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The Scout 1 - CubeMAP Mission: an agile development for an innovative Payload

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ABSTRACT

A new category of SmallSat research missions, called Scouts, is introduced by ESA. Scout missions distinguish themselves from Earth Explorers by relying on the New Space paradigm, by giving industry and non-profit R&D/academia a more pro-active role. This allows a low-cost approach (≤30M€) and a rapid development cycle (3 years from KO to launch) while using disruptive sensing techniques. CubeMAP is one of the two first Scout missions selected for implementation. CubeMAP is a constellation of three identical 12U satellites, each being designed to perform limb-sounding measurements of atmosphere transmission. Each satellite carries a payload made of two kinds of instruments. The first one, the High-resolution Infra-Red Occultation Spectrometer (HIROS), is a high spectral resolution spectrometer operating in LWIR narrow spectral range (1 cm^{-1}) with high resolution (0.005 cm^{-1}). It is based on the measurement of the interferences between the observed Sun scene and an on-board Quantum Cascade Laser (QCL), whose signals propagate through a Hollow Wave Guide (HWG). This configuration limits the sensitivity to shot noise in a compact design with low volume and mass. The second one, the Hyperspectral Solar Disk Imager (HSDI), is a multi-spectral Sun Disk imager. It aims at providing accurate pointing reference to the payload as well as pressure and aerosol measurements. The overall payload allows a spectroscopic measurement of the atmosphere transmission with high vertical resolution (~ 1 km FWHM) between 6 and 50 km altitude.

Keywords: Atmospheric remote sensing, Spectroscopy, Cubesats

1. INTRODUCTION

1.1 The new ESA Scout satellites

Nowadays the space sector is benefiting more and more from the so-called “New Space” paradigm shift, which allowed the creation of many new opportunities. At the beginning the development of this new approach was to focus on the feasibility demonstration. Now the maturity is high enough to move to the next step which is the evaluation of new ways to exploit the potential benefits of New Space. These relatively new ideas complement the more consolidated fast in-orbit demonstration of new technologies. In the context of Earth Observation (EO), we can already count a number of successful implementations both in the institutional and commercial sector, which demonstrate the benefits of small satellites and the need to consolidate their current roadmaps. The directorate of Earth Observation Programmes (EOP) in the European Space Agency (ESA-EOP) benefits from the “New Space” approach. Throughout the years, ESA-EOP has matured comprehensive and well-established ideas specifically targeting EO applications. The advantages of small satellite missions rely on different aspects like the generally relaxed requirements due to the short lifetime, the components standardization, and the rideshare launches that together concur to simplify the overall mission lifecycle. The major more evident consequence of this simplification is the overall cost reduction and schedule compression, allowing to fly more frequently or in constellation increasing temporal resolution and coverage. When correctly exploited, these advantages can guarantee a fast access to space balancing the higher risks. Due to reduced cost and schedule, it offers more opportunities to try new innovative EO techniques (innovative instruments or enabling technologies such as Artificial intelligence). It is also possible to fly established EO instruments within small constellations to enhance revisit time to complement large institutional missions by giving a specific focus on reduced areas.

Hence small and nano-satellites represent not only an excellent complement to the EOP scientific and application-driven flagship satellites, but also a way to quickly validate new approaches and technologies like AI, super resolution or in-orbit data processing.

ESA-EOP develops world-class Earth observation (EO) systems particularly with European (e.g. European Union, EUMETSAT) and global partners to address the scientific challenges identified in the Living Planet Programme and other societal challenges. The key principle is that all these missions are user driven. They are centered on two broad components:

- Research missions cover primary scientific objectives of ESA's EO Science strategy for demonstrating innovative EO techniques
- Earth Watch missions, typically driven by operational services, are developed with and for partners such as EUMETSAT for meteorological missions and the European Commission (EC) for Copernicus missions.

Within these broad component lines, the European Space Agency (ESA) has specifically designed and put in place missions to support the use of small and nano-satellites for specific Earth Observation mission. In particular, ESA-EOP has created a new framework, called Scout missions: as part of Research missions, they aim at implementing novel Earth Observation techniques in Earth science and related non-commercial applications.

The Scout missions are the first ESA-EOP Research missions driven by scientific objectives and based on reduced budgets (30 M€) and schedule (3 years from KO to launch), hence the interest for small satellites. The study of the first set of Scout missions has been initiated in 2019 and two pioneer missions, CubeMAP and HydroGNSS, are in the implementation phase and are due to be launched respectively in Q2 2025 and Q4 2024. This paper focuses on the innovative payload of the CubeMAP mission.

1.2 The CubeMAP mission objectives and observation requirements

CubeMAP (Cubesats for the Monitoring of Atmospheric Processes) mission aims at improving our understanding of atmospheric processes in the Upper Troposphere and in the Stratosphere (UTS), with geographical emphasis on the tropics (and subtropics). The tropical tropopause layer (TTL) is subject to the injection of tropospheric air masses, chemical tracers and aerosol (precursors) through deep moist convection, and it provides an input to the ascending branch of the meridional Brewer Dobson Circulation (BDC) in the middle atmosphere. The Upper Troposphere Lower Stratosphere (UTLS) also constitutes a key interface layer, stage to Stratosphere Troposphere Exchange (STE) processes. It is critical to fundamental climate feedbacks, such as those associated with the atmospheric water cycle and high-level clouds, especially cirrus. Here, the interplay between chemical, dynamic, and radiative processes entails a delicate balance in the climate system, small changes of which result in a large climate sensitivity. Beyond deep moist convection, pyro convection associated with large biomass burning events, explosive volcanic eruptions, and large-scale but slow ascent associated with monsoon systems, also provide a source and entry point for pollutants, precursors, particulates, and radiatively important gases into the stratosphere. Tropospheric pollutants and ozone-depleting substances in particular may affect the ozone layer chemistry upon entry into the stratosphere, and stratospheric ozone can be transported downwards into the troposphere, where it constitutes a pollutant with impact on plant and animal/human health. Likewise, stratospheric cooling through increased greenhouse gases can influence the ozone chemistry, mainly by decelerating destruction cycles, and may increase the BDC and accelerate transport of ozone from the tropics towards the poles. In short, the UTS is a key region for atmospheric composition, chemistry and air quality, atmospheric dynamics, transport pathways and weather forecasting, as well as global climate, climate change, and underlying feedback mechanisms.

More information on the science background and guiding science questions behind CubMAP are provided in [1]. Specifically, CubeMAP seeks to shed light on: 1) how water vapour in the UTS responds to climate change and feeds back on climate; 2) how climate change affects stratospheric ozone and its recovery; 3) how surface greenhouse gas (GHG) emission estimates and surface-level ozone (from spaceborne nadir sounders, data assimilation and source/sink inverse modelling) can be improved through better representation of the equivalent quantities in the UTS; and 4) how the tropical UTS composition and its response change in response to increasing anthropogenic and natural emissions.

These broad science topics directly translate into four top-level **mission objectives** for CubeMAP [1], that are:

- **MO-1**: To quantify water vapour in the UTS to understand its response to changing temperatures and its feedback on climate;
- **MO-2**: To quantitatively study and understand the impact of climate change on stratosphereic ozone and UTS ozone interactions in Numerical Weather Prediction (NWP);
- **MO-3**: To provide an accurate representation of the vertical distribution of UTS GHGs to better constrain regional emission estimates from the nadir sounder infrastructure; and
- **MO-4**: to quantify the changing composition of the UTS and its response to increasing anthropogenic and natural emissions.

The top-level CubeMAP **mission requirements**, and notably the observational requirements, follow from the preceding objectives, and are captured in the Mission Requirements Document. Key observational requirements are briefly summarized hereafter.

In terms of **geophysical parameters**, CubeMAP targets UTS water vapour (H_2O) as well as methane (CH_4) as a stratospheric H_2O source (MO-1), ozone (O_3) throughout the UTS (MO-2), the key greenhouse gases CH_4, carbon dioxide (CO_2) and nitrous oxide (N_2O) in the UTS to better constrain surface emissions (MO-3), and the same species, H_2O, O_3, and CH_4, for assessing STE and convection in a changing UTS (MO-4). Processes targeted by these tracers include UTLS radiative forcing (H_2O, O_3, CH_4, CO_2, N_2O), the UTS-component of the hydrological cycle (H_2O, CH_4), changes in the BDC (O_3), STE (H_2O, O_3), and indirectly, surface-level emissions (CH_4, CO_2, N_2O). In addition, CubeMAP seeks to provide information on particulate matter in terms of the aerosol extinction coefficient and Angstrom exponent. Finally, some isotopologue ratios are to be experimentally retrieved, notably δHDO to support understanding of the hydrological cycle, $\delta^{15}N_2O$ to constrain emission and help determining N_2O sink pathways, and $\delta^{13}CH_4$ to improve discrimination between biogenic, thermogenic and biomass burning sources.

CubeMAP focuses on the determination of the vertical distribution (altitude profiles) of the above parameters, with emphasis on the tropical tropopause layer (roughly between 12 and 18 km) and the lower stratosphere (up to ~25 km), extended into the deeper stratosphere to characterize the BDC and radiative forcing (up to ~50 km), and ideally, lower down into the free troposphere to better constrain emissions (down to ~6-8 km). This gives a total **altitude range** of between approximately 12 km and 25 km (and up to 50 km for H_2O, O_3 and CH_4; down to 8 for H_2O and O_3 and 6 km for CH_4, CO_2, and N_2O).

Adequate **vertical resolution** is critical throughout the UTLS, since it is a region characterized by steep vertical gradients, thin layering in the statically stable stratosphere, and well-defined narrow features such as tropopause folds and STE intrusions, as well as horizontal structures such as streamers and filaments, contributing to vertical and horizontal mixing processes through transport barriers. Water vapour gradients across the tropical tropopause cold trap are particularly noteworthy, as are those for ozone. The region may furthermore exhibit the imprint of gravity waves. CubeMAP aims at a vertical resolution of ~1 km (~2 km for radiative forcing and BDC characterization), but no coarser than the ~3-5 km associated with past limb sounding measurements.

The vertical trace gas mixing ratio profiles are to be determined with a **total uncertainty** ("accuracy") of mostly between roughly 5 and 10%. This is deemed to yield significant improvement over data from former limb measurements. The Angstrom exponent, providing information on aerosol size, is targeted with a 30-50% uncertainty. In addition, isotopologue ratios estimation with accuracy between 10 and 20‰ are sought.

The geographic emphasis of CubeMAP is on the tropics and the ascending branch of the BDC. Consequently, a **latitude coverage** spanning the latitude region between ± 25º latitude is baselined. An extension of the band to the subtropics, covering approximately ± 35º latitude, would bring additional scientific benefits in terms of characterizing isentropic exchange between the tropical upper troposphere and the extratropical transition layer; that is, mixing across the tropopause boundary which descends towards significantly lower altitudes in the extra-tropics, and intersecting the subtropical jet.

CubeMAP does not target horizontally-resolved measurements. Conversely, a **geographically homogeneous coverage** is sought, characterized by the global sampling distribution of vertical profiles. Within a global spatial horizontal grid of roughly synoptic scales (~1000 km) across the desired latitude span, a full and roughly "gap-free" sampling coverage

(<10% gaps) with even sampling density is targeted over a time scale ("**revisit time**", understood here as the average time between two profile observations within the same grid cell) of a month, to capture the seasonal changes embedded within longer-term climate variability. The details associated with individual convective events and diurnal cycles will not be resolved by the mission. However, sampling a partial coverage on a shorter time scale (e.g., 30% in 10 days) is expected to contribute to characterizing organized convection and its continental-scale effects.

CubeMAP aims at providing enough data to cover the interannual variability of the climate system associated with shorter natural oscillations such as the El Niño Southern Oscillation (ENSO) and the Quasi Biennial Oscillation (QBO). To cover this interannual variability, a scientific dataset over a **mission lifetime** of 4 years is planned for.

1.3 Flight segment system architecture

The CubeMAP mission is a constellation of 3 identical 12U satellites. The platform is based on GOMX-5 from Gomspace in Denmark which is the prime contractor whereas the payload is delivered by RAL Space in the UK. The complete setup is shown on Figure 1. These satellites will be orbiting on non-sun-synchronous inclined orbits with an altitude of 565 km at beginning of life down to 450 km at end of life.

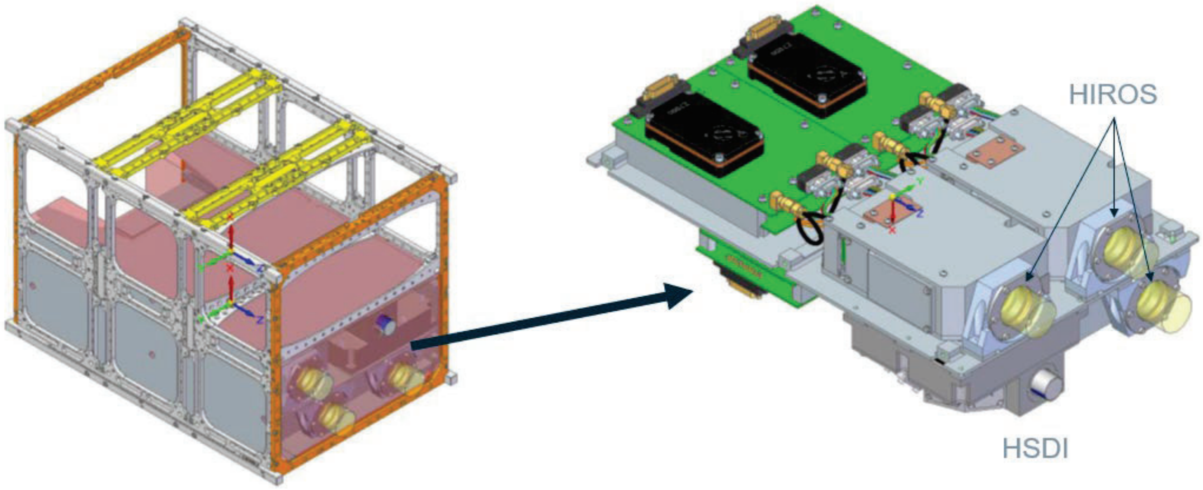

Figure 1: View of the complete satellite structure (left) and on the Payload (right). The Payload is constituted of one HSDI and three HIROS Instruments.

The payload (6U / 10 kg) is constituted of 4 different optical instruments each operating in limb-sounding mode. All instruments are coaligned and pointed toward the Sun at each sunset and sunrise. By comparing the observed spectrum when the sun is observed directly or through atmosphere, one can retrieve absorption spectra at different tangent heights in the atmosphere and then retrieve high vertical resolution gas profiles. The sounding geometry is shown on Figure 2, it is the same as the recent ACE experiment run by Canada [2].

The main instruments, providing the high spectral resolution spectroscopy measurement (0.005 cm-1,) are the HIROS. Each satellite carries 3 HIROS instruments. Each of the 3 HIROS is dedicated to a small specific window of typically 1 cm^{-1} range targeting specific gas species. The FoV of the HIROS is almost punctual (it is a straight line). The HIROS design and requirements are further described in 2.1.

The HSDI on the contrary is a Sun disk multi-spectral imager. It aims mainly at providing high accuracy pointing reference for the HIROS instruments. It also provides complementary measurements of aerosol attenuation and Angstrom coefficient vertical profiles. The HSDI design and requirements are further described in 2.2.

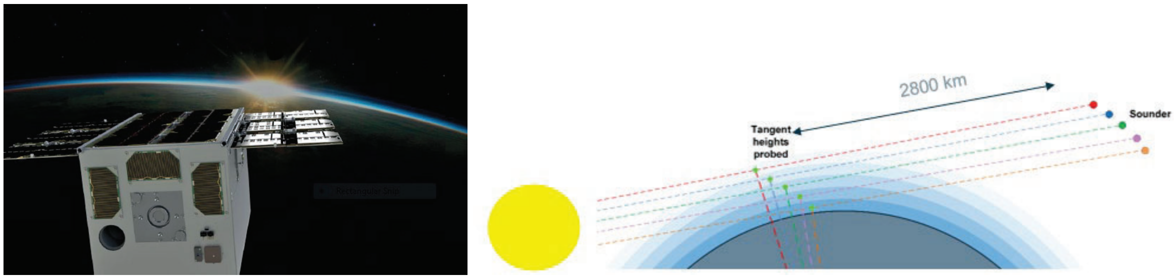

Figure 2: Optical sounding geometry of the 3 CubeMAP satellites. Observations are made at each sunset and sunrise, twice per orbit from an orbit altitude between 450 and 565 km. This results in tangent observations through the atmosphere at a distance of 2800 km at probing altitudes between 6 and 50 km through atmosphere. A full occultation event lasts approximately 60 seconds.

Opposite to the vertical resolution, this limb sounding geometry is obviously providing poor horizontal resolution (hundreds of kilometers) but this does not contradict with the mission objectives. The coverage is ensured and optimized through an orbit inclination between 25 and 45 degrees (to be confirmed); the threshold and goal spatial coverages being +/-25 and +/-35 degrees latitude (equatorial area). The number of satellites (3) has been optimized along with the inclination of the orbit to meet moderate temporal coverage requirements. Indeed 30%, respectively 90% of the 4x4 degrees grid (approx. 500x500 km on ground) nodes shall be covered over 10 days, respectively a month.

The spacecraft bus is based on a standard 12U cubesat developed by GomSpace. Nevertheless, some challenges imposed by the specific instrument and application have required the spacecraft bus design to be tailored toward the mission. The two main challenges are:

- The pointing accuracy of the instrument including on ground alignment and in-flight misalignment;
- Thermal interfacing

The first challenge derives from the requirement to acquire up to a very low Tangent height (6km). Such a low altitude implies a strong vertical compression of Sun image due to atmospheric refraction (up to 80% vertically). This implies a very accurate pointing of the platform to ensure that the payload (more particularly the HIROS instrument) Line of Sight points at the Sun disk. A specific technique has been implemented requiring specific Line of Sight paths to be uploaded to the platform for each occultation. Also, to guarantee a very low alignment accuracy between the instruments and the platform reference frames, all instruments and star tracker have been mounted on the same optical bench (see also 2.2, Table 1). Specific thermal interfaces minimize thermal distortions.

The second challenge refers to the thermal control of the payload. There is a stringent requirement regarding the operational temperature range of the instruments as well as regarding its thermal stability. Because the platform cannot guarantee appropriate thermal interfaces, the selected strategy is to decouple the Payload and the platform. Payload thermal control is then ensured at Payload level. To do so, part of the radiator pointing toward cold space is allocated to the cooling of the instruments.

2. HARDWARE DEFINITION AND PERFORMANCES

2.1 The High-resolution Infra-Red Occultation Spectrometer (HIROS)

The HIROS instrument is an heterodyne interferometer as shown on Figure 3 [3,4]. The signal from the observed scene (sun seen through atmosphere in a limb view) is combined with a monochromatic QCL after propagation through HWG. Each spectral component of the broadband solar spectrum produces a sinusoidal beating with the laser. This results in a Radio Frequency (RF) signal whose power is measured by the fast sensor. The electrical bandwith of the rapid detection chain is directly delimitating the spectral portion of the observed scene detected around the QCL frequency and drives the spectral resolution of the instrument (0.005 cm^{-1}). This very high resolution is necessary in order to discriminate the main targetted atmosphere constituents in the different layers of the atmosphere by spectroscopy. A complete scene spectrum is obtained over approximately 1 cm^{-1} range (around central wavelengths of 1135, 1239 and 1252 cm^{-1} which are in LWIR region) by tuning the frequency of the QCL using a ramp shape input current (one full spectrum measurement every seconds).

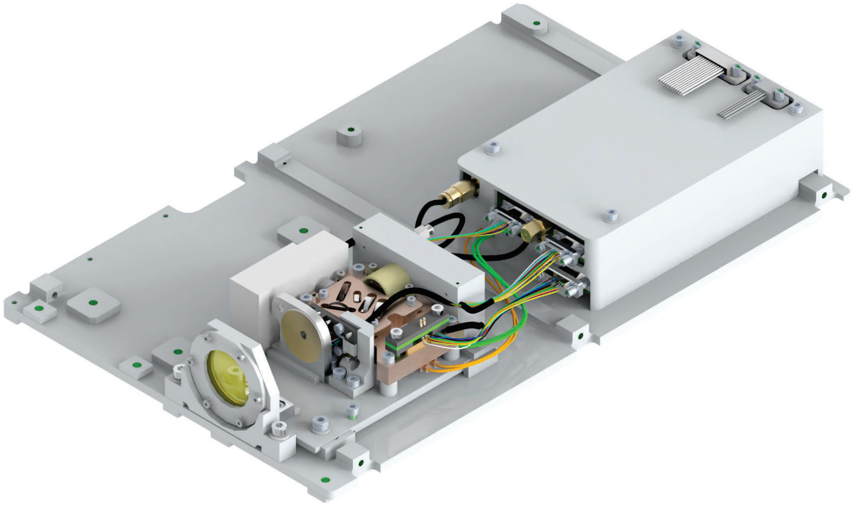

Figure 3: One of the HIROS instrument installed on the bottom panel of the spacecraft. A ~5x6 cm copper alloy block is used for the hollow-waveguie integrated optical breadboard. The light from the Sun is collected by a 25 cm diameter fromt end telescope. The HIROS backend electronics includes laser and detector control (current and temperature) and data acquisition and processing. The overall volume is 1x3x0.5 U.

As it comes from an interferometric beating, the power spectral density of the electric signal from the fast detector is proportional to the electric field amplitude of both the QCL and the sun scene. It results from this property that the noise from the rapid detection chain can be made negligible compared to the useful RF signal simply by adjusting the QCL power level. In the end the solar scene detection is shot noise limited. In order to further reduce the noise (avoid the 1/f electronic noise) of the detection chain, reduce straylight and thus limit the necessary QCL output power, a classical setup involving the modulation of the input signal and synchronous detection is designed. The chopping of the signal is obtained through a vibrating tuning fork (between 1 and 10 kHz) placed at the entrance of the HWG. The oscillating RF power on the detector is then demodulated on board digitally ; both the useful signal and the measurement noise (quadrature signal) are finally delivered and downloaded to ground (Figure 5).

The atmospheric scene from the Sun disk is focalized by a Cassegrain telescope at the entrance of the HWG (Figure 4). By the appropriate design oμμf the HWG propagation as well as the selection of the QCL spatial properties, one ensures that only the fundamental spatial mode of the HWG is excited on the fast detector. It results that only the fraction of the Sun scene exciting the same fundamental spatial mode of the HWG is finally detected. The FoV of the instrument is then the theoretical back propagation of the HWG fundamental mode up to the Sun which means a diffraction limited beam with a waist of 11.5 mm. When propagated up to the atmosphere tangent point at 2800 km distance (Figure 2), the footprint size is 1.6 km (for a wavelength of 9 µm a M^2 of 1.2 and a diameter at 1/e2) which is in line with the targetted high vertical resolution (1 km FWHM). Obviouly, the HWG propagation also has as a direct consequence the compacity and robustness of the design to mis-alignments which is a key asset for the CubeMAP mission.

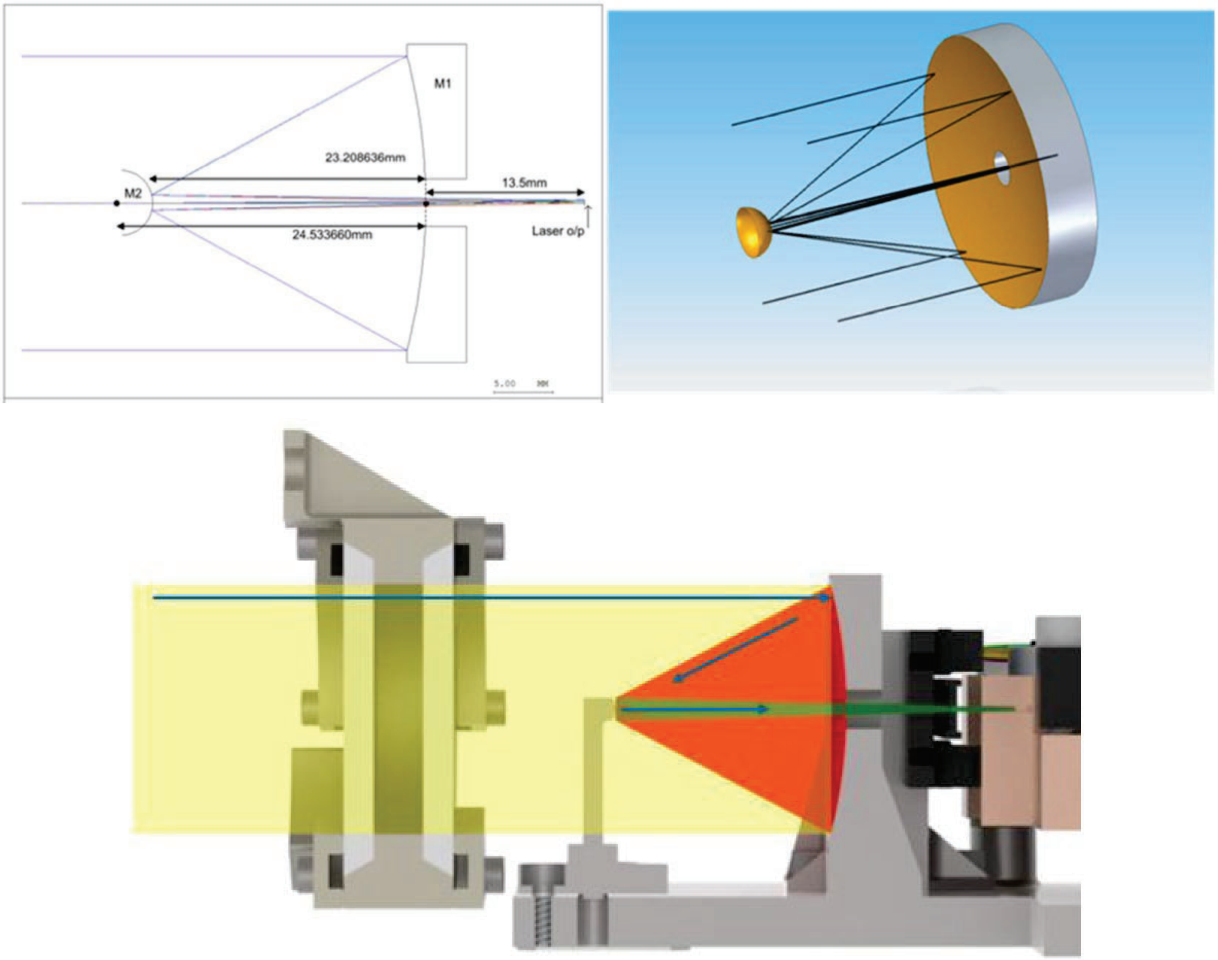

Figure 4: Optical design of the HIROS collection telescope. The scene from the Sun is focalized at the entrance of the HWG using a Cassegrain telescope with an entrance pupil of 25 mm and focal length of approximately 0.9 m. This telescope is directly mechanically interfaced with the HIROS Optical Bench. A vibrating tuning fork is placed at the entrance of the HWG in order to benefit from synchronous detection.

The HIROS instrument has already demonstrated a very good maturity level thanks to the existence and operation of an on-ground demonstrator for several years [5]. The main remaining risk retiring activities for this instrument are mainly related to the tuning fork (currently a rotating chopper on the demonstrator), the qualification of the opto-electronic subsystems (including QCL and its low noise driver) and the HWG optics mounts for space environment and launch.

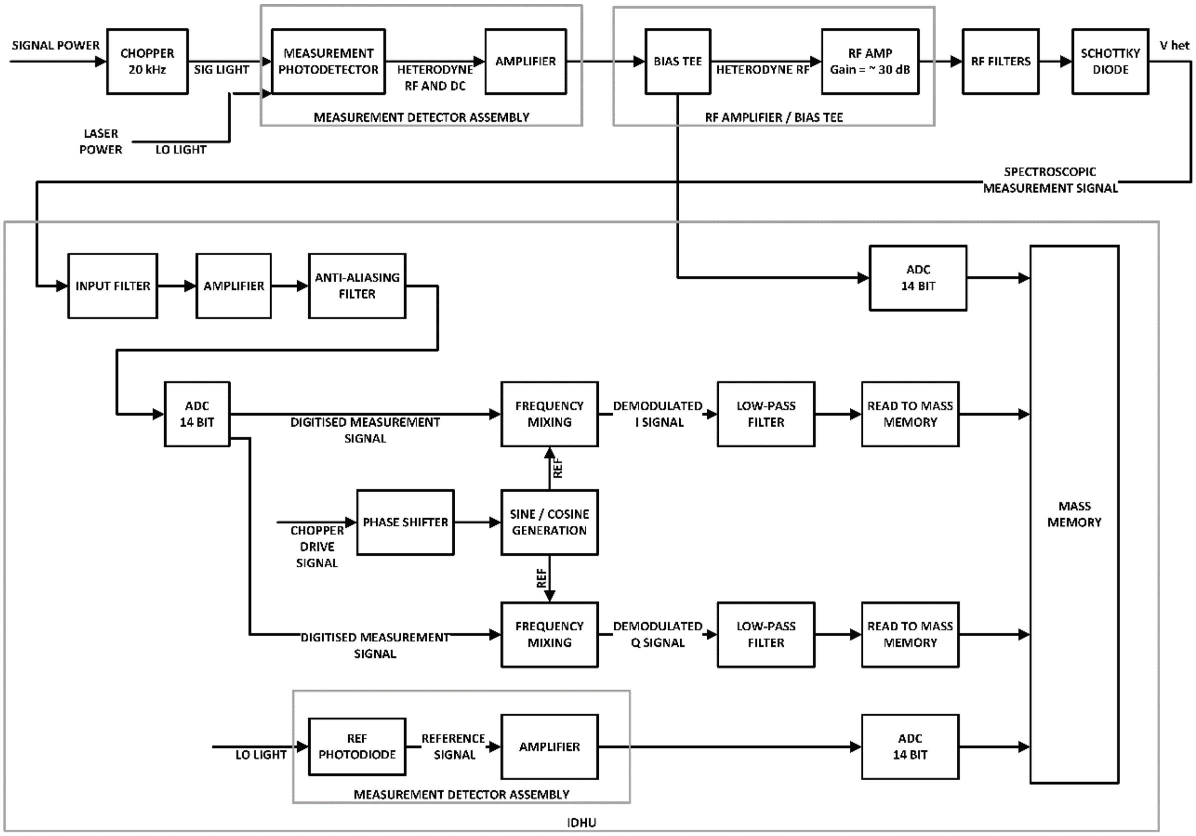

Figure 5: Complete electronic chain processing at the output of the rapid detector.

2.2 The Hyperspectral Solar Disk Imager (HSDI)

HSDI is a multispectral imager. As shown on Figure 6, this instrument is composed of a robust, adjustment free, monolithic aluminium body on which the telescope lenses and a set of 6 folding aluminium mirrors are directly inserted. The front telescope is composed of two lenses as well as a neutral density to match the dynamic of the scene (sun disk) with the one of the sensor. Finally, a PCB including the selected sensor from IMEC is bolted below the structure. CMOSIS CMV2000 selected sensor. This sensor is a Bayer kind 4x4 matrix arrangement directly deposited on the retina thus providing a set of 16 channels of 10-20 nm spectral width. The sensor size is 2048x1088 with 5.5 µm square pixels (macro pixel of 22x22 µm), the full well depth is 13400 and the read-out noise is of 13 electrons rms.

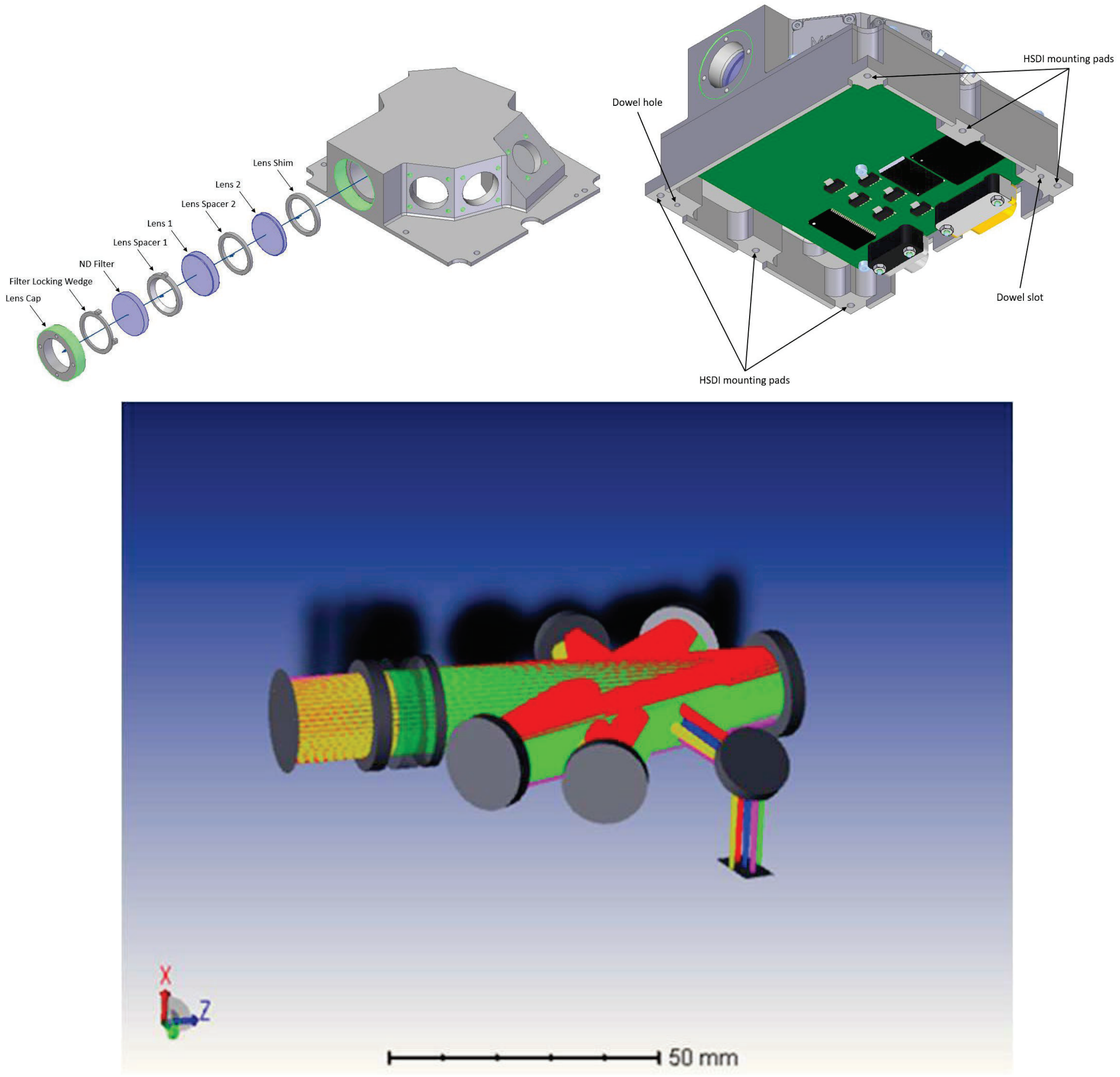

Figure 6: Opto-mechanical assembly of the HSDI instrument. The upper left figure shows the interface between the front telescope lenses and the mechanical body. The upper right figure shows the interface between the sensor PCB (see **Error! Reference source not found.**) and the mechanical body. The figure below shows the optical path.

The aim of the HSDI is twofold:

- To provide the reference altitude-pressure level at which HIROS measurements are done. The targeted uncertainty is approximately 150 m at 1 sigma. At low altitude (<25 km), this is done by measuring the O_2 concentration. At high altitude the O_2 pressure is too low and cannot be measured with the required accuracy, an indirect measurement is thus necessary. The HSDI provides the required high accuracy pointing knowledge of the payload with respect to the atmosphere. From this the tangent height of the HIROS (and thus the altitude-pressure) is obtained with very low uncertainty.

- To provide direct measurement of aerosol and water vapor attenuation as well as Angstrom coefficient. This is performed by comparing for each spectral channel the image of sun disk seen through atmosphere with exo-atmospheric case. The attenuation of the atmosphere for a large set of tangent heights and for each spectral channels is thus derived with high spatial vertical resolution. The advantage of such procedure is that there is an « autocalibration » on the sun disk since exo-atmospheric images are taken as a reference.

The main measurement requirements associated with these 2 missions are summarized in Table 1.

Table 1: High level measurement requirements of the HSDI instrument

Description	Requirement
HSDI Spectroscopic measurement requirements	
Noise on the transmittance	< 0.0002 at 1σ
The gain, offset and non-linearity error in transmittance for each channel	< 0.5%
Uncertainty on frequency scale of each channel's spectral response	< 1 cm^{-1}
Uncertainty on the offset of the frequency scale of each channel's spectral response	< 0.1 %
Uncertainty on spectral width of each spectral channel	< 1%
Pointing requirements	
Pointing knowledge uncertainty of the HSDI wrt Sun	<13 µrad at 1σ
Pointing knowledge uncertainty of the HSDI wrt HIROS	<13 µrad at 1σ

The focal length has been optimized to 430 mm to ensure that the sun disk image is not only entirely covered by the sensor but is also large enough with respect to the pixel size. This latter aims at providing a low noise on the instrument pointing knowledge with respect to the sun disk. For the same reason the entrance pupil diameter is set to 21 mm in order to achieve a sufficiently high MTF at Nyquist frequency. Overall, this design is expected to meet the demanding pointing knowledge requirements of the HSDI with respect to the sun disk as well as the SNR.

This design is complemented by an accurate and extensive on-ground and in-flight characterization program (presented in 3) to address the rest of the requirements listed in 3.2.

3. AN AGILE DEVELOPMENT

3.1 Instruments models philosophy

Both HIROS and HSDI will follow a Proto Flight Model (PFM) approach for the qualification which means that it is not intended to develop a Qualification Model (QM). The qualification will be shared between the Engineering Model (EM) and the PFM. The main function of the Engineering Model (EM) is to enable early functional tests and de-risking of the equipment in a representative enclosure and environment. The exact distribution of the tests between EM and PFM are still under review and will be a balance between retiring risk early and schedule.

The general logic of the development plan is presented on Figure 7. In contrast to classical project developments, as a way to cope with stringent schedule requirements, the main adjustments that have been made are:

- Absence of Structural, Thermal and Qualification models. Instead, the qualification will be balanced between an early breadboarding and EM activities for the elements with lowest TRL and the PFM tests for the rest.
- The EM will not be representative of the full payload, only one HIROS will be integrated while the two others will be replaced by mass dummies.

- It is accepted than some technologies will still be at TRL 5 instead of 6 at PDR. The goal is to avoid freezing design awaiting the outcome of remaining risk retirement activities.

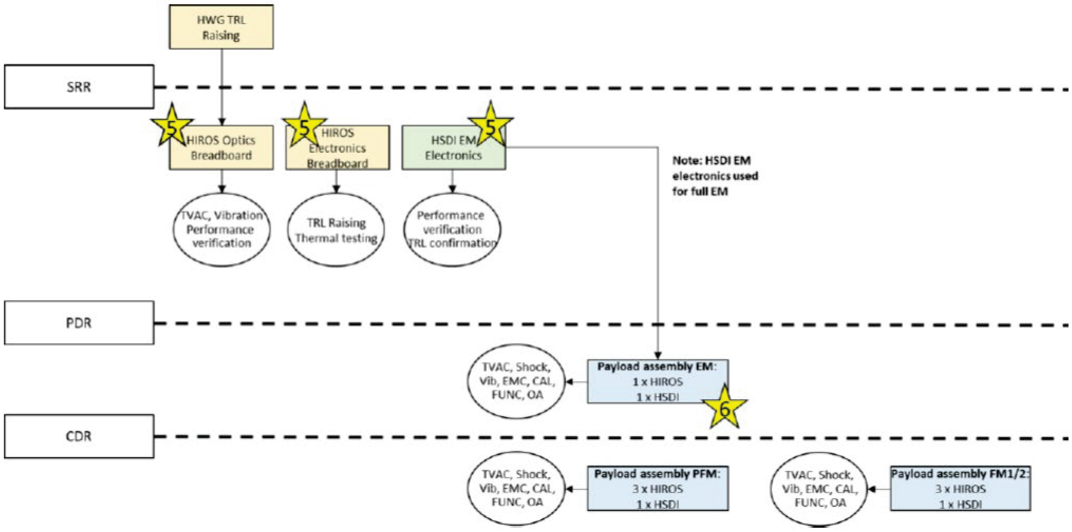

Figure 7: Overall logic of the payload development. The list of tests presented is still tentative and has to be further assessed in the frame of the SRR. For simplicity, this figure doesn't show that the HIROS electronic breadboards and the HSDI EM are both sent to GOMSPACE to form a complete FlatSat.

Next to these simplifications, the Product Assurance and the ECSS standard requirements has also been entirely tailored to find the best balance between accepted risks and Scout programmatic constraints.

3.2 Calibration plan

As demonstrated in section 2, the compliance to measurement requirements relies on the accurate calibration of the payload. More precisely the strategy is to carry out a comprehensive on-ground characterization complemented by in-flight calibrations when it is necessary, possible and in line with availability constraints. The list of the main activities is shown in Table 2. The approach is to minimize the number of these activities, always demanding in terms of schedule and cost, without endangering the compliance to the mission requirements.

Table 2: List of calibration operations at Instrument level

Description	**Uncertainty (at 1σ)**	**Main GSE**
Payload on-ground calibration		
HIROS non linearity/offset and gain knowledge	<0.5%	1600 K Reference Black Body
HSDI non linearity/offset and gain knowledge	<0.5%	Calibrated integrated sphere
HIROS spectral width	<3%	Second QCL reference laser
HSDI spectral width	<1%	FTS spectrometer or monochromator
HIROS spectral grid knowledge	$<3.10^{-4}$ cm^{-1}	Lambdameter / gas cell
HSDI channels response spectral grid knowledge	<1 cm^{-1}	FTS spectrometer or monochromator
Knowledge of the HIROS LoS wrt HSDI	<13 µrad	Theodolite / transfer mirror or high performances translation stage (**Error! Reference source not found.**)
HIROS FoV knowledge	<5%	Collimator with Black Body source and variable circular aperture (or high accuracy angular stage).

Payload in-Flight calibration		
HIROS offset and gain knowledge	<0.5%	Exo-atmospheric + dark measurement at each orbit
HSDI offset and gain knowledge	<0.5%	Exo-atmospheric + dark measurement at each orbit
HIROS spectral grid knowledge	$<3.10^{-4}$ cm^{-1}	Use of Fraunhofer lines and at each orbit (+ on-board filter etalon at coarse measurement)

All calibration GSE are currently under design and will not be described, but a focus on one of the most important ones can be made in this paper.

4. CONCLUSION

The HIROS instrument is an instrument demonstrating unique technical assets such as shot noise limitation, robustness and low mass and volume. This qualified it as the perfect candidate to be implemented in a Scout mission. Thanks to this innovative instrument, CubeMAP is paving the way to this new era of low cost, short development, and industry driven science missions. Currently the mission is under the System Requirements Review. The launch is in the second quarter of 2025.

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