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TRISHNA TIR instrument development and performance status

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TRISHNA TIR instrument development and performance status

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ABSTRACT

The TRISHNA program marks a step further in the fruitful cooperation built between CNES and ISRO since many years, through a new Earth observation mission dedicated to the improvement of water cycle understanding and water resource management. Thanks to its unprecedented high spatial resolution in the thermal infrared domain, together with a high revisit frequency, TRISHNA mission will significantly contribute to the detection of ecosystem stress and to the optimization of water use in agriculture in a context of global climate change.

The TRISHNA payload is composed of two principal instruments: the VNIR-SWIR imager provided by ISRO, and the TIR (Thermal InfraRed) imager. CNES is responsible for the TIR instrument development with Airbus Defence and Space as a prime contractor. The targeted launch date for TRISHNA satellite is 2025, being then positioned as a precursor of the LSTM Copernicus mission from ESA.

This paper presents a status of the TIR instrument development, currently in phase C after a successful Preliminary Design Review in 2021. The equipment development status is detailed, and the progress of validation activities at Airbus level is addressed, focusing on the tests at detection laboratory with a full detection chain including a Development Model (DM) detector, and the preparation of the extensive test campaign to be done on an Engineering Model (EM) of an equipped cryostat (including EM detector, filters, and cryocoolers).

An overview of the instrument predicted radiometric, spectral and geometric performances is also presented, as well as some measured elementary performances already available on FM optics.

Keywords: TIR, TRISHNA, thermal infrared

1. INTRODUCTION

1.1.1 TRISHNA mission requirements

From the global scale to much more regional scales, water is both an essential element for life and the main vector of heat exchange in the meteorological and climate system. Today, the change in temperatures and rainfall regimes, combined with the continuous increase of water use for irrigation over the past decades, leads to a more frequent scarcity of freshwater reserves. In this context, TRISHNA mission [1; 2] addresses scientific, economic and societal needs linked to the monitoring of ecosystem water stress and the optimisation of water resource management, which is mainly driven by the agricultural use (70% of global freshwater use).

The key climate variable to be retrieved from TRISHNA measurements is evapotranspiration. To access it, the surface temperature and its dynamics are precise indicators of the evaporation of water from soils, transpiration of plants and of the local climate.

Besides the water stress monitoring, TRISHNA surface temperature data are also very interesting for the study of coastal and inland waters. Additional scientific or applicative themes as cryosphere, solid Earth and urban ecosystem monitoring will also benefit from the TRISHNA data.

In order to fulfil these objectives, TRISHNA mission must combine high spatial resolution in the thermal infrared domain and high frequency acquisitions.

A global coverage is required, with a full resolution of 57m at nadir over all continental land surfaces (including inland waters) and coastal waters up to 100km from the shore. The chosen orbit has a cycle of 8 days, at an altitude of 761 km. The large swath of +/-34° corresponding to a field of more than 1000 km gives access to a revisit frequency of at least 3 acquisitions per 8-day period, depending on the latitude.

The total spectral domain of the mission covers 11 bands from visible to thermal infrared. The TIR instrument is dedicated to the thermal infrared domain, with 4 spectral bands which are used for emissivity and surface temperature retrieval.

Band name	Wavelength Center (µm)	FWHM (µm)
TIR 1	8.65	0.35
TIR 2	9.0	0.35
TIR 3	10.6	0.7
TIR 4	11.6	1.0

Table 1. TRISHNA TIR spectral bands requirements

A high radiometric performance is required for the TIR instrument, with a radiometric noise better than 0.2K in the most demanding bands, and an absolute radiometric calibration accuracy better than 0.5K. The specified lifetime is 5 years.

1.1.2 TRISHNA system overview

The TRISHNA mission (Thermal infraRed Imaging Satellite for High-resolution Natural resource Assessment) is a cooperation between the French (CNES) and Indian (ISRO) space agencies. The Figure 1 illustrates the sharing of responsibilities between CNES and ISRO.

TRISHNA space segment is composed of a platform based on IRS-1k developed by ISRO, carrying the VNIR/SWIR instrument under ISRO responsibility and the TIR instrument under CNES responsibility. The TIR instrument development contract has been awarded to Airbus in 2020.

On the ground segment side, the command and control center is under ISRO responsibility. The processing of science data coming from both TIR and VNIR-SWIR instruments is done by two mission centers, one at CNES and one at ISRO, each one generating and distributing products up to Level 3.

The launcher and launch services are provided by ISRO. The targeted launch date for TRISHNA satellite is 2025, being then positioned as a precursor of the LSTM Copernicus mission from ESA.

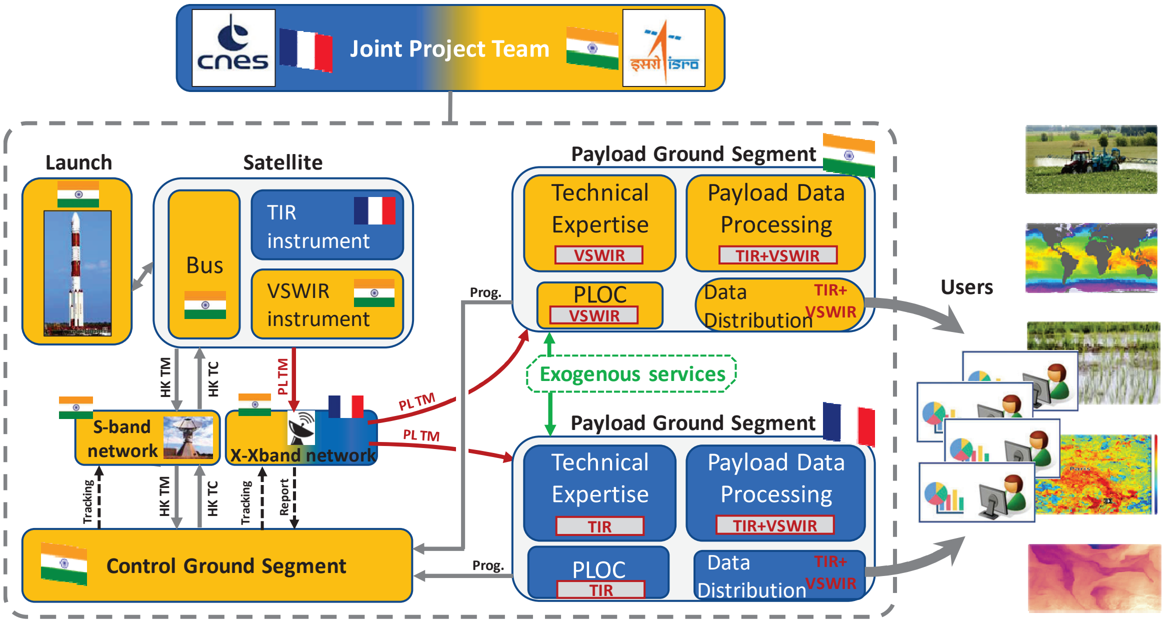


Figure 1. TRISHNA system architecture

2. TIR INSTRUMENT DESCRIPTION

2.1.1 Instrument functional overview

The TIR instrument is based on a scanner concept imposed by the large required swath of +/-34° and the limited detector array length of TIR detectors. The scan mechanism continuously rotates the entrance plane mirror so that the telescope optical FOV scans the full swath over the so-called Basic Repeat Cycle (BRC), as well as an internal warm blackbody target and a deep space view. The collected optical beam is focused on the focal plane by a Three Mirrors Anastigmatic (TMA) telescope. A field lens just in front of the focal plane guarantees the same beam incidence on each of the four strip filters to avoid spectral de-centering effect.

The detector and filters are cooled down to 60K (nominal working point) through a Cold Thermal Link by two cryocoolers LPT6510 in hot redundancy. This cold optical assembly is thermally insulated from the rest of the instrument by a cryostat using Additive Layer Manufacturing (ALM) technology. The detector outputs data to the TRISHNA Front End Electronic Module (TFEEM) through a flex allowing to minimize thermal heat leaks. The instrument Control Unit (ICU) controls three downstream electronic modules dedicated to: mechanism drive (MDE), Cryocooler Control (CCE), and detector signal read-out and digitalization (TFEEM). It also acquires and controls the Black-body absolute temperature, ensures data processing and instrument operational thermal control. Each of the two CCEs driving a Cryocooler Mechanical Assembly (CMA) is driven by both ICUs to ensure hot redundancy cooling.

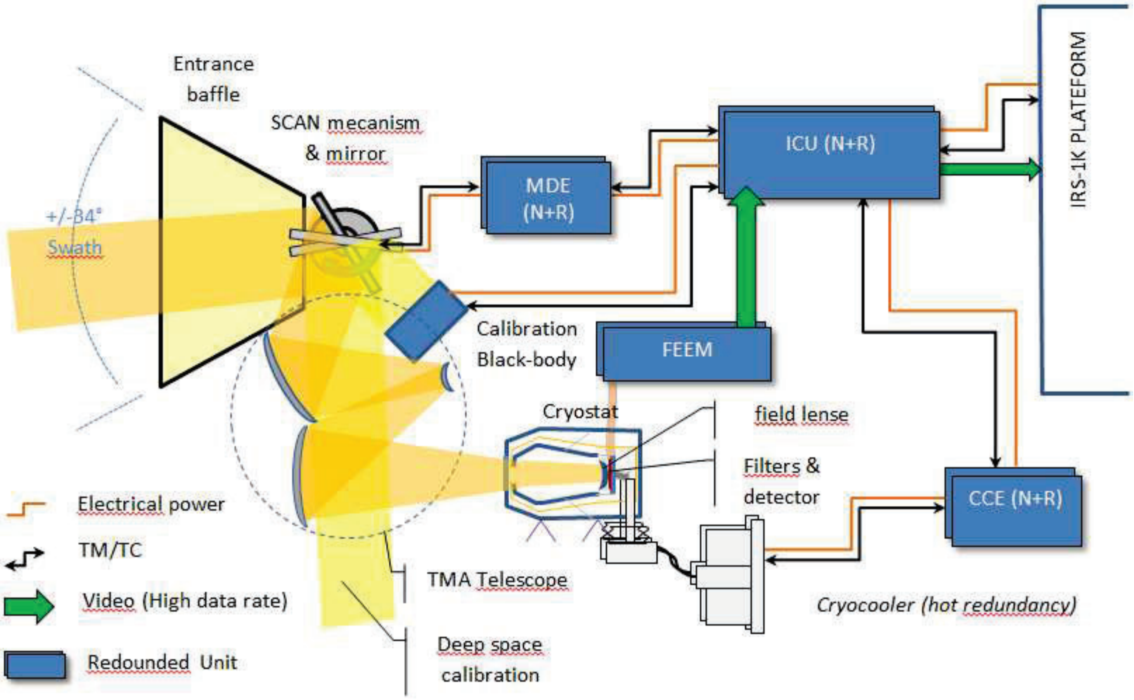


Figure 2 : TIR instrument functional overview

2.1.2 Detector

The LYNRED four-band Mercury-Cadmium-Telluride (MCT) detector features two monoliths with different stoichiometry for SNR optimization: 10 µm cutoff (for TIR1 and TIR2) and 12.7 µm cutoff (for TIR3 and TIR4) at 60 K. In practice, the inter-band distance is 4 mm across track. The detector is composed of 600 pixels along track. For each spectral band, each of the three available Time Delay Integration (TDI) stages is composed of four pixels, the best one being selected among four.

2.1.3 Optical configuration

The TIR instrument implements a reflective optical configuration favoring general accommodation and stray-light mitigation. The GSD is adapted to the detector 30 µm pixel size thanks to a tilted three-mirror anastigmatic (TMA) telescope providing the adequate focal length, an intermediate focal plane and an aperture stop placed at cryostat entrance which acts as exit pupil. The 150 mm equivalent diameter entrance pupil is fully adapted to the existing blackbody product. A field stop is placed at the intermediate focal plane, limiting the stray light levels. All mirrors are coated with bare gold to optimize the instrument transmission in the useful TIR spectral range. A ZnSe field lens enclosed in the cryostat ensures the same beam incidence on each filter for each detector pixel.

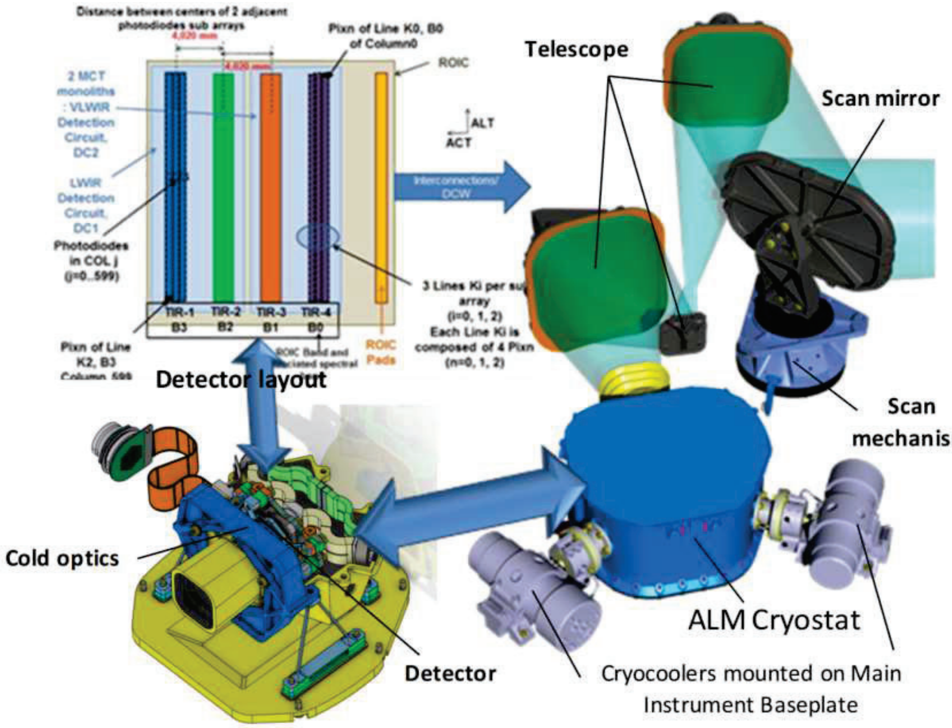


Figure 3: LYNRED detector layout and TMA telescope optical configuration

LYNRED detector ROIC and detection circuit topology with 4 bands of 600 pixels each (up to 3 TDI stages per band) is dedicated to TRISHNA TIR instrument and can be reused for TIR imaging missions.

2.1.4 Scanning and calibration

The scan mirror is mounted on a scan mechanism and its drive unit inherited from other program and reused with an adapted control loop. Angular position restitution is done by an encoder. The Basic Repeat Cycle (BRC) baseline duration is around 5 sec. After swath scan, the mirror continues its rotation journey until black-body angular position passing in front of the deep space calibration port during outward and return journey. Deep space and black-body acquisitions are performed during each BRC after the earth scene scanning period, allowing to update the gain and offset correction coefficients in the ground processing every 5 seconds for each pixel.

The black-body (fully recurring flight model from IASI-NG) is passively maintained around 293K, and the absolute temperature seen by each band of the detector is known with an uncertainty lower than 50 mK (NEDT) thanks to high precision dedicated temperature measurement chain.

2.1.5 Main mechanical and thermal architecture concepts

The TIR instrument mechanical architecture is designed as three main sub-systems:

- The interface frame responsible for the instrument mounting via feet bolted along its perimeter on the platform interface plateau.
- The Electronic Equipment module composed of the Main Instrument Baseplate (MIB), designed as a box including the electronic units. The MIB supports also the radiators and two phase thermal hardware. The MIB is mounted on the interface frame circumference via numerous pods dispatched, guaranteeing TIR instrument mechanical and thermal insulation from the platform.
- The optical subsystem, which includes the optical bench supporting all optics including detector and cold optics inside the cryostat, the TMA telescope, the scan mirror and mechanism. It is mounted on the MIB by three bipods.

The TIR instrument thermal control is based on:

- An optical bench thermal regulation at 20°C to guarantee the line-of-sight (LOS) stability needs.
- Detector and filters cooled down to 60K within the cryostat through cryocoolers in hot redundancy. The detector temperature is maintained at 60K even with a single active cryocooler. LPT6510 cold finger and compressor are cooled by the radiator located on +Z panel through heat-pipes.
- Electronics thermal control, the MIB servicing as thermal conductor between the supported equipment and the +/-Y radiators.
- MLI insulation from platform on –X side, and from the external space environment on +X side.

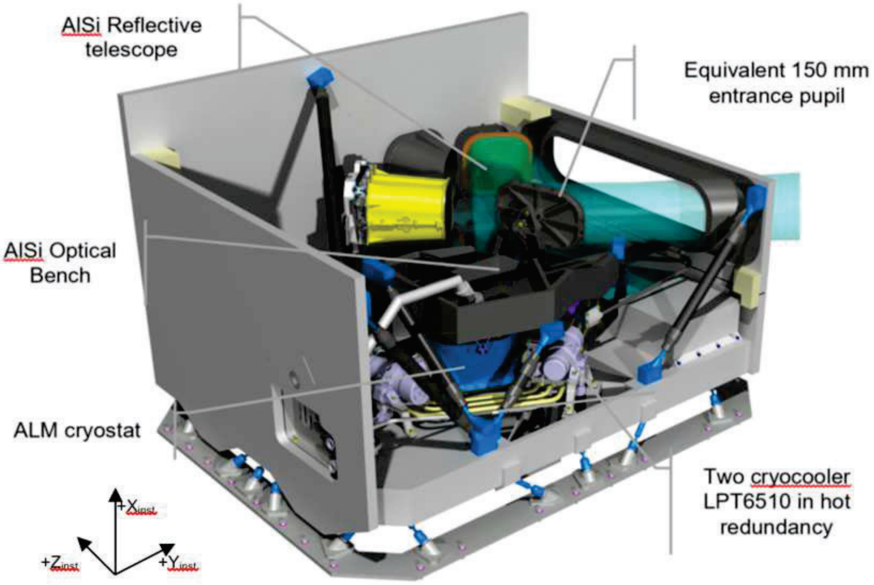


Figure 4 : TIR instrument key features

3. TIR INSTRUMENT DEVELOPMENT STATUS

3.1.1 Global instrument development status

The TIR instrument development by Airbus was started beginning of June 2020. It is developed throughout a classical schema top-down Preliminary Design Review (Instrument PDR before equipment's PDR) and a bottom-up Critical Design review (instrument CDR to be closed after all equipment's CDRs). The instrument PDR was held in mid 2021. Then phase C started immediately with equipments preliminary design reviews, cryostat and main structures detailed design. Phase C implements also all remaining de-risking activities before the instrument proto-flight model (PFM) assembly to be started with the telescope on optical bench in the end of 2022. The derisking activities are mainly:

- The filters support mock-up,
- The ROIC and detector DM testing in Airbus detection laboratory,
- The EM Flat Instrument,
- And the EM cryostat.

As shown by the three photos of Figure 7, the filters selecting the four thermal bands so-called TIR1 (8.6 µm) to TIR4 (11.6 µm), are directly mounted in the filters support. The latter is itself mounted on a specific baseplate also supporting the detector. As the filters working temperature is close to the detector one (i.e. 60K or lower), the filters support design must guarantee integrity and proper mechanical stability of the filters (mainly made out of Germanium) from ambient to operating working temperature (60K). That is why a mock-up was developed since phase B and was tested in July and August 2021. It demonstrated that after 12 representative thermal cycles and conservative mechanical environment test, filters integrity is fully guaranteed, and their mechanical stability is much higher than the need. This confirmed after cryostat design review performed in September 2021 (and all ALM part validation performed before instrument PDR), that cryostat EM manufacturing could start.

Filters support Breadboard assembled

Filters support BB thermal cycling under vacuum

Figure 5 : Filters support breadboard test

The ROIC tests performed in Airbus premises are the first detection chain coupling tests checking successfully the ROIC proper behavior when driven by the EGSE specifically developed by Airbus for detector component. These tests demonstrated measurements in line with supplier's one. Then, the ROIC was coupled to the TFEEM, and showed again adequacy of the proximity electronic to the ROIC electrical interfaces. At the time of writing this article, all tests on a DM detector model are fully performed, and post processed, confirming the good electro-optical performances measured by the supplier LYNRED (see details in §4.1.2).

In parallel, a flat instrument model was started by June 2022, thanks to the delivery by STEEL Electronique of a reduced ICU model called "ICU EM Light" associated to a preliminary flight software, with the objective to allow as early as possible a coupling to the main instrument functions: cryocooling with the CCEs, detection chain management and science data processing with TFEEM and scanning with the MDE. Coupling tests with CCE are performed until end of July 2022, while TFEEM coupling is checked in beginning of September. MDE Bread-board coupling is expected by the end of 2022.

The Cryostat EM is the main model before PFM as it demonstrates in a flight representative manner, the full functioning and performances of the EM detection chain from telescope optical beam input in the cryostat, until ICU science data output. So, it allows before PFM to check radiometric performances like total background, geometric stability of the pixels with respect to the instrument frame, and also spectral performances. The Cryostat EM is also the first model verifying the adequacy between cryocoolers heat-lift expected working point and cryostat thermal budget corresponding to detector dissipation added to all conductive and radiative heat leaks.

As stated here above, all focal plane mechanical parts and also surrounding EM cryostat parts were manufactured from October 2021 to Summer 2022.

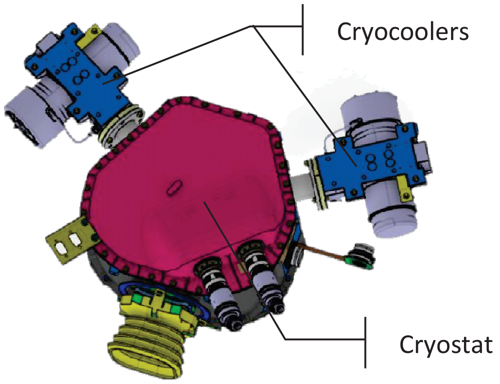


Figure 6 : 3D view of the Cryostat EM assembly including cryocoolers

First, the cold focal plane was assembled starting by the four filters in their support, detector EM mounting on its baseplate, and then global filter and detector assembly with a specific optical alignment of the filters useful area on the detector pixels lines. Then the cold optics were also added to the previous assembly in order to obtain in June 2022 the full Cold Focal Plane Assembly. Then, the CFPA was integrated progressively in the cryostat, with as usual a specific routing for the detector flex and thermal wires, with minimum mechanical alignment thanks to the use of ALM technology. EM cryocoolers delivery by end of August 2022 by Thales Cryogenics BV, allow their direct assembling and connection to the so-called Thermal Link Assembly EM developed and delivered by Absolut System. At the time of delivery of this paper, the final closing of the cryostat EM and start of tests is expected by mid-October. The test sequence comprises a thermal balance/ thermal cycling and performance test with cryostat vacuum pumped in ambient environment, followed by a mechanical test (vibrations and shock).

Filters support front side

Filters support rear side

Filters support vs detector

Figure 7 : Filters mounting on detector package

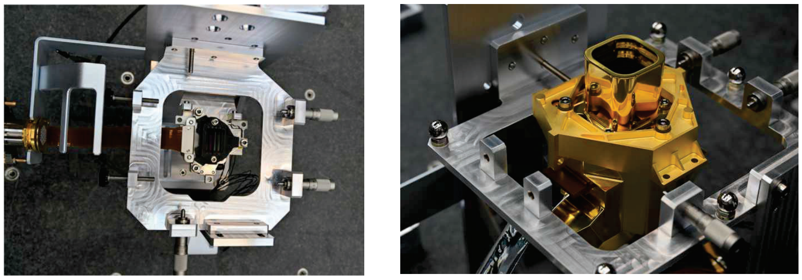


Figure 8 : Cryostat cold focal plane integration

3.1.2 Instrument performances status in phase C

The TIR instrument performances presented at this stage are calculated from predictions and EM and FM measurements.

3.1.2.1 Radiometric performances

The total noise of the instrument is calculated as the linear summation of the temporal noise due to the detection chain and the spatial noise mainly due to calibration error and spectral response knowledge. The total noise is expressed as the Noise Equivalent Differential Temperature (NEDT) for an average pixel in Figure 9. All pixels are within goal requirements after pixel selection (1 pixel among 4 is selected for each pixel of each band).

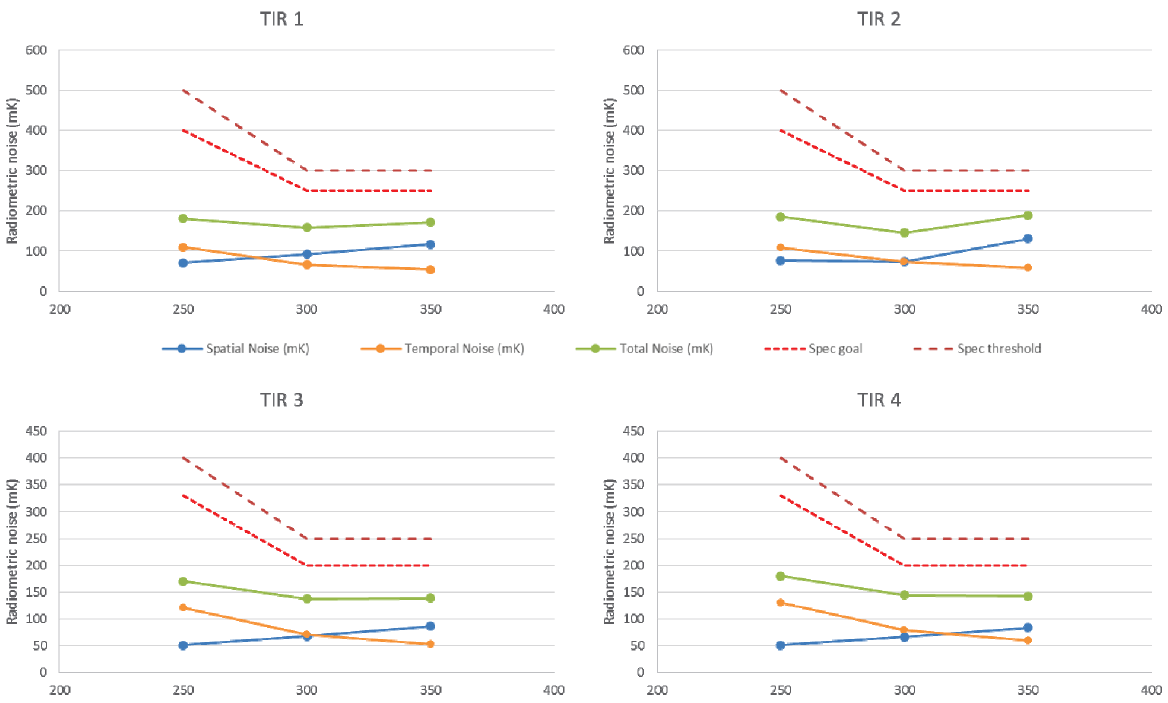
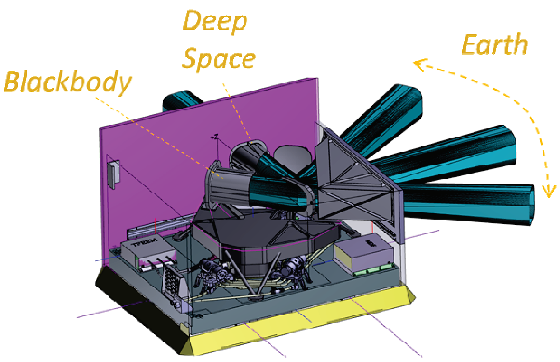
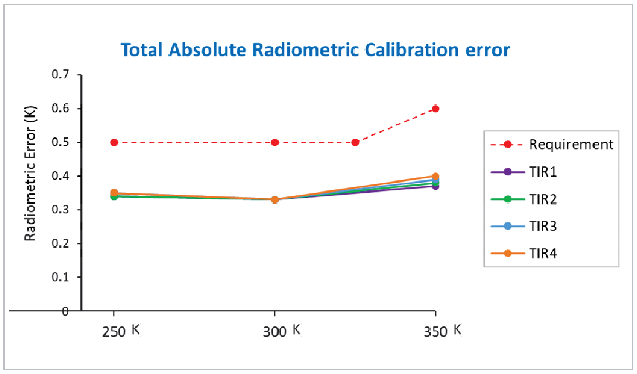


Figure 9 : Noise Equivalent Differential Temperature for all bands for an average pixel (abscissa is the scene temperature in Kelvin).

The TIR radiometric calibration is ensured by both the on-ground characterization and the in-orbit calibration. First, the on-ground characterization provides the detection chain linearity function, the instrument Spectral Response Function and the internal blackbody emissivity. Then, in-orbit, at every Basic Repeat Cycle (BRC), the calibration is ensured by the TIR acquisitions of the internal black body (which temperature is accurately monitored through ICU) and the deep space respectively as hot and cold reference targets. The temperature of the black body is accurately monitored in flight (less than 50 mK equivalent temperature) to ensure the proper calibration. The performances are within the specifications as shown in Figure 10.



In orbit Calibration principle



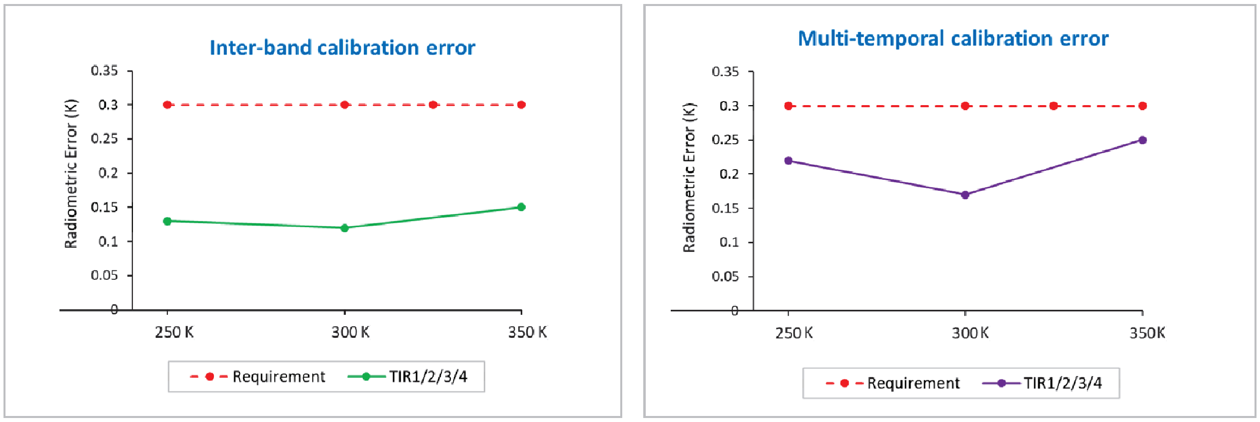


Figure 10 : Absolute Radiometric Accuracy performances

3.1.2.2 Geometric performances

The main geometric performances are the Ground Sampling Distance (GSD) of 57m at Nadir (ensured by a scene satellite distance of 761km), the overlap between 2 scanning strips which is higher than 12 pixels and the Modulation Transfer Function (MTF).

The main contributors of the MTF are the optical Point Spread Function (PSF) of the telescope and optical elements, the detector MTF, the smearing and the Time Delay Integration (TDI) desynchronization.

	TIR 1	TIR 2	TIR 3	TIR 4
Specification Min MTF	0.05	0.05	0.05	0.05
Min ACT MTF	0.13	0.13	0.11	0.09
Max ACT MTF	0.24	0.23	0.18	0.16
Min ALT MTF	0.19	0.19	0.16	0.13
Max ALT MTF	0.33	0.32	0.27	0.23

Table 2. Modulation Transfer Function at Nyquist frequency

The most challenging geometrical performances are related to the sampling regularity and the short term line of sight variations. The good performances in terms of detector pitch dispersion, the optical distortion, micro vibration levels, scan mechanism speed stability, detector and scan mirror alignment ensure a sampling regularity lower than 5% both along track and across track and short term line of sight variation lower than 0.6 pixels.

3.1.2.3 Spectral performances

The spectral bands shall respect the requirements defined in ***Table 3***. The inter-pixel variations of the Instrument Spectral Response Function (ISRF) must be minimized in order to ensure that all pixels of an image acquire the same spectral content. The required performance are ensured thanks to a very high spatial uniformity of spectral filters transmission and of detector Spectral Detection Efficiency (SDE).

The ISRF in ***Figure 11*** is calculated from FM filters measurements and typical detector SDE. The ISRF will be fully characterized on-ground at instrument level. First end to end measurements will be made during EM cryostat tests.

	TIR 1	TIR 2	TIR 3	TIR 4
λ eq	8.65 ± 0.1µm	9.0 ± 0.1µm	10.6 ± 0.15µm	11.6 ± 0.15µm
FWHM	0.35 ± 0.07µm	0.35 ± 0.07µm	0.7 ± 0.15µm	1.0 ± 0.15µm
In-field variations of spectral bands	0.20%	0.20%	0.20%	0.20%
Local variations of spectral bands	0.10%	0.10%	0.10%	0.10%

Table 3 : Instrument spectral requirements

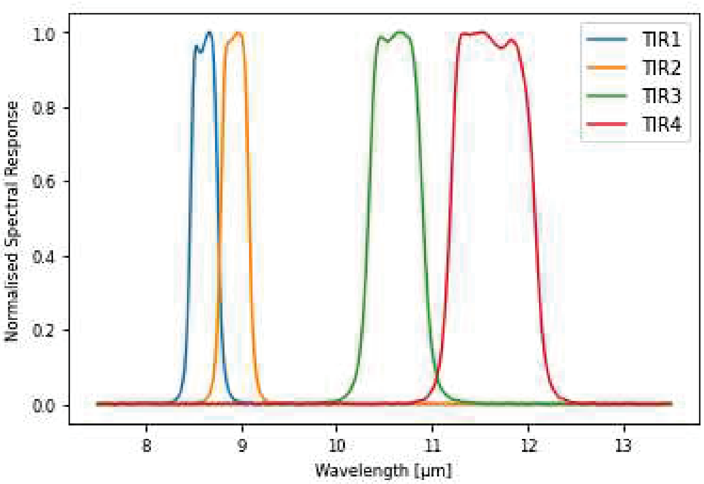


Figure 11 : Instrument estimated spectral response function

4. EQUIPMENTS DEVELOPMENT STATUS

As already presented, the TIR instrument requires the development not only of the full flight model, but also of progressive couplings and characterization of: the detection chain performed in Airbus dedicated laboratory, the EM cryostat and the electrical functional model, so-called flat instrument. Each of these instrument models requires the implementation of dedicated equipment's models, presented here after.

4.1.1 Detector DM and EM

The TIR detector is developed by Lynred to meet the needs of TRISHNA mission and initiate a versatile multilinear/multispectral product line for thermal infrared space applications [3]. The development started in 2019 under CNES contract with the design phase of the readout circuit (ROIC) and then continued within the TIR instrument program. The detector PDR phase was validated in September 2022 and the CDR phase is still ongoing with a completion target date in the last quarter of 2022. In the frame of TRISHNA development, a Demonstration Model (DM) and an Engineering Model (EM) were delivered by Lynred to Airbus respectively in December 2021 and March 2022. The DM is used to test the flight representative detection chain of the TIR instrument as exposed here after. The EM is, on the other end, integrated in the cryostat EM and it will serve as first step validation of the instrument performances.

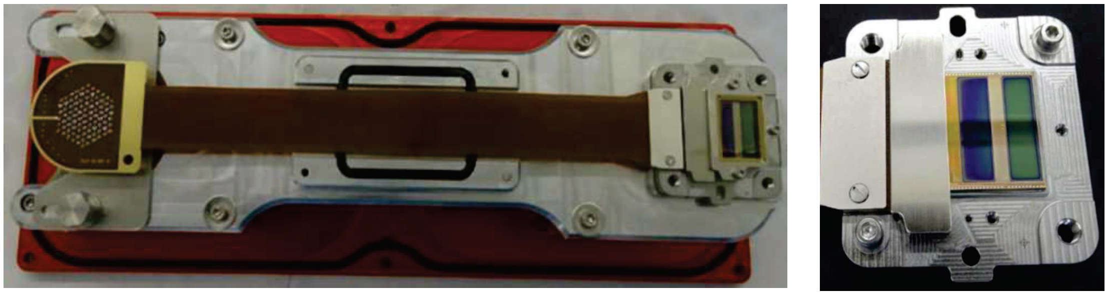
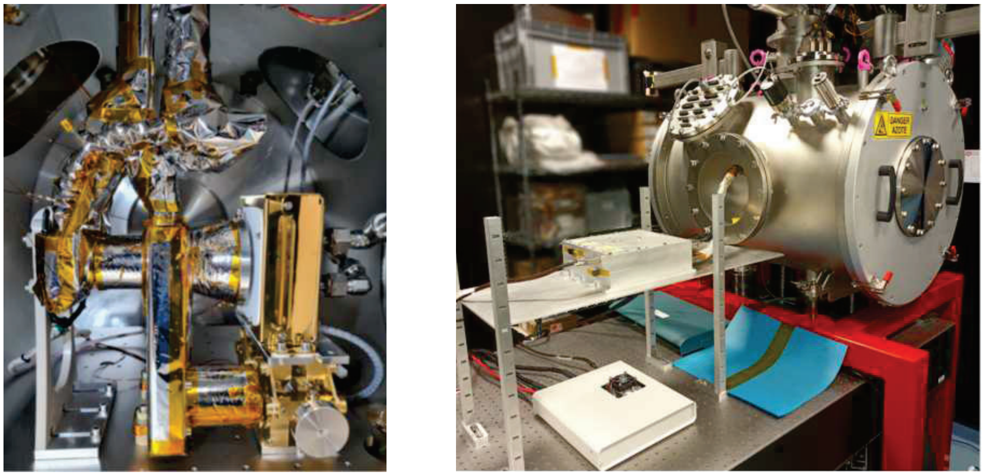


Figure 12 : Lynred EM Detector for TRISHNA TIR instrument

4.1.2 Detection chain

The TRISHNA detector is controlled and readout by the TRISHNA Front-End Electronics Module (TFEEM). After a one-year design phase, the PDR of this equipment has been validated in September 2021 and the CDR is foreseen in November 2022 with a flight model manufacturing review planned in September 2022. Three TFEEM models (breadboards (BB) and EM) have been developed and used for parallel validations at CRISA level and Airbus Toulouse level. The development philosophy of the detection chain consists in early validations of its functionalities and performances prior launching flight model manufacturing. To do that a specific lab test bench, depicted in Figure 13, has been developed at Airbus detection lab. It is composed of a cold-vacuum optical setup based on a DM detector assembly, cooled down to operational temperature (60K), and illuminated by a black-body through a cold shutter wheel, the readout front-end electronics is kept at ambient. The first validation phase consisted in electrical interfaces tests at ambient with a Lynred ROIC (ReadOut Integrated Circuit) coupled to Airbus' lab electronics. The next step consisting in characterizing the DM detector performances in operational conditions using Airbus' lab electronics demonstrated very good electro-optical performances. They will be confirmed in the coming months with a complete representative detection chain test campaign based on the TFEEM-EM coupled to the DM detector. A first TFEEM-Breadboard / detector coupling test was also performed. It confirmed all interfaces and the required functionalities. It has also been used to perform an EMC test campaign which preliminary results confirmed the detection chain robustness and compliance to the instrument environment.



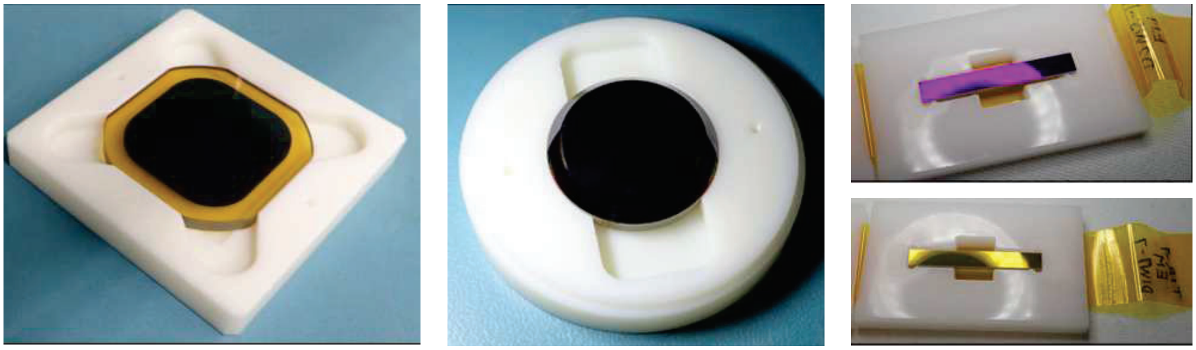
Cold-vacuum optical setup with DM Lynred detector

DM Lynred detector coupling tests with the TFEEM-BB1 in Airbus detection lab

Figure 13 : Detection tests testing at Airbus detection laboratory

4.1.3 Optics

The Cryostat includes Cold Optics presented in Figure 14 : the cryostat optical port so-called Anti-pollution Window (APW), the Field Lens responsible for telecentricity conditions (i.e. homogeneous optical beam incidence on each detector pixel avoiding spectral response bias from one pixel to another) and the filters for each of the 4 bands.



APW with its protection (EM and FM delivered by supplier)

Field Lens with its protection (EM and FM delivered)

Filters (EM and FMs delivered)

Figure 14 : APW, Field lens and Filters EM and FM manufactured

Field lens and APW are polished by ISP and are coated by Safran Reosc. A Coating delta qualification is under progress at Safran Reosc for adaptation to TRISHNA thermal range.

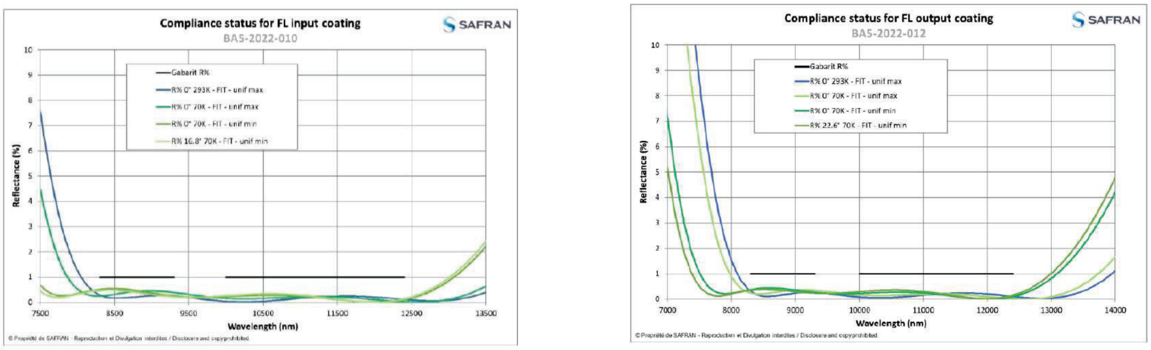
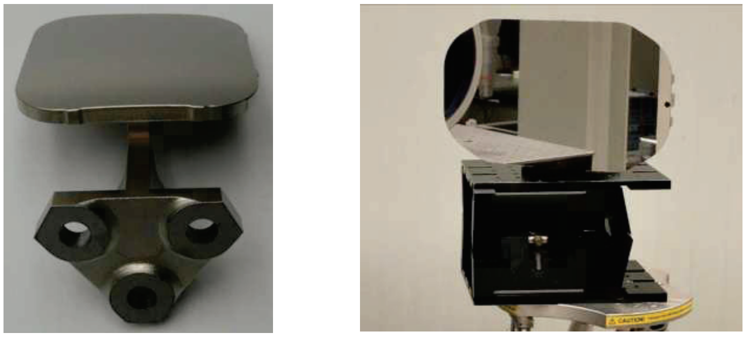


Figure 15 : Field lens transmission performance (Courtesy of SAFRAN REOSC)

The Field Lens anti-reflexion coating maximizes the transmission on the 8-12 µm wavelength range. The APW is responsible both for maximizing transmission in the 8-12 µm wavelength range, and minimizing the radiative thermal exchange between its two sides in order to minimize the cryostat thermal budget. These optical performances are reached by the Safran Reosc anti-reflexion and band-pass coating. Figure 15 demonstrates that anti-reflexion coating measurements on both side fulfil the reflexion requirement (1%) with comfortable margins.

The 4 filters (TIR1 to TIR4) were procured since the beginning of instrument phase B2 starting by a qualification review. EM filters where delivered in the first quarter of 2022 and directly mounted into the EM Cold focal plane. Consent to Ship was pronounced end of June for the FMs now delivered and stored by Airbus. All filters show good performance margins for transmission (> 0.82 for TIR 1 and 2, and 0.83 for TIR3 and 4) and spatial uniformity of spectral response.

The TIR instrument counts four AlSi mirrors bare gold coated supplied by Media-Lario: the flat scan mirror directly mounted on the Scan mechanism and the three free-form telescope mirrors. The detailed design of the mirrors was frozen for the Manufacturing Readiness Review in September 2021. Since that date, all mirrors were machined, diamond turned and NiP coated. In July 2022, both scan and M2 mirrors are fully polished with mirror surface error (MSE) better than requirement (50 nm). All mirrors are expected to be coated within November 2022.



M2 mirror before polishing

Polished scan mirror before bare gold coating

Figure 16 : AlSi mirrors : Scan mirror and M2 mirror (Courtesy of Media-Lario)

4.1.4 Scan mechanism

TRISHNA Scan mechanism beneficiates from a design already implemented on other optical instrument applications either for the pivot linkage or for the encoder function. Indeed, the TIR instrument inherits from IASI-NG where it is used for both scan mirror and interferometer movements. The encoder function is also fully inherited from MicroCarb's one, with a closed loop position control law adapted to TIR Instrument geometric performances requirements.

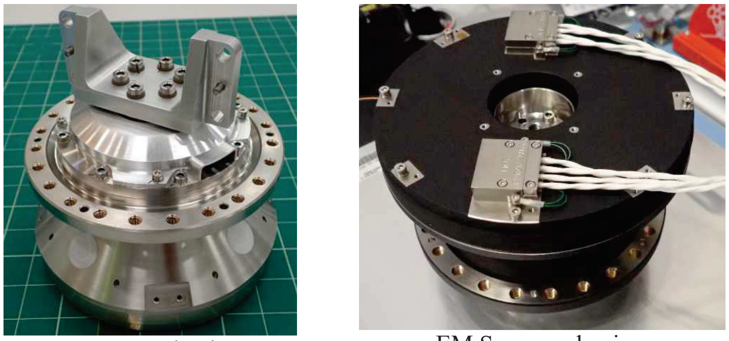
Through an EQSR held in autumn 2020, it was demonstrated that IASI-NG program covers TIR instrument main qualification needs except for mechanical shocks, and life-time where IASI-NG heritage covers globally the needs (number of cycles, angular range, velocity, Basic Repeat Cycle (BRC) sequence) by several partly representative lifetime-tests for the bearing. It was then decided at the beginning of the program to perform a bearing life-time test corresponding exactly to the TIR instrument BRC. Indeed, the scan mechanism equipment counts mainly four models and two breadboards: the Structural Model (SM), the Bearing Life-Time Test model (BLTM), the Engineering Model (EM) and the PFM. The breadboards concern early wobble (BBW) and encoder (BBE) performance validation, as required realized position and knowledge performance are between one and two orders of magnitude higher than for IASI-NG and MicroCarb applications.

The BBW dedicated to wobble validation in April 2021 showed very good results well below the allocation of 10 µrad for the impact of wobble on along track absolute pointing accuracy (total budget requirement of 50 µrad) and TIR overlapping repeatability (total budget requirement of 18.75 µrad over the BRC period of 5 sec). This wobble is to be confirmed by measurement on BLTM, EM and at the end on PFM. The BBE dedicated to encoder calibration method validation was integrated from May 2021 until February 2022. Tests confirmed the feasibility of sub-µrad stability and knowledge over the frame period, which is well compatible with instrument system requirements.

The SM was introduced to validate encoder mechanical integrity after the application of representative mechanical shock. These tests were performed successfully in December 2021.

The BLTM was procured (components) and assembled by Airbus during year 2021. It will be submitted to the following test sequence for the life time qualification of the bearings: wobble, mechanical environment including shocks, wobble and accelerated life testing (for an estimated duration of 1.5 year). Initial wobble tests performed in January 2022 confirmed BBW measurements.

At Scan mechanism CDR time (April 2022), the EM model manufacturing was initiated, and assembly was finished in July 2022. The EM mechanism is dedicated to wobble and encoder calibration stability monitoring through mechanical thermal cycling (under vacuum) environments. These tests are expected within the beginning of 2023. The EM mechanism, will also confirm by measurement that exported torques and exported micro-vibrations computed since the beginning of the program remain well within the specifications. A passive Anti-Rotation Device (ARD) guarantees that during the launch phase with maximum mechanical loads, the scan mirror is maintained in safe position. Then a fully flight representative ARD is integrated on the EM mechanism by mid-October 2022 in order to qualify the ARD performance in representative mechanical environment.


BLTM mechanism

EM Scan mechanism

Figure 17 : Integrated TRISHNA Bearing Lifetime Model (BLTM) and EM scan mechanism

4.1.5 Cryocoolers

The CryoCooling System (CCS) consists in two CryoCooler Units (CCU), each one made up of a Cryocooler Mechanical Assembly (CMA), a CryoCooler Electronics (CCE) and a pair of harnesses.

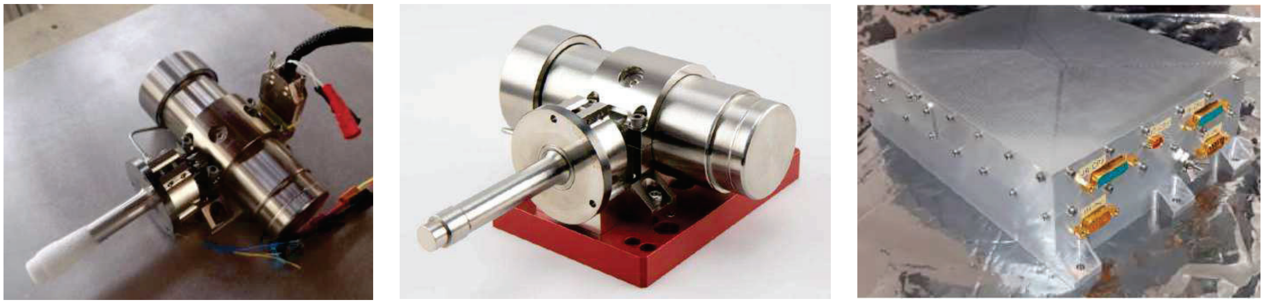
The CMA LPT6510 is a self-funded product developed by TCBV and Absolut System, enhanced in the frame of TRISHNA TIR instrument development to become a space product following the usual space standards and to meet the specific performance need of TRISHNA. The system is optimized to work at functional point 52 Hz / Rejection temperature -12°C / Cold tip at 57 K in hot redundancy.

After an EQSR held in October 2020 further development phases took place in order to reach the qualification of the LPT6510 completed in July 2022, including first magnetic moment characterization on such a product. A 6 years lifetime test will start in September 2022 to complete the development.

Development of the CCE is in progress; PDR is about to be closed in September 2022, although the qualification elements are on going on a CCE EQM model until October 2022. Concurrently, the software is following a lean development with TRB expected in October 2022.

Within the frame of TRISHNA TIR instrument development, two CMA EM (EM01 and EM03) were delivered in August 2022 for assembly in the Cryostat EM tests. The first CCE EM1 has been delivered to ADS in July 2022 and the second one is expected in September 2022. Another CMA EM (CMA EM02), allowed performing magnetic moment measurements in June 2022, and is ready to perform life-time testing starting from September 2022.

The two FM CCUs will be delivered in April 2023.



CMA EM2 during magnetic moment test CMA EM2 (Courtesy from Thales Cryogenics BV) CCE EQM (Courtesy from STEEL Electronic)

Figure 18 : TRISHNA Cryocooler LPT6510 Mechanical Assembly (CMA) and Control Electronic (CCE)

4.1.6 Structures & Cryostat

The TRISHNA TIR instrument main structural parts detailed design is now frozen including the cryostat and cooling chain, the Telescope and its optical bench (OB), the Main Instrument baseplate (MIB), the Interface Frame and the radiators responsible for cooling the electronics (+Y_{inst} and –Y_{inst} oriented radiators) and the cryocooling chain (+Z_{inst} deep space oriented radiator).

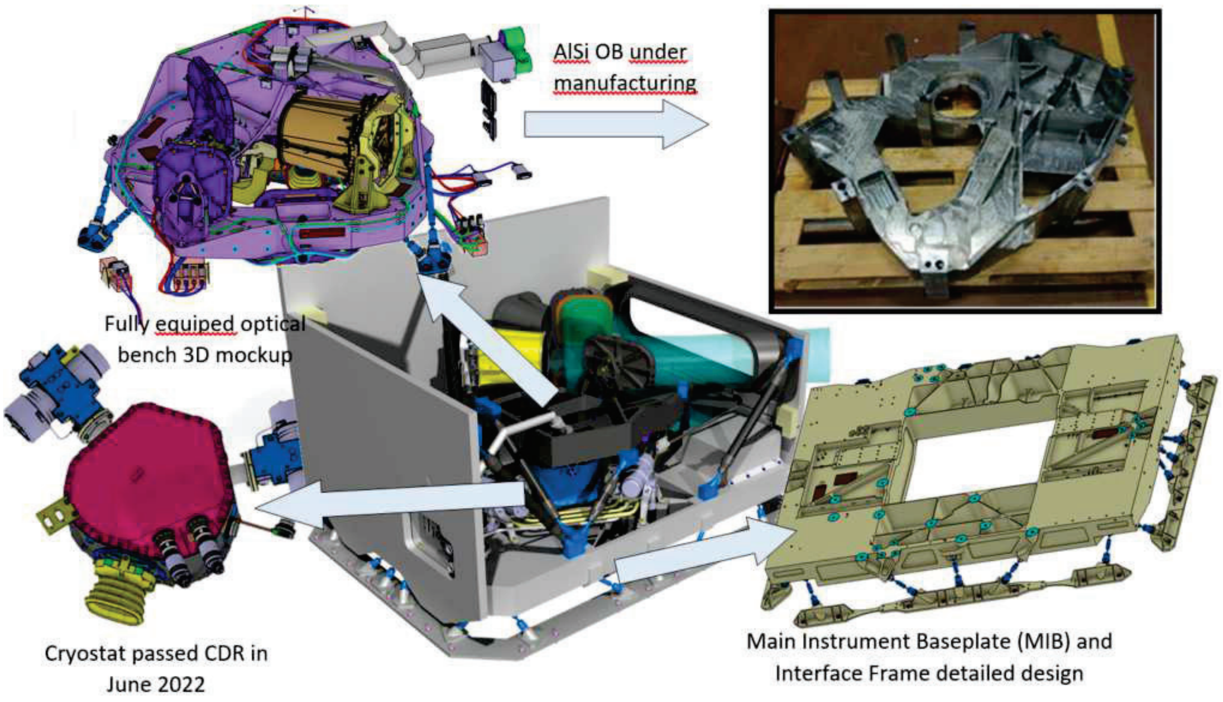


Figure 19 : TRISHNA Main Structures detailed design and manufacturing status

The OB detailed design was started before PDR and reviewed for CDR and MRR in March 2022. The manufacturing is currently in progress, as shown on Figure 19, and delivery to Airbus is expected in October 2022. The OB detailed design, authorized quickly after instrument PDR the beginning of the main structure MIB detailed design to be frozen through its MRR also within September 2022. The Cryocoolers cooling link to deep space radiator was also detailed and detailed design is now frozen. It considers three heat-pipes with multiple bending allowing direct coupling between cryocoolers cold plate interface and the +Z_{inst} oriented deep space radiator based on honeycomb panel externally covered with SSM coating. The latter's thermal efficiency is maximized thanks to several heat-pipes integrated into the honeycomb. From cryocoolers cold plate to deep space oriented radiator, the three heat-pipes insure cooling capacity considering redundancy. This means that two heat-pipes out of three guarantee both required heat-transport and thermal conductance between their hot and cold interface. The final cryocooler cooling assembly optimizes thermal efficiency, mass combined with mechanical design simplicity.

The Cryostat preliminary design was reviewed in Oct 2021, and a CDR was held in June 2022. An EM cryostat is under assembly until end of September 2022 as stated in §3.1.1.

Due to TRISHNA TIR instrument short development cycle, the FM cryostat design is already frozen at summer 2022, in order to allow all parts manufacturing cycle before integration beginning expected in the first semester of 2023.

5. CONCLUSION

At the present stage of instrument development, some significant steps have been achieved :

- first detector models are available and allowed to start the detection chain validation activities,
- cold optics and spectral filters (EM and FM) are available,
- scan mechanism key performances have been validated on breadboard models,
- cryocooler has been qualified for TRISHNA environment and EM models are available,
- the EM focal plane has been assembled and the integration of the full EM cryostat is ongoing.

The next activities will be the completion of electronic couplings via the EM "flat instrument" tests and the cryostat EM test campaign which is a major validation step for the consolidation of radiometric and spectral performances.

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