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GROUND TEST EQUIPMENT DESCRIPTION FOR NISP INSTRUMENT VALIDATION ON GROUND

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I. INTRODUCTION

EUCLID mission [1] has been selected by ESA in 2012 in the context of the Cosmic Vision program to understand the nature of the dark energy and the dark matter. It is designed to map the geometry of the dark Universe by investigating the distance-redshift relationship and the evolution of cosmic structures. Two scientific instruments are used: the Near Infrared Spectroscopic Photometer (NISP) [2] and the Visible Instrument (VIS) [3]. The NISP instrument of EUCLID is dedicated to measure the redshift of millions of galaxies and to analyze their spatial distribution in the Universe with two instrumental modes: the photometry using broadband filters to acquire image of the galaxies, the spectroscopic mode using gratings to obtain their spectra in the Near-IR spectra region.

NISP instrument is made by a European consortium led by Centre National des Etudes Spatiales (CNES) that includes laboratory and industries mainly from France, Germany, Italy and Spain. NISP will be fully assembled and aligned at Laboratoire d'Astrophysique de Marseille (LAM) in France. The Flight Model (FM) has also to be tested under vacuum and thermal conditions in order to qualify the instrument in its operating environment and to perform the final acceptance and performance test before delivery to the payload. The test campaign will regroup functional tests of the detectors and wheels, performance tests of the instrument, calibration procedure validation and observations scenario test, all done at LAM during two test campaigns done before and after the vibration test campaign. One of the main objectives of these test campaigns will be the measurement of the focus position of NISP with respect to the EUCLID object plane.

To achieve these tests campaign, a global Ground Support Equipment (GSE) called the Verification Ground System (VGS) is in development at LAM to allow the performance test of NISP FM. The VGS is a complex set of GSE, developed by LAM and its partners that will be used into the ERIOS chamber, a thermal vacuum chamber designed to test space instrument in cryogenic-vacuum conditions. The VGS is made of i) a telescope simulator to simulate the EUCLID telescope and to inject light into NISP for 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 the different main technical specifications of the VGS and the main objectives of the NISP test campaign. Then we will describe the telescope simulator, the thermal GSE and the metrology mean. Current design and concepts chosen for the NISP test will be shown, in particular the trade-off made for the design of the thermal and mechanical GSE and the foreseen configuration for the test into ERIOS. We will discuss the main difficulties we are facing: design of thermal interface for detectors at 80K with 4mK stability and the development of a metrology system using a laser tracker which has to measure the focus position within 150 μ m in cold and in vacuum through a curved window.

II. NISP TEST CAMPAIGN: OVERVIEW AND OBJECTIVES

A. NISP description

NISP instrument is at the beginning of phase D. The goal is to deliver the Flight Model (FM) to ESA and AIRBUS in 2018. Its design is well advanced and described in detailed in [2]. It is made of 3 main assemblies: the NI-OMA (Opto-Mechanical Assembly), composed of the mechanical support structure and the optical elements, the filter and the grism wheels and the calibration unit; the Focal Plane Array (NI-FPA) and the Sensor Chip System (NI-SCS) that compose the Detector System Assembly (NI-DS). It is made of 16 H2RG detectors and associated 16 ASICS (Sidecars), passively cooled at operating temperature (<100K for the detectors; 140K for the ASICS Sidecar). Thermal stabilization of the detector is "naturally" obtained thanks to the very good thermal stability provided by the Euclid PLM at the NISP interfaces; the Warm Electronics Assembly (NI-WE), composed of the Instrument Data Processing Unit and Control Unit (NI-DPU/DCU), and the Instrument Control Unit (NI-ICU).

A Structural and Thermal Model (STM) of NISP has been manufactured, and tests in 2016 at LAM [2]. The STM has shown that the design of NISP instrument was compliant with the requirements in term of mechanical

and thermal response. The first TB/TV of NISP STM has been done in ERIOS chamber as shown in Fig. 1 and as explained in subsection III, parts of the Thermal Ground System Equipment (TGSE) used during the STM campaign will be re-used for the Flight Model test campaign.

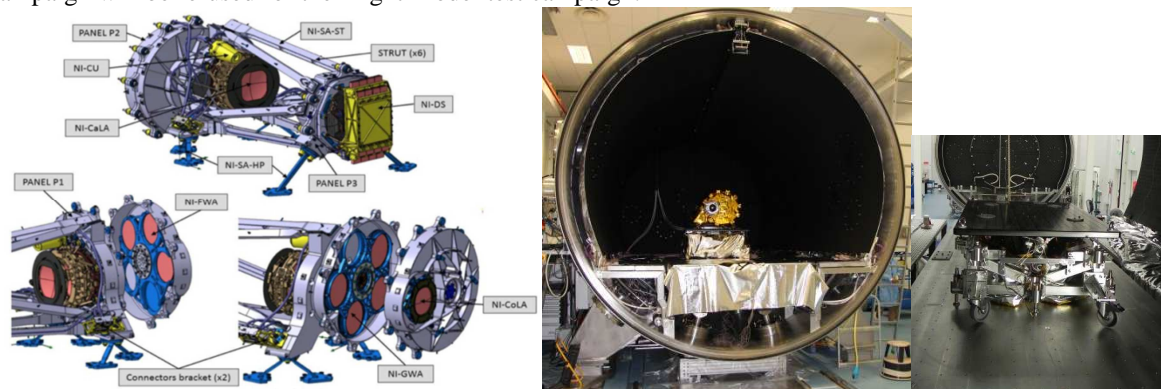


Fig. 1. Left: NISP instrument description. Middle: NISP STM in ERIOS chamber for the STM TB/TV test. Right: zoom on the NISP thermal interfaces without MLI.

B. NISP test campaign objectives

NISP instrument will be tested at LAM in vacuum and cold conditions to mimic the behavior of the instrument during the observations with EUCLID. The goal of the thermal performance test will be to validate the performance of the instrument before delivery to the PLM. The main objectives of the test campaigns are:

- The verification of the performance requirements 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;
- The measurement of the object plane position of NISP with respect to NISP reference frame at Operational Temperature (OT) to provide information for the alignment of NISP on the PLM;
- The verification of the functionality of NISP: observation scenario will be tested and validated including wheel, detector acquisition, data reduction and communication with spacecraft sequences;
- The study for the calibration strategy 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 in ERIOS chamber, already used to test NISP STM. It is required to develop a set of GSE called the Verification Ground System (VGS) to test NISP performance in appropriate conditions.

III. NISP Verification Ground System (VGS)

The VGS is a mean developed by LAM and its partners to test NISP performance on ground fully described in [7]. The main objectives of the VGS 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 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. This functionality is provided by NI-TMVS, NISP Thermal and Mechanical Verification System: it is the thermal and mechanical environment to be used for NISP thermal balance and verification and all the thermal and mechanical interfaces needed for the test and to stabilize NISP in temperature. This part of the VGS is developed by LAM;

- 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 $\pm 0.5^\circ$ of the sky. The source from the telescope should provide selectable monochromatic wavelength in the band 0.4 to $2.1\mu\text{m}$, multi-lines spectrum from 0.9 to $2\mu\text{m}$ and continuum spectrum from 0.9 to $2.02\mu\text{m}$. 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. This functionality is provided by NI-VTS, NISP Verification Telescope System: it is a telescope simulator of EUCLID telescope that injects light into NISP for optical and performance tests. The NI-VTS is developed by a Danish consortium between DTU space and Dark Cosmology Centre;
- 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. This functionality is provided by NI-MVS, NISP Metrology Verification System: it is a set of metrology tools used to measure the positions and orientations of the components during the test in the vacuum chamber. It is developed by LAM and a detailed presentation of the concept can be found in [4].

In addition, the NI-WEVS, NISP Warm Electronic Verification System is developed to control the instrument during the test on ground. This set of GSE is provided by an Italian consortium. A complete description of the EGSE is provided in [5] and in [6].

All the parts of the VGS will be installed into ERIOS chamber, which is a large (the size of the envelope is 4 meters in diameter by 6 meters long) vacuum space simulation chamber. ERIOS combines vacuum and temperature close to -200°C and provide a high stability of the environment. A specific test configuration, shown in Fig. 2, is designed to design and organize the different GSE needed for NISP performance test. NISP will be installed on the center of ERIOS chamber on a baseplate used as a thermal interface between NISP and the environment in ERIOS. The NI-VTS is set in front of NISP to inject light into the science detectors to characterize NISP performance. The NI-MVS is installed outside ERIOS on the entrance door to measure position through a window and to keep the metrology means warm. Several interfaces and mechanical structures are needed and shown in Fig. 2 into ERIOS. We propose now to describe in detailed the NI-VTS, the NI-TMVS and the NI-MVS to provide an overview of the complexity of this GSE.

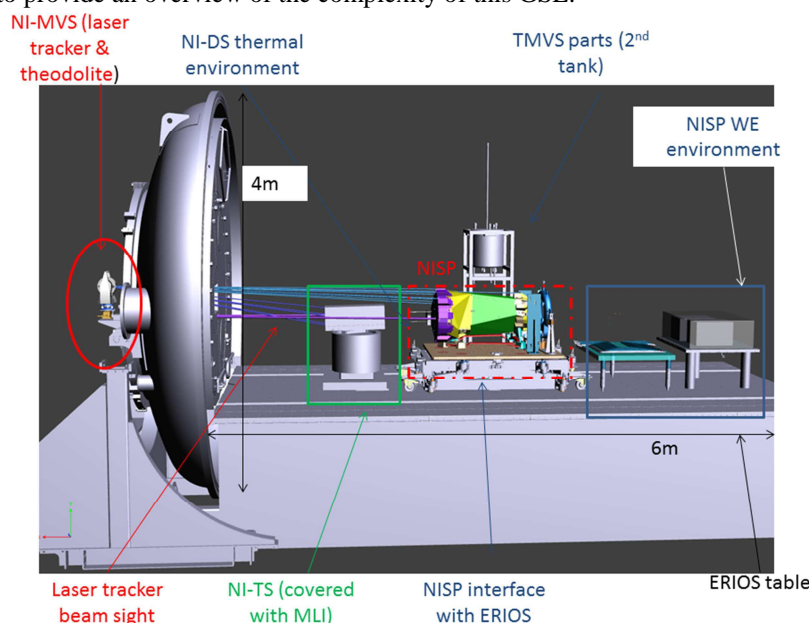


Fig. 2. View of the VGS into ERIOS chamber. The different parts are shown.

One of the main important components of the VGS is the NI-TS (NISP Telescope Simulator) that simulates the F/20 EUCLID telescope beam. It is made of an elliptical mirror positioned on translation and rotation stages that allow the telescope to move in five degrees of freedom to illuminate the entire NISP Field of View (FoV). 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 environment done by the thermal flexures made with a low conductivity material between the telescope itself and the motor assembly to provide a thermal isolation between the 2 items. This is one of the main challenges for the NI-TS design as the different parts of the NI-TS operate at different temperatures and in a warmer environment than NISP. The Active Telescope Support unit (ATS) moves the Telescope Simulator (TS), around to illuminate the full NISP FoV. The ATS is an assembly of 5 motors with a large moving range to commit with NISP need and to allow a scanning of the focus to find NISP best: 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 but working at 293K. They ATS will be covered by MLI blanket to be kept warm and to avoid being cooled down by the cooling shrouds. The ATS is directly in interface with ERIOS bench thanks to 3 shims under the last translation stage baseplate. The TS is made of an off-axis elliptical mirror assembled to a baseplate thanks to optical contact. 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 should be 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 170K to limit impact of the temperature on the stability of the focal distance. The telescope is illuminated through a 2 μ m diameter pinhole placed in the primary focus and provides 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. It is also needed to measure the focal distance of the TS at ambient temperature thanks to a Coordinate Measurement Machine (CMM) with high precision to know precisely the focus position with respect to laser tracker targets set on the back surface of the telescope. The TS is designed to provide a WFE lower than 30nm rms over the 160mm diameter aperture to ensure a good image quality on NISP during the performance test. A view of the telescope design is shown in Fig. 3. In order to minimize stray light during NISP test, the telescope will be surrounded by a baffle made of several vanes.

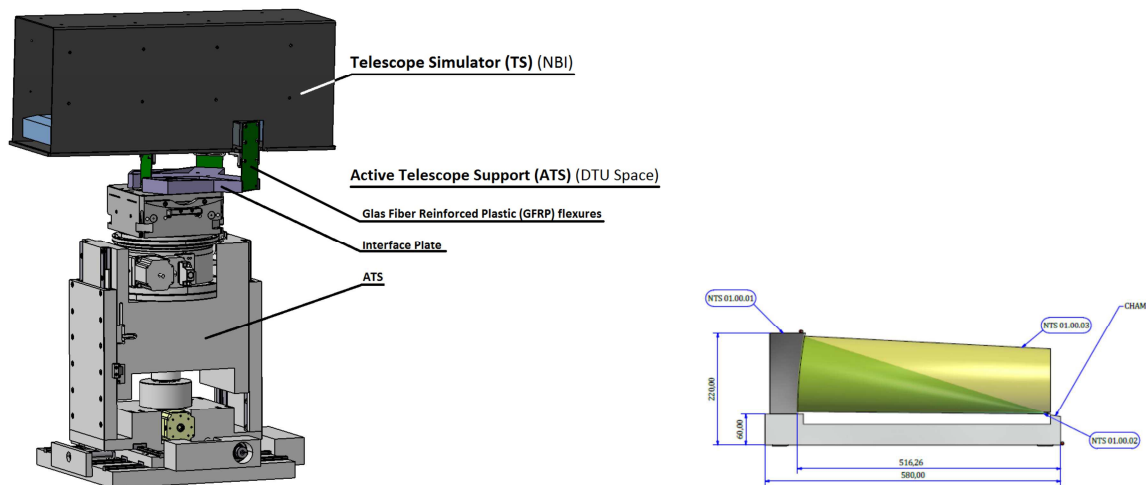


Fig. 3. Left: the NI-TS without MLI showing the motor assembly and the telescope in its baffle, right: the optical layout of the telescope.

The illumination system used for the NI-TS is made of a fiber connected at the entrance focus and of a monochromator that is fed 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 NI-TS will be provided with a Telescope Control Computer (TCC) to control the motors position, the light illumination and intensity.

B. Thermal and mechanical ground support equipment

The Thermal and Mechanical Ground Support Equipment also called TMVS provides thermal and mechanical interfaces for NISP needed for the performance test. It should simulate the PLM thermal environment. The radiative thermal environment consists of ERIOS liquid nitrogen shrouds. To avoid 300K background coming from the optical windows needed for the metrology measurement (see subsection III-C) a cold baffle is fixed between LN2 shrouds and the windows. In addition, a shutter activated from outside by a ferrofluid feed through is placed between this baffle and the windows to cut light coming from the windows when the metrology is not used during performance test of NISP detectors. The TMVS has also to provide conductive interfaces for NI-OMA, the Warm Electronic (WE) and for the intermediate harness as described in Table 1.

Table 1. Thermal Test case for NIOMA

Case		NI-CSS	NI-SSS	Feet	Comments
cOT1	Temperature	80K +/-2K	120K +/-2K	120K +/-2K	The case is the detector related performance test case
	Stability	4mK/1210s 0.8K/month	0.2K/1210s 0.8K/month	0.8K/1210s 0.8K/month	
	Gradient	+/-0.5K	+/-1K	+/-5K	
	Heat load	2.3W	4W	0W	
cOT2	Temperature	90K +/-2K	130K +/-2K	130K +/-7K	This case is the optical performance stability and Thermal balance
	Stability	20mK/1210s 0.8K/month	0.2K/1210s 0.8K/month	0.8K/1210s 0.8K/month	
	Gradient	+/-0.5K	+/-1K	+/-5K	
	Heat load	2.3W	4W	0W	
cOT3	Temperature	95K +/-2K	135K +/-2K	135K +/-7K	This case is the optical performance stability and Thermal balance
	Stability	20mK/1210s 0.8K/month	0.2K/1210s 0.8K/month	0.8K/1210s 0.8K/month	
	Gradient	+/-0.5K	+/-1K	+/-5K	
	Heat load	2.3W	4W	0W	

To meet these requirements, the TMVS is composed of four different parts:

- The cold plate in aluminium, linked to a liquid nitrogen tank placed under these table. This part of the thermal environment has been used for the NISP STM Thermal Balance Test. In the STM configuration, it was used as mechanical and thermal interface for NIOMA, NI-CSS thermal interfaces and NI-SSS thermal interfaces. The temperature of the plate is 90K and the STM tests have shown a stability of 2.3mK over 1000s (NISP exposure time) which was well within the stability required. Fig. 1 shows the STM cold plate into ERIOS before NISP integration;
- The NISP Thermal Frame (NI-TF), a frame in Invar, is the mechanical interface with NISP feet to guarantee mechanical interfaces for NISP. The frame is installed on the cold plate by an isostatic mount and is thermally linked to the plate by cold braids. To control the temperature (between 120K and 135K) the frame is equipped with heaters uniformly distributed on the bottom side;
- The NI-CSS thermal interface shown in Fig. 4 is composed of four copper braids directly linked to an annular liquid nitrogen tank in order to ensure a cold case at 80K. Warmer temperatures and stability are ensured by heaters at the end of the braids controlled by a Lakeshore PID controller. The LN2 tank is supported by the aluminium cold plate;
- The NI-SSS shown in Fig. 4 is composed of brackets supported by the cold plate but insulated from it and controlled in temperature. Four thermal braids are linked between brackets and NI-SSS. The NI-SSS thermal interface shall also provide connector bracket at 130K for SCE connectors.

To allow reaching the good temperature, a liquid nitrogen loop has been designed to fill the tanks under the cold plate and behind NISP detectors assembly. The principle is shown Fig. 5. A supply tank is positioned in the upper part of ERIOS. This tank permits to have autonomy of 30 hours between two fillings. It also permits to manage the cooling down phase in order to keep detectors warmer than the rest of the instrument. In addition to NIOMA, the TMVS has to provide conductive thermal interfaces for the harness and the warm electronic. The harness thermal unit is a stainless steel plate, where the NISP intermediate harness is fixed, with a temperature

gradient between operational temperature (130K) to room temperature. The cold part of the unit is linked by thermal braids to the NIOMA cold plate and the warm part is regulated by heaters. The warm electronic thermal enclosure provides thermal interfaces for DPU and ICU electronic boxes between 253K and 303K. The interface plate is an aluminum plate thermally regulated by a heat transfer fluid circulation. The fluid temperature is adjusted by a thermostated bath (Bain Lauda) outside the chamber. To avoid molecular contamination from NI-DPU and NI-ICU, a cold trap will be implemented in front of an aperture in the cover of the enclosure.

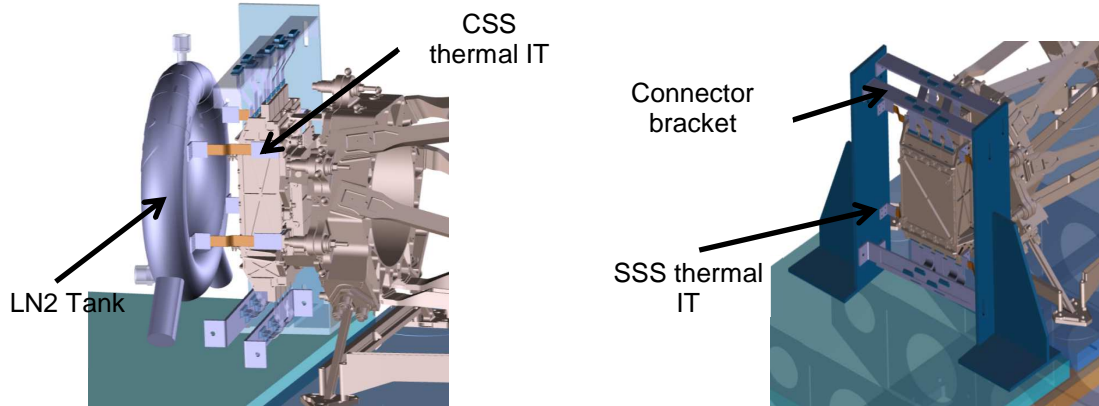


Fig. 4: NI-CSS (left) and NI-SSS (right) Thermal interfaces

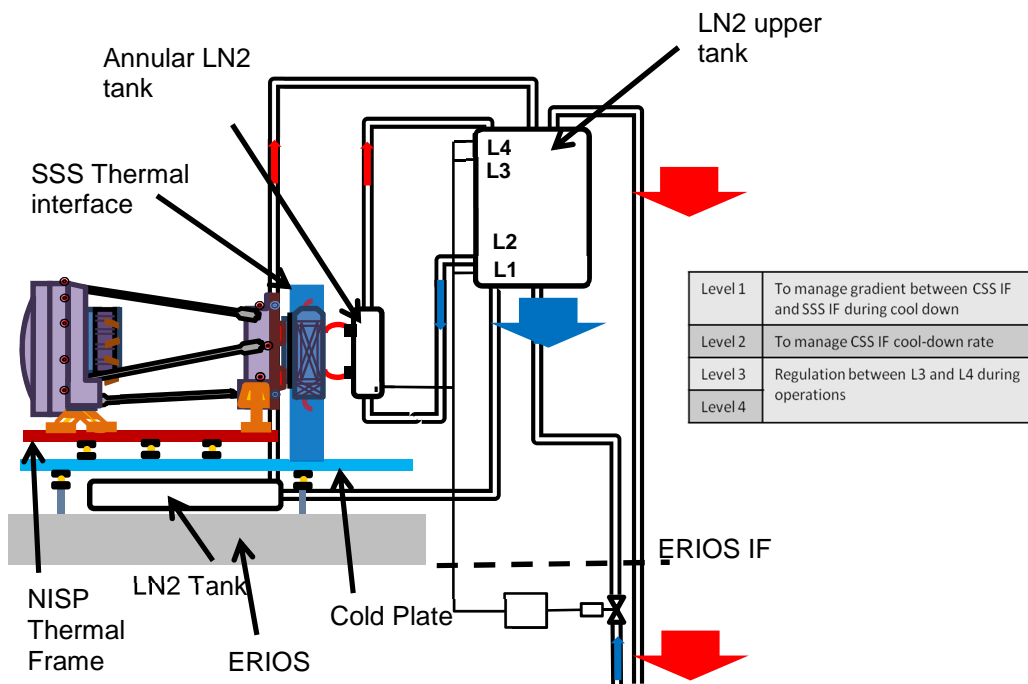


Fig. 5: TGSE LN2 loop

C. The NI-MVS: Metrology Verification System

In addition to the classical ground support equipment, it is needed to develop a Metrology Verification System (MVS) to provide at operational temperature the measurement of references frames set on the telescope simulator and NISP, the knowledge of the coordinates of the object point source provided by the telescope simulator and the measurement of the angle between the telescope simulator optical axis and NISP optical axis. The MVS concept is based on the use of two devices put outside ERIOS chamber: 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 will be done through a window seeing the reflectors into ERIOS. The current configuration foreseen is to use a curved window. More details on the laser tracker configuration can be found in [4]; 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 principle of the measurement of the laser tracker is the measurement of the position of reflectors set respectively on the NI-TS and on NISP instrument. The goal of this measurement is to deliver the position of

NISP reference frame R_u with respect to NISP object plane R_{nisp} at Operational Temperature (OT) (i.e. 130K) with accuracy within $\pm 150\mu\text{m}$ to Airbus, the responsible of EUCLID PLM, which will align NISP on the EUCLID payload thanks to this information. To provide this information, a sequence of measurement is needed at NISP instrument level:

- Measurement at room temperature with a Coordinate Measurement Machine (CMM) of the frame R_u with respect to the laser tracker reference frame R_{lt} . R_u is a reference frame set at NISP interface with the PLM i.e. NISP feet. R_{lt} is defined by a set of laser tracker reflectors installed on NISP entrance panel P1.
- Measurement at OT with the MVS of R_{lt} with respect to R_{nisp} . The main difficulty is that R_{nisp} cannot be measured directly as it represents the NISP object plane. To be able to provide this information, the TS and the VFP are used. The focus point of the TS will then provide the knowledge of R_{nisp} through the measurement of a reference frame R_{ts} made of a set of laser tracker reflectors installed on the TS. The knowledge of the transfer matrix between R_{ts} and R_{nisp} is obtained thanks to a measurement of the TS best focus on the VFP at OT in ERIOS using the MVS. Then during NISP TB/TV, the transfer matrix between R_{ts} and R_{lt} is measured with the MVS and allows to obtain the relationship between R_{lt} , thus R_u , and R_{nisp} that is delivered to Airbus. Fig. 6 represents a scheme of the measurement philosophy with the MVS.

The metrology done during the NISP test campaign will be particularly important as it will provide the knowledge of the position of the NISP focal plane with respect to the telescope simulator. From these measurements, the real NISP focus will be known. The theodolite measurement will be used to monitor the angular position of the TS will respect to NISP with accuracy giving the FoV position seen on NISP detectors.

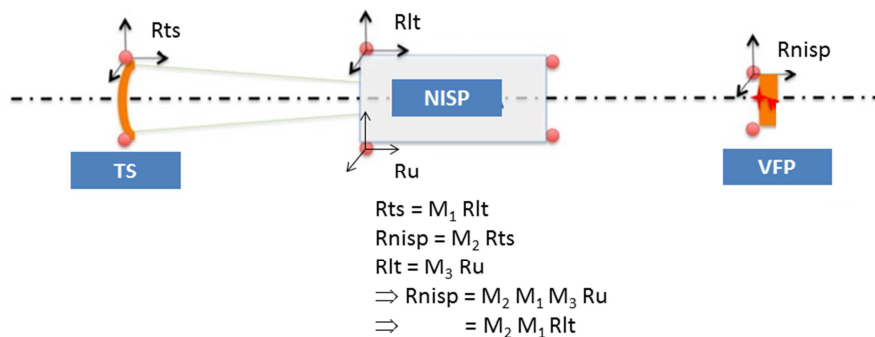


Fig. 6. Schematic of the measurement to be done with the MVS. The frames to be measured are shown

The concept and the feasibility study of the MVS are fully described in [4]. The laser tracker and the theodolite will be placed out of ERIOS chamber and will do the measurement through a window. One has to take into account the measurement errors introduced by the glass in the laser tracker measurement. A mechanical interface will allow the positioning of the both components on ERIOS chamber door to measured reflectors set inside ERIOS. Fig. 7 provides a view of the MVS for the NISP performance test. The beam sights are shown to validate the position of the test set-up (NISP and TS) and the laser tracker into ERIOS.

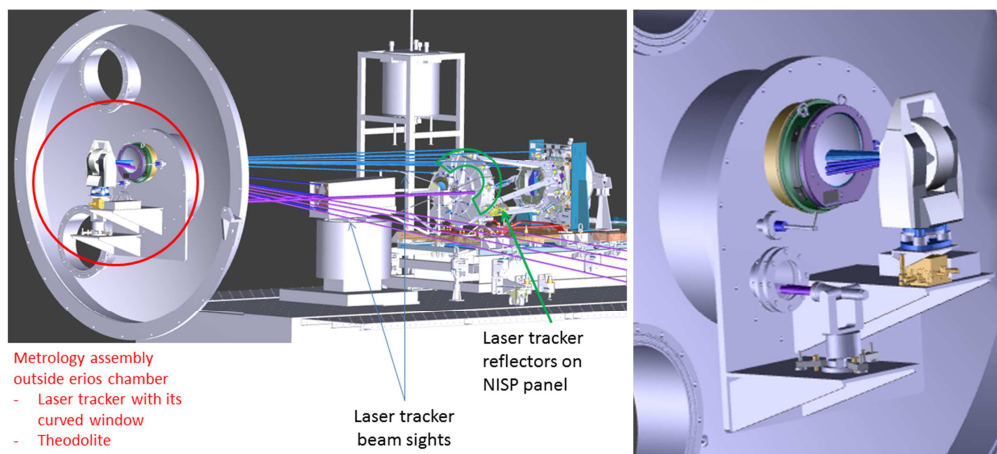


Fig. 7. Zoom on the metrology system. Outside erios the laser tracker and the theodolite, inside ERIOS, the reflectors and mirrors.

IV. 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 under development to be ready for NISP test campaign by end of 2017. To reach this challenging goal, different development phases are foreseen. The TS is already being manufactured to be delivered to LAM for Fall 2017. In parallel the ATS will be tested with a simulated mass of the TS to make sure that the components will be ready in time. In addition, a dedicated acceptance test of the metrology is foreseen by beginning of 2017 to demonstrate the performance and the accuracy reached by the laser tracker in NISP test configuration. Then the TMVS will be tested together with the telescope simulator to validate the thermal behaviour of the VGS.

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