EUCLID PAYLOAD MODULE: THERMAL BALANCE AND THERMAL VACUUM TEST AT CSL PREMISES

Sylvie Liébecq (1), Isabelle Tychon (1), Lionel Jacques (1), Benoît Marquet (1), Etienne Lallemand (1), Valérie Samain (1), Anthony Kellens (1), Christophe Grodent (1), Yves Martin (2),Nicolas Saltalamaccia (2), Jonathan de Ville(2) , Pascal Jacq (3), Marc Zanoni (3, Denis Montperrus (3), Sylvie Valente (3), David Filleul (3), Lionel Carminati (3), Laurent Brouard (3) ,

(1) *Test Lab, Centre Spatial de Liège, Avenue Pré Aily, 1, 4031 Angleur, Belgium, Email: csl@uliege.be*
(2) AMOS, rue des Chasseurs Ardennais, 2, 4031 Angleur, Belgium , Email :info@amos.be
(3) Earth Observation and Science space systems, Airbus Defence and Space, Rue des Cosmonautes, 31 31400 Toulouse, France, Email: mktg-space-systems@airbus.com

KEYWORDS

Thermal Balance, Helium liquefier, EUCLID, environmental test, CSL.

ABSTRACT

This paper presents the test setup and the results of EUCLID PLM (PayLoad Module) TB (Thermal Balance)/TV (thermal Vacuum) Test at low temperature.
Euclid is an ESA optical/near-infrared survey mission designed to study the dark Universe and understand the origin of the accelerating expansion of the Universe.
The Euclid Spacecraft is composed of a Service Module (SVM) and a Payload Module (PLM).
The Payload Module, consists of a 1.2 m class telescope and accommodates the two instruments, the Visible imager (VIS) and the near-infrared spectrophotometer (NISP), both covering a large common field-of-view of the sky.
The Centre Spatial of Liege (CSL) was in charge of the environmental test setup around the PLM.
The temperature evolution of the instrument and its environment has been measured during the test with a large amount of thermal sensors. A Helium liquefier cooled the main environment around the telescope down to a mean temperature of 25 K.
Airbus Toulouse measured performances thanks to a collimator installed under vacuum and cooled by a dedicated thermal tent down to the liquid Nitrogen temperature.
Finally, a second cycle has been performed to confirm the telescope settling effect.

1. EUCLID MISSION

The mission of EUCLID is to map the geometry of the Universe to better understand dark matter, dark energy and gravity. The mission will investigate the distance-redshift relationship and the evolution of cosmic structures by measuring shapes and cosmological redshifts of galaxies and clusters of galaxies to a look-back time of 10 billion years, covering the entire period over which dark energy played a significant role in accelerating the expansion of the Universe.
The shape of galaxies is distorted by gravitational deflection of light due to dark matter concentrations. The galaxy clustering is the non-random distribution of galaxies in the Universe resulting from the action of gravity. EUCLID demands very high precision measurements and the ability to survey the sky at visible near-infrared (NIR) wavelengths, that cannot be met from the ground.
The nominal mission lifetime is six years [1].

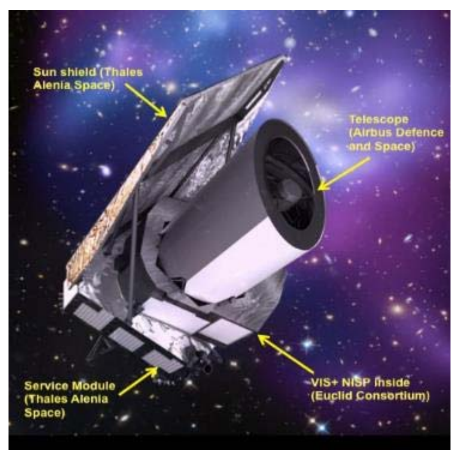


Figure 1-1: EUCLID spacecraft

2. PAYLOAD DESCRIPTION AND TEST SPECIFICATIONS

2.1. PayLoad Module Description

The Payload Module (PLM) comprises the telescope, the PLM thermal control system, the Fine Guidance Sensor (FGS), the VIS and NISP instruments (delivered to Airbus Defence and Space division by the Euclid Consortium). It is developed under the responsibility of Airbus Defence and Space.

The prime contractor is Thales Alenia Space, Italy.

The telescope is a 1.2 meter on-axis 3-mirror Korsch cold telescope.

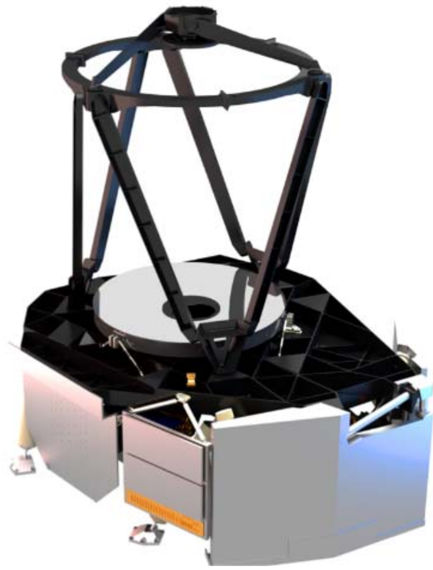


Figure 2-1: EUCLID Telescope overview

M1 is maintained at a temperature below 130K with thermal stability better than 50 [mK]. The mirrors and structures are all made in Silicon Carbide, a material with adequate thermo-elasticity, ~~and~~ stiffness properties and immune to radiations.

Both instruments share a large common field of view. VIS provides high quality images to carry out the weak lensing galaxy shear measurements. NISP performs imaging photometry to provide near-infrared photometric measurements for photometric redshifts, and also carries out slitless spectroscopy to obtain spectroscopic redshifts.

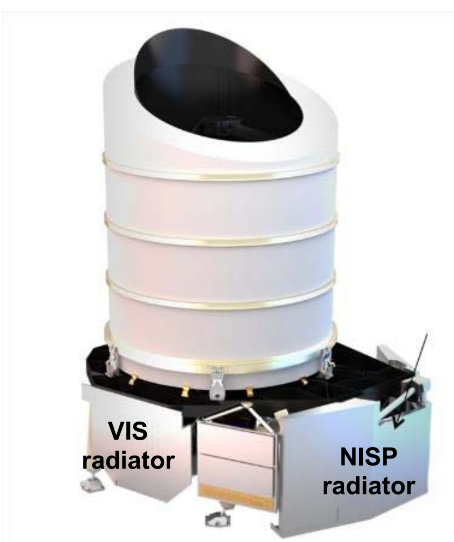


Figure 2-2: EUCLID PLM representation

An external baffle – the cylindrical structure – protects the optical surfaces and the instruments from stray light and guarantees a thermally stable environment [2].

2.2. Test Specifications

In order to meet the scientific performance requirements, such as having internal background well below the zodiacal sky background, the telescope must operate at a reduced temperature - a maximum operating temperature of about 240 K can be tolerated for the telescope.

Therefore, the translated specifications provided by Airbus Toulouse to CSL, in terms of temperatures and gradients requirements, concern 5 different parts on the CSL setup :

- NISP & PLM tent
- Collimator tent
- The SVM shrouds at the back side of the PLM
- WU (Warm Electronics) Shrouds
- VIS Shrouds in front of the VIS radiator

These parts are identified and detailed in the next chapters.

The pressure specification is to be below 1 10^{-5} [mb].

The main constraint is the way to avoid contamination on the NISP instrument during transient phases (cooling down and warming up).

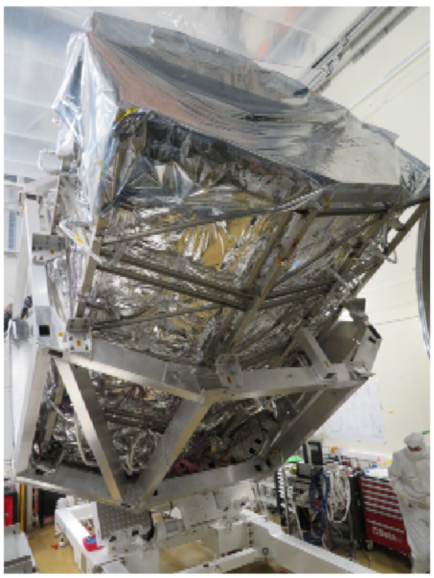
3. SETUP DESCRIPTION

3.1. Focal 5 Description

3.1.1. ISO 5 Area

The Focal 5 ISO 5 area has been improved to fit with the handling of EUCLID during the preparation phase of the test.
Indeed, in order to protect the instrument from damages during the thermal tent integration, the setup is prepared in the vertical configuration.
It is then rotated and installed in the horizontal configuration on the optical bench of the vacuum chamber.
This rotation determines a maximum allowable height for the ISO 5 area, which was higher than the existing working area.

Picture 3-1: Setup rotation



Picture 3-2 : Setup on its manipulator

Therefore, a new working area has been built, with a motorized roof to be able to use the crane of the clean room (max 5.3T) all over the ISO 5 area.

Picture 3-3: Focal 5 new ISO 5 area

In addition, the floor has been reinforced to withstand the heavy mass (about 8.7T) of the complete setup with the instrument on its manipulator. A study has been performed to determine the positioning of the pillars in the basement, under the working area.

3.1.2. Vacuum Chamber

The vacuum chamber used for the EUCLID test is FOCAL 5 (Facility for Optical Calibration At Liege). This chamber is a cylindrical stainless steel vessel of 120 [m³], 7 [m] long, with an horizontal axis and a diameter of 5 [m].

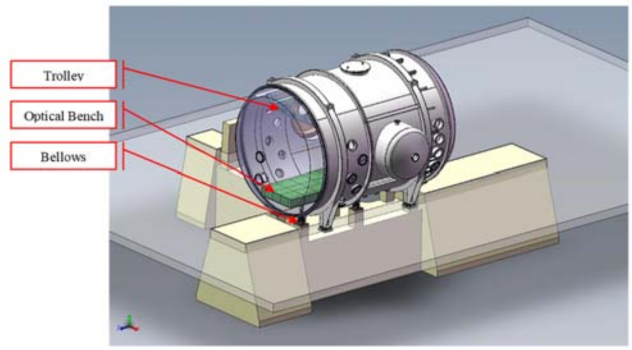
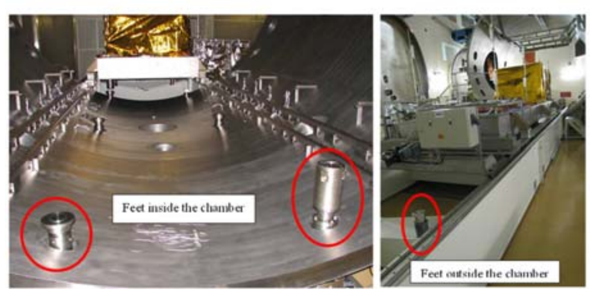


Figure 3-1: Focal 5 Description

The optical bench (6.8 m x 1.8 m) is made of stainless steel and has a flatness of 10^{-5} [m/m]. It is supported by 6 feet, 3 of them are used for a point-line-plane system, passing through the wall of the vessel and is insulated from mechanical vibrations by bellows, which also ensure vacuum tightness. These feet stand on a seismic block.

The microvibration level is 100µg RMS in the 0-400 Hz bandwidth.

The optical bench can be removed from the chamber, by means of a carrier trolley using rails, to be able to use the crane of the clean room for integration phase.



Picture 3-4: Railway inside and outside F5

3.2. EUCLID Setup General overview

First of all, a preliminary study has been performed with AMOS to evaluate the feasibility of the test in our Focal 5 vacuum chamber.
The main output of this study concerns the location

of the Warm Electronics.
In the satellite, Warm electronics are installed inside the SVM. But they have been moved to the top of the PLM Thermal Tent to avoid a significant and heavy transformation of the vacuum chamber.

Figure 3-2 shows the PLM (in blue) tested in Focal 5, under ISO 5 environment and the Warm Electronics (in light green).

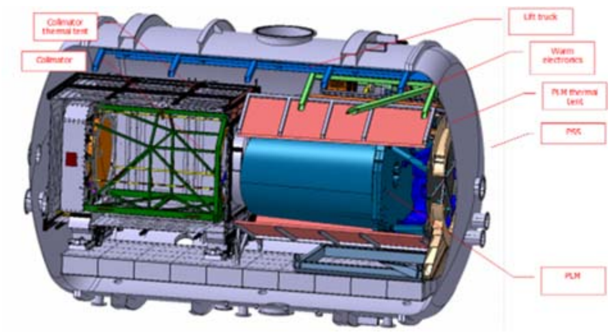


Figure 3-2: EUCLID Test in Focal 5

The PLM is surrounded by a thermal tent (PLM thermal tent) composed of 50 shrouds, provided by AMOS with their structure, mainly fed by cold gaseous Helium (GHe).

Picture 3-5: PLM Thermal Tent

This PLM is installed in front of its collimator, surrounded by its own thermal tent (Collimator thermal tent) composed of 21 shrouds fed by liquid Nitrogen.

The Collimator is designed and provided by AMOS.

Picture 3-6: EUCLID Collimator

The reason why the collimator is not kept at ambient temperature inside the vacuum chamber is due to the fact the environment around the collimator has to be cold enough to minimize the heat load transferred to the PLM environment. Indeed, for optical measurements, a large aperture between both tents is needed. But, for stabilization reason, the collimator itself is regulated at ambient temperature with heaters controlled by a dedicated EGSE (Electrical Ground Support Equipment), provided by AMOS.

The collimator is installed on motorized feet (MASF) and heightens, in order to align its optical beam with the PLM one.

The PLM is fixed on its PSS (PLM Supporting Structure, provided by AMOS), which is installed on the optical bench of Focal 5. This PSS is about 3.6 [m] long, 3 [m] wide and 3.7 [m] high for a mass of about 1 ton.

Picture 3-7: Setup on F5 Optical Bench

Both thermal tents are suspended on the Focal 5 wall by means of a dedicated trolley, called lift truck, also provided by AMOS. The aim of this MGSE (Mechanical Ground Support Equipment) is to decouple thermal tents from the optical interfaces. Indeed, shrouds induce vibrations, due to the cryogenic fluid circulation through the pipes, and optical measurements could be then degraded.

Picture 3-8: Lift truck

All MGSE have been submitted to a proof test by AMOS and supervised by an authorized company before delivery.
The main challenge was the planning. The MGSEs have been manufactured, tested and delivered in less than 1 year, during the COVID period.

3.3. PLM Thermal Tent Description

The PLM thermal tent is composed of 50 shrouds, distributed in 6 parts.
The 3 first parts are fed by a single GHe (Helium shrouds) line:

- NISP part in front of the NISP radiator
- PLM part for shrouds located around the PLM baffle
- PLM FRONT part for the face in front of the collimator

The 3 last parts are fed by Nitrogen (liquid (LN2) and/or gaseous (GN2)) (Nitrogen shrouds):

- VIS part in front of the VIS radiator
- SVM part under the PLM feet
- WU part under the WU panels (electronics)

This tent is 3.5 [m] long, 2.5 [m] wide and 4.5 [m] high for a mass of about 2 tons.

AMOS designed, manufactured, mounted and tested all parts before delivery.

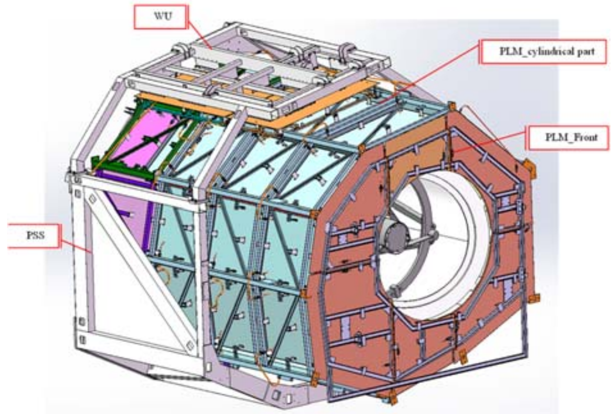


Figure 3-3: PLM Thermal Tent – 1/2

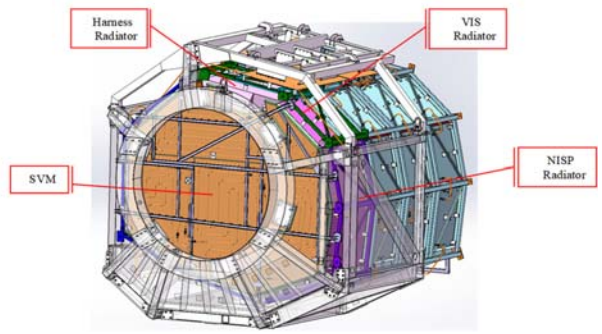


Figure 3-4: PLM Thermal Tent – 2/2

Helium shrouds are made of Copper plates where pipes are brazed on one side for the cryogenic fluid circulation and the other side is covered with Honeycomb (for cryogenic specifications at PLM level) and black painted with MAP PU1. This kind of shroud is a heritage of the Planck Spacecraft test at CSL, used to increase the emissivity of the shroud at low temperature [3].

Indeed, in order to meet the temperature specifications at the baffle level, very low temperatures are needed and generated by one single line of cold gaseous Helium flowing through the shrouds from a Helium liquefier.

The Helium tent has no Nitrogen guard around it. Then the test MLI used for thermal insulation is a 20-layers blanket and all connections between structures and shrouds are closed with black painted flaps.

Figure 3-5 gives the exploded view of the Helium thermal tent, from shroud #1 to shroud #41. Shrouds #36 to #41 are at the PLM front side.

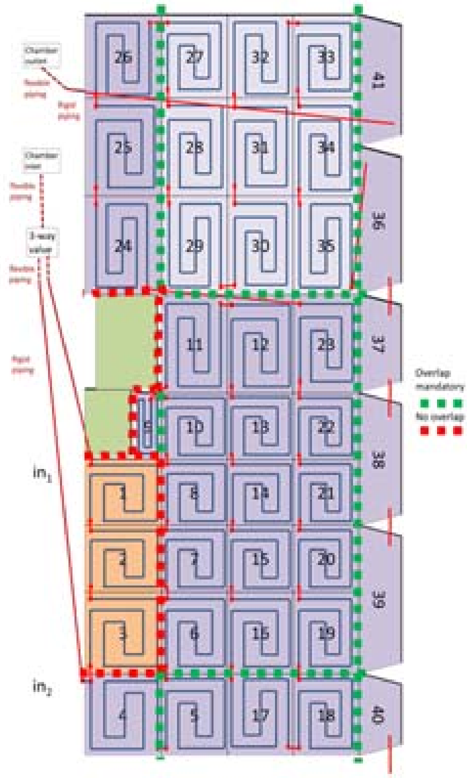


Figure 3-5: GHe line

For contamination reason, the shrouds in front of the NISP radiator, which are the first three shrouds of the Helium line, have to be kept warmer than the rest of the shrouds in the line during transient phases (cooling down and warming up phases).
The principle is to start the cooling down by the fourth shroud in the line and wait for the complete cooling down before cooling the NISP shrouds down to about 13 K.
This constraint has been respected by using a 3-way cryogenic valve, by-passing the NISP shrouds at the beginning of the baffle cooling down.

The 3 other parts, using Nitrogen shrouds, are fed by 3 independent Nitrogen lines. These lines can be regulated from -150 °C to +80 °C with gaseous Nitrogen (GN2) or cooled down to -185 °C with Liquid Nitrogen (LN2).

3.4. Collimator Thermal Tent Description

The collimator thermal tent is composed of 21 shrouds, all fed by Liquid Nitrogen (LN2), by means of 3 independent thermal lines. Shrouds in a same line are connected in series, here 2 faces of the tent per line.

The PLM Front side, which is in front of the PLM baffle, is equipped with a ring, black painted on the internal side, to close the gap between both thermal tents.

This tent is 3.3 [m] long, 2.1 [m] wide and 2.3 [m] high for a mass of about 1.2 ton.

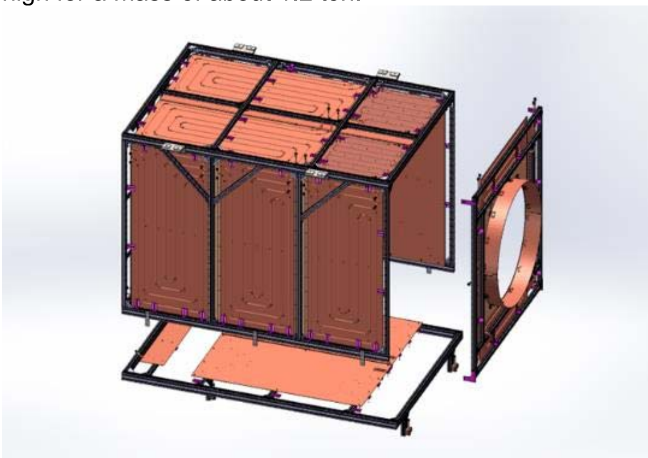
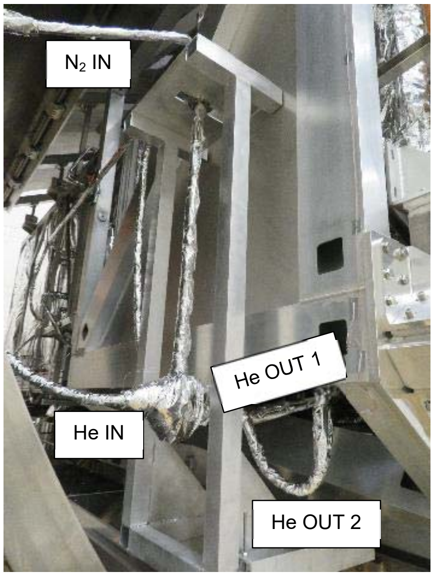


Figure 3-6: Collimator Thermal Tent

3.5. 3-way Cryogenic Valve

The 3-way Cryogenic Valve is a home-made valve designed to be able to by-pass some shrouds in a single line. This valve is manually operated by switching gaseous Nitrogen on or off, actuating a spring which allows the cryogenic fluid flowing to one or the other direction.



Picture 3-9: 3-way Cryo Valve

3.6. Temperature Sensors

For very low temperature (< 70 [K]), Silicon Diodes are used to monitor the temperature.
These 4-wire diodes are LakeShore DT-670 CU packaging class B for an accuracy of ± 0.5 [K] between 2 [K] and 305 [K].

Figure 3-7: Silicon Diode DT-670

Therefore, the PLM thermal tent (NISP shrouds and baffle) is equipped with this kind of sensor, typically two diodes at the centre of each shroud.

For Nitrogen shrouds (collimator thermal tent, SVM shrouds, VIS shrouds), two other kind of sensor are used: 2-wire thinfilm standard PT1000 for monitoring (class A) and 4-wire thermal-ribbon PT100 (class B) for regulation.
This last sensor is also used for heaters regulation.

For temperature monitoring above 90 [K], thermocouples (T-type) class 1 are used on GSE (Ground Support Equipment).

3.7. Heaters

The PSS is the interface between the optical bench of the vacuum chamber and the PLM.
Feet of PLM are temperature controlled for stability reason by six independent regulation lines. Therefore, heaters are used at the six feet interfaces of the PSS. They are controlled in PWM (Pulse Width Modulation) mode by a home-made software.

Picture 3-10: Feet Interfaces on PSS

Additional heaters are installed on the shrouds in front of the NISP and VIS instrument radiators for decontamination and warming up phases.

3.8. Contamination

Test preparation is performed in ISO5 conditions.
The contamination is monitored by contamination samples distributed inside the working area, which are MOC (MOlecular Contamination) and PFO (Particle Fall Out). A portable Airborne is added to monitor the area every hour.

During tests under vacuum, MOC and PFO are also used to follow the contamination of the instrument and the vacuum chamber itself.

Furthermore, a RGA is installed on a flange of the vacuum chamber to track a possible leak of Helium coming from the PLM thermal tent.

Picture 3-11: RGA on Focal 5

4. TVAC TEST

For CSL, the main task is to perform one cycle on the payload with the shrouds having a temperature between 20 [K] and 291 [K] around the baffle and at about 90 [K] around the Collimator.

The constraint is on the NISP shrouds, where NISP must stay a bit warmer than the baffle during the transient phases (cooling down and warming up) for contamination aspects.
Finally, CSL performed 2 cycles to confirm the telescope settling effect, for a total duration of 62 days under vacuum.

5. TEST RESULTS AND DURATIONS

The results given here concern only the CSL setup and not the performances of the Telescope. Details are given for the first cycle.

After a pumping down of about 8 hours to reach 5 10^{-5} [mb] and a decontamination phase of 39 hours, the cooling down is started with NISP shrouds by-passed by means of the 3-way cryogenic valve.

5.1. Cooling down

The 21 shrouds of the Collimator tent are cooled down to Liquid Nitrogen (LN2) temperature in 2.5 hours before the PLM tent cooling down. Therefore, the collimator tent is used as a cold trap for the Telescope environment.

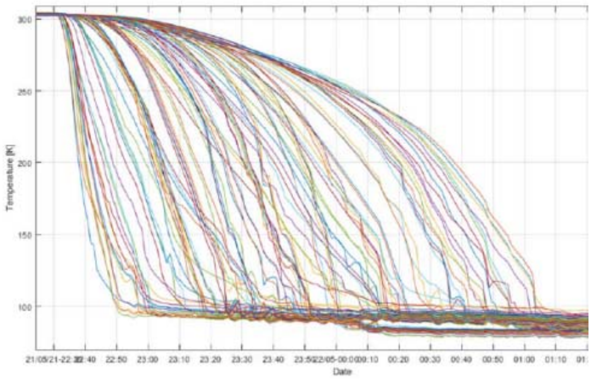


Figure 5-1: Collimator Tent cooling down

After that, the 41 shrouds of the Helium tent are cooled down to a mean temperature of about 25 [K], using a single line of cold gaseous Helium coming from the liquefier.

Cold Box
TCF20

Picture 5-1: Helium liquefier

After 13 hours of cooling down of the first part of the tent, the NISP shrouds, which are the 3 first shrouds in the Helium line, are cooled down to a final range between 11.2 [K] and 38.5 [K] on the complete line after 8 more hours. Therefore, the final duration of the cooling down is about 21 hours for the shrouds, but about 3 more days are needed for the Telescope to be under 130 [K].

Figure 5-2 shows the complete cooling down of the PLM tent with the Helium line.

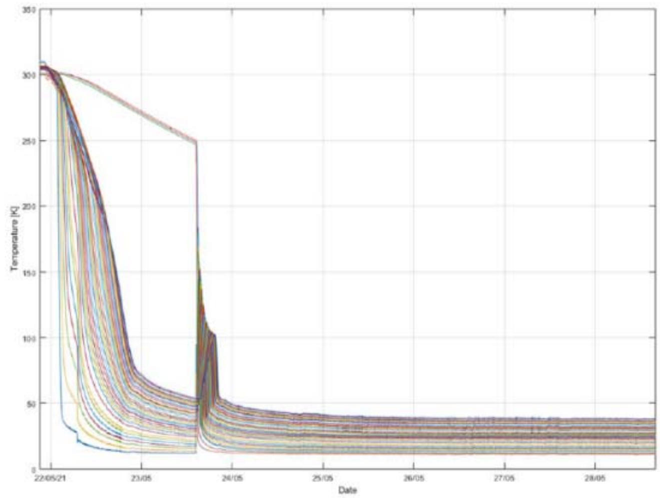


Figure 5-2: Helium tent cooling down

The fact that NISP shrouds are cooled down with a delay creates an impact on the temperature of all shrouds (Figure 5-3) and then on the pressure inside the vacuum chamber (Figure 5-4), due to the outgassing generated by the temporarily warming up of the PLM shrouds.

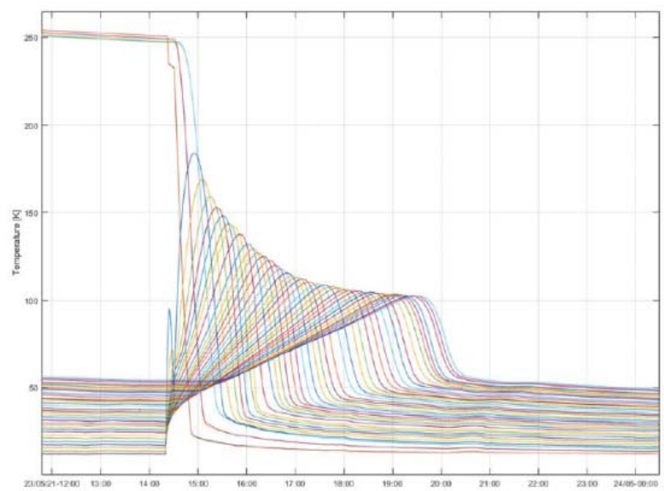


Figure 5-3: Temperature impact on PLM GHe shrouds

This impact on the chamber pressure is not negligible for the pumping system and a special attention is needed during this phase. The Nitrogen, trapped on the cold shrouds, outgasses and is transferred from warmer shroud to colder shroud.

Figure 5-4 shows the impact of the Helium tent cooling down on the chamber pressure.

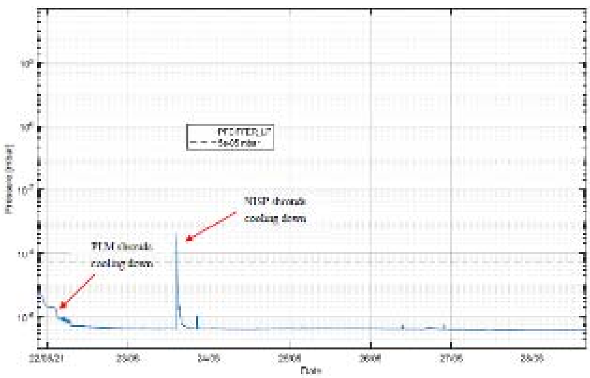


Figure 5-4: Chamber pressure impact

At stabilization, the PLM tent works as a cryo-pump and the minimum pressure reached inside the vacuum chamber at stabilization is about 4 10^{-7} [mb].

During the first cycle, both tents (PLM and Collimator) are maintained cold for about 42 days for performance measurements.

5.2. Warming up

The warming up of the PLM Tent has the same constraint on the NISP temperature, still for contamination reason.
As there is no temperature control of the Helium line, heaters are installed on the NISP shrouds to better control the warming up of the line. As NISP shrouds are the 3 first shrouds in the Helium line, they are the coldest point during performance measurements. But, for transient phases, the coldest point has to be far away from the NISP instrument and the Telescope baffle.

Then, before the PLM tent warming up, the baffle is warmed up by internal heaters managed by Airbus. This determines the rate for the PLM tent warming up.

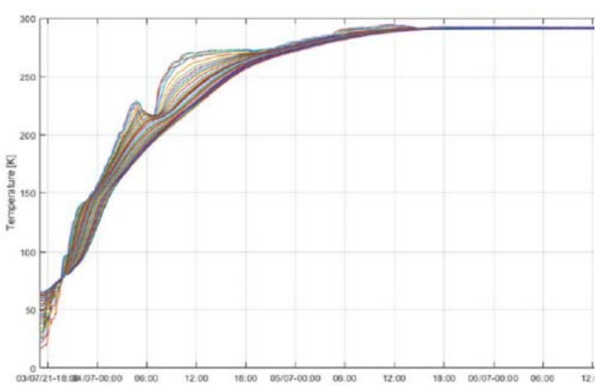


Figure 5-5: Cycle 1 warming up

After the PLM tent warming up, the Collimator tent is slowly warmed up to ambient temperature in 32 hours.

Indeed, the Collimator tent is used as the coldest point with respect to the PLM tent in order to avoid contamination on the Telescope.

Figure 5-6 shows the impact of the warming up on the chamber pressure.
For Helium shrouds, the higher peak (~ 1 10^{-2} [mb]) appears when the last shroud warms up to 35 [K], due to the outgassing of the Nitrogen trapped on this shroud.

For Collimator shrouds, the higher peak (~ 1 10^{-4} [mb]) appears when the last shroud warms up to 200 [K], due to the outgassing of the Water trapped on this shroud.

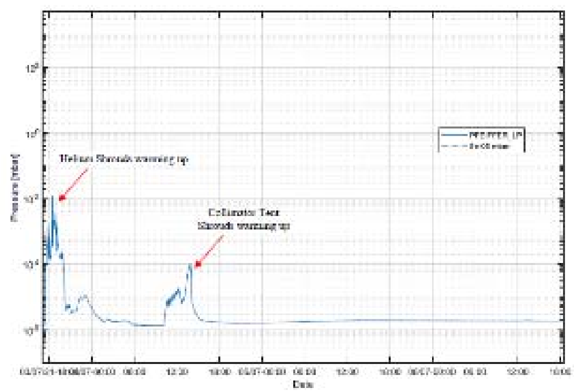


Figure 5-6: Pressure impact of warming up

In conclusion, when shrouds are cooled down to very low temperature for several weeks, the outgassing during the warming up is an important aspect to control, in order to protect the pumping system and to avoid any corona effect on electrical parts with high voltage.
In that case, high voltages are preventively switched off and the primary pumping system is started separately to be ready to replace the turbomolecular pumps, if needed.

5.3. Cycle 2

Figure 5-7 shows the temperature of the PLM tent during the second cycle on the Telescope.
The total duration of the Cycle 2 is about 9 days.

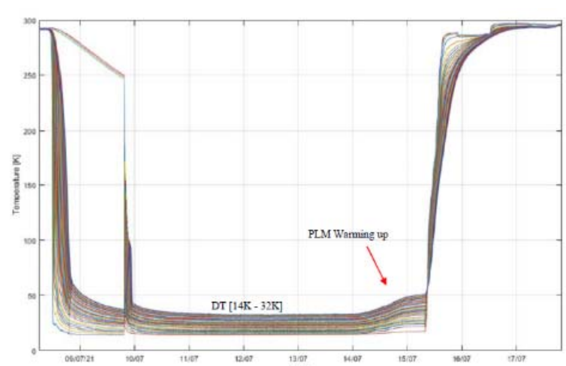


Figure 5-7: PLM Tent Cycle 2

Both tents are maintained cold for about 7 days.

6. TEST AT LOW TEMPERATURE

After Planck Spacecraft, Herschel, JUICE Solar Panels, CSL tested EUCLID PLM at low temperature with the CSL Helium closed loop liquefier/refrigerator.
Low temperatures need special attention on material used, harnesses and thermal insulation.

EUCLID test did not reach the limit of the liquefier, which is 20 [K] with 300 [W] of heat load on a shroud inside our furthest vacuum chamber.

CSL has the experience for future science missions requiring cryogenic environment for large instruments.

7. CONCLUSION

The development of the TVAC test set-up for the complete qualification of the Euclid PLM was a significant challenge in terms of thermal performance, assembly with integration constraints and cleanliness requirements.
The short planning and the COVID period added some difficulties to be ready in time.
The deep collaboration between the AMOS experienced team, CSL and the Airbus Toulouse Customer conducted to a full success of this Tetris game.
Despite the very low accessibility inside the CSL Focal 5 chamber, the final integration sequence, including various supports, the complete dedicated thermal tents and the PLM itself was reached according to specifications. Additionally, the thermal circuitry was optimized for avoiding, during the transient phases and especially during the warm up sequence, cold spots on the PLM itself and preventing from unexpected contamination. The support of the End-Customer chain, ESA and TAS-I was also fully appreciated.

8. REFERENCES

1. https://sci.esa.int/web/euclid
2. https://www.cosmos.esa.int/web/euclid
3. Jamotton, P, (2004) *Measurement of the absorptance-emittance of black paint surfaces at temperatures from 10 to 120[K]*, CSL