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Design, manufacturing, alignment and testing of the Geometrical and Spectral Test Assembly (GESTA) for the on-ground characterization of the MeteoSat Third Generation InfraRed Sounder (MTG-IRS)

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ABSTRACT

The Meteosat Third Generation is the new generation of European operational geostationary meteorological system. The MTG series will comprise 4 imaging (MTG-I) and 2 sounding (MTG-S) satellites. The MTG-S sounding satellites, whose development is led by OHB System (Wessling, Germany), will carry 2 instruments: an Infrared Sounder (IRS) and an Ultraviolet Visible Near-Infrared spectrometer (UVN). The aim of IRS instrument is to provide detailed vertical profiles of atmospheric temperature and water vapor at a high spatial resolution of 4km. These data will be used in the future for numerical weather prediction and nowcasting.

In the framework of this project, AMOS (Liège, Belgium), as a subcontractor of OHB, is the responsible for the design, manufacturing, integration, alignment and testing of the Geometrical and Spectral Test Assembly (GESTA) for the performance tests and calibration if the IRS under operational conditions. GESTA is an Optical Ground Support Equipment (OGSE) used for optical measurements during the alignment and test phases of the Infra-Red Sounder (IRS) instruments.

The GESTA is composed of three different main subassemblies:

The source Assembly (SA), designed by Bertin Technologies (Aix-en-Provence, France) is composed of a heated pattern plate mounted on an XY translation stage enabling to position it across the focal plane of the collimator. A Cold Black Body, operated at 90K, ensures the necessary contrast for the geometrical measurements. An Integrated Sphere is fed with MWIR and LWIR laser outputs, which are located outside of the vacuum chamber, and hence generates a uniform monochromatic output towards the collimator and ultimately the IRS.

The Gas Cell, designed by Centre Spatial de Liège (CSL – Liège, Belgium), consists of a Hot Black Body, operated at high temperature (295K, 523K), as broad-band MWIR/LWIR light source and an atmospheric gas cell, operated at 293K with the possibility to fill it with up to 4 different gases in order to check the spectral and radiometric sensitivities of the IRS.

The collimator, designed by AMOS, consists in a four mirror anastigmatic telescope with focal length of 2600 mm and an entrance pupil size of 320mm, operated at ambient temperature (293K). The collimator mirrors are made out of light-weighted aluminum structure with gold coating. The mirrors are mounted on a baseplate, which is of the same material and allows low stresses and deformations due to differential thermal dilatation.

In view of its qualification, GESTA underwent an extensive testing campaign including thermal control performances, alignment stability and radiometric performances under operational conditions (i.e. same conditions as the ones encountered with the IRS instrument in front of GESTA). The results of the tests allow to demonstrate the compliance of the GESTA OGSE to the requirements.

Keywords: MTG, IRS, OGSE, aluminum optics, collimator, thermal control, opto-thermo-mechanical analysis, alignment, system performance measurement, radiometric performances.

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1. INTRODUCTION

The next generation of the European geostationary meteorological satellite constellation (Meteosat Third Generation – MTG) is a joint program between ESA and EUMETSAT. The mission is based on a twin-configuration concept: an imaging satellite (MTG-I) and a sounder satellite (MTG-S). The MTG-I satellite accommodates a Lightning Imager (LI) and a Flexible Combined Imager (FCI) while the MTG-S accommodates an InfraRed Sounder (IRS) and an Ultraviolet, Visible and Near-Infrared (UVN) instrument. The program will ensure continuity of the forecast services provided by the second generation of the weather satellites (MSG) and address future challenges in weather forecasting [1]. The first satellite (MTG-I) is currently planned to be launched by end 2022 while the MTG-S will be in-orbit one year later.

The Infrared Sounder (IRS) is one of the two instruments hosted on board the MTG-S satellites. The IRS is a unique Fourier-transform based interferometer that will provide measurements of the time evolution of horizontal and vertical waper vapor structures and temperature distribution in the atmosphere. The development of this state-of-the-art instrument is led by OHB-System in Munich (Germany).

To achieve this challenge, AMOS (Liège, Belgium) has developed, along with Center Spatial de Liège (Liège, Belgium) and Bertin Technologies (Aix-en-Provence, France), a new Optical Ground support Equipment (OGSE) dedicated to characterize and calibrate the IRS instrument under vacuum which is called GESTA: Geometrical and Spectral Test Assembly. In addition, with the GESTA OGSE, radiometric, spectral, geometrical characteristics and optical performance test will be performed.

The design, manufacturing, integration, alignment and testing of GESTA is under responsibility of AMOS company.

A simplified version of the GESTA, called ASP-MT – Ambient Simplified Performance Measurement Tool – had been also developed to perform a reduced set of optical measurements with the IRS instrument in ambient environment.

The main requirements for the GESTA are listed in Table 1-1.

GESTA FUNCTIONAL & PERFORMANCE REQUIREMENTS	
Optical Requirements	
Wavelength range	4.38 µm to 6.76 µm (MWIR)
	7.38 µm to 16.95 µm (LWIR)
Field of View (FoV)	+/- 1.12° (square FoV)
Transmitted WaveFront Error	< 110 nm rms with max 50 nm rms defocus
Line-of-Sight (LoS) stability	< 0.7 arcsec over 15 seconds
Target Plate with different patterns	MTF, Distortion, knife-edge (0/90 & 45/135)
Radiometric Requirements	
Illumination configuration #1	
• Hot Black Body + Gas Cell	adjustable radiance at hot temperature
Illumination configuration #2	
• Integrated Sphere + Laser Sources + Target Plate	adjustable spectral radiance at two laser wavelengths (MWIR + LWIR)
Illumination configuration #3	
• Cold Black Body + Target Plate	adjustable radiance at cold temperature
Limited Background radiance in all illumination configurations	

Table 1-1. Main requirements and design drivers for the GESTA

This paper is organized as follows: the optical and mechanical design of the OGSE is described in Section 2, and the different illumination configurations are presented in Section 3. Section 4 is related to the manufacturing and alignment of the collimator, while Section 5 is dedicated to the acceptance test campaign.

2. OPTO-MECHANICAL DESIGN OF THE OGSE

The Calibration and Characterization OGSE is composed of (See Figure 2-1):

- GESTA: the optical sub-system, mounted on top of the optical bench in the vacuum chamber (the same optical bench on which the IRS is mounted), consisting of all the necessary optical equipment for a full geometrical and spectral calibration of the IRS instrument;
- Light Source Sub-system (LSS): located outside of the vacuum chamber with the MWIR and LWIR lasers and associated optics for integration of the laser beam in GESTA;
- Gas exchange sub-system: a gas cabinet, located outside of the vacuum chamber, contains all gas bottles (NH_3, NO, CO and N_2 gases) and gas circuit for preparation of the gas environment in the Gas Cell. For H_2O gas production, a water vapor supply is placed close to the gas cabinet.
- Electrical cabinets, located outside of the vacuum chamber, for the control of GESTA.

The GESTA sub-system itself is composed of three different main sub-assemblies (Figure 2-2):

- Source Assembly, to provide several opto-mechanical paths configuration to support the tests of the IRS.
- Gas Cell Assembly to illuminate the GESTA Cold Stop in a homogeneous way
- Collimator, operated at ambient temperature (293 K):
    - Equipped with a Cold Stop operated at 90 K to remove the thermal straylight outside the pupil.
    - Mounted on separate optical baseplate.

The three GESTA sub-units are mounted individually on the GESTA supporting structure.

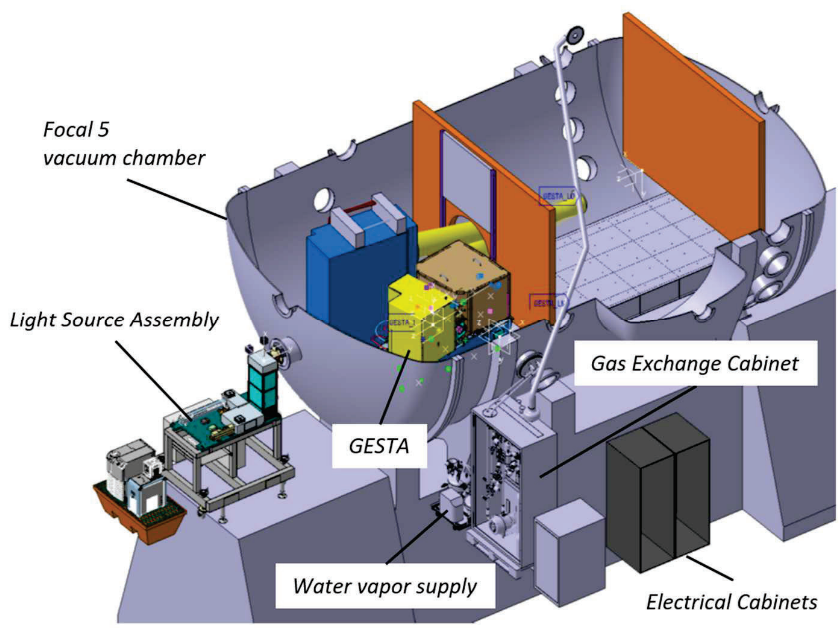


Figure 2-1. Light Source Assembly, Gas Exchange cabinet, water vapor supply and electrical cabinets are outside of the vacuum chamber, while the GESTA, the Black bodies CBB/VBB (not part of the GESTA contract) are both located inside of the vacuum chamber

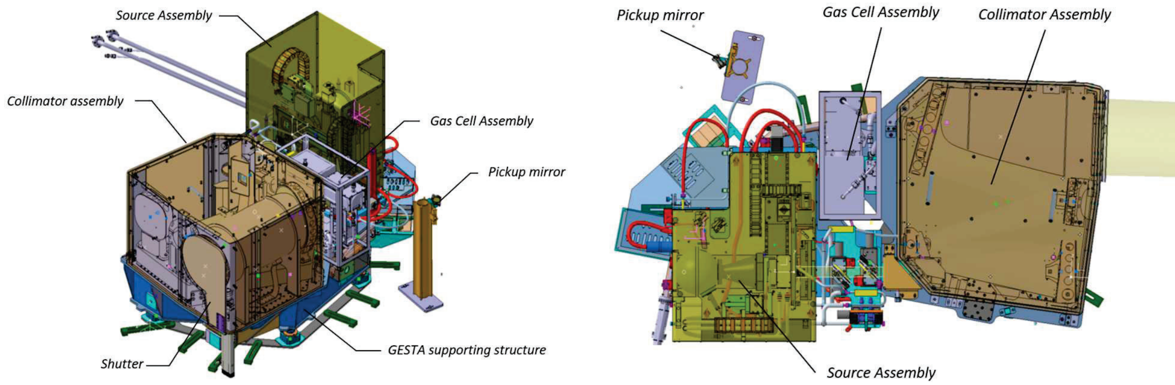


Figure 2-2. Left – General overview of the GESTA. Right – Top side overview of the GESTA

2.1 Design of the collimator

The optical design of the collimator is based on a Four-Mirror off axis Anastigmat (FMA). It has a focal length of 2596 mm, an entrance aperture of 62.5 mm diameter and an exit aperture of 322.1 mm (in the nominal configuration) diameter coincident with the IRS aperture. It is conceived for imaging, without any vignetting either obscuration, a field of view of 1.2 deg square.

The four mirrors are mounted on a rigid baseplate. The four mirrors and the baseplate are machined in Aluminum. The surface of the mirrors are first figured by diamond turning. Then, both faces of each mirror are covered by a thin layer of Nickel for further polishing and ion-beam. This procedure insures a high precision on the geometry, reducing the time necessary for alignment. At the very end, an unprotected gold coating (from CILAS, France) is applied on the mirrors.

The collimator optical design is shown in the Figure 2-3 below.

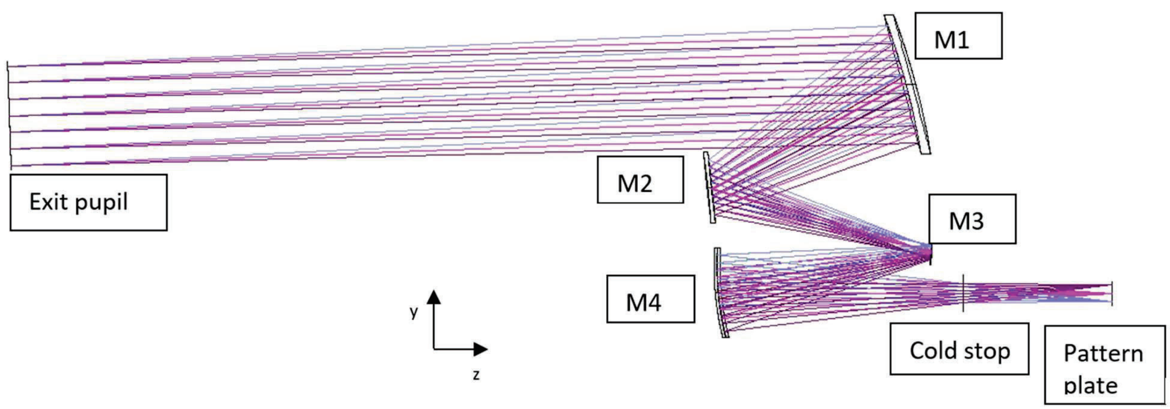


Figure 2-3. GESTA Collimator Optical Design – Four Mirror Anastigmat Configuration

2.2 Design of the Source Assembly

The Source Assembly was designed and manufactured by Bertin Technologies (Aix en Provence, France). This sub-system is composed of:

- Pattern Plate: a representation of the collimator focal plane containing specific patterns to check the geometrical performances of the IRS (Knife edge, distortion, MTF, etc…). This pattern plate can be heated to a moderate temperature (until approx. 350 K) and is mounted on an XY translation stage enabling to position it across the focal plane of the collimator;
- Cold Black Body, operated at 90 K to ensure the necessary contrast for the geometrical measurements;

- Integrating Sphere (IS) operated at ambient temperature (293 K) with the IS output conjugated to the Cold Stop of the collimator. The Integrating Sphere is fed with LWIR and MWIR laser outputs and hence, with the help of a speckle scrambling function, generates a uniform monochromatic output towards the collimator and ultimately the IRS;
- Focus Adjustment function, achieved by translating the Source Assembly carriage over ±1 cm stroke. It consists of an optical fiber source and a CCD camera that allows to characterize the defocus of the Target Plate and compensate it before the use of GESTA under vacuum;
- Radiance calibration function consisting of two cooled IR detectors (one for MWIR, one for LWIR), allowing to check if the radiometric sources are operational and able to deliver the required radiances in the required ranges before beginning a mesurement campaign of IRS instrument.

2.3 Design of the Gas Cell Assembly

The Gas Cell Assembly was designed and manufactured by Centre Spatial de Liège. This dedicated source pack is composed of:

- Hot Black Body, operated at high temperature (295-500 K) as broad-band LWIR/MWIR light source;
- Atmospheric gas cell, operated at 293 K, with the possibility to fill it with different gases (NH_3, NO, CO) and water vapor in order to check the spectral and radiometric sensitivities of the IRS to the particular earth gases;
- A separate baseplate.

2.4 Design of the Light Source System

The Light Source System was designed and manufactured by Bertin Technologies. It includes the following main units:

- MWIR laser: a continuous CO laser source which operates @5.42µm, with typical 2.0W peak single line power;
- LWIR laser: a continuous CO_2 laser source which operates @10.56µm, with typical 8.0W peak single line power;
- A visible alignment laser to provide a guiding-beam for aligning the infrared laser beams to the GESTA. The source light proposed hereafter is a red He-Ne laser, with single line at 633nm, with 1.5 mW output power;
- The mechanical support structure for lasers which is accommodated outside of the vacuum chamber and placed on the same seismic block as the optical bench inside of the vacuum chamber;
- A beam-transfer mechanism to safely relay the light from the laser sources which are outside of the vacuum chamber to the Integrating Sphere of the GESTA Source Assembly inside of the vacuum chamber.

3. ILLUMINATION CONFIGURATIONS DESCRIPTION

Under usual operations the GESTA is placed in front of the IRS and illuminates and simulates spectral, radiometric and geometric features in order to perform pre-launch calibrations of the IRS instrument. Three different working configurations are foreseen in the GESTA, each with its own specificities and functionalities (See Figure 3-1).

In illumination configuration #1, a Hot Black Body is used as a light source. A Gas Cell is located between the GESTA Hot Black Body and the focal plane of the collimator. A Folding Mirror is used to redirect the light towards the collimator Cold Stop (entrance pupil). Using this configuration, the sensitivity and responsivity of the instrument to different atmospheric gasses can be tested and calibrated.

In illumination configuration #2, light originating from the Light Source Assembly is injected into an Integrating Sphere. A ZnSe lens is located between the exit port of the IS and the GESTA Target Plate (located at the collimator focal plane) and assures a homogeneous illumination of the Target Plate and the IRS Entrance Pupil. This configuration is used to measure spectral characteristics or stray-light performances of the IRS.

In illumination configuration #3, the entire laser path is replaced by a Cold Black Body which constructs high contrast target images in the collimator focal plane. This is used to measure line spread functions, distortion or stray-light performances.

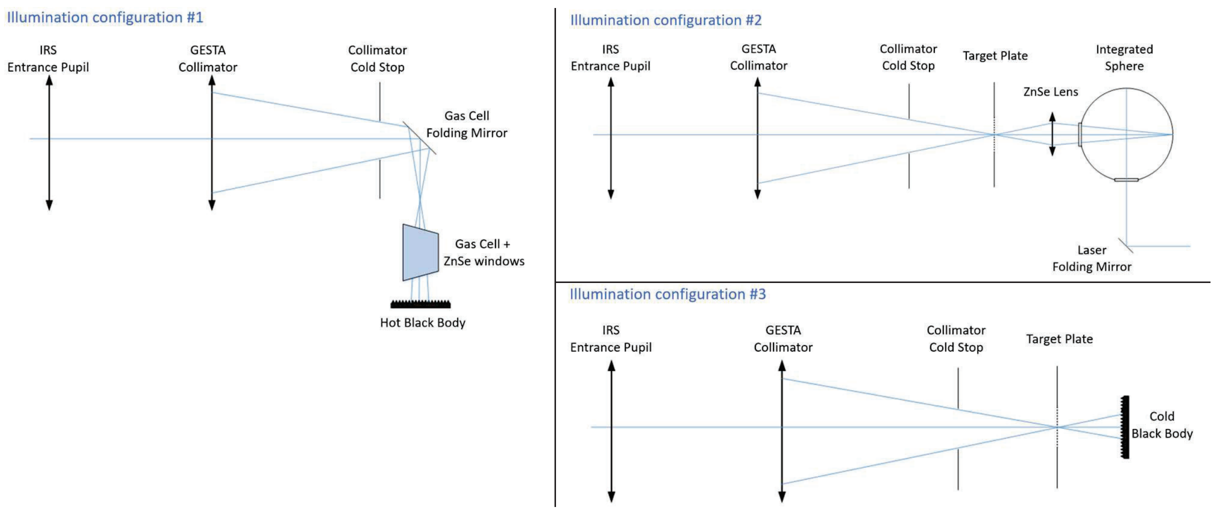
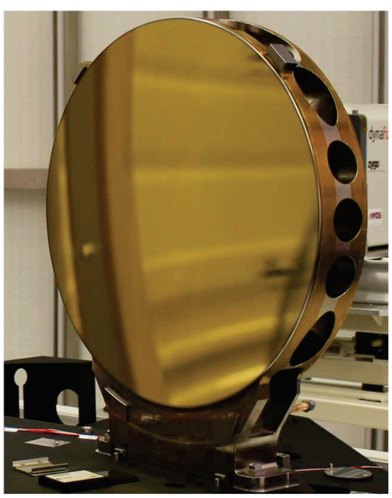


Figure 3-1. The three GESTA illumination configurations

4. MANUFACTURING AND ALIGNMENT OF THE COLLIMATOR

The 4 collimator mirrors are made from Aluminum 6061 T6. The required surface shape is obtained by ion-beam figuring and post-polishing steps. The mirror surface qualities are verified by interferometric tests that required Computer-Generated Holograms (CGH). The deviations of the mirror surfaces from their nominal shapes are better than 25-45 nm RMS, and the mirror micro-roughness are of the order of 1 nm RMS. These performances are in line with both WFE and stray-light performance requirements. At the final step of mirror manufacturing, an unprotected gold coating layer is deposited on top of the mirror. The larger mirror of the collimator – M1 mirror with a diameter of 450mm – is shown in Figure 4-1.

The collimator baseplate is manufactured from AL6061 T6 material block. The baseplate is treated with a Aeroglaze Black paint compliant with outgassing constraints and straylight requirements. The thermal hardware (composed of thermal sensors and cable harnesses) is mounted on dedicated area on the baseplate and on the mirrors as seen in Figure 4-1.



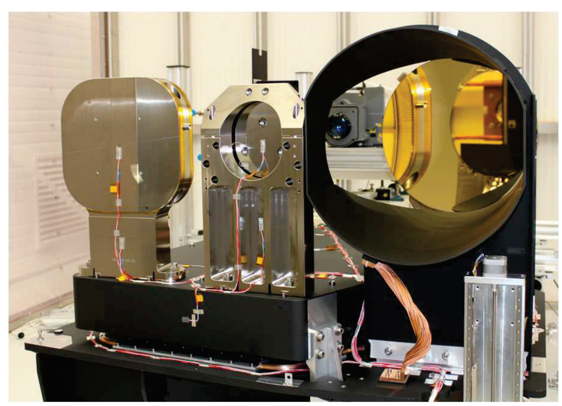


Figure 4-1. Left – M1 mirror with gold coating. Right – GESTA baseplate with thermal hardware, mirrors and baffles

For the alignment of the collimator, the philosophy consists to use the M2 mirror with an hexapod to minimize the WFE (See Figure 4-2). The mirrors M1, M3 and M4 are first placed on their mechanical nominal positions. An interferometer placed at the Focal Plane (FP) position sends a collimated beam toward the collimator. The exit pupil features a flat mirror and is placed at the nominal position (IRS entrance pupil) as shown in Figure 4-2. It allows to measure the double-pass wavefront error of the collimator.

The collimator wavefront error is first measured at the center of field-of-view (FoV) and is optimized by adapting the position of M2 mirror with the help of the hexapod. After few iterations, the WFE alignment is complete and the WFE is characterized in the complete FoV. The WFE of the collimator is < 110 nm RMS over the complete GESTA FoV as shown in Figure 4-3. At that stage, the M2 mirror is glued to its support and the hexapod is removed. Finally, the Cold Stop is aligned with respect to the center of the exit pupil.

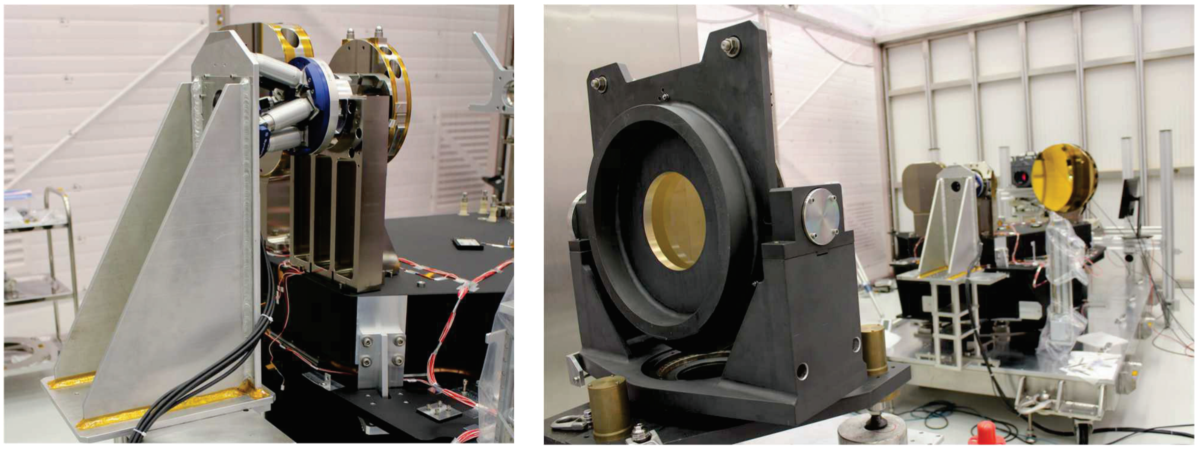


Figure 4-2. Left – M2 mirror with the hexapod. Right – Flat mirror at exit pupil nominal position (IRS entrance pupil)

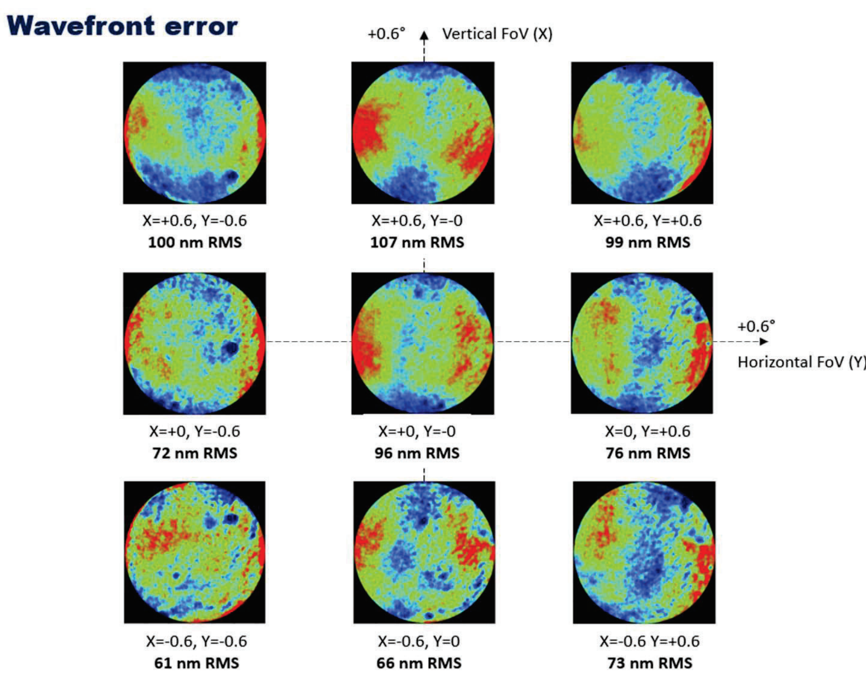


Figure 4-3. WFE phase map for each point of the FoV after alignment and M2 gluing

5. QUALIFICATION TEST CAMPAIGN

Prior to the final acceptance campaign, the different components of GESTA were tested individually and a full functional test was performed under ambient conditions. The GESTA acceptance test campaing took place from March to May 2022 in CSL facilities (Centre Spatial de Liège, Belgium). The complete OGSE was tested under environmental conditions that are derived from the upcoming IRS instrument campaign. The test setup is shown in the Figure 5-2. The following test flow was foreseen :

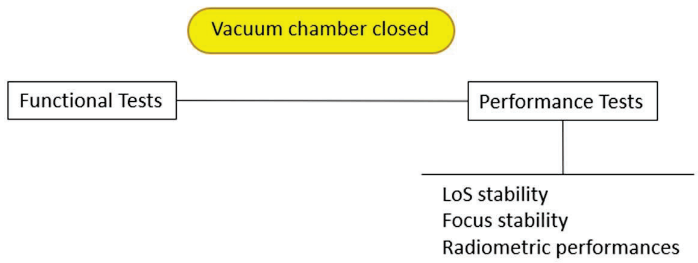


Figure 5-1. GESTA test flow

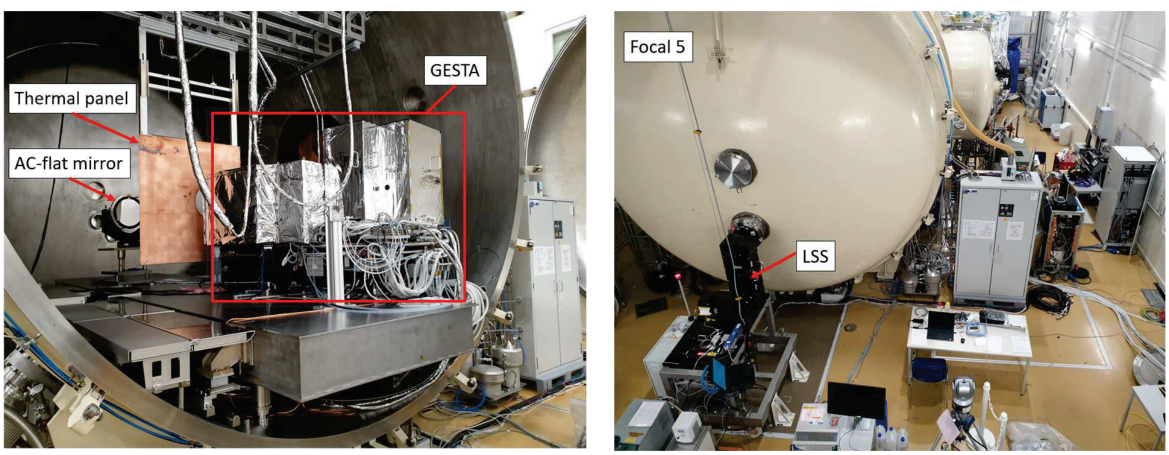


Figure 5-2. Left – Test setup and GESTA facility overview just before Focal 5 (Centre Spatial de Liège - CSL) vacuum chamber closure. Right – Light Source System installed and aligned after F5 vacuum chamber closure

5.1 Focus stability tests

The measurements were realised with the Focus Adjustment System (FAS) which is described in the Figure 5-3.

The FAS is composed of a fiber-coupled SLED source with a beam waist diameter of 2µm. The SLED is used as a point source and is located at the GESTA focal plane. The image of the spot introduced by the SLED is steered to the flat autocollimation mirror through the collimator and sent back to the FAS Camera which is also located in the GESTA focal plane. Two out-of-focus images are acquired with a distance of 0.34 mm between them. The defocus error is reconstructed from these images thanks to the wavefront curvature sensing technique (see [2]). The focus error is computed with a dedicated AMOS custom software and the offset value of focal plane is provided (See Figure 5-4).

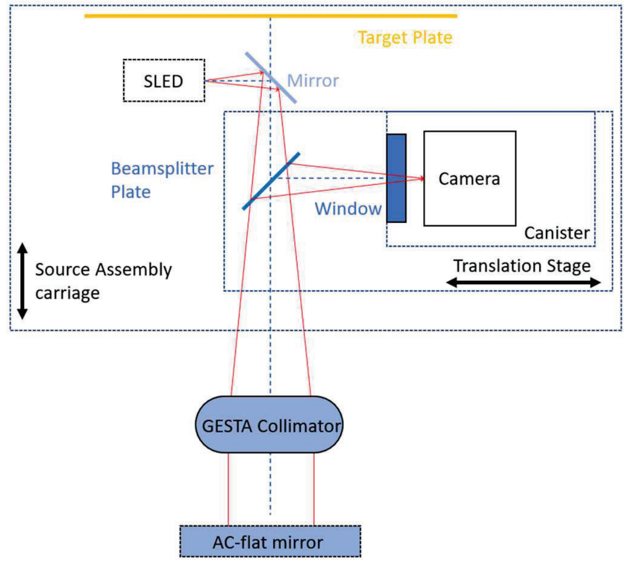


Figure 5-3. Optical scheme of the Focus Adjustment System (FAS)

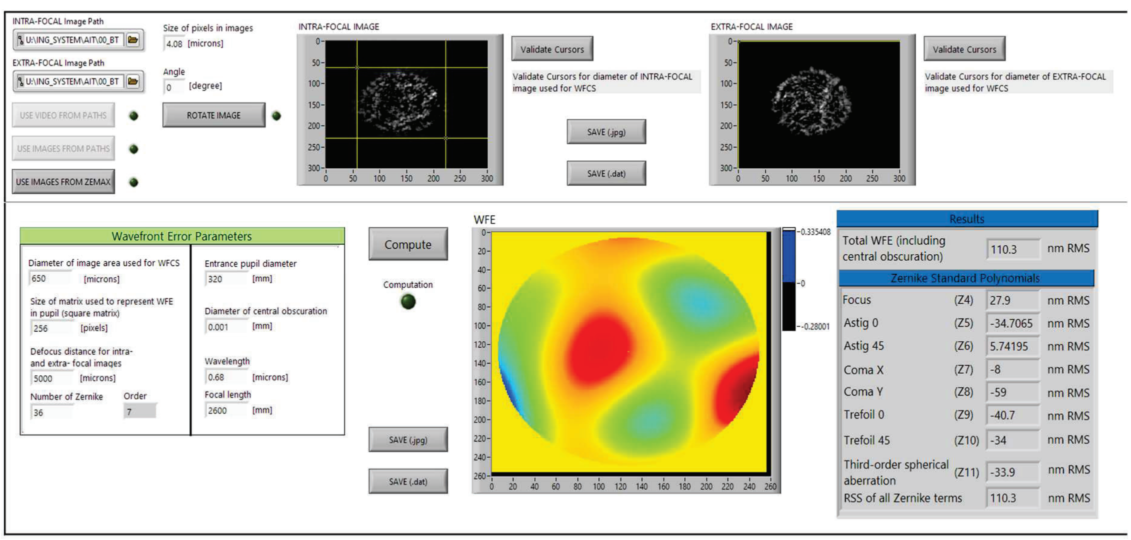


Figure 5-4. Wavefront curvature Sensing software. The wavefront is reconstructed on the basis of Zernike polynomials thanks to the out-of-focus images

The focus stability tests are evaluated during the complete GESTA acceptance test campaign. The main objective is to verify the thermal control architecture ability to keep the OGSE optical performances (focus stability) under the requirements in operational conditions.

To achieve this target, a thermal panel is used to simulate the IRS thermal behavior. Two sequences of operational thermal configuration were provided to the test facility to conduct the setup correctly: a COLD and an HOT phases. All GESTA sub-systems are enveloped with thin aluminium housing that is wrapped in MLI to isolate them thermally from the environment.

The average defocus resulting from all focus measurements is 36nm rms WFE which is below the maximal required defocus corresponding to 50nm rms WFE. Defocus measurements during operational thermal conditions are presented in the table below:

Time (s)	Defocus (nm rms)
40082	13.9
57232	15.5
71344	20.0
124656	28.0
146902	15.1
165816	36.0

Table 5-1. Defocus measurement during operational thermal conditions

5.2 LoS stability tests

The measurement is realised with the Focus Adjustment System (FAS) (See details in Figure 5-3). The image of the SLED is captured on the camera after double-pathing in the collimator with the flat autocollimation mirror. The images are post-treated in Matlab software in order to extract its centroid position. The displacement of the centroids as a function of time leads to calculate the LoS stability. The acquisitions are performed at 512 Hz. The test is performed with all active systems ON in the vacuum chamber (speckle scrambler in the Integrated Sphere at nominal speed and all cooling lines enables). The RMS over 15 sec is less than 0.4 arcsec and smaller than the requirement of 0.7 arcsec. The results are shown in Figure 5-5.

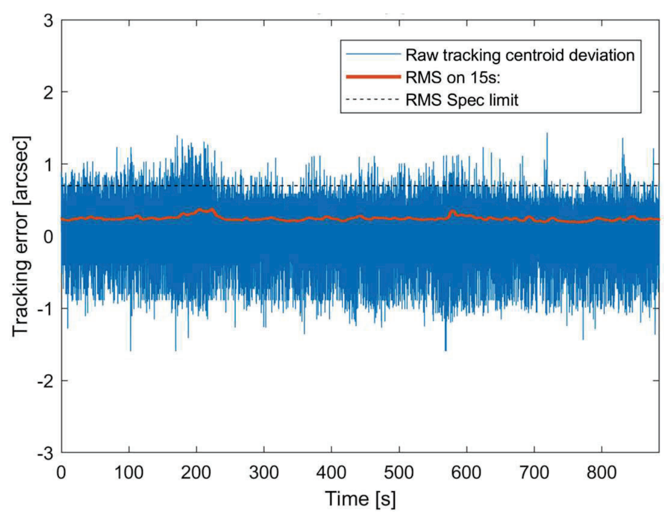


Figure 5-5. LoS stability over 900 s with all equipment ON.

5.3 Radiometric performances tests

In order to measure radiance output in the different illumination configurations and to check that the required radiometric levels are fulfilled, two Stirling cooled infrared MCT (Mercury Cadmium Telluride) detectors are used : one optimized for the MWIR bandwidth measurements, with a sensor response peak at 5.4µm, the other optimized for the LWIR measurements with a sensor response peak at 14µm. The two infrared detectors are embedded in the Source Assembly static baseplate. A folding mirror, fixed on a motorized linear stage and located between the Target Plate and the collimator

Cold Stop is used to deflect the radiance output to the detectors. The two detectors are fixed on a motorized linear stage for detector selection.

Nominal and background radiance values were measured in the three illumination configurations. The results are in line with the required radiometric levels. The measured nominal radiance values are used as reference for checking the system prior to the IRS measurement campaign.

6. CONCLUSIONS

This paper presents the design, manufacturing and acceptance testing of the GESTA OGSE to be mounted in front of the IRS instrument.

In view of its acceptance, the OGSE was subjected to an extensive testing campaign including: thermal-vacuum configuration sequences, measurement of the optical performances (Focus, LoS) under ambient and operational conditions and radiometric performances tests. The results of the tests have demonstrated the very good behavior of the system under operational conditions and its compliance to the demanding requirements.

7. ACKNOWLEDGEMENT

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