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## *The microcarb instrument*

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# THE MICROCARB INSTRUMENT

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## I. INTRODUCTION

The COP21 climate conference has taken place in December 2015 in Paris, France. The agreement signed has enlightened the criticality of greenhouse gases in the global warming process. In this context, France has decided to kick-off the MicroCarb project that will allow for monitoring of the major greenhouse gases as $CO_2$. The mission main objective is to monitor carbon fluxes between the atmosphere and the Earth surface. The project will provide data continuity after 2020 from a European source to the worldwide climate scientific community: MicroCarb will help improving the understanding of the carbon cycle and its implication on climate change.

AIRBUS Defence and Space has been selected by the French Agency CNES for the design and development of the MicroCarb instrument, able to monitor very precisely greenhouse gases concentration (better than 1 ppm for $CO_2$) in the atmosphere through passive sounding thanks to a very compact spectrometer, offering probationary capabilities to prepare next generation satellites (spectral imagery capability). MicroCarb will be launched in 2020. It will follow on the American OCO2, launched in 2014, the Japanese GoSat and Gosat-2 (2009 and 2017) and the Chinese TanSat (2017) from 2020 to 2025.

This article describes the operating principle of the instrument, an innovative concept selected for its flexibility to accommodate the required spectral channels at a high level of performances. The selected baseline concept including four spectral bands and one imagery channel is presented. The operational modes are described, including the nadir pointing, sun glint tracking, and scanning capabilities, as well as probatory modes. Finally, the main elements of the development plan and the industrial team will be given.

## II. INSTRUMENT REQUIREMENTS

An exhaustive set of instrument specifications has been established by CNES in order to meet the MicroCarb mission requirements. Most of the instrument design and performance parameters are not defined as fixed or limit values, but through an acceptable range. The selection of these parameters within their acceptable range is constrained by a figure of merit (see [2]) allowing providing a given level of system performance (*i.e.* the $CO_2$ measurement accuracy). This approach allows optimizing the instrument design towards the end-to-end mission performances without constraining each and every instrument design parameter.

The specification includes four spectral bands and two optional ones, leading to four possible combinations of four, five and six bands. Beside the number of channels, all instrument design parameters such as number of FoVs, FoV & IFoV size have been scanned within their specified domains. Design solutions have been proposed by AIRBUS DS for all these configurations, thanks to a versatile instrument concept. Following a trade-off led in co-engineering with CNES, a four channels configuration has been selected, in order to minimize development risks and secure the development plan schedule. The instrument design parameters have also been determined jointly in order to provide the best mission performances.

Tab. 1 provides a synthesis of the mission requirements and the selected instrument baseline design parameters. The instrument design is mainly constrained by the Factor of Merit p defined as:

$$p = \frac{k}{\Delta\sigma^{\alpha} \cdot SNR^{\beta} \cdot R^{\gamma} \cdot N^{\delta} \cdot M^{\delta}},$$

with $\Delta\sigma$ the spectral bandwidth, SNR the signal to noise ratio, R the resolving power, N & M the number of FoVs in the across and along track directions, k, $\alpha$, $\beta$, $\gamma$ and $\delta$ being normative coefficients determined by CNES. Actually p represents the expected level of $CO_2$ concentration accuracy (spatial & spectral noise component), and is specified between 0.58 and 0.43 ppm. The parameters of the formula combine the results obtained for spectral bands B1, B2 and B3, the channels dedicated to $CO_2$ measurement. Thanks to the proposed instrument concept, AIRBUS DS has been able to commit to a Factor of Merit lower than 0.39, providing further system margin with regard to the mission requirements.

Beside the basic requirements listed in Tab. 1, the specification includes very stringent requirements related to the knowledge of the in-orbit instrument line shape. These requirements are leading to a very accurate on-ground characterization of the instrument spectral characteristics, and very high stability of the spectrometer optics.

| **Item** | **Specification** | | **Baseline** | **Remark** |
|---|---|---|---|---|
| | **Threshold or min** | **Goal or max** | | |
| **Spatial requirements** | | | | |
| Altitude | 649km | | | |
| FoV area | 46km$^2$ | 9km$^2$ | 40km$^2$ | |
| Form factor | 2 | 1 | 2 | Ratio ALT/AXT |
| Number of FoV AXT | 1 | 5 | 3 | |
| Number of FoV ALT | 2 | 4 | 5 | Over 50km |
| Slit height | | | 0.58km | Indirect requirement |
| Interband coregistration | 0.05 | 0.015 | C | |
| Intraband coregistration | 280µrd | 140µrd | C | |
| **Spectral requirements** | | | | |
| Number of bands | 4 | 6 | 4 | CNES decision |
| Central wavelength B1 | 13 030 cm$^{-1}$ | 13 070 cm$^{-1}$ | 13 099 cm$^{-1}$ | Final spectral band selection and definition by CNES |
| B2 | 6 225 cm$^{-1}$ | 6 245 cm$^{-1}$ | 6 223 cm$^{-1}$ | |
| B3 | 4 875 cm$^{-1}$ | 4 899 cm$^{-1}$ | 4 909 cm$^{-1}$ | |
| B4 | 1 643 nm | 1 683 nm | - | |
| B5 | 1 267 nm | 1 273 nm | 1 274 nm | |
| B6 | 2 331 nm | 2 367 nm | - | |
| Bandwidth B1 | 50 cm$^{-1}$ | - | 172 cm$^{-1}$ | B1 shall include one Fraunhofer line |
| B2 | 30 cm$^{-1}$ | 65 cm$^{-1}$ | 77 cm$^{-1}$ | |
| B3 | 30 cm$^{-1}$ | 50 cm$^{-1}$ | 65 cm$^{-1}$ | |
| B4 | 12 nm | - | - | Final spectral band selection and definition by CNES: relaxed spectral resolution providing larger bandwidth |
| B5 | 17 nm | - | 17 nm | |
| B6 | 30 nm | - | - | |
| Resolving power | 25 000 | 42 000 | ≈24 000 | |
| Spectral oversampling | 2.6 | 2.8 | 2.7 | |
| **Radiometric requirements** | | | | |
| SNR B1 | 200 | 500 (*) | ≈430 | |
| B2 | 200 | 500 (*) | ≈550 | (*) max value considered for the Merit function. |
| B3 | 133 | 333 (*) | ≈280 | |
| B4 | 200 | - | - | Predicted values based on instrument radiometric model, including system margin. |
| B5 | 200 | - | ≈460 | |
| B6 | 130 | - | - | |
| Absolute accuracy | 4% | 2% | C (≈3.3%) | |
| Interband relative accuracy | 3% | 1.5% | C (≈2.4%) | |
| Intraband relative accuracy | 0.3% @ 3σ | - | C (≈0.28%) | |
| Polarisation Glint/Nadir | 0.25% / 5% | 0.1% / 0.7% | C (≈0.20%) | B1, B2, B3 |
| **Merit Function** | | | | |
| Merit Function | 0.58 | 0.43 | < 0.39 | |
| **Interfaces** | | | | |
| Mass | < 70kg | | C (≈65kg) | Compatibility with Myriade platform |
| Volume | L1200 x W 700 x H 450 | | C | |
| Power | < 57W | | C (≈55W) | |
| Data rate | < 500Gbits/day | | 270Gbits/day | |

**Tab. 1.** Major instrument requirements and selected operating point

## III. SELECTED INSTRUMENT CONCEPT OPERATING PRINCIPLE

In order to ease the comprehension, the instrument operating principle is described following the opposite direction of light propagation, *i.e.* starting from the detector array towards the telescope entrance.

### *A. The array section*

Let's consider a set of $N_{band}$ spectral bands (B1 to B4 in the illustration): these spectral bands are uniformly distributed across the array in the horizontal direction X of Fig. 2. The vertical direction corresponds to the spectral direction: for each band, a line corresponds to a spectral sample. The spectral sampling is driven by the spectrometer optics, in particular the grating characteristics and the imager focal length. Along the X direction each band extends over a number of pixels, corresponding to the AXT (Across Track) projection on ground of the instrument Field of View. This projection is at post-processing level split into a number of $N_{FoV}$ elementary spatial sample, each one including $N_{bin}$ photodiodes.

The total number of useful photodiodes in the AXT direction is therefore $N_{band}$ x $N_{FoV}$ x $N_{bin}$; in-between each band is a dead zone used as dark signal monitoring.

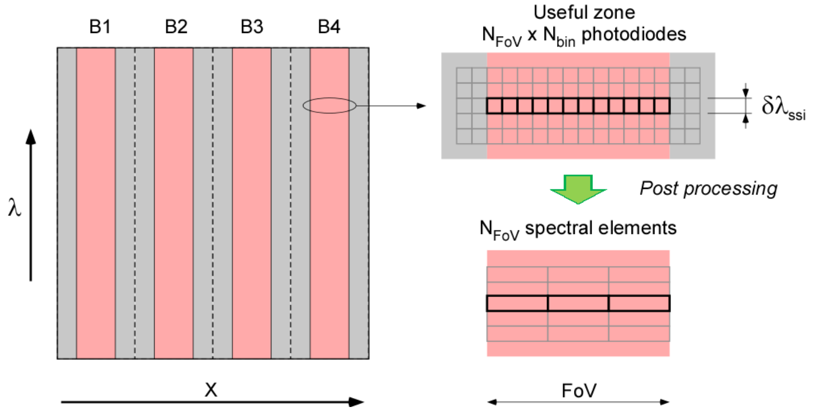


**Fig. 2.** Distribution of spectral bands over the array

The detector array is the NGP (New Generation Panchromatic) detector currently under development at SOFRADIR; the NGP is an HgCdTe photodiode array mounted on a Silicon CMOS ROIC. It features 1024 x 1024 pixels; according to the above description, this format is the basic intrinsic instrument limitation in terms of spectral range and number of spectral bands, meaning that more scientific data would be obtained with the same instrument concept using a larger array.

In front of the array are placed spectral bandpass filters limiting the incoming radiation to the useful spectral band, plus a margin to avoid signal drop at the edges of the array. The main purpose of these filters is to block parasitic diffraction orders and thermal self emission of the spectrometer. They are placed very close to the array as they physically limit the optical beam aperture in the across-track direction, as illustrated below. Ideally, the the filter assembly operates as the detector window: this allows reducing the optical distance and so maximizing the signal throughput. The feasibility of this approach is under discussion with SOFRADIR.

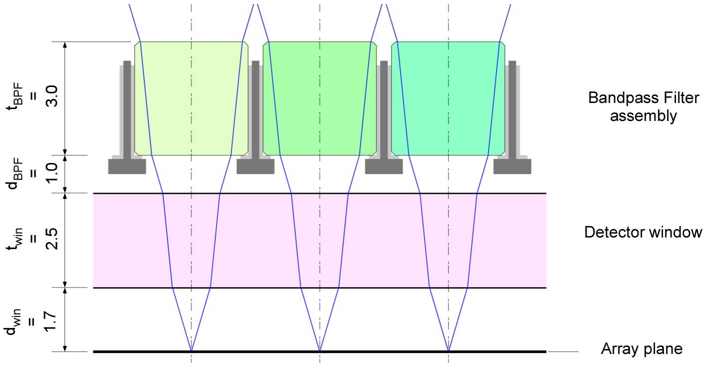


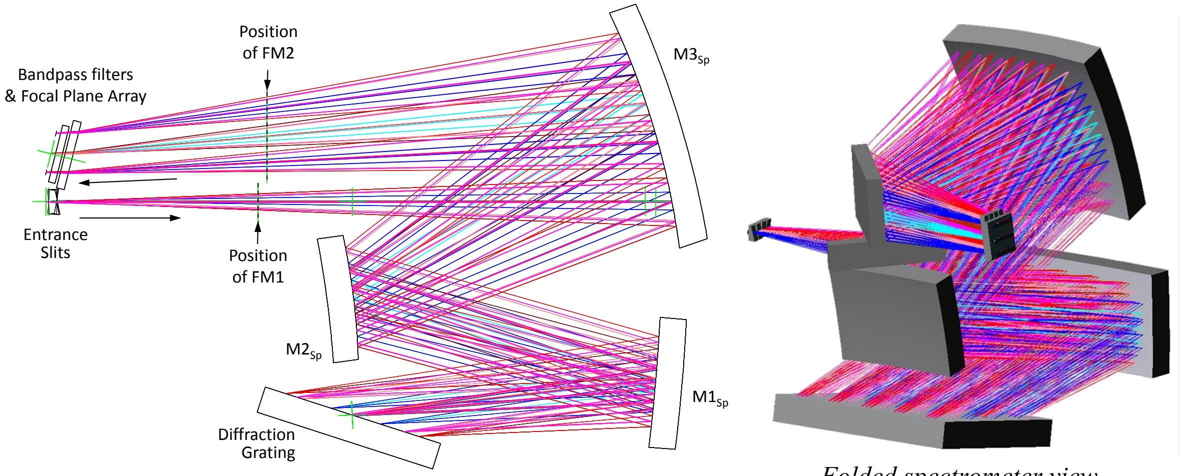
**Fig. 3.** Implantation of bandpass filters (typical dimensions are given)

### *B. The spectrometer section*

The spectrometer is an echelle grating spectrometer proving the angular dispersion required to meet the spectral resolution requirements. The grating characteristics (ruling, inclination) are optimized to cover the required spectral bands, by selecting the appropriate diffraction order for each band. This task has been performed by CNES taking into account the distribution of chemical species of interest over the visible and infrared range (see the selected spectral bands in Tab. 1). The selected spectrometer concept operates in quasi-Littrow configuration: this provides a very compact design, but different optical combinations could be considered.

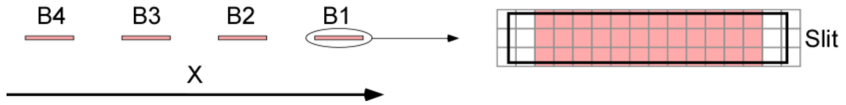
According to this optical layout, the spectral bands as defined on the array are (backward) imaged onto the spectrometer entrance focal plane onto a set of $N_{band}$ slits, in the vicinity of the detector array because of the Littrow configuration, as illustrated in Fig. 4. The height of the slits (approximately) defines the FWHM of the instrument spectral response, usually referred to as the spectral resolution. According to the mission requirements a spectral oversampling in the range of ≈2.7 has to be implemented, meaning that the slit is covering the height of ≈2.7 photodiodes. The slit is oversized in the AXT direction, the FoV size being determined by selection of the useful pixels.

To avoid mechanical conflicts between the slits and the array, two folding mirrors are implemented in such a way that the slits and the detector array are facing each-other. Beside the optical components, the spectrometer includes some baffling elements not represented in the figure in order to prevent straylight issues between the slits and the array.



*Unfolded spectrometer view*

*Folded spectrometer view*



*Slit positions at the entrance of the spectrometer, i.e. the telescope focal plane*

**Fig. 4.** The spectrometer optics

Another optical component is part of the spectrometer, but it will be described only at the end of this chapter, for a better understanding of its function.

As a direct consequence of this configuration, the spectral bands are distributed along the AXT direction in the telescope focal plane, the distance between each slit being equal to the distance between the spectral bands on the detection array. As the instrument is expected to provide the spectral analysis of the given area on ground, it is necessary to implement a specific device within the telescope to realign the slits towards the same pointing direction.

### *C. The telescope section*

The spectral bands being in-field separated in the telescope focal plane, it is necessary to realign them on the same on-ground position. The alignment principle is illustrated in Fig. 5, with only three spectral bands for sake of clarity.

Fig. 5A) represents schematically the telescope, including the entrance pupil, the telescope optics, and the focal plane: the entrance pupil illuminates the three spectral band positions in the focal plane, with the corresponding pointing directions towards the Earth, given by the focal length of the telescope.

In Fig. 5B) we assume that we are able for each band to limit the telescope collecting area to a sub-pupil, each sub-pupil being separated from the other by a physical gap. The angular pointing direction of each band remains unchanged with regard to Fig. 5A).

In Fig. 5C) the pointing direction of each band is corrected thanks to a prism placed in the sub-pupil in such a way that all bands are pointing in the same direction on ground. These prisms are termed PSP for « Pupil Separation Prisms ». Each band having a narrow spectral bandwidth, the chromatic dispersion of the prism remains negligible (actually the residual chromatism is corrected within the spectrometer).

By this way the spectral bands have been realigned on the same on-ground position. However, each sub-pupil is illuminating each spectral band in the focal plane with different pointing directions, as illustrated in Fig. 5D) for spectral band B2. It is so necessary to block the directions not coming from Nadir. This is achieved by two means:

1) each PSP includes a narrow bandpass filter limiting the incoming beam of each sub-pupil to its associated spectral bandwidth. For a given band Bi associated to the sub pupil Pi, the out of field radiation coming from the sub-pupils Bj will be limited to the flux passing through spectral bands Bj, and blocked by the detector array bandpass filter.

2) a field mask is implemented in front of each entrance slit in such a way that the radiation coming from the other sub-pupils is blocked. This solution is theoretically sufficient to block the out of field signal; however, the mask has to be oversized with regard to the nominal beam envelope, which makes possible cross-talk signals from other sub-pupils, for example by diffraction. For this reason the association of solutions 1) and 2) is deemed to be necessary.

The drawback of this so-called split-pupil approach is that the telescope collecting area has been reduced for each band, which means that the telescope entrance area is finally multiplied by the number of spectral bands. This is not critical for MicroCarb since the instrument size is actually driven by the size of the spectrometer section. The radiometric requirements are met with a pupil equivalent diameter in the range of 1 to 2 centimeters depending on the band. For 5 spectral bands the entrance pupil diameter is therefore increased to, say 5 cm, which remains acceptable in front of the spectrometer pupil size close to 10cm.

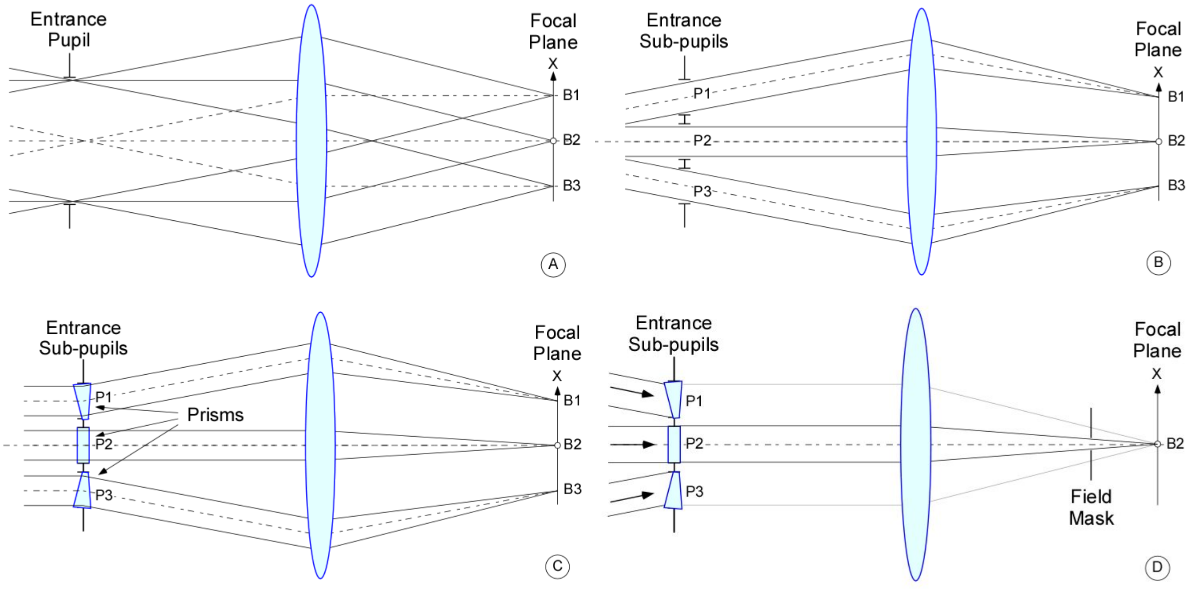


**Fig. 5.** Principle of the split pupil telescope concept

The split pupil concept also permits the implementation of one or more sub-pupils dedicated to high resolution imagery, by implementing a specific detection array in the telescope focal plane.

### *D. Coupling the telescope and the spectrometer*

The spectral resolution requirements implies a very high angular dispersion for the diffraction grating, with resolving power as large as 25 000. In order to ease the grating design and ensure high performance levels, it is desirable to reduce the angular dispersion by introducing a pupil magnification ratio between the telescope and the spectrometer: the angular dispersion is then relaxed by the pupil magnification ratio. By design the telescope entrance pupil is reimaged onto the spectrometer pupil *i.e.* on the diffraction grating: considering the proposed split pupil concept, a large pupil imaging ratio would lead to extremely large grating size, not compatible with the manufacturing capabilities, and leading to large a spectrometer size not compatible with the MicroCarb available envelope.

In order to limit the grating size and the overall spectrometer volume, the pupil imagery is modified by introducing right being the spectrometer entrance slits small prisms deflecting the optical beam: for each spectral band (hence for each sub-pupil of the telescope), the prism, termed PAP for « Pupil Alignment Prism », deflects the optical beam towards an exit pupil common to all the spectral bands. Doing so, the spectrometer pupil is limited to the envelope of all the co-centered telescope sub-pupils. The size of the spectrometer optics is therefore only driven by the largest of the entrance sub-pupils.

The alignment and stability of the PAP is not critical as a prism rotation results in the optical beam displacement at grating level, which is not critical considering standard mechanical oversizing. The PAP are sized at the minimum of deviation, which make them insensitive to mechanical and thermal perturbations.

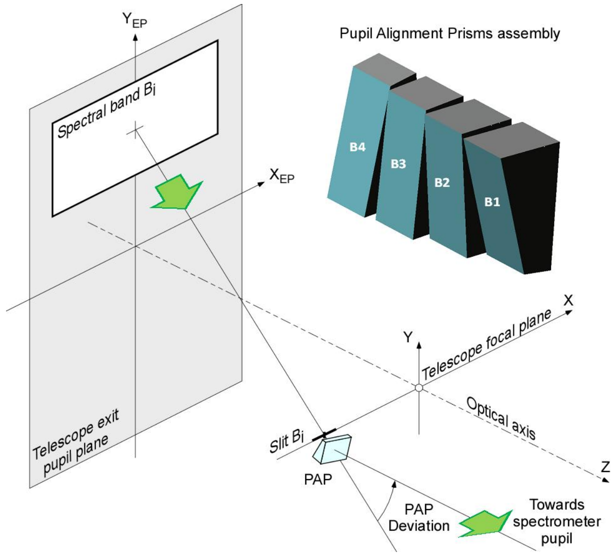


**Fig. 6.** Pupil imaging: for each spectral band, the PAP aligns the telescope exit sub-pupil of each spectral band with the diffraction grating in the spectrometer pupil plane.

As designed, the PAP allows recentering the entrance sub-pupil of a given spectral band Bi onto the spectrometer grating, as illustrated in Fig. 7 in case of a six spectral bands instrument. In consequence, for that spectral band Bi, the sub-pupils of the spectral bands Bj are imaged outside the spectrometer useful pupil: the incoming flux impacting the detector Bi can only come from the sub-pupil Pi. This provides a third blocking feature with regard to the potential sub-pupil cross-talk discussed previously, in addition to the spectral filtering of the PSP and the field masks in front of the slits. At the end, the instrument behaves as a set of independent monochromatic instruments; the only potential remaining source of cross-talk is due to optics diffusion within the spectrometer.

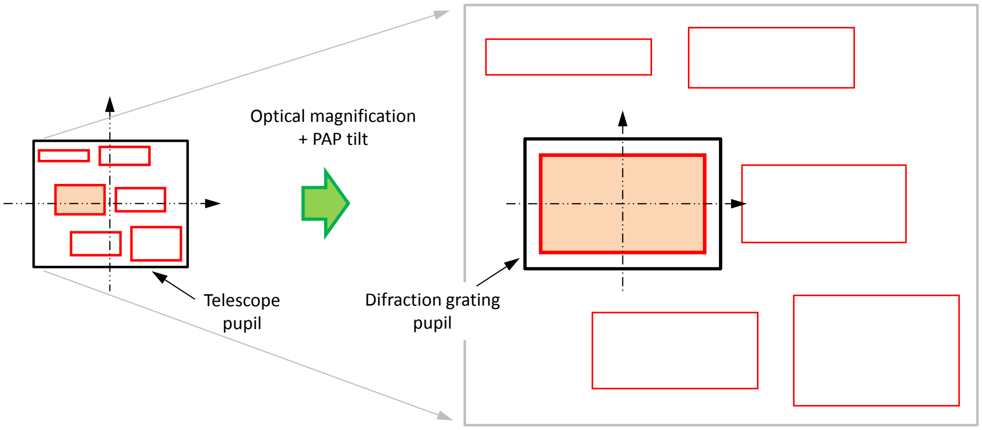


**Fig. 7.** Pupil imaging: for each spectral band, the PAP aligns the entrance sub-pupil with the diffraction gratings: the flux coming from the other sub-pupils is excluded from the nominal spectrometer optical path.

*D. Advantages of the concept*

The instrument concept selected for MicroCarb features significant advantages with regard to a standard grating spectrometer; they are briefly discussed in the following.

- Flexibility of the spectral band selection: the design principle consists in positioning the required spectral bands on the array, without constraints imposed by the wavelength range or by the diffraction order of the grating. The selection of the spectral band positions can be optimized considering any criteria, for example the straylight protection between adjacent bands. It allows the use of a single array covering all the spectral bands, with the only limitation of the number of available pixels.

- The split pupil concept allows a large flexibility on the sub-pupil shape and dimensions for each spectral band. This allows for example to balance the detection signal levels between all the spectral bands by adjusting the sub-pupil area to the expected ground radiative flux. The adaptation of the sub-pupil width along the spectral direction allows compensating for the differential diffraction effect and providing instrument spectral response functions identical for all bands. The flexibility on the pupil positions allows also the implementation of an imaging channel using an additional sub-pupil. The selection of the pupil shape directly drives the diffraction grating size and allows fitting precisely the manufacturer sizing constraints. An example of possible sub-pupil arrangement in the telescope entrance port is given in the figure below for the five spectral bands case.

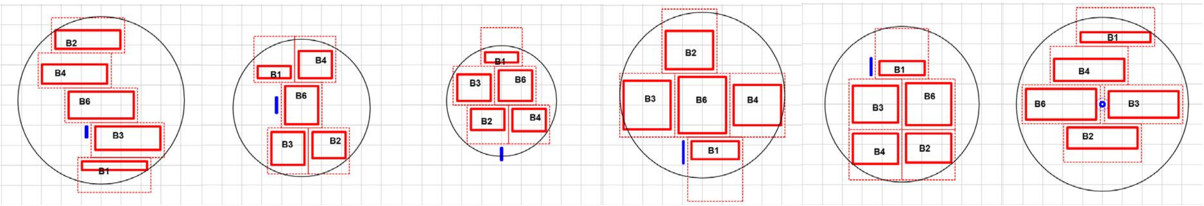


**Fig. 8.** The six sub-pupil candidate configurations of the telescope analysed for the five spectral bands case. (the blue line indicates the position of the imaging channel pupil)

- Using a single focal plane array to cover all the spectral bands provides a very compact spectrometer design allowing passive cooling not only of the focal plane array but also of the spectrometer optics, with minimized radiator size. This allows cancelling the background radiation of the spectrometer, and therefore improving the radiometric performance of the longwave IR channel, the most critical one because of the small signal levels. This performance gain results in a possible pupil size reduction, which turns in a further reduction of the instrument size.

- The combination of the split pupil concept with the dual spectral band filtering achieved at PSP and detector array levels provides a nearly perfect spectral rejection for each band, and minimum straylight levels. This is a key issue for the MicroCarb mission where the detection of low signal levels in the atmospheric absorption lines calls for cancellation of any parasitic signal. The performance estimate of straylight rejection performed in case of the most critical configuration with six spectral bands demonstrated significant margins with regard to the specification, as illustrated in the following figure.

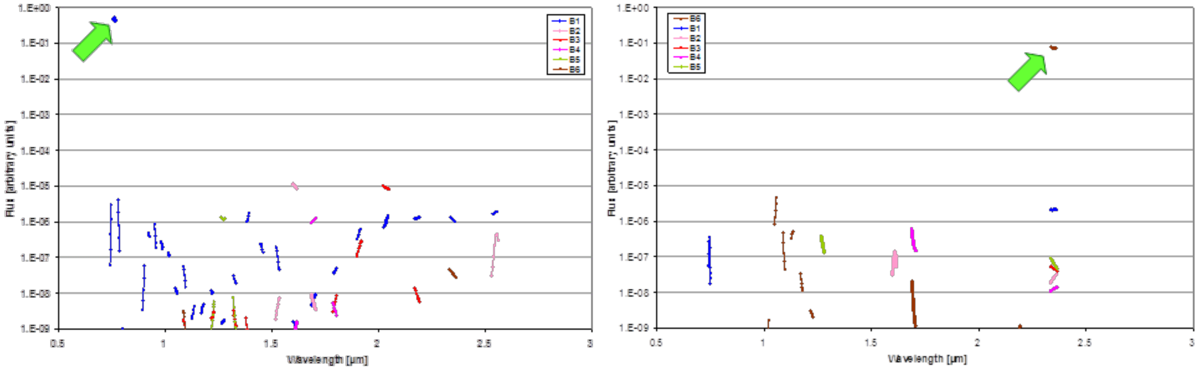


**Fig. 9.** Example of parasitic flux rejection estimate for spectral bands B1 & B6 in the six spectral bands instrument case. The arrow indicates the nominal signal. The other points indicate the parasitic signals due to other diffraction orders and diffused straylight. The resulting integrated parasitic flux ranges between one and two orders of magnitude below the levels imposed by the specification

The MicroCarb instrument concept is subject of an AIRBUS DS patent.

## IV. BASELINE DESIGN OVERVIEW

### *A. The optical system*

Following the CNES decision, the baseline instrument finally includes four spectral bands and an imaging channel. The instrument optical overview presented below shows:

- The pointing mirror at the instrument entrance port, allowing the across track pointing function, the along track pointing for sun glint monitoring being performed by the spacecraft AOCS.
- The polarization scrambler, the pupil mask and the pupil separation prisms, placed close to the telescope entrance pupil plane.
- The entrance telescope, including a field stop at the primary mirror intermediate focal plane, the folding mirror in the exit pupil allowing separation between the sounding channels and the imaging channel. The array used for the imaging channel is placed in the telescope focal plane.
- The cryostat anti-contamination window in front on the slit and pupil alignment prisms assembly.
- The TMA spectrometer operating in near-Littrow configuration, with the echelle grating in the pupil plane.
- The band pass filter assembly and the detector array.

The overall optical design is optimized to cancel smile and keystone at array level (residual errors less than 1/10th of a pixel). The optical layout includes in addition a set of folding mirrors providing the proper orientation of the instrument with regard to the Earth pointing direction on one hand and placing the detector array in the right position for passive cooling towards deep space on the other hand. The resulting optical configuration is very compact and fits within the spacecraft accommodation constraints.

The spectrometer optics are mounted onto a support structure, the assembly being the intermediate stage of the cryostat cooled @225K. The detector array and the bandpass filters are mounted on a second stage of the cryostat cooled @150K.

All optics and structural elements are in silicon carbide; the All-SiC technology provides highly stable instruments; this is especially mandatory for the spectrometer section which requires unprecedented thermos-elastic stability in order to guaranty the in-orbit accurate knowledge of the instrument spectral response function.

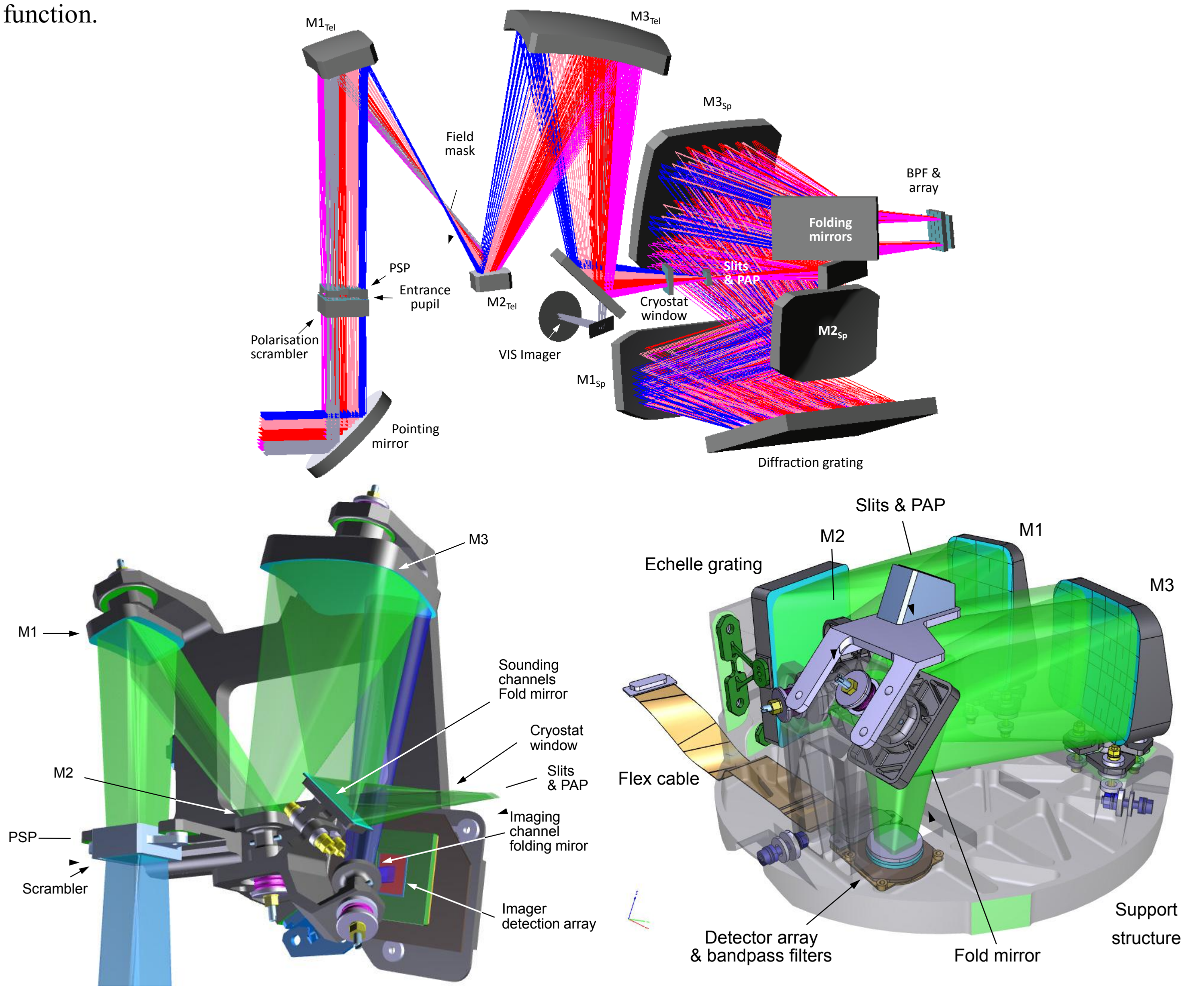


**Fig. 10.** Baseline instrument optical layout and accommodation

### *B. The sounding channel detection chain*

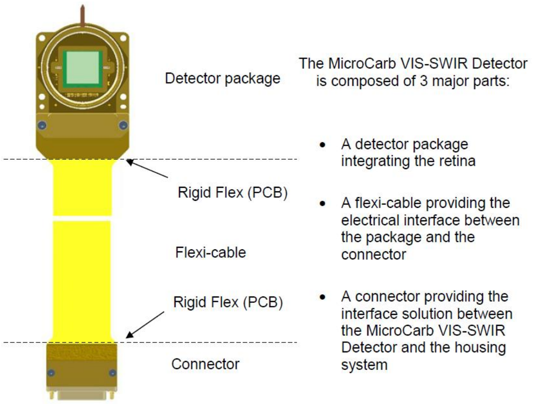
The detection chain of the MicroCarb sounding channels is based on a single NGP detector array from SOFRADIR, connected to the Proximity Video Module (MVP) which provides the array management and video processing. Both NGP and MVP are currently under development on the Sentinel-5 instrument under ESA contract.

**The NGP array**: a single NGP array provides the detection of the four spectral bands from the visible (B1) to the SWIR spectral range (B3). The detector includes an HgCdTe array hybridized on a silicon CMOS ROIC. The detector includes four differential analogue video outputs, each one operating 256 x 1024 pixels. The ROIC design takes into account the flex cable and the connector. The MCT array is adapted to operation in the SWIR region, and the manufacturing process developed by the manufacturer allows the extension of the detection range down to the visible domain. It also features a dedicated broadband anti-reflection coating.

The ROIC ensures the polarization of the photodiode and the conversion to electric signal using a capacitive trans-impedance amplifier. The CTIA allows high performance (linearity, noise) and stability in the low flux range well adapted to the MicroCarb signal levels. The array is operated in Integrate While Read mode, well adapted to the spectrometer operation.

**The Proximity Video Module (MVP)**: the MVP generates the biasing and sequencing of the NGP array. It also manages the detector operation allowing pixel selection or deselection. These functions are implemented in a FPGA also managing the TM/TC interface with the functional electronics. The positioning of the bands on the array is such that one band correspond to one array output; this allows a simple data processing management, *e.g.* for gain and offset correction, without possible electrical cross-talk between bands.

**The Instrument Control Box (BIC)**: the instrument control box completes the detection chain: it provides the secondary voltages to the MVP from the primary power bus delivered by the platform, and the clocks necessary to the MVP sequencing. It also manages the TM/TC and provides the digitization of these TM/TC (voltage and temperature measurements).



The MicroCarb VIS-SWIR Detector is composed of 3 major parts:

- A detector package integrating the retina
- A flexi-cable providing the electrical interface between the package and the connector
- A connector providing the interface solution between the MicroCarb VIS-SWIR Detector and the housing system

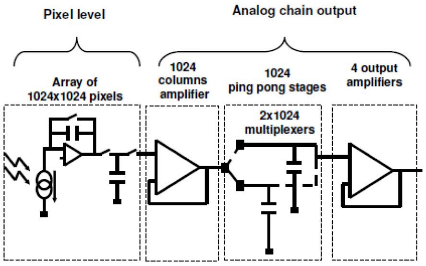


**Fig. 11.** The NGP detector array developed by SOFRADIR

### *B. The imaging channel detection chain*

**The detector array**: the detector selected for the imaging channel is the COBRA2M developed by AIRBUS DS for the GOCI instrument, launched in 2010 on the COMS satellite for the Korean government. The detector is a silicon CMOS array featuring 2 MPixels (1415 lines and 1430 columns), including 4 analogue outputs. Only a small part of the detector sensitive area is used for the imaging channel, due to the limited field of view.

**The detection chain**: The detection chain architecture is similar to the sounding channels: it includes an Imager Proximity Module (MPI), generating biasing and sequencing signals to the array, selecting the useful detection area, and providing the analogue to digital conversion. The BIC provides secondary power lines and master clocks.

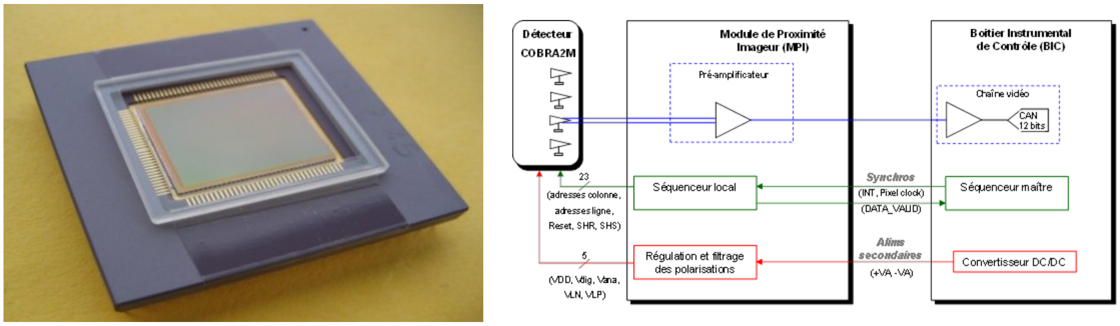


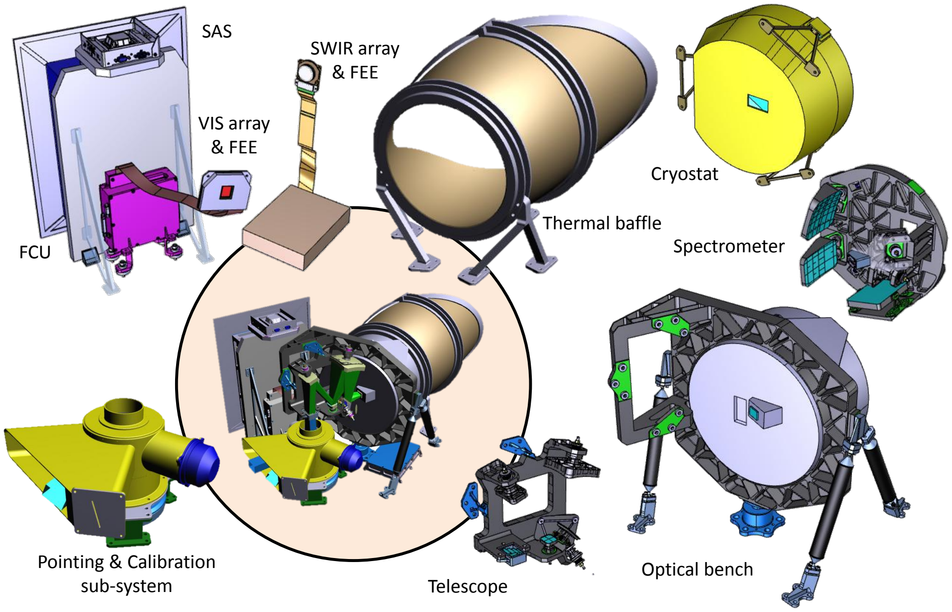
**Fig. 12.** The COBRA2M detector array and the imager detection chain

### *C. The instrument overall architecture*

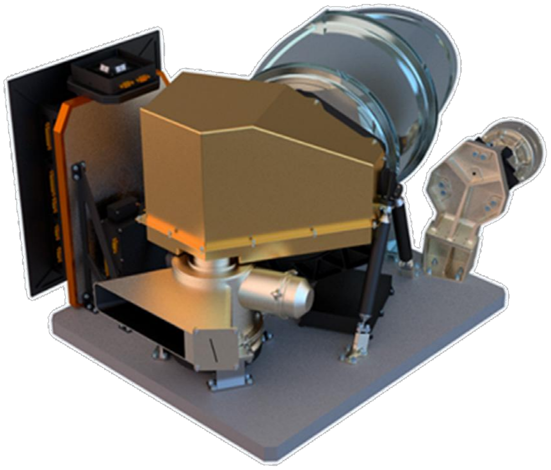
The telescope and spectrometer optics are mounted on a SiC optical bench, directly fixed onto the spacecraft interface platform by a set of bipods providing isostatic mounting. In front of the telescope is placed the calibration assembly, also mounted on the platform, providing sunlight calibration for absolute radiometric accuracy and a set of internal sources for inter-band and intra-band relative calibration. The pointing mirror ensures the pointing of the line of sight during the scan mode, and periodic observation of the calibration sources.

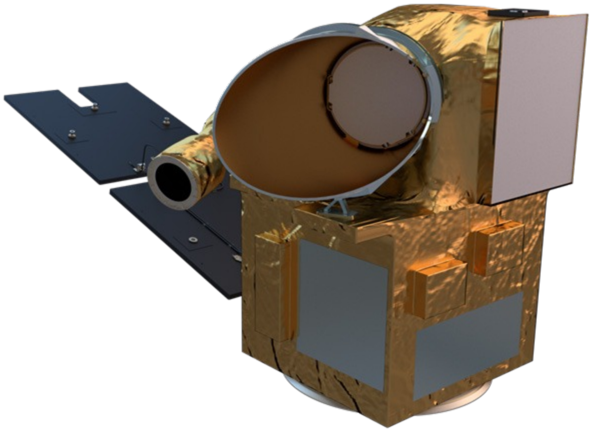
The spectrometer optics are protected within the cryostat by a set of thermal screens; low conductive suspensions provide thermal decoupling with the platform environment. The radiative areas used to cool the spectrometer optics and the detection assembly are protected from direct sun and earth radiations by a thermal baffle. The baffle geometry is optimized as a function of the earth and sun directions which are changing due to the spacecraft pointing in the sun glint observation mode. The baffle is mounted on the spacecraft platform.

Front-end electronics of the imaging and sounding channels are connected to the detector arrays by means of flex cables. The functional electronics (BIC) are mounted beside the telescope, on the anti-sun side of the spacecraft, allowing power dissipation by means of a dedicated radiator.



*Exploded view of the MicroCarb instrument*





*The MicroCarb instrument mounted on a Myriade platform*

**Fig. 13.** Overview of the Microcarb instrument

## V. MICROCARB OPERATING MODES

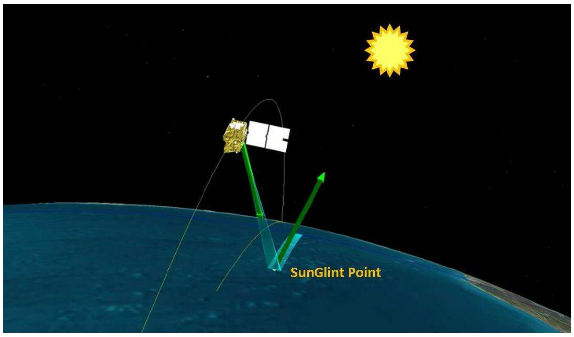
To fulfill its mission of measuring the global $CO_2$ surface fluxes, four main mission acquisition modes have been designed. Moreover probationary modes are considered in order to demonstrate the ability to quantify fluxes at local scales.

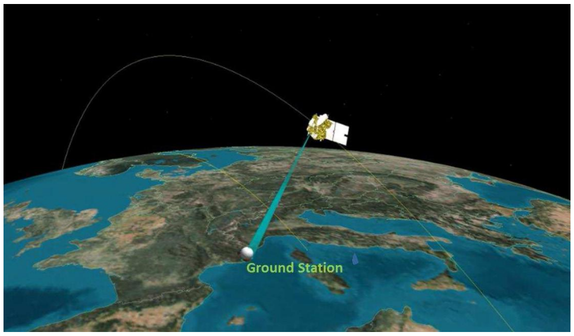
### *A. Nominal modes*

**Nadir pointing mode**: in this mode, the instrument line of sight is close to the geocentric pointing. This mode represents the nominal mission pointing mode over the emerged lands and during eclipse. Its resolution will allow global fluxes measurements. Moreover, the effect of the earth rotation will be compensated to avoid or reduce the global field of view distortion.

**Glint pointing mode**: over the seas, due to the darkness of water in near infra-red spectral domain, nadir measurements are not exploitable. To collect sufficient solar reflectance flux towards the instrument, the line of sight will point towards the glint area *i.e.* the solar specular reflection point on Earth.

This pointing will allow MicroCarb instrument to measure $CO_2$ concentration in the atmosphere over the seas. As for the Nadir pointing mode, the global field of view distortion due to its projection on the rotating earth surface will be compensated as much as possible.

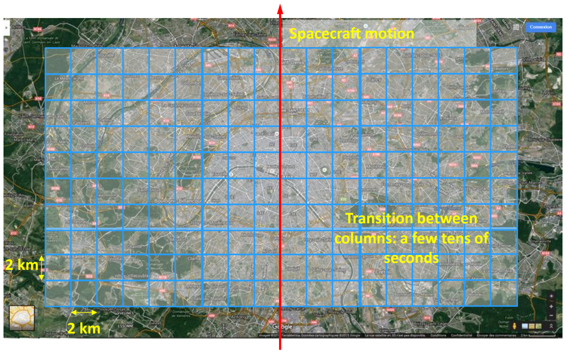




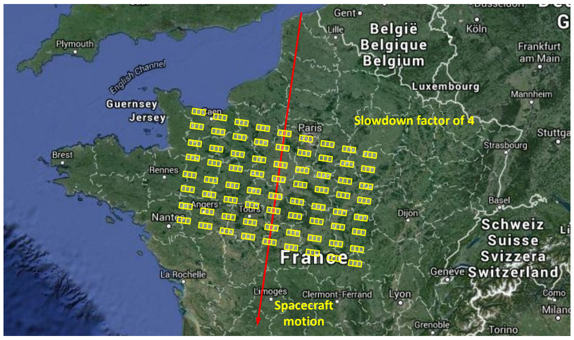
**Target pointing mode**: for calibration purpose, a target mode will be implemented allowing continuous measurement during few minutes over a specific area, such as a ground station. It will be used to compare MicroCarb measurements with on ground products.

**Scan Mode**: this mode aims in gradually off pointing the line of sight from the Nadir with a ground distance excursion of ±200km allowing 5 uncorrelated measurements.

### *B. Probationary modes*



**City Mode**: this mode consists in a scan resulting of three chained acquisitions over a 40km wide zone. It will demonstrate the capacity to map $CO_2$ emissions at regional or city scales.



**Regional mode**: on the same principle as the scan mode, a country mode will be available. The sampling will be increased to have a measurement every 50km, offering a dense coverage of a 400km×400km region.

## VI. DEVELOPMENT SCHEDULE.

The MicroCarb instrument development plan is based on a single model approach (proto-qualification flight model), with risk reduction validations performed on breadboards in the program early phases. This aggressive approach is justified by the tight schedule constraint (overall development in 41 months) and the high level of heritage, gained on on-going or former AIRBUS DS programs that the baseline definition can claim:

- The spectrometer detector and detection chain takes benefit of the Sentinel-5 SWIR channels development.
- The scanning mechanism and the imager are recurrent from GOCI.
- SiC mirror and structure are now baselined in most AIRBUS DS instruments.
- Instrument electronics functional blocks are derived from IASI NG and GOCI electronics units.

The program starts classically with a phase B, lasting 11 months, concluded by a Preliminary Design Review (PDR). Intensive co-engineering between CNES and AIRBUS DS is performed during this period to consolidate the specification, optimize the instrument parameters, and define the interfaces with the spacecraft. A set of key points, each dedicated to a specific performance or interface feature, are defined throughout the phase B to progressively achieve the freezing of requirements and the instrument definition.

The phase B is also used to perform the early validation of the MicroCarb innovative element and risk reduction actions:

- An optical breadboard is developed in order to validate the small optical element manufacturability and the tight alignment capability (PAP & PSP).
- A thermal breadboard is used to confirm the spectrometer passive cooling performances.
- Detection chain breadboard is tested to validate the MicroCarb specific operating conditions.

After the RDP, the instrument detailed definition is performed through a 10 months phase C that ends with the Critical Design Review. This phase is also devoted to the equipment design review and manufacturing release.

Then PFM integration and qualification tests are performed during the phase D. The AIT sequence is based on a modular and a progressive verification approach, inherited from tight schedule export programs, to provide flexibility towards the equipment availability and reduce the risk of problem detection in the late test phases. The qualification test sequence includes EMC, sine and random vibrations, shock test on a STM platform, and thermal vacuum, during which an extensive radiometric and spectral calibration is performed.

Key point between CNES and AIRBUS DS are also performed during the phase C/D to define the in-orbit operation and the on-ground data processing. Two additional breadboards of the main electronics are delivered to CNES to perform the validation of the electrical interfaces between the instrument and the spacecraft as well as the operation through the satellite on board calculator and central software.

AIRBUS DS is prime contractor for the instrument development, is in charge of the instrument integration and test and manufactures the spectrometer electronics. The industrial team includes the following sub-contractors that all have a strong experience in their fields: SOFRADIR for the spectrometer detector, WINLIGHT OPTICS for the PSP and PAP, CILAS for the spectral filters, HORIBA for the grating, SODERN for the scrambler, EREMS for the imager electronics, CODECHAMPS / SAGEM / ADR for the scanning mechanism elements, BOOSTEC for the SiC mirrors and structural elements, REOSC for the mirror polishing and MECANO ID for the calibration sub-system.

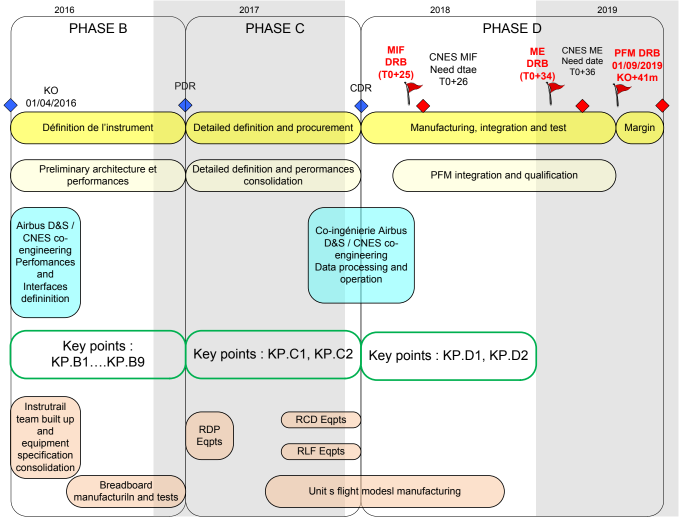


**Fig. 14.** MicroCarb development schedule

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