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ABSTRACT

The Laboratoire d'Astrophysique de Marseille (LAM) is deeply involved in the development and the test of the NISP (Near Infrared Spectro-Photometer) instrument for the ESA EUCLID mission that will be launched in 2020. The goal of the mission is to understand the nature of the dark energy responsible for the accelerating expansion of the Universe. NISP is one of its two instruments operating in the near-IR spectral region (0.9-2 μ m) to map the geometry of the dark Universe. The integration of the NISP flight model (FM) has been started at LAM to allow its delivery in 2019 to the payload after vibration test and two thermal vacuum test campaigns to demonstrate the performance of the instrument. The thermal vacuum test will take place in ERIOS chamber, a 90m³ chamber developed by LAM to test optical instruments at cryogenics temperature and high vacuum. In addition to the chamber, a full and specialised set of ground support equipment called the Verification Ground System (VGS) is developed to fill the goal of the NISP test campaign. The test campaign combines functional tests of the detectors and wheels, performance tests of the instrument, calibration procedure validation and observations scenario test, all done at LAM. One of the main objectives of the test campaign is the measurement of NISP focus position with respect to the EUCLID object plane. The VGS is made of i) a telescope simulator to simulate the EUCLID telescope for optical performance tests, ii) a thermal environment to simulate the Euclid PLM thermal interfaces, iii) the NISP Electrical GSE (EGSE) to control the instrument during the test and iv) a Metrology Verification System (MVS) to measure the positions of NISP and the telescope simulator during the test. We present the set of GSE developed for NISP and their performance already validated during two blank tests: thermal blank test and metrology blank test. In addition, a blank test with all the VGS parts (thermal, optical, metrology) is scheduled in the coming months to validate the overall performance of this GSE including the telescope simulator. The goal is to measure with a high precision the focus distance of the telescope simulator at cold and the stability of the focus in time, and to demonstrate the functionality of the telescope simulator for NISP test campaign needs. Finally, we describe the thermal vacuum test configuration for the "end to end" test on the NISP flight model foreseen by beginning of 2019.

Keywords: NISP, ground support equipment, ERIOS, metrology, laser tracker, telescope simulator

1. INTRODUCTION

EUCLID mission¹ has been selected by ESA in 2012 in the context of the Cosmic Vision program to study the nature of dark energy and dark matter. The launch of the mission is foreseen in 2021. The mission is designed to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures thanks to two scientific instruments: the Near Infrared Spectroscopic Photometer (NISP)² and the Visible instrument (VIS)³. The NISP channel of Euclid is dedicated to measure the redshift of galaxies and to analyze their spatial distribution in the Universe. NISP works with both photometric and spectroscopic modes by switching between broadband filters and grisms, mounted on two rotating wheels, to acquire data of the same field. NISP instrument is made by an European consortium led by Centre National des Etudes Spatiales (CNES) that includes laboratory and industries mainly from France, Germany, Italy and Spain.

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The Laboratoire d'Astrophysique de Marseille (LAM) is deeply involved in the development and the test of the NISP as LAM is responsible for the integration, alignment and test of the instrument. The integration of the Flight Model (FM) is already started and will be finished by end of 2018. The NISP FM will be tested and validated under vacuum and thermal conditions at LAM in ERIOS chamber⁴, a 90m³ chamber developed by LAM to test optical instruments at cryogenics temperature and high vacuum. The goal of this TB/TV test is to qualify the instrument in its operating environment, to measure the optical performance of the instrument, and validate its functionality before its delivery to the payload module. To realize properly the test in ERIOS, a global Ground Support Equipment (GSE) called the Verification Ground System (VGS) is developed by LAM and its Danish partners. The VGS is a complex set of GSE made of i) a telescope simulator to simulate the EUCLID telescope for NISP optical performance tests, ii) a thermal environment to simulate the Euclid PayLoad Module (PLM) thermal interfaces, iii) a set of mechanical interfaces to align and install all the parts into ERIOS, iv) the NISP Electrical GSE (EGSE) to control the instrument during the test and v) a Metrology Verification System (MVS) to measure the positions of NISP and the telescope simulator during the test. We present in this article first the test objectives and configuration of the NISP campaign. Then we describe the different parts of the VGS and their performance.

2. NISP TEST CAMPAIGN DESCRIPTION

2.1 NISP test campaign goal

After the integration and alignment of NISP instrument², it is required to validate the optical performance of the full-assembled instrument and its main functionality. It is then foreseen to do two complete thermal performance tests of NISP FM to validate the instrument before and after the acceptance vibration test of the instrument. The test, realized in thermal-vacuum environment, shall:

- Verify the performance requirement compliance of the NISP instrument. In particular a thermal balance will be performed to validate NISP thermal behavior and its thermal stability. The performance compliance in operational environment will be tested: detector noise (read-out and dark) at the coldest interface range, Point Spread Function (PSF) acquisition to measure encircled energy of NISP, full width half maximum of the images and image quality, limited plate scale measurement at the center and the corner of the Field of View (FoV), rough estimation of the stray-light sensitivity and check of the absence of ghosts;
- Provide the object plane position of NISP with respect to NISP reference frame at Operational Temperature (OT) to align NISP on the payload module;
- Verify the functionality of NISP: observation scenario will be tested and validated including wheel, detector acquisition, data reduction and communication with spacecraft sequences;
- Provide information and strategy for the calibration of the instrument. The calibration scenario foreseen will be tested, data from ground calibration will be acquired and the in-flight calibration procedure will be verified through the acquisition of PSFs used for modeling of NISP PSF. The spectral dispersion law of the grisms will be measured.

The NISP test campaign will take place at LAM in ERIOS chamber⁴ and will be done thanks to the Verification Ground System (VGS), a set of Ground Support Equipment (GSE) specially developed for NISP. The VGS is installed in ERIOS and simulates the EUCLID telescope and the thermal interfaces of the payload to ensure that the NISP test will be done in the needed conditions. The VGS is a set of GSE that allows testing NISP FM before the launch. NISP test campaign and the development of the VGS represent a great challenge due to the complexity of the installation and components to provide. Figure 1 presents the CAD view of the NISP test configuration inside ERIOS. We show in this figure the telescope simulator, part of the VGS, the thermal and mechanical interfaces for the test, and the metrology system and of course NISP instrument. In addition, NISP is surrounded by a thermal enclosure, not shown here, to ensure the good thermal environment during the test.

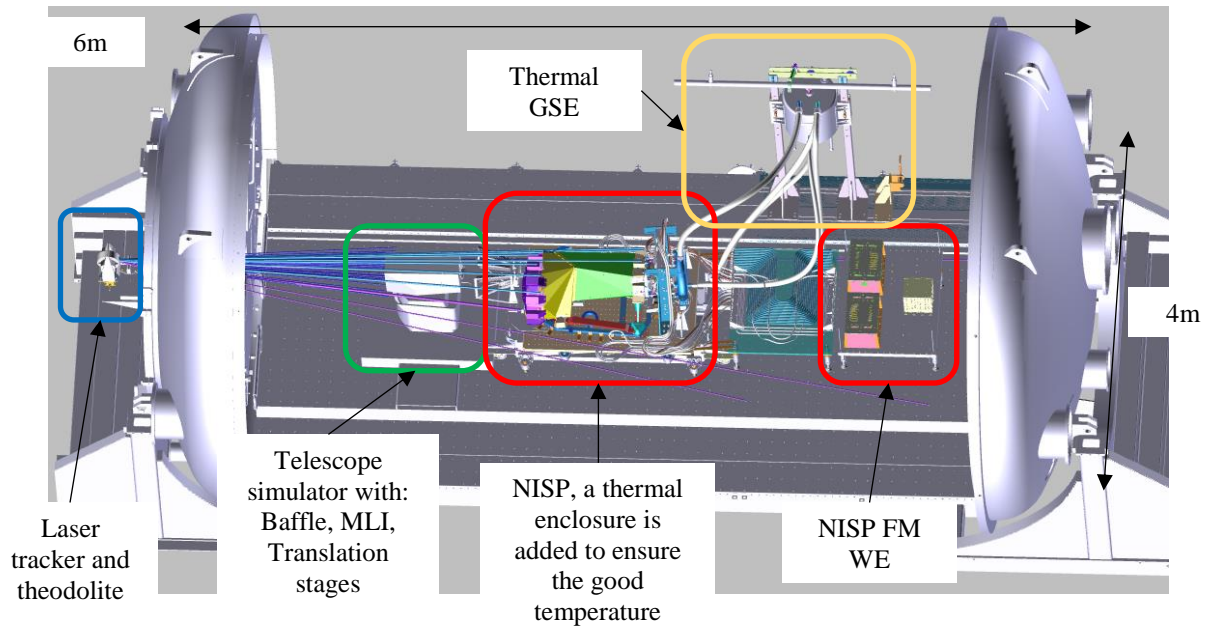


Figure 1. NISP TB/TV test configuration inside ERIOS.

2.2 VGS technical specifications

The VGS has to answer to technical specifications provided by NISP Assembly Integration Verification (AIV) team. The main specifications are:

- To provide a thermal environment compatible with the flight environment of NISP: interface of the NISP Sidecar Support Structure (SSS) should be between 120K and 135K, interface of the NISP Cold Support Structure (CSS) between 80K and 95K and the NISP feet interface should be at 120K to 135K. In addition, the VGS shall provide a radiative thermal interface to select temperature in a range between 80K to 140K with a stability of +/- 2K during 1500s. Gradient of the conductive interface should be lower than +/-1K on the SSS, +/-0.5K for the CSS and +/-5K on NISP feet. Finally, NISP should be cooled down from Room Temperature (RT) to Operation Temperature (OT) assuming 10K/h max at conductive interfaces. The CSS interface shall be kept at least 10K warmer than the SSS and NISP first panel P1. The CSS shall be cooled down after the other parts to OT,
- To provide a simulation of EUCLID telescope to test NISP optical performance. The telescope should illuminate the NISP pupil with at least a F/20 beam and should provide object in the full NISP FoV covering +/- 0.5° of the sky. The source from the telescope should provide selectable monochromatic wavelength in the band 0.4 to 2.1µm, multi-lines spectrum from 0.9 to 2µm and continuum spectrum from 0.9 to 2.02µm. The flux of the source should be adjustable to test a large range of flux of NISP. The WaveFront Error (WFE) quality should be better than 30nm rms over the FoV. The telescope should not introduce unexpected stray light to NISP FoV,
- To provide a way to measure the reference coordinate system defined by laser tracker reflectors put on NISP instrument and the telescope simulator to allow an accurate metrology through the vacuum chamber.

3. VERIFICATION GROUND SYSTEM DESCRIPTION

The VGS, described in the following sections, answers to these specifications to provide the good GSE for NISP test campaign purpose. It is made of an optical GSE, thermal GSE, mechanical GSE and a metrology mean.

3.1 The Optical Ground Support Equipment (OGSE): the telescope simulator

The concept of the OGSE developed for NISP is to simulate the F/20 EUCLID telescope beam thanks to an elliptical mirror positioned on stages that allow the telescope to move in five degrees of freedom to illuminate the entire NISP FoV wherever it is needed. The OGSE is made of two main parts: the NISP Telescope Simulator (NI-TS) itself that mimics EUCLID telescope, and a Focal Plane Unit (FPU) that is used to simulate the EUCLID object plane i.e where the focal plane will be in absence of NISP optics. The two parts are shown respectively in Figure 2 and Figure 3. The FPU is only used to validate the NI-TS functionality at cold during the acceptance of the VGS and will be not used during the test with NISP. The main goal of the NI-TS is to provide a stable focal distance to NISP to allow the measurement of the position of NISP object plane. To achieve this goal, the NI-TS is designed with a stable thermal interface done by the thermal flexures between the telescope itself and the motor assembly. This is one of the main challenges for the NI-TS design as the different parts of the NI-TS operate at different temperature and in a warmer environment than NISP.

The NI-TS itself is made of two units: the Active Telescope Support unit (ATS) that moves the second unit, the Telescope Simulator (TS), around to illuminate the full NISP FoV. The ATS is an assembly of 5 motors providing 5 degrees of freedom. It is made of 3 linear and 2 rotational high precision stages with remote controlled motor and absolute encoder to provide position of the unit. These stages are vacuum compatible and with a large moving range to commit with NISP need and in particular, to allow a scanning of the focus to find NISP best focus. The ATS is directly in interface with ERIOS bench thanks to 3 shims under the last translation stage baseplate. The TS is an off-axis elliptical mirror assembled to a baseplate thanks to optical contact done by Winlight Optics⁵. On the same baseplate, a pinhole is set at the entrance focus to provide an interface for the source. It is a single surface optical design, which provides an unobstructed system. The design of the TS is to provide a first focal point at 500mm while the distance from the mirror vertex to the second focal point is 3000mm. The whole TS assembly is made of Silica to ensure a good stability of the focal distance of the telescope and will operate at 165K to limit impact of the temperature on the stability of the focal distance (the CTE of the silica being null at this temperature). The telescope is illuminated through a 2 μ m diameter pinhole placed in the primary focus and should provide uniform illumination of the 160mm diameter aperture. The focus of the telescope should be known with a precision better than 20 μ m at operational temperature meaning that the distance from the pinhole to the mirror should be stable within 0.5 μ m. An accurate measurement of the focal distance is done at ambient temperature thanks to a Coordinate Measurement Machine (CMM) with high precision and then at cold temperature thanks to the Metrology Verification System (MVS), described in subsection 3.3. The WFE is lower than 30nm rms over the 160mm diameter aperture to ensure a good image quality on NISP during the performance test. In order to minimize stray light during NISP test, the telescope is surrounded by a baffle made of several vanes. More details on the NI-TS design and on the FPU design can be found in [4].

At the entrance of the TS, a cold fiber is connected to the illumination system used for the NI-TS. It is made of a monochromator that feeds from a continuum laser source. The output from the monochromator is delivered to a cryogenic fiber through a pair of vacuum windows in interface with ERIOS chamber. A cooled Neutral Density (ND) filter suppresses the thermal background. The flux can be adjusted in large steps via ND filters mounted in a filter wheel also serving as order-sorter for the grating based monochromator. The flux can be fine-tuned using a variable rotating ND filter. A spectral lamp and an etalon are available for wavelength calibration and can be selected using linear motions. The source module, installed outside ERIOS chamber, is shown in Figure 3. The NI-TS is provided with a Telescope Control Computer (TCC) to control the motors position, the light illumination and intensity and to read data from the FPU and the thermal control of the NI-TS.

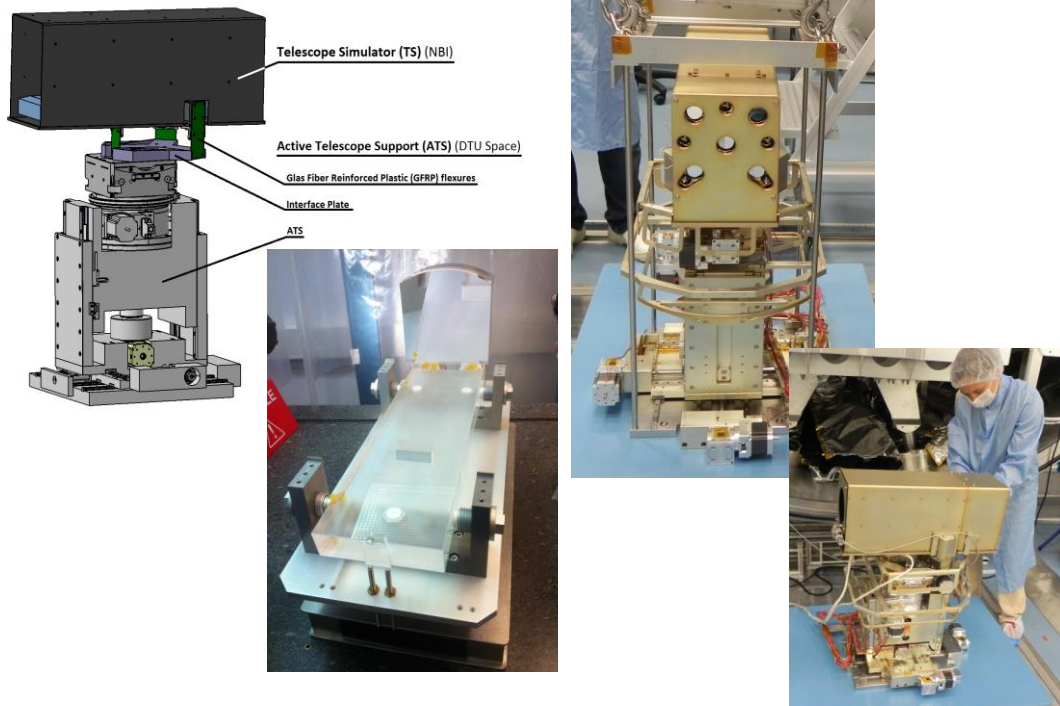


Figure 2. Left: model of the NI-TS with the telescope and ATS. Middle: picture of the telescope simulator before integration. Right: pictures of the final ATS during its integration at LAM.

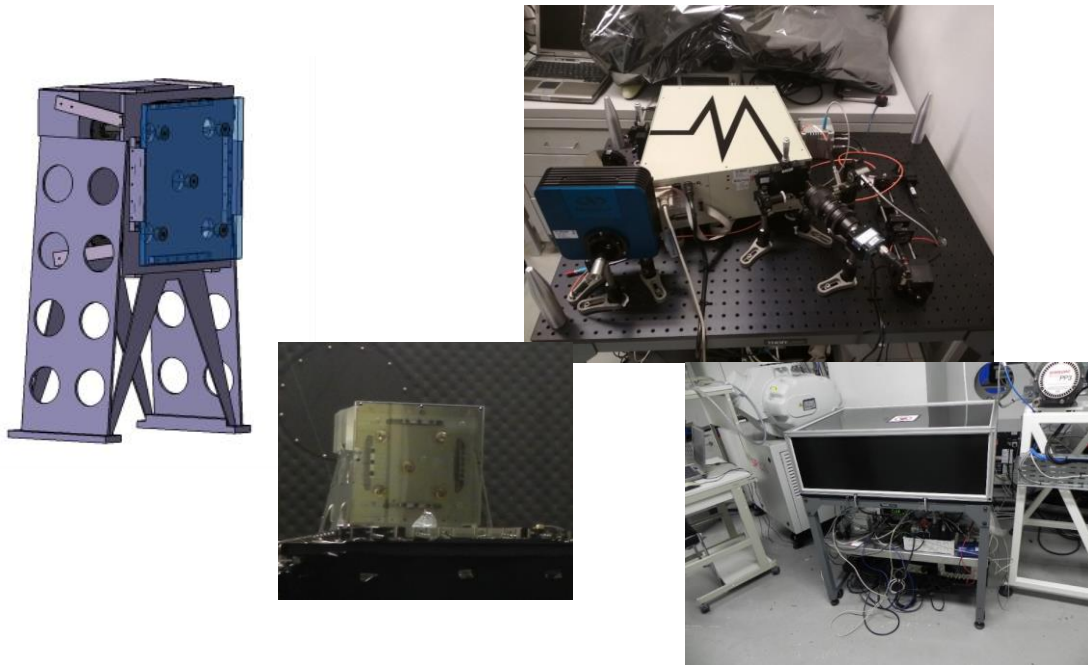


Figure 3. Left: the FPU unit during its integration in ERIOS. Right: the source unit that feeds the NI-TS with light.

3.2 Thermal and mechanical ground support equipment

The Thermal and Mechanical Ground Support Equipment also called TMVS provide thermal and mechanical interfaces for NISP. It simulates the PLM thermal environment. The radiative thermal environment consists of ERIOS liquid nitrogen shrouds that are cooled down at 90K. The TMVS has also to provide conductive interfaces for NIOMADA, Warm Electronic and for the intermediate harness of the NISP detector system. A complete description of the TMVS is provided in [4]. For the optical performance test case, the temperature of the detector is set at 90K with a stability of 20mK/h while the rest of the instrument is maintained at 130K. Intermediate liquid nitrogen loops are designed to fill auxiliary tanks under NISP, near the detector system and near the configuration to ensure the best regulation of the thermal interfaces. We have an autonomy of 30 hours between two filling and we manage the cooling down phase in order to keep detectors warmer than the rest of the instrument during the cool down. Figure 4 shows the different elements of the TMVS during the blank test done in December 2017. We show in this picture the mechanical interfaces of NISP that is used to cool down the NISP feet and the auxiliary tanks.

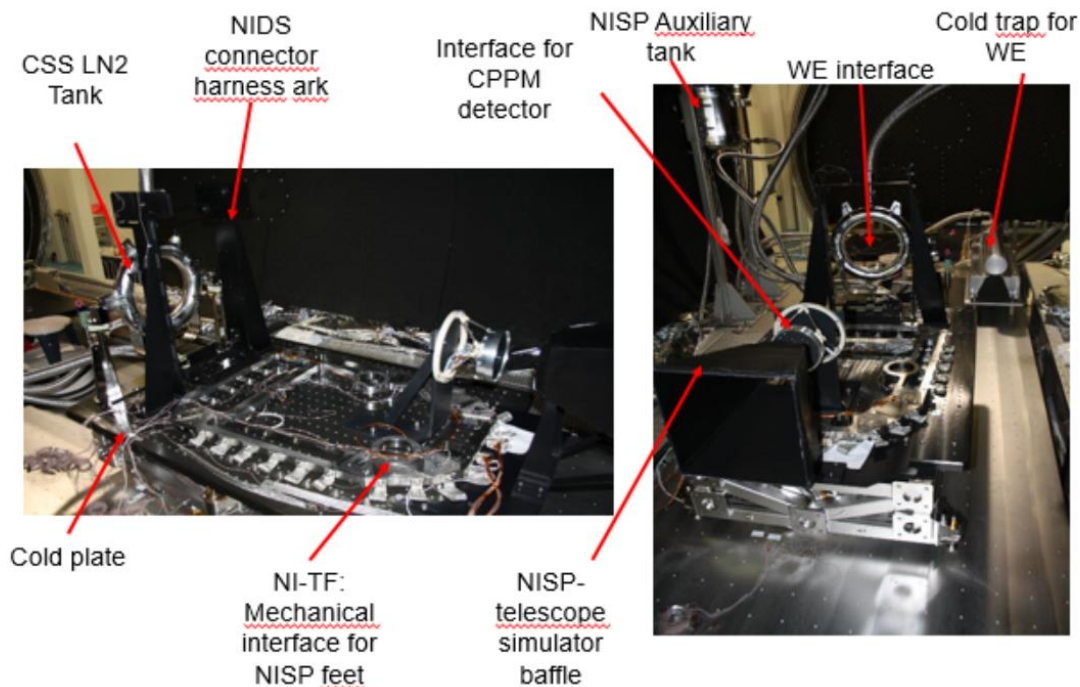


Figure 4. TMVS hardware during the blank test in December 2017. All parts are presented, details can be found in [4].

The whole system has been installed in ERIOS chamber to perform an acceptance test of the thermal interfaces and to demonstrate that the thermal performance needed for NISP TB/TV can be reached. The test done in December 2017 was successful, as it has validated:

- The LN2 loop handling and performance;
- The temperature operational range required for NISP test has shown on Figure 5 and in particular the stability of the detector thermal interface better than 20mK and estimated around 4mK;
- The temperature on NISP feet interfaces;
- The warm electronics interfaces.

In addition, we have characterized the thermal conductance of the detectors and its electronics cold straps and measure the cold fiber interface temperature used by the telescope simulator to avoid introducing thermal background with the source. We have also installed during the test an engineering model of one NISP detector near the pupil of the instrument to estimate the thermal background of the chamber during NISP test. Even if the measurement is coarse, it has shown a

measured dark current around 52 ADU/f that is fully compatible with the needs for NISP test. Finally, this test has also allowed measuring a set of reflectors at cold and has validated a new step for the metrology described in the following section.

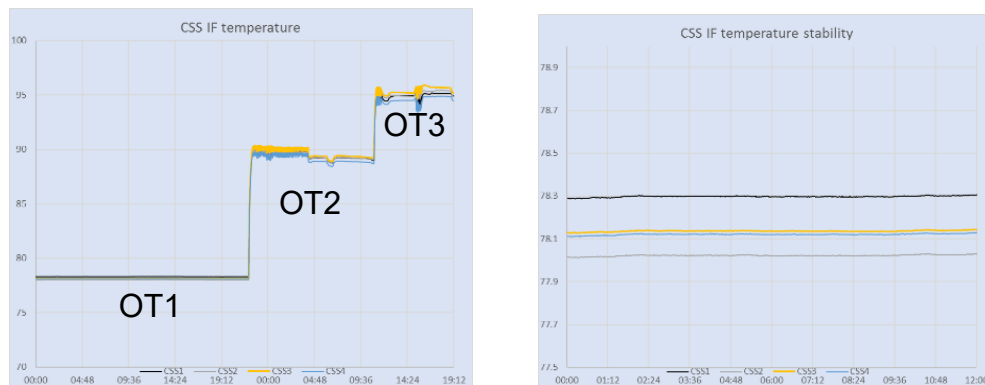


Figure 5. Left: steps of temperature reached on NISP detector interfaces and NISP feet interfaces during the TMVS blank test. Right: stability of the detector interfaces measured during the blank test.

3.3 Metrology equipment

The VGS included also a Metrology Verification system (MVS) to provide at operational temperature the measurement of reflectors installed on the NI-TS and on NISP. The metrology system is specially developed for NISP purpose and it is made of:

- A laser tracker, which is a portable coordinate measuring machine provided by Leica that allows extreme accuracy over large distances. The measurement with the laser tracker is done through a curved window seeing the reflectors into ERIOS. More details on the laser tracker configuration can be found in [4] and [5];
- A theodolite, which is a portable angle measuring system, to measure accurate angle between two mirrors, one put on NISP and one on the NI-TS.

The metrology configuration is shown in Figure 6. The metrology has been developed in parallel of the other parts of the VGS. In particular, it has been required to demonstrate the performance that can be reached by the laser tracker in this configuration that was not usual. A dedicated test campaign has been done in September 2017 to validate the measurement of the laser tracker through a curved window and at vacuum. All details of this study can be found in [5]. We have demonstrated with this test that the measurement of the laser tracker for NISP purpose will have an error better than 100 μ m at vacuum and cold temperature.

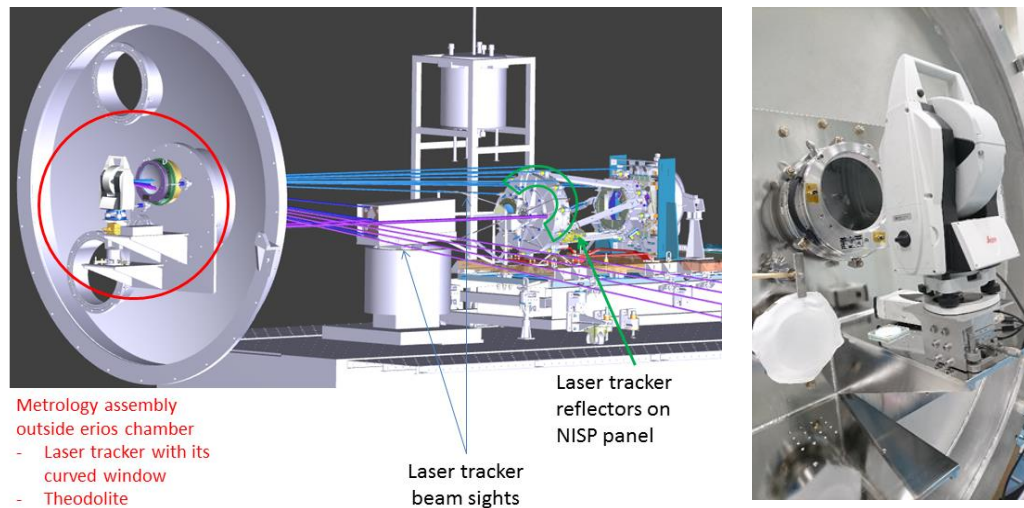


Figure 6. Zoom on the metrology system. Outside ERIOS, the laser tracker and the theodolite, inside ERIOS, the reflectors and mirrors. Right: picture of the laser tracker and window installed on ERIOS chamber.

3.4 Control / Command configuration

The whole VGS will be in interface with NISP and its Electrical GSE (EGSE) for NISP FM TB/TV test. A full description of the EGSE is provided in [7] and [8]. We only present in this article the architecture provided for the test that will allow having a simple interface between all the VGS parts and NISP. The NISP EGSE is made of the NI-WE SCOE, the NISP Central Checkout System (NI-CCS), the EGSE harnesses between the computers and the hardware and the NISP Instrument WorkStation (NI-IWS). All these parts are on an internal network that should be compatible with the PLM network and the NISP performance test. The EGSE is developed for the test of NISP instrument on ground and its goal is to control NISP instrument during the test phase. It will launch the scripts for the test, acquire the data from the detectors and provide all the telemetry from the instrument. For the NISP performance test, it is needed to add an interface between NISP instrument and the NI-TS to control the light sources and the motor of the telescope during the acquisition sequence planned for NISP test. This link is done by the EGSE through the EDEN protocol. In addition, a Database Builder (DB) will recover all information from ERIOS, the VGS and NISP EGSE. It will build the high-level database permitting to associate the complete set-up configuration for the instrument and the GSEs to each instrument exposure. It will be a memory of the tests performed at LAM with the VGS. Finally, an analysis computer will be linked to the whole architecture to allow analysis in real time or from remote of the data.

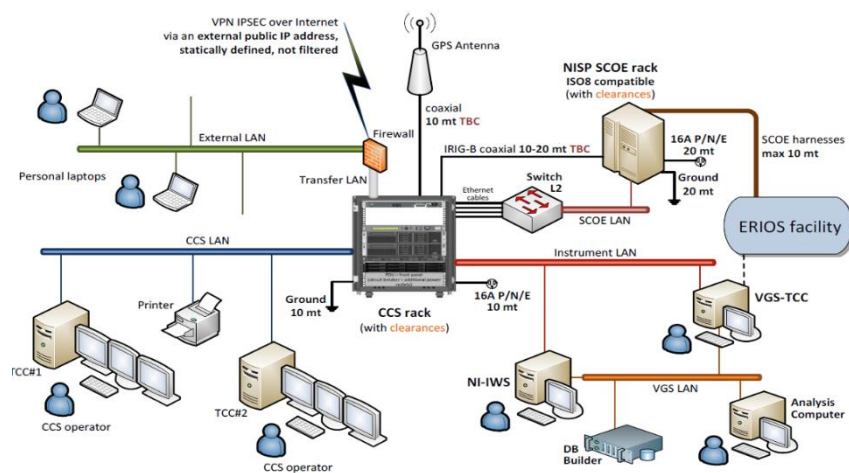


Figure 7. Layout of the control/command system for the NISP performance test.

4. CONCLUSION

We have presented in this article a complete description of the VGS, a ground support equipment developed at LAM to test NISP instrument at vacuum and cold. The VGS will be used during the performance test campaign of NISP to validate the main functionality of the instrument and its main performance in photometric and spectroscopic modes. The VGS is made of an optical part, which simulates the EUCLID telescope, a set of thermal and mechanical parts to ensure the thermal stability of NISP during the test, a control / command system to control the instrument together with its GSE during the test and a metrology system. The VGS is currently fully delivered at LAM and final validations have been started for the telescope simulator. We have already shown the good performance reached by the metrology and the TMVS. A blank test of the complete VGS is scheduled for October 2018 to demonstrate the performance and quality of the optical GSE. The VGS will be delivered to NISP project in November 2018, just before the start of the NISP test campaign, scheduled in January 2019. The development of the VGS represents a great challenge as many functionalities are required and many institutes are involved.

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