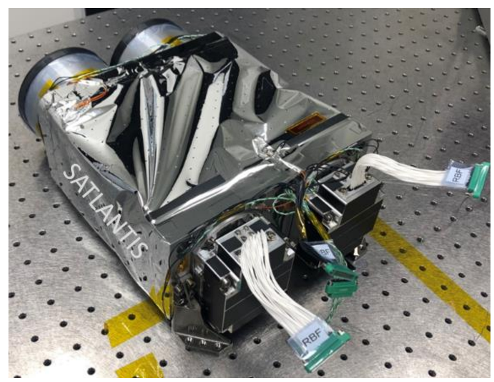


Figure 6: iSIM-90 VNIR camera for URDANETA mission

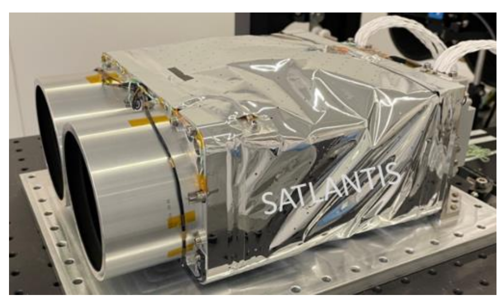


Figure 7: iSIM-90 VNIR camera for MANTIS mission

Overall Description of iSIM-170 SWIR

After flight validation of iSIM-90 SWIR camera in GEI-SAT Precursor (a 16U CubeSat), the iSIM-170

SWIR camera will be the payload of the following satellites:

- Microsat (92 kg, ~100 kg/h detection threshold, 0.8 m resolution @VNIR and ~7 m resolution @SWIR, up to 1700 nm).
- Microsat expanding spectral capabilities, with similar resolution and better detection threshold (92 kg, ~50 kg/h (TBC) detection threshold, 0.8 m resolution @VNIR and 9m resolution @SWIR, up to 2300 nm).

For the second type of Microsat, that will work up to 2300 nm, a new detector technology with cryogenic cooling will be implemented.

As it can be seen in the following figure, working at ~2300 nm allows detecting CH4 more easily, as the absorption peak is deeper than at ~1600 nm.

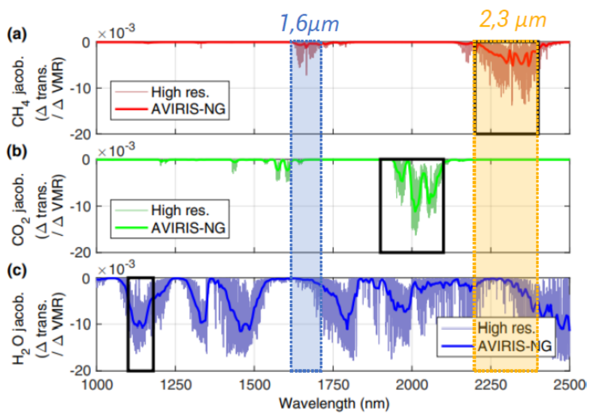


Figure 8: CH4 absorption at 1600 and 2300 nm.[3]

Flight heritage of iSIM-170

iSIM technology was fully demonstrated during iSIM-170 IOD (In-Orbit Demonstration) mission in 2020. iSIM-170 IOD was launched the 20th of May 2020 and successfully demonstrated in orbit between June and September 2020, onboard the i-SEEP platform of the Japanese module KIBO of the International Space Station (ISS).

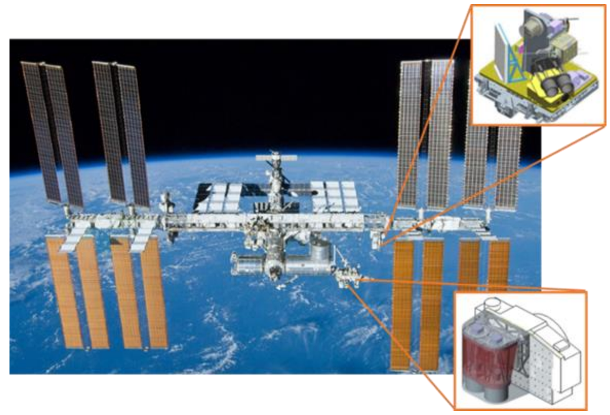


Figure 9: iSIM-170 IOD mission. Top: At SATLANTIS. Bottom: At the ISS (bottom right)

METHANE DETECTION WITH GEI-SAT

The proposed methane detection method is the Multispectral Differential Photometry, carried out in collaboration with ENAGÁS, by taking images with several filters and, using the different signal values measured at each different wavelength, obtain the methane absorption. Before being able to do that, the acquired images must be corrected for atmospheric effects using radiative transfer models in order to pass from detector units (e-/s) to column concentration units (ppb·m). Additionally, these concentration units must be corrected for wind effects, using meteorological models in order to pass from column concentration units to flux units (kg/h).

The high spatial resolution that GEI-SAT provides in its SWIR channel, together with the geo-localization provided by its very high resolution VNIR channel, will allow an unprecedented ability (4 to 16 times better than other satellites) to distinguish the exact location of the methane leak or uncontrolled emission at a global scale.

SATLANTIS proposed solutions could be used in combination with methane mapper satellites as Sentinel-5P being a natural complement to Copernicus program, not only in terms of resolution but also for quantification of CH4 emissions.

In fact, GEI-SAT constellation can be operated in coordination with Sentinel-5P to perform quantification of point sources of CH4, based on a Tipping and Cueing satellite concept, where possible issues within an area of interest are identified at a low resolution (tip) and further zoomed in with higher resolution satellites tasked to a specific area (cue).

When deployed, GEI-SAT constellation will contribute to improve and verify annual reporting on methane emission with higher frequency measurements and prepare for global certification on CH4 emissions reduction in future legislation world-wide.

GEI-SAT MODELS AND TESTS

This section describes the iSIM-90 SWIR models and tests that SATLANTIS is performing for the precursor of the GEI-SAT constellation.

Engineering Model description and tests

The first model was the EM (Engineering Model). It was built in 2020 to demonstrate the feasibility of the proposed concept for CH4 detection. Especially with respect to the performance of the custom design of the SWIR filters and their wavelengths, the selection of the SWIR COTS detector and its performance, and the observational strategies and algorithms.

Figure 10: EM during validation campaign at ENAGÁS Zaragoza calibrated test bench

It was tested first in the clean room, observing CH4 inside a gas cell and, afterwards, in extensive field test campaigns, detecting CH4 at distances ranging from 5 m to 40 m at different test sites (Leioa, Madrid, Zaragoza).

Presently, it is still used to improve the on-ground calibration and quantification of CH4 detection, measuring the absorption in function of methane concentration.

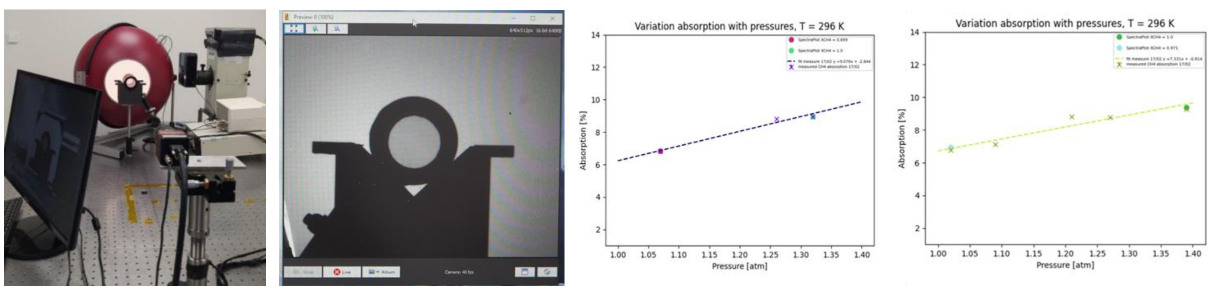
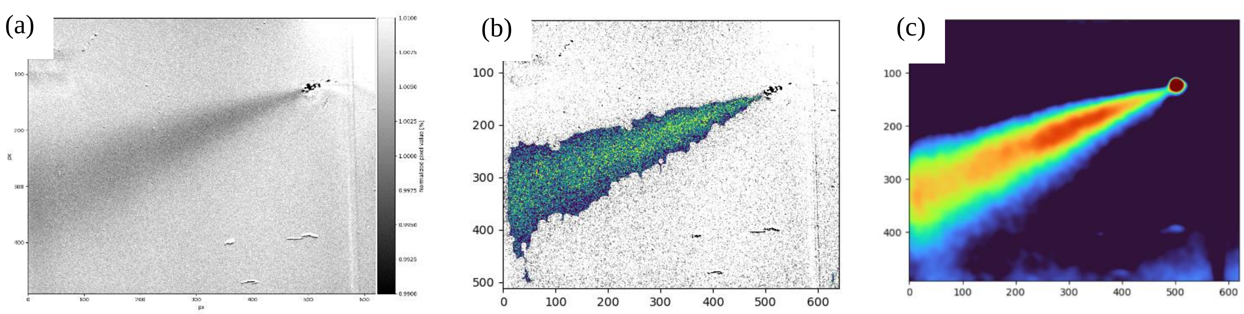


Figure 11: EM validation with the gas cell. SpectraPlot © values (dots) vs EM measurements (crosses) and fit (dashed lines)



(d) (e) (f)

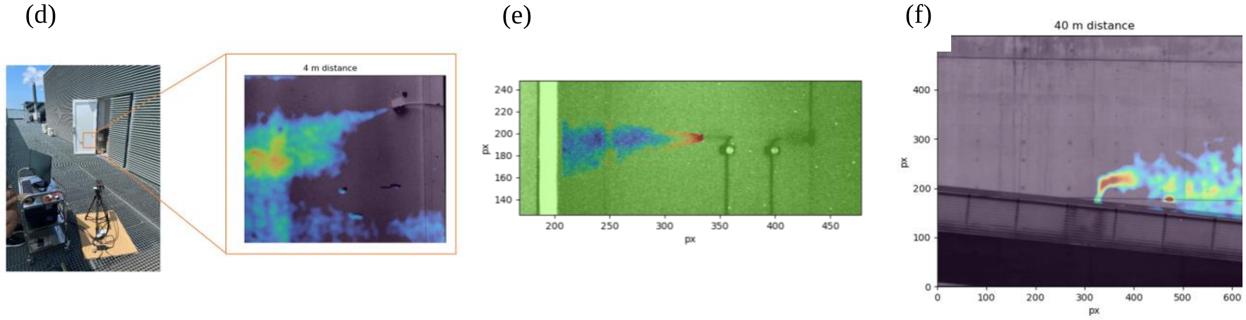


Figure 12: EM field tests and color maps indicating different CH4 concentrations at different distances: 4 m (a, b, c, d), 17 m (e) and 40 m (f)

Plane Model description and tests

The second model was the iSIM-90 SWIR PM (Plane Model). It was built in 2021 and its purpose was twofold: to demonstrate the validity of the iSIM-90 SWIR design and to demonstrate the ability of detecting CH4 from an airborne platform (plane, helicopter, etc.).

The PM (Figure 2 and Figure 3) has 4 VNIR filters and 4 SWIR filters, i.e. 1 filter less per channel than the FM.

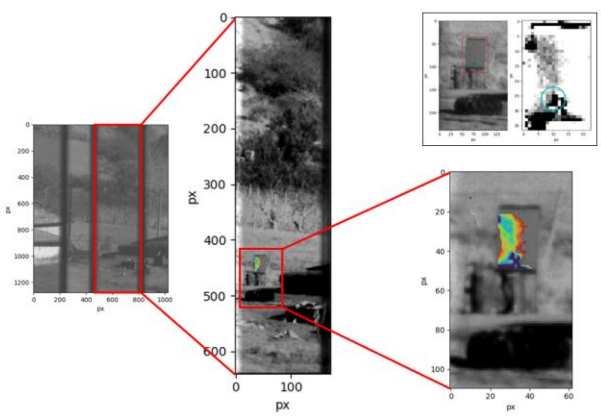


Figure 13: PM on-ground test and color map indicating different CH4 concentrations, at 1 km

Figure 14: PM installed and flying in a helicopter

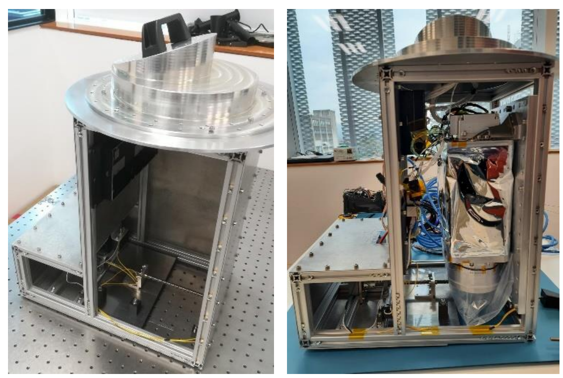


Figure 15: Structure without (left) and with (right) PM inside. Lateral cover removed

Before the helicopter flight campaign, the PM and the retrieval algorithm were tested on-ground at 1 km distance (Figure 13). The retrieval algorithm applies the multispectral differential photometry (MDP) technique by combining the bands optimized for the detection of methane. MDP translates the variations in atmospheric transmittance into column concentrations of methane. Figure 13 shows CH4 concentration as a gradient colour map.

Following the on-ground tests, the PM was mounted in a helicopter, which flew over an ENAGÁS compressor station. The camera flew over the target during a controlled gas release (see Figure 16). The helicopter flew at a distance from the source of emissions of approximately 3,000 m.

Figure 16 shows a preliminary analysis of images using the MDP. The column concentration at the vent stack is in the 125,000 – 175,000 ppm·m range. This value is in line with independent measurements performed on ground with a hand-held device, an Optical Gas Imaging camera. The OGI camera obtained values of around 144,000 ppm·m. In addition to the MDP, the image shows the isolation of methane from the background thanks to the application of statistical methods and morphological operations applied to the column concentration image. Current efforts are devoted to estimate the flowrate by considering the mass of the plume, the wind speed, and the cross-sectional length of the cloud.

This trial in ENAGÁS was the first time that the iSIM-90 camera was tested at a long distance and cross-checking the values with an independent measurement device. Considering that the processing algorithms are still to be optimized and that the camera was not designed to fly at 3 but at 500 km altitude, this first helicopter flight campaign is considered a success.

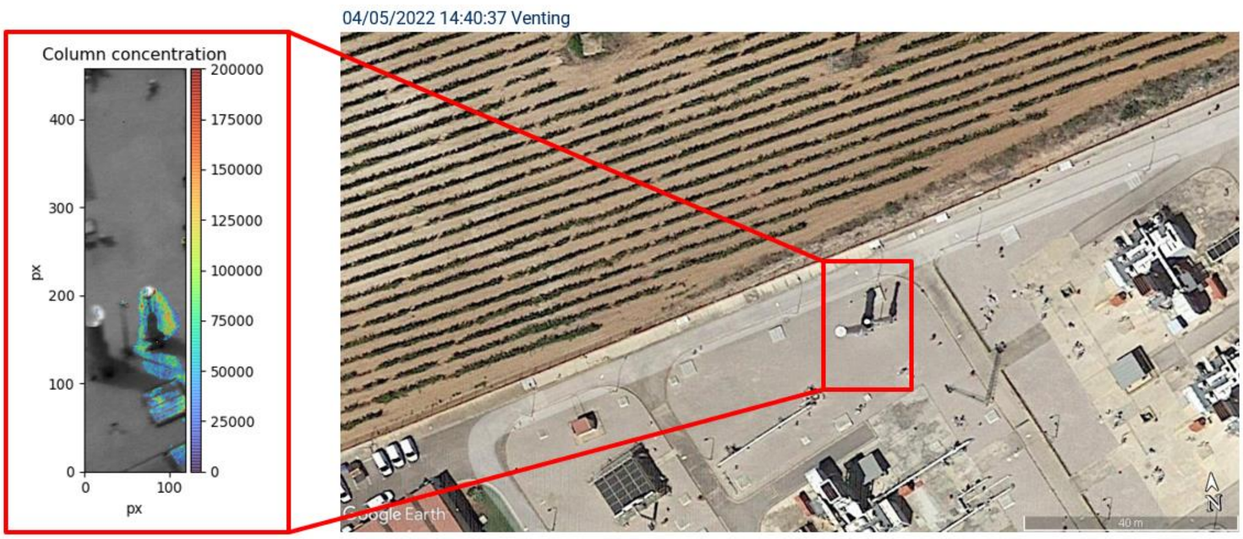


Figure 16: ENAGÁS facilities and CH4 plume observed with the column concentration values (ppm·m) at the venting area

In spite of the intensive flight campaigns ahead, the on-ground tests of the PM continue. These tests involve a flow meter to improve the quantification of flowrates (kg/h) from column concentration images.

Flight Model description

The third model is the iSIM-90 SWIR FM (Flight Model) that is under AIV. It will be fully tested and space qualified before the delivery to the platform in Q3 2022.

CH4 DETECTION AND QUANTIFICATION SIMULATIONS

As mentioned above, the images acquired by iSIM-90 SWIR must be corrected for atmospheric effects, using radiative transfer models, and for wind effects, using meteorological models. Extensive simulations are currently ongoing to help on the understanding of these two topics: atmospheric RTMs (radiative transfer models) and other effects (wind, turbulence, etc).

Other topics related to simulations and image processing algorithms have been also investigated to help in the postprocessing of the raw images, e.g.:

- Methane plumes injection simulation.
- Influence of boundary conditions: wind, illumination, atmosphere type, land cover, etc.
- Influence of the camera: detector noise, pixel size, optics image quality, orbit altitude, frame rate, etc.
- Automatic plume masking creation.
- Other aspects that have a relevant impact on the estimated column concentrations (ppb·m) or flow rates (kg/h).

GROUND SEGMENT

SATLANTIS is developing with other partners a mission architecture composed of: 1) Mission Operations & Control Centre for definition/scheduling of the operations, and monitoring and control of the satellites and antennas; 2) Ground Stations Network (GSN) for communication with the satellites; 3) Data HUB for data storage, processing, and distribution. These elements and the associated facilities are currently being developed and integrated.

SATLANTIS Mission Operations & Control Centre is comprised by two centres/units: (1) Mission Control Centre, and (2) Mission Control Software.

REFERENCES

1. EDF: https://optics.org/news/11/9/26, 2020.

   MethaneSAT: https://www.edf.org/sites/default/files/MethaneSAT%20Technical%20considerations-May%202019.pdf, 2019.

2. Guzmán R., et al. "*A Compact Multispectral Imager for the MANTIS Mission 12U CubeSat"*, CubeSats and SmallSats for Remote Sensing IV, Proc. of SPIE Vol. 11505, 1150507, https://doi.org/10.1117/12.2568080, 2020.

3. Thorpe A. K., et al. "Airborne DOAS retrievals of methane, carbon dioxide, and water vapor concentrations at high spatial resolution: application to AVIRIS-NG", Atmospheric Measurement Techniques, 10, 3833–3850, https://doi.org/10.5194/amt-10-3833-2017, 2017.