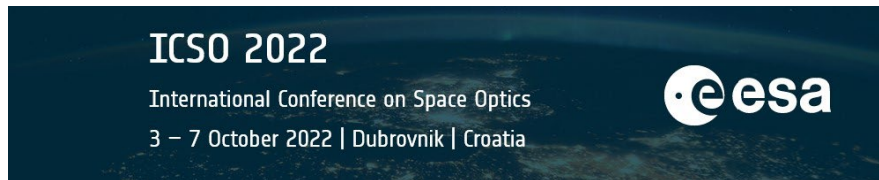


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## *IASI-NG Instrument development status*



# IASI-NG Instrument development status

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## ABSTRACT

The Infrared Atmospheric Sounding Interferometer New Generation (IASI-NG) is a key element of the second generation of EUMETSAT European Polar System (EPS SG) dedicated to operational meteorology, oceanography, atmospheric chemistry, and climate monitoring. A series of three IASI-NG instruments will be embarked on the second generation of European Meteorological Operational satellites (METOP SG) developed by ESA. CNES (Centre National d'Etudes Spatiales) is in charge of IASI-NG overall system including the ground processing, the Technical Expertise Center and the Instrument, which is developed by Airbus Defence and Space. It will continue and improve the IASI mission in the next decades (2020-2040). The performance objective is mainly a spectral resolution and a radiometric error divided by two compared with the IASI first generation. The measurement technique is based on wide field Fourier Transform Spectrometer (operating in the 3.5 - 15.5  $\mu\text{m}$  spectral range) using an innovative Mertz compensated interferometer to manage the so-called self-apodization effect and the associated spectral resolution degradation.

We present here a synthesis of the development strategy, including the EM instrument campaign in parallel of the PFM, and the main milestones achieved on PFM instrument, which should be delivered for integration on Satellite in September 2022. In parallel, FM2 subsystems are under integration and first results on focal plane and interferometer should be available in third quarter of 2022.

## 1. INTRODUCTION

IASI-NG (Infrared Atmospheric Sounding Interferometer New Generation) is the follow on mission of IASI. It shall provide operational meteorology data such as temperature and humidity atmospheric profiles and also monitor other gases like ozone, methane or carbon monoxide on a global scale.

The IASI-NG instrument performs spectral measurement in the infrared between 3.6 $\mu\text{m}$  and 15.5 $\mu\text{m}$  using Fourier Transform interferometry. Compared to IASI, the new generation instrument shall improve the radiometric signal to noise ratio and the spectral resolution by a factor of two. Table 1 gives the main instrument requirements:

SPECIFICATIONS			
GEOMETRY	SOUNDER PIXEL SIZE	~12 km	SAME AS IASI
	SPATIAL SAMPLING	~25 km	
	GEOLOCATION ERROR	0.5 km	
SPECTRAL	BAND	645 $\text{cm}^{-1}$ to 2760 $\text{cm}^{-1}$	2 TIMES BETTER THAN IASI
	RESOLUTION	0,25 $\text{cm}^{-1}$	
	SAMPLING	0,12 $\text{cm}^{-1}$	
	CALIBRATION ERROR	$d\sigma/\sigma = 5.10^{-7}$	
RADIOMETRY	CALIBRATION ERROR	0,25K @ 280 K	
	NEDT	NedT ~0.1 K to 0.4 K within spectrum	

Table 1: Instrument specifications

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Due to volume and mass constraints, it was not possible to improve IASI radiometric performances by increasing the pupil size. The chosen solution is then to increase the Field Of View (FOV) size and thus the measurement time. The resulting FOV is in the order of  $100 \times 100 \text{ km}^2$ . To compensate the associated field effects, such as drastic loss of radiometric contrast, a compensation is done directly in the pupil. This is the first time that such a so-called Mertz Concept Interferometer is used in space. It is possible by inserting dynamically varying glass thickness in the interferometer during its swing to correct the off-axis optical path difference (OPD) variations. In practical, this is done with two pairs of KBr prisms driven by a dual swing mechanism moved by a unique motor. The instrument spectral resolution and sampling are divided by two by doubling the OPD of the interferometer to about 8 cm in total ( $\pm 4 \text{ cm}$ ).

## 2. INSTRUMENT DESCRIPTION SUMMARY

A detailed instrument description and principle explanation has been given in ref[1]. We then only recall here the main functions represented on Figure 1.

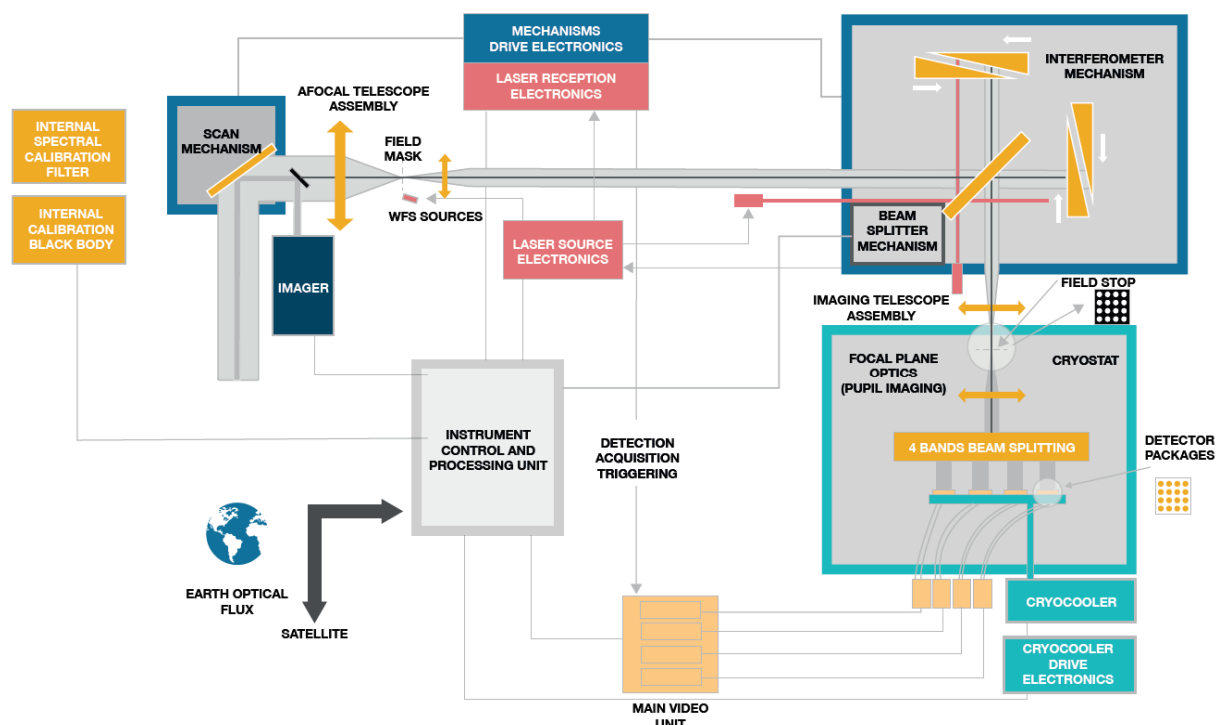


Figure 1: overall instrument functional description

The beam enters the instrument via a two axes pointing mirror used to select the Earth views and to compensate the satellite velocity. It then passes through an afocal telescope used to reduce the pupil size before entering the interferometer. At interferometer output, an imaging telescope focuses the beam on the field mask located at the entrance of the cryostat containing the four detection arrays for the four spectral bands.

A stabilized laser metrology beam source (LASE) divided into five sub-beams is also injected inside the interferometer and then acquired and processed by LARE electronics. This electronics is in charge of triggering the detection chain using the central metrology beam to provide constant OPD sampling and to record interferometer elements displacements provided by the other four lateral beams and used in the ground post-processing of the interferogram. Main characteristics of the instrument are resumed in Table 2. Overall budget gives a mean power consumption of about 520W, a total mass of 430kg, and mean data rate of 6Mb/s.

MAIN CHARACTERISTICS	
SWATH	~ 2000 KM
FOR	+/- 3°
PUPIL DIAMETER	~ 90 MM
ATA MAGNIFICATION	2.3
MAXIMUM OPTICAL PATH DIFFERENCE	4,2 CM
ACQUISITION DURATION	~730 MS
SCAN LINE DURATION	15.6 s : 14 EARTH VIEWS + 1BB + 1CS
CO-REGISTRATION	INTEGRATED IMAGER
SPECTRAL CALIBRATION	FABRY PEROT SOURCE

Table 2: instrument main characteristics

As shown on Figure 2, the instrument is split into two modules: Optical Head (I-OH) and Electronics Module (I-EM).

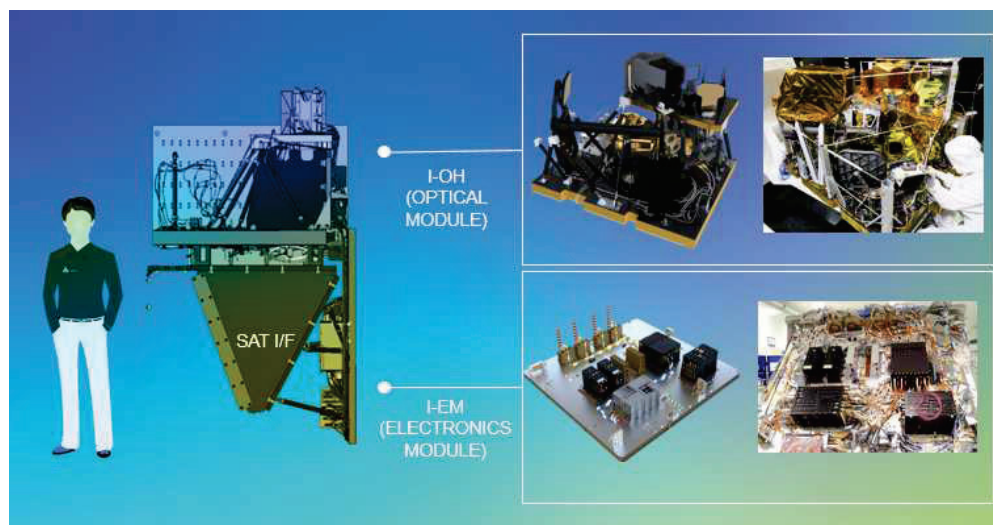


Figure 2: instrument global view (with as designed and as built pictures)

### 3. DEVELOPMENT LOGIC

IASI-NG Instrument is based on an innovative concept and very challenging technologies. In order to be able to deliver a PFM Instrument only 3 years after the CDR (held end of 2019), it was then necessary to optimize the development plan with an EM Instrument model used in parallel of the PFM integration.

EM Instrument is well representative of PFM with the following main differences: EM subunits are used without redundancy, and no telescope neither metrology channel are implemented. The main purpose of the EM instrument is the qualification of the main critical subunits, and derisking activities not compatible with the schedule at PFM Instrument level, since the PFM elements availability is later than the EM ones. The most critical assembly parts of IASI-NG are the interferometer and the focal plane, which are both designed and integrated by Airbus Defense and Space.

Interferometer is made of several sensitive optical parts in KBr, with a global alignment giving a wavefront tilt less than 10  $\mu$ rad at Zero Path Difference (ZPD). Even if the qualification of KBr especially with regard to humidity sensitivity was passed with success, it is mandatory to also have an earlier assessment after mechanical and thermal environment at assembly level to check the potential effect of induced stress and to insure there is no unexpected misalignment. A dedicated qualification campaign was then foreseen with the Interferometer EQM (Engineering Qualification Model).

Focal plane is also a complex assembly requiring a full qualification (mechanical, thermal, EMC and performances) to guarantee the alignment stability, cooling efficiency and overall integrity after environment.

The EM Instrument derisking activities have been numerous. The first one was the conducted EMC full qualification that could be done because the electronics subunit are representative of the FM. The second one was an end-to-end characterization of micro-vibration sensitivity. Micro-vibration, by generating parasitic modulation of contrast and/or metrology OPD, may drastically affect the spectral performance by adding parasitic peaks in Instrument Spectral Response Function (ISRF) and inducing pseudo noise in front of atmospheric scenes. It was identified that the modelled microvibration level could have a non-negligible impact on performance and then a campaign on EM Instrument was relevant. EM instrument was also the opportunity to perform first functional tests and to validate the flight software with this EM version and to anticipate the adaptation and corrections to be done on PFM version. To finish, EM Instrument was also delivered to Satellite for validating the test procedures on a simulator and preparing the PFM campaign.

In parallel, the Instrument PFM campaign was on-going with the step-by-step integration and alignment of optical parts on I-OH and electronics subunits on I-EM. A global qualification at instrument level has been performed: mechanical environment and Thermal Vacuum (TVAC), radiated EMC (conducted EMC done on EM instrument), and performance qualification. The performance is verified in two steps. First at ambient, detector cooled, mainly for the geometric performances; and the second one during the TVAC for the spectral and radiometric performances.

### 4. EM INSTRUMENT CAMPAIGN

#### 4.1 Critical Subunits qualification

The EM FPCA and interferometer qualification has been already presented in ref[2]. We will just recall the main outcomes.

EM FPCA allowed validating the overall concept with regard to thermal and mechanical environment as well as the cooling capacities. After alignment, specific sequence with EM detectors cooled validated also the preliminary radiometric performances and the radiated field susceptibility (auto-compatibility).

The interferometer show very stable optical and dynamic characteristics after environment tests (thermal and mechanical). During thermal environment simulating worst non-operational case, the thermal gradient and slopes inside the KBr mounts (prisms and beam splitter) were as predicted and well in the limit fixed to prevent from any material injury. The mechanical tests confirmed the integrity of KBr prisms up to ~20g.

#### 4.2 Microvibration campaign

An end-to-end microvibration campaign was performed mainly on EM Instrument and EM interferometer, as illustrated on Figure 3.

Proc. of SPIE Vol. 12777 127771U-6



chain filtering have shown a great efficiency to reject perturbation, no susceptibility could be evidenced, promising no parasitic spikes from METOP-SG electronics or other instruments.

First functional tests with representative SW allowed identifying some minor anomalies and corrections/adaptations to be applied on final PFM SW. After delivery to Satellite team end of 2021, the procedure validation campaign on a Satellite simulator was a success, allowing preparing the PFM activities.

## 5. PFM INSTRUMENT CAMPAIGN

### 5.1 Critical PFM Subunits verification

PFM FPCA and Interferometer validation campaign have been described in ref[2].

Concerning FPCA, the radiometric performances were compliant with the expectations. A first set of IPSF figures was also measured (see Figure 5).

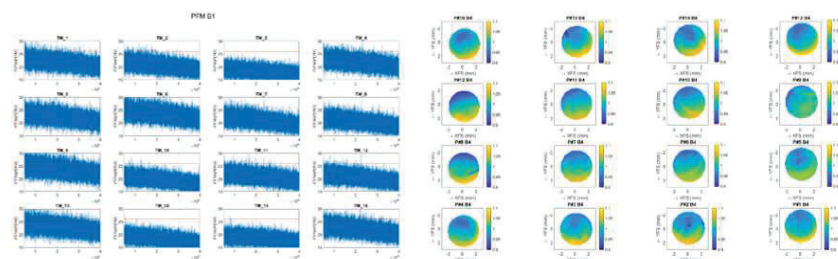


Figure 5: B1 noise measurement (left) and B4 IPSF (right) on the 16 FPCA sounding pixels.

At interferometer level, the spectral performances were assessed under thermal vacuum in Gaïa vacuum chamber with different sources including a laser @  $3.76 \mu\text{m}$  and a gas cell (see Figure 6). In particular, the absolute spectral calibration and its stability were excellent and well in line with the predictions. It is already confirmed in B4 that the relative stability will be better than  $5.10^{-7}$  and the a posteriori relative spectral error below  $1.4.10^{-6}$  (limitation of the measurement accuracy being around  $1.5. 10^{-6}$ ).

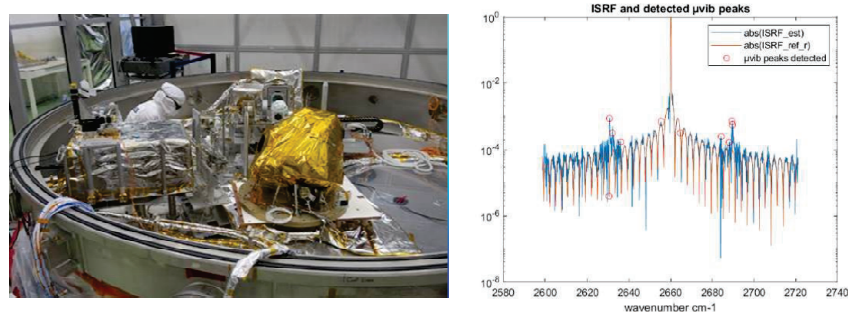


Figure 6: PFM interferometer in Gaïa chamber (left) and ISRF measurement (right).

After this thermal vacuum test,  $\pm 1g$  measurements allowed confirming the order of magnitude of necessary beam splitter adjustment with regard to orientation at satellite level and with no gravity (less than  $200\mu\text{rad}$  of wavefront tilt variation).

## 5.2 Instrument integration and alignment

After integration and fine alignment of optical units (telescopes, FPCA, Interferometer), they are integrated one by one on the I-OH optical bench. First, the FPCA, then the interferometer, the ITA, the ATA, the scan mirror, the imager, and to finish the calibration sources. The overall alignment is performed through dedicated reference cubes. The Figure 7 illustrates an intermediate step just before integrating the ATA.

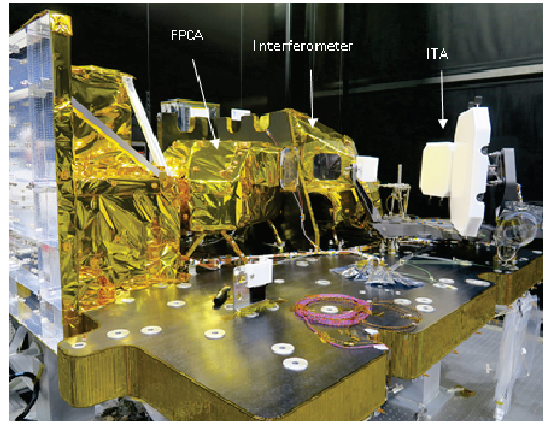


Figure 7: I-OH before ATA integration

After integration, the metrology emission and receiving beams have also been verified to present sufficient margins to insure robustness to mechanical or thermoelastic moves in order to guarantee instrument operations and nominal post processing corrections.

## 5.3 Mechanical qualification

Quasi-static, sine and acoustic qualification of the instrument was performed in december 2021 and separately for the 2 modules as shown on Figure 8.

During acoustic test, the specified levels were passed with success and the instrument behaviour was as expected. During sine test, the instrument response was very close to the prediction and the maximum authorized level was passed on the most sensitive parts. In particular for the KBr prisms for which this maximum level was confirmed after Interferometer EQM qualification (around 20g).

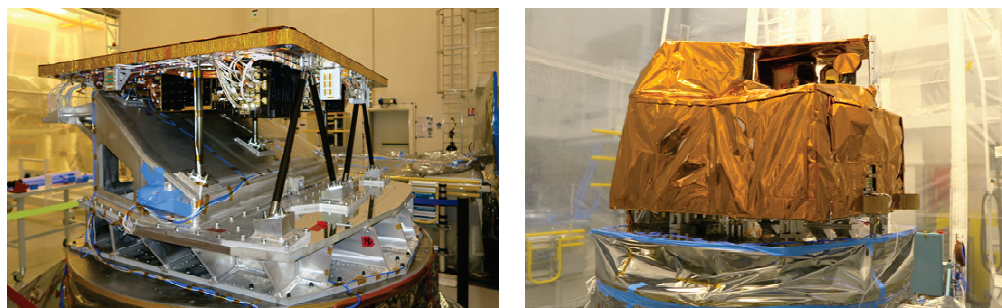


Figure 8: Instrument I-EM (on left) and I-OH (on right) modules under sine qualification.



After mechanical tests, the Hardware integrity was checked, in particular the mechanisms and the overall optical alignment. Scan and Interferometer mechanisms showed very stable functional behaviour.

Overall, optical alignment was confirmed as nominal through reference optical cubes. Interferometer showed a wave front tilt variation of around  $150\mu\text{rad}$ , well below the value derived from EQM interferometer qualification. The beam splitter has been well re-aligned with the on board dedicated actuator. To finish, the metrology beams remain well aligned, confirming the overall robustness of optical design with regard to the mechanical environment.

#### 5.4 Functional tests and ambient tests

Ambient test is the first performance test performed on assembled PFM Instrument. The purpose is to have a full geometric characterization, including: LOS measurement of each Sounding Pixels for coregistration with the imager, Instrument Point Spread Function (IPSF), inter-pixels crosstalk, far field induced signal. Functional tests were performed just before to identify potential SW issues, and did not reveal any blocking point.

The ambient test used dedicated OGSE with 3 mirrors collimator, blackbody source, and different optical masks. Installation of this OGSE is illustrated on Figure 9.



Figure 9: Ambient test set-up installation in front of the instrument

The test was run successfully in May 2022 and results are still under analysis to compute the different geometric characteristics. Nevertheless, we can highlight the main preliminary encouraging results. First, it is confirmed that the overall alignment is excellent, without any vignetting neither decentering. Then, a first assessment of microvibration was done by analyzing the wavefront tilt variation through the metrology. It confirmed the very low level of microvibration compared to the CDR predictions with amplitudes less than  $1\mu\text{rad}$  as shown on Figure 10.

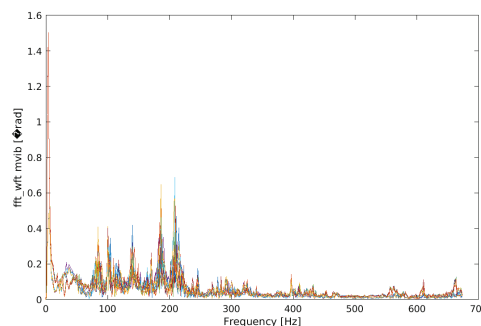


Figure 10: wavefront variation tilt induced by microvibration (in  $\mu\text{rad}$ )

The first instrument raw spectrum acquired in clean room over the 4 bands was obtained on this occasion and is presented in Figure 11.

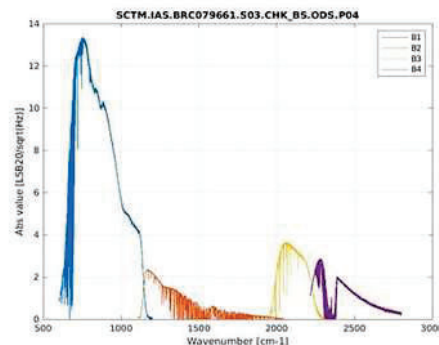


Figure 11: First IASI-NG raw spectrum

### 5.5 Thermal vacuum test

The thermal vacuum test occurred during June-July 2022, with the main objectives to proceed to the thermal qualification of the instrument and to assess the full spectral and radiometric performances.

This test required quite impressive thermal and optical installations in the so-called Gaïa vacuum chamber at Airbus Defence and Space premises (see Figure 12). Several targets are used for instrument characterization. Two warm black bodies, a Gaz Cell for the spectral calibration, and 8 laser sources (2 per band) for spectral calibration and ISRF shape. To be noticed that three cold black bodies are also used, one for the cold calibration in front of cold space view, and two others associated to Fabry Perot and Gas Cell views.

From thermal point of view, this test allowed to qualify the instrument compliance to the interface requirements with hot and cold non-operational configuration and one hot plateau and one cold plateau.



Figure 12: Gaïa chamber with targets (left); with instrument and thermal tent installation (right)

All the measurements done are still under analysis. Fabry Perot and Gas Cell views acquisitions are presented in Figure 13 with the corresponding spectral signatures (respectively lines comb and gas chemical components absorption lines).

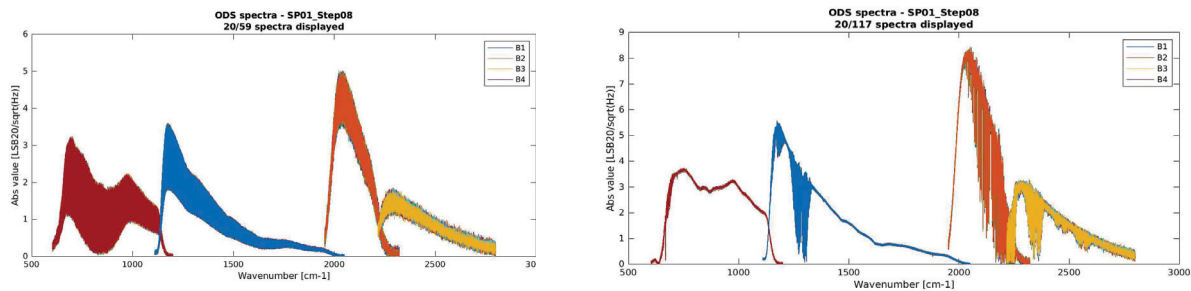


Figure 13: Fabry Perot (left) and Gass cell (right) views measurement

The spectral acquisitions with laser sources do not show any apparent parasitic interferogram, indicating that the optical diopter wedges and tilts have been well specified, as shown on Figure 14.

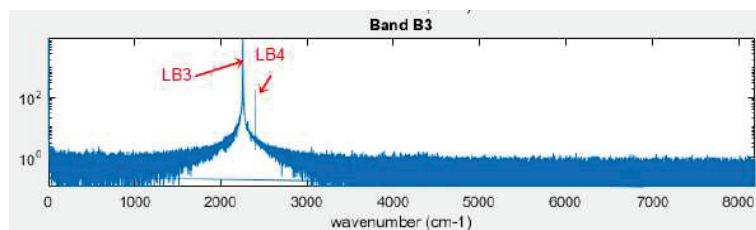


Figure 14: B3 laser spectrum (showing the two B3 and B4 laser wavelength peaks)

It is also confirmed that the microvibration levels due to internal contributors are very low.

To finish, fine radiometric performances (NedT and absolute calibration) will be derived from the acquisitions with the hot black bodies at different temperatures. First NedT raw assessment @300K gives very encouraging results, and it is a major milestone as it is the first end-to-end radiometric verification.

## 6. CONCLUSIONS AND FUTURE ACTIVITIES

The overall development plan recalled in Figure 15 allowed overcoming the different challenges and being able to deliver the PFM Instrument beginning of September 2022 (current expecting date) with an appropriate level of qualification. The performances will be attentively reviewed after fine analysis before end of 2022, but are well secured considering all the available information from the different test campaigns.

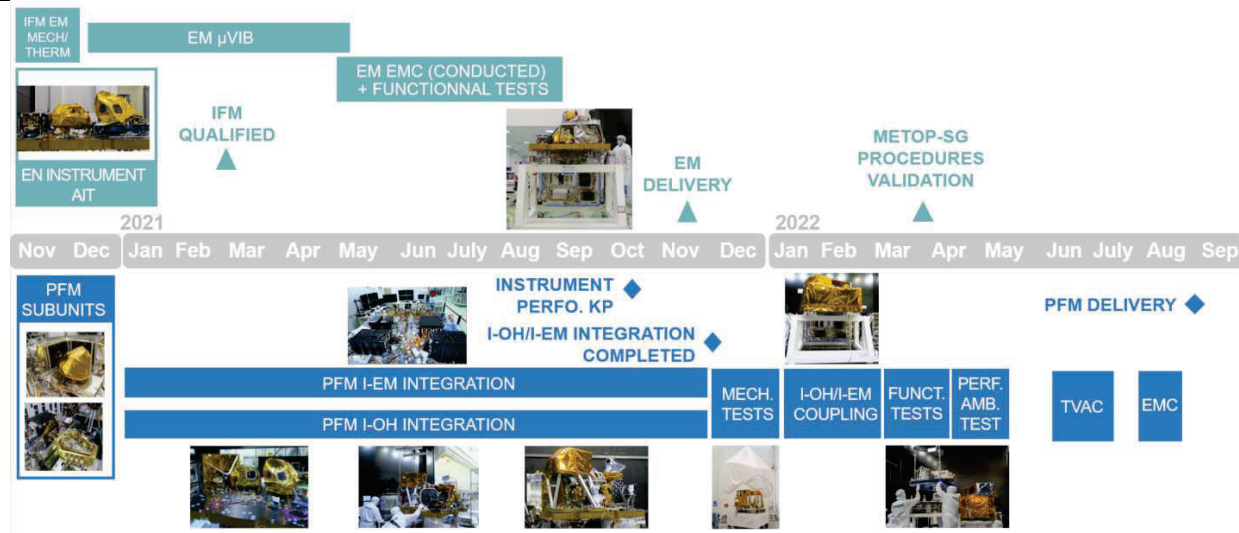


Figure 15: Overall development plan synthesis

At Satellite level, mechanical environment campaign will be performed end of 2022, and TVAC during first quarter of 2023. In parallel, the FM2 development is well advanced, with all HW available. FPCA is integrated and aligned and the performance test verification is foreseen in October 2022. Interferometer completion is foreseen end of October 2022 (current expectation) and ambient test in November. The FM2 TVAC is foreseen end of 2023/beginning of 2024.

FM3 subunits are also available, and FM3 instrument delivery is expected end of 2024.

## REFERENCES

- [1] Calvel, B., Bernard, F., “IASI-NG development status” Proc. ICSO Conference, Oct. 2018.
- [2] Calvel, B., Penquer, A., “IASI-NG development status” Proc. ICSO Conference, Oct. 2020.