# THE EUCLID AOCS and FGS VERIFICATION on the PROTO-FLIGHT MODEL (PFM)

**M. Saponara [(1)], A. Bosco [(1)], J.S. Llorente [(2)], L. Meijer [(3)], C. Rosso [(4)]**

[(1)] *Thales Alenia Space Italy, Strada Antica di Collegno 253,10146 Torino, Italy, +39 0117180880, massimiliano.saponara@thalesaleniaspace.com*

[(2)] *Sener, Severo Ochoa, 4 - 28760 Tres Cantos – Madrid, Spain, +34 918077225, salvador.llorente@aerospacial.sener*

[(3)] *Airbus Netherlands B.V, P.O. Box 32070, 2303 DB Leiden, The Netherlands, +31 (0)715245345, L.Meijer@airbusDS.nl*

[(4)] *ESA/ESTEC, Keplerlaan1, Postbus 299, 2200 AG Noordwijk, The Netherlands, +31(0)715655660, Carole.Rosso@esa.int*

## ABSTRACT

EUCLID is the next medium-class mission of ESA's Science Program, which launch is foreseen in July 2023. Thales Alenia Space Italy (TAS-I) is the Prime contractor, but some significant verification activities have been maintained at system level. In particular, TAS-I is in charge to execute the Attitude and Orbital Control Subsystem (AOCS) tests with HW units in the loop, up to the Proto-Flight Model (PFM) level. Furthermore, the Fine Guidance Sensor (FGS), which is the main attitude sensor of the mission, is supported in the overall test campaign by TAS-I as well. The testing of FGS and spacecraft in representative thermal conditions was a fundamental block of the overall validation activity carried out to verify the achievable performance.

## 1 INTRODUCTION

Thales Alenia Space in Italy (TAS-I) is Prime contractor of the EUCLID Medium Class mission that, belonging to the ESA 2015-2025 Cosmic Vision plan, is currently in the E phase. The mission aims at understanding why the expansion of the universe is accelerating and what is the nature of the source responsible for this acceleration, which physicists refer to as dark energy. According to the data provided by previous missions (the Plank results disclosed in March 2013), today dark energy represents around 70% of the energy content of the universe. Dark matter and dark energy dominate the universe's matter-energy content, of which ordinary matter makes up only about 5%. Dark matter and dark energy control the past, present and future evolution of universe, but their nature is unknown.

EUCLID will explore how the universe evolved over the past 10 billion years to address questions related to fundamental physics and cosmology on the nature and properties of dark energy, dark matter and gravity, as well as on the physics of the early universe and the initial conditions which seeded the formation of cosmic structure.

The imprints of dark energy and gravity will be tracked by using two complementary cosmological probes to capture signatures of the expansion rate of the universe and the growth of cosmic structures: Weak gravitational Lensing and Galaxy Clustering (Baryon Acoustic Oscillations and Redshift Space Distortion).

In EUCLID, the cosmological probes will be studied with a 1.2 m diameter Silicon Carbide (SiC) mirror telescope feeding two instruments, VIS and NISP: a high quality panoramic visible imager (VIS), a near infrared 3-filter (Y, J and H) photometer (NISP-P) and a slitless spectrograph (NISP-S). With these instruments physicists will probe the expansion history of the universe and the evolution of cosmic structures by measuring the modification of shapes of galaxies induced by gravitational lensing effects of dark matter and the 3-dimension distribution of structures from spectroscopic red-shifts of galaxies and clusters of galaxies.

The observation will be conducted from a high-amplitude eclipse-free libration orbit at the L2 Sun-Earth Lagrange point. In its six-year mission, EUCLID will observe 15,000 $deg^2$ of the darkest part of the sky, that which is free of contamination by light from both the Galaxy and the Solar System. Two EUCLID Deep Fields, covering around 20 $deg^2$ each, close to the ecliptic poles, will be observed at regular intervals, extending the scientific scope of the mission to the high-redshift universe. About 10 billion sources will be observed by EUCLID. More than 1 billion will be used for weak lensing whereas 50 million galaxy redshifts will be measured and used for galaxy clustering. The complete survey will comprise hundreds of thousands of images and several tens of Petabytes of data.

The extremely accurate pointing performance requested by the mission ([1], [2]) is achieved through the use of the Fine Guidance Sensor (FGS), which provides very precise attitude measurement to the Attitude and Orbit Control System (AOCS) control loop during the scientific mode. The FGS is accommodated inside the Payload Module (PLM) in order to limit the contribution of deformation between FGS and instruments field of view.

The program is organized allocating all Sub-Systems to different European industries, and in particular, SENER and Airbus Netherlands (Airbus NL) are in charge of the AOCS design, implementation and verification. Furthermore, the FGS is developed by Leonardo Firenze.

Some significant verification tasks at both AOCS and FGS level are performed by TAS-I. In particular, TAS-I has arranged a complete closed loop validation facility around the Proto-Flight Model (PFM) of EUCLID, with the objective to enable testing the S/C also in the final environmental campaign through a dedicated Thermal Vacuum – Thermal Balance (TVTB) test. Furthermore, TAS-I was fully involved in the FGS test campaign belonging to the PLM level TVTB tests, where optical stimulation of the sensor was possible.

The paper will present the architecture of the PFM test facility and the main results of the TVTB test campaign at system level. Furthermore, it will describe the FGS test facility and will present the results obtained either in the PLM and System TVTB campaign.

## 2 THE EUCLID PFM TEST FACILITY CONFIGURATION

### 2.1 General

The EUCLID PFM is surrounded by the Electrical Ground Support Equipment (EGSE), which shall ensure the S/C command and monitoring in any of the testing phases of EUCLID.

The EGSE architecture is based around two major functional blocks: the Overall Checkout Equipment (OCOE) and the Special Checkout Equipment (SCOE).
The OCOE will be mainly in charge of the command/control and monitoring of the EUCLID on-board equipment and of the EGSE itself. It shall include the CCS (Central Check-out System).

In order to automatize the operations with the SCOEs, a CCS (Central Checkout System) is introduced in the EGSE giving the test conductor the possibility to:

- Acquire and archive in real-time all the data going to/coming from the S/C;
- Acquire and archive in real-time all the data going to/coming from the different SCOEs;
- Display in human-readable format all the received TeleMetry (TM) items, both coming from S/C or from the different SCOEs;
- Compose and send TeleCommands (TCs), both to the S/C or the different SCOEs;
- Develop and execute automated test sequences, in order to perform the different test activities.

The full EGSE is available for tests running in the clean room, while not all the EGSE elements have to be used during TVTB test: the list below reports only the various elements used in the TVTB:

- **CCS**
- **Power SCOE**
  - **Umbilical/Launch Power Supply (LPS) SCOE**: used to handle all S/C umbilical analogue lines, comprising power, separation straps;
  - **Solar Arrays Simulator (SAS) SCOE**: used to simulate the solar array, in terms of power provision and thermistor simulation;
  - **Battery Simulator (BS) SCOE**: used to simulate the flight battery, both in charge mode (i.e. simulating a load) and in discharge mode (i.e. providing power)
- **TM/TC Data Front-End (DFE)**: used to handle all S/C umbilical TM/TC lines, providing also an interface between the Ground CFDP and the S/C;
- **Tracking, Telemetry & Command (TT&C) SCOE**: used to handle all Radio Frequency (RF) interfaces, both X-band and K-band;
- **AOCS SCOE**: used to simulate the attitude-and-orbit-control environment by substituting the relevant units at proper interfaces;
- **FGS Electrical Stimuli Generator (ESG)**: used to simulate the FGS CCD+PEC at its Electronic Unit interface, connected to AOCS SCOE during closed loop with FGS in the loop;
- **Ground CCSDS File Delivery Protocol (CFDP)**: used to handle all transactions relevant to the CFDP protocol between MMU and ground;

The following items are not part of the EGSE, but are connected to it:

- **Network Data Interface Unit (NDIU)**: this equipment allows the communication between EGSE and Mission Control System (MCS) in order to execute the System Validation Test (SVT) and System Operations Validation Tests (SOVT), can be put in listening mode during TVTB if requested by ESOC;
- **Instrument Stations**: these workstations receive from the instruments (VIS and NISP) the Housekeeping (H/K) and scientific data, forwarded from the CCS, for analysis purposes

The set up for the test campaign in TVTB is identified in Figure 1.

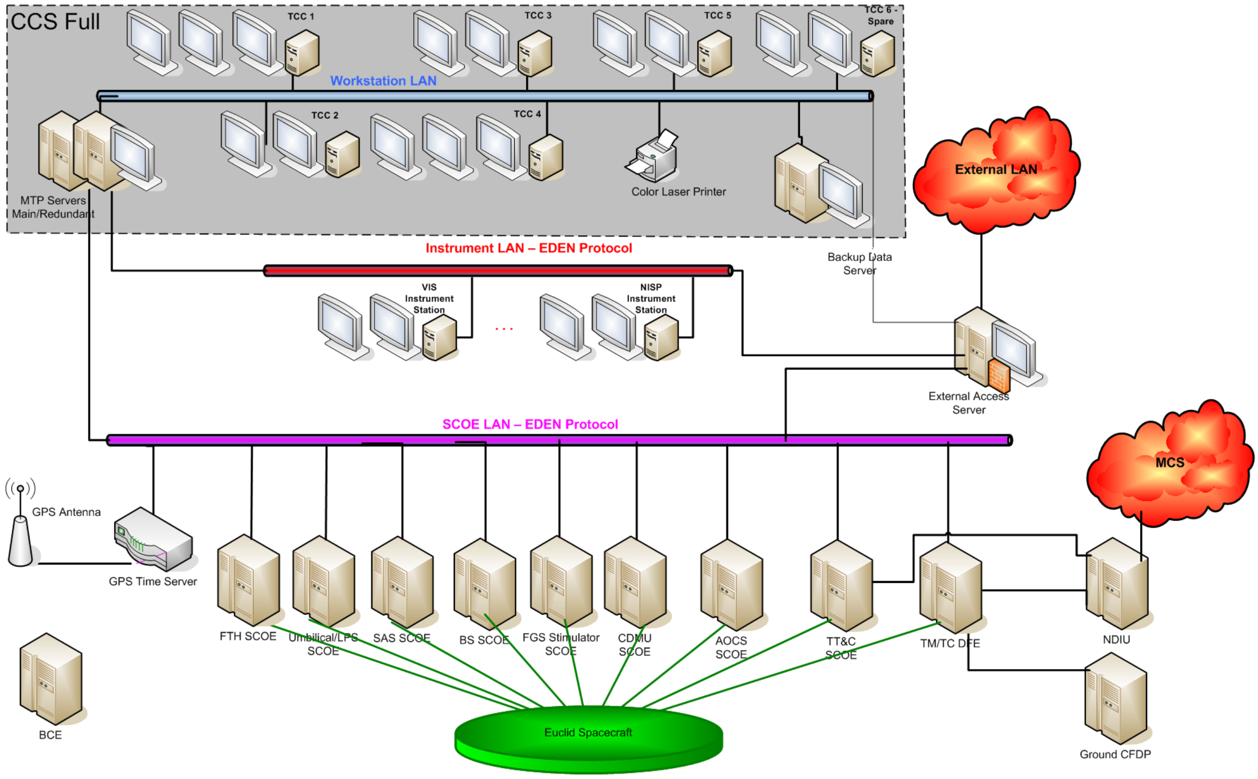


Figure 1. Schematic of PFM test setup and EGSE

The AOCS SCOE is the core of the closed loop simulation capability of the PFM test facility. It is in charge to simulate the kinematic/dynamics of the S/C by means of a Real Time Simulator (RTS), together with the behaviour and performances of AOCS sensors and actuators. In the final configuration for the TVTB tests, the AOCS SCOE is setup to manage and stimulate the real AOCS sensors/actuators as follows (Figure 2):

- it generates the equivalent currents sensed by the cells belonging to the passive Sun sensors embarked in EUCLID (called respectively Sun Acquisition Sensor (SAS) and Fine Sun Sensors (FSS));
- it provides a stimulus signal for the gyroscope (GYR), running on MIL1553 bus, which is used to compensate for the Earth rotation rate and to inject the S/C simulated dynamics into the sensors;
- it provides a stimulus signal through a dedicated electric interfaces to the Accelerometers (ACC), which is used to compensate the Earth gravity and to inject the S/C dynamics into the sensors;
- it provide the attitude quaternion to either Star Tracker (STR) and Fine Guidance Sensor (FGS) EGSEs;
- it generates the equivalent angular rate measurements provided by the Coarse Rate Sensor (CRS), which is then put in the On-Board Data Handling (OBDH) bus by the real CRS

thanks to a direct connection through RS422 with the AOCS SCOE;

- it updates the RTS dynamics exploiting the actual Reaction Wheels (RWL) speed estimated through the tachometer output of the real HW;

EUCLID embeds also two different propulsion subsystems, the hydrazine Reaction Control System (RCS) and the Nitrogen Micro-Propulsion Subsystem (MPS): none of them can be really actuated in the TVTB test campaign, therefore from the AOCS point of view they are fully simulated in the RTS of the AOCS SCOE.

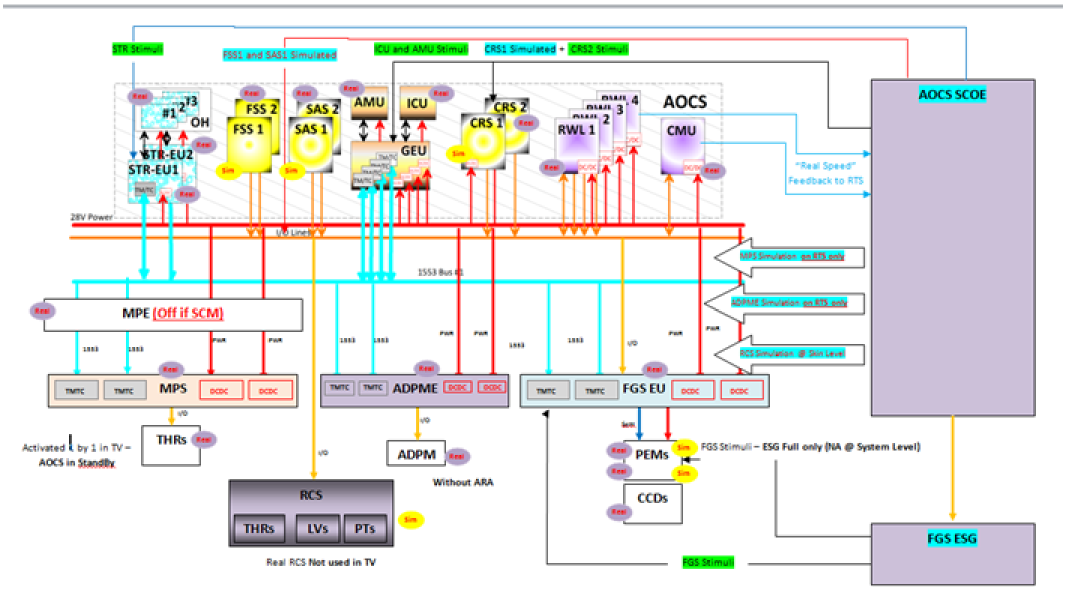



Figure 2. AOCS Electrical Schematic for TVTB Test

## 2.2 FGS test facility description

The system level closed loop test was designed to exploit the real FGS hardware (EQM or PFM) and relevant FGS Application SW stimulated by dedicated EGSE and as backup, to overcome temporary unavailability of FGS hardware when involved in PLM tests, it has been conceived a solutions to allow verification of AOCS subsystem on both Avionic Model bench (AVM) and on PFM. The two solutions are the following:

- a <u>SW model representative of FGS input/output</u> interfaces integrated with the AOCS RTS and then in the AOCS SCOE. The SW model developed by TAS-I is able to synchronize itself with on board computer, to accept TCs and to provide TM via 1553-Milbus protocol according to real FGS SW behaviour, including representative transitions from the different operative modes. It includes a mathematical core to be called at 10Hz frequency simulating the FGS measurement error; it takes in input the current simulated dynamics and corrupt the quaternion with representative bias/noise error, providing in output the absolute and relative quaternion. The internal state machine is built to simulate the tracking sub-phases (acquisition phase, intermediate cycle and tracking) respecting the 2s cycle of the FGS, with measure taken at mid-exposure time and provided externally to the AOCS with latency of 1.3seconds as per real FGS.
  The model allows also error injection to simulate on purpose wrong and/or invalid attitude quaternion, frozen measurement, attitude acquisition failure and tracking loss.
  The mathematical core has been written in Matlab and integrated in the AOCS Engineering

Simulator Environment (ESE), developed by AOCS sub-contractor. The ESE is then autocoded in C-code and integrated on Real Time Simulator which include the I/O part of the FGS model.
The FGS model has been used by AOCS subcontractor for performance simulation and subsequently for AOCS Application SW validation in the Software Verification Facility (SVF) and computer-HW in the Loop (HILF). Integrated in the SCOE, is also widely used at EUCLID System level in the AVM and PFM benches for System level functional tests.

- an Electrical Stimuli Generator (ESG) to provide realistic simulation of the data generated by Charge Coupling Detectors (CCD) or after Proximity Electronic Module (PEM) pre-processing. The ESG has been procured by Leonardo Florence and used for acceptance test of FGS equipment in AVM and PFM test bench. The main aim of the ESG is the generation of an electrical signal reproducing the digitized video output of the FGS detector in a simulated operational environment, for functional testing. This signal, reproducing the CCD output immediately after the A/D conversion at the end of the analogue chain, is sent as input to the PEM through a dedicated connector or can be processed again at ESG level to feed directly the Electronic unit (EU) through SpaceWire (SpW) link.
  In short the ESG is able:
    - to simulate the optics characteristics in terms of focal length, Field Of View (FoV), distortion and aberration.
    - to simulate the detector characteristics, in terms of photoresponse noise, spatial non-uniformity, defective pixels.
    - to simulate the analogue chain and A/D converter resolution.
    - to simulate the presence of external disturbing parameters like straylight, large objects, Single Event Upset (SEU).
    - Perform closed loop testing thanks to connection with the AOCS SCOE for receiving updated S/C dynamics data at 1Hz.

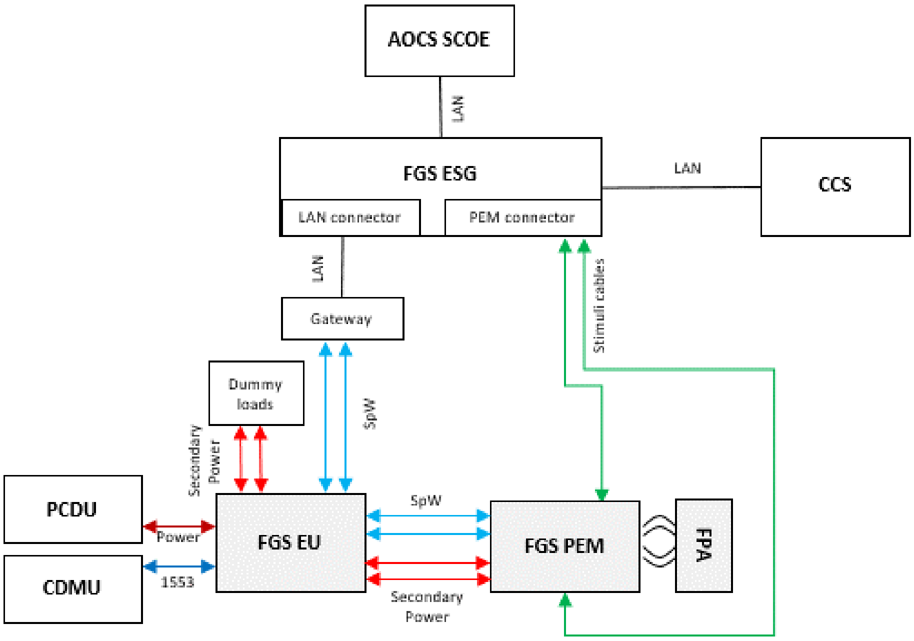
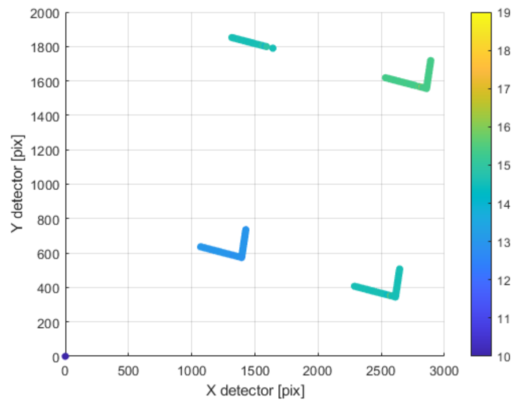



Figure 3. FGS and ESG configuration for AOCS closed loop configuration.

For the Absolute Tracking Mode exercising the FGS SW is feed with an on board star catalogue including the FGS target for the part of the sky interested by the functional test. Symmetrically, for the sky scene simulation, the ESG shall take in input a catalogue matching with the one uploaded to the FGS SW. As per real flight life, a new on-board catalogue is uploaded to FGS for each EUCLID scientific observation but the catalogue input to ESG shall include all the pointed regions of the test (see [3], [4] for further details). This ESG catalogue is built specifically for each AVM/PFM test by using the FGS Input Star Catalogue database provided by INAF Astrophysical Observatory of Turin.

## 3 FGS TESTING IN PLM TVAC

An important and unique test for the confirmation of the achievable attitude performance is the end-to-end demonstration that the Fine Guidance Sensor is able to perform tracking at operative temperature (around 150K in the PLM cavity close to the detectors) through optical stimulation of the EUCLID telescope chain. This has been achieved successfully during the Thermal Vacuum (TVAC) test of the PLM module done in Liege in May-June 2020 at CSL laboratories. The test setup consisted of EUCLID telescope, its baffle and the PLM module with the instrument electronic unit inside the TVAC chamber. In front of the telescope, still inside the chamber, it is placed a collimator based on a Cassegrain telescope with an emission plane having a set of optical fibres which extremities are used as source point. This setup allows to have up to 4 diffraction limited sources pointed simultaneously in the FoV of one FGS CCD. The acquisition of the 4 spots from the FGS in Photo Mode (Figure 5) with the telescope in focus position shows the good quality of the setup.



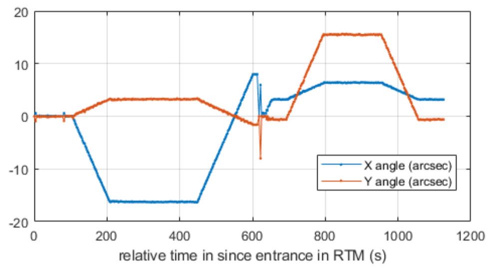




Figure 4. Spot position evolution in CCD reference frame (left); color scale for the measured magnitude. Angle evolution from FGS relative attitude measurement (right). Jump close to 600s due to temporary loss of tracking and consequent reset of reference attitude.

During the test the FGS was able to acquire and track the star-like objects providing relative attitude measurement (i.e. delta attitude with respect to the first acquisition) and relative angular rate estimation. When the tracking is stably acquired the four spots were moved acting at fibre stage level, allowing a spot motion speed lower than 0.3arcsec/s, ~3pix/s at detector level. From the FGS it was derived the position of the spots at each FGS cycle (2 sec) to reconstruct the evolution in detector reference frame (see Figure 4). The orientation of the fibres in the collimator plane was such that the motion was not exactly parallel to telescope X and Y axes generating a coupled motion when commanding a single fibre axis. The measured displacement of the spots was about 1.6 pix/s along main motion axis and 0.6pix/s along minor motion one well compatible with the maximum sustainable rate of FGS. The test has been also used as FGS end-to-end polarity. In fact by knowing the motion commanded to the fibres, measuring the motion of the spot at detector level and comparing with the FGS relative measurement attitude it has been possible to confirm the sign of FGS SW algorithm chain.

The EUCLID science consortium requested during 2020 through ESA the EUCLID spacecraft to be capable of supporting the so-called Phase Diversity Calibration, a science observation in which the telescope is intentionally defocused to a well-defined level, still ensuring nominal Relative Pointing Errors (RPE) performance ([1],[2]). The aim of this calibration is to improve the in-orbit knowledge of the VIS instrument Point Spread Function (PSF) shape far from the central peak to increase the fidelity of the PSF model and to reach the target quality for the science post-processing, in particular for the weak gravitational lensing probe. This request implies that FGS shall be capable to track with nominal relative performance a defocused spot. With an important effort from Leonardo Florence, a dedicated modification of the FGS Relative Tracking mode has been made to ensure that the original architecture can cope with this unexpected usage of the FGS in the AOCS loop. An updated FGS SW was uploaded just before the PLM TVAC to allow the end-to-end verification with the real defocused spot. During the PLM TVAC, the M2 mirror has been moved at +18µm and -18µm positions away from the nominal focus position by commanding 3 dedicated motors. The out-of-focus appearance of the spot is a PSF much broader with smoothed peak (Figure 5 right panel).

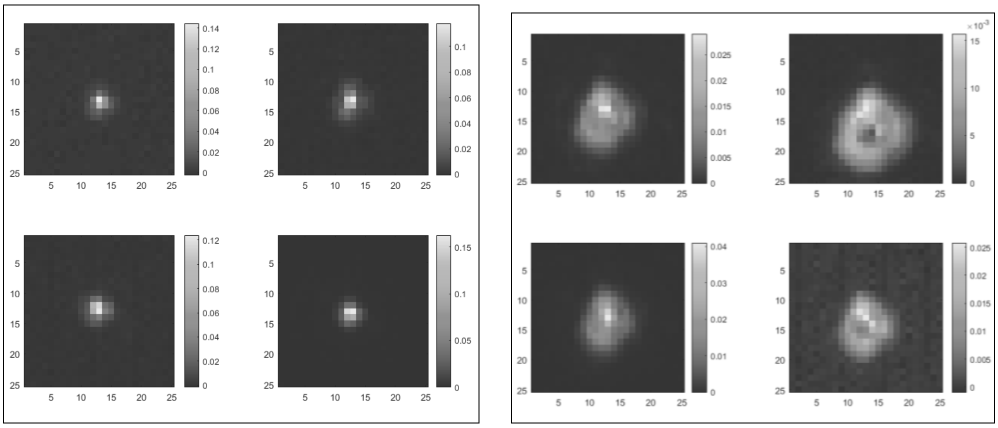


Figure 5. Acquisition of the 4 spots by FGS in Photo Mode at telescope focus condition (left) and at -18um M2M defocus level (right). Gray scale provides the percentage of spot energy inside each pixel.

Under defocused configuration, the FGS upgraded SW succeeded in relative tracking at +18µm of Mirror 2 (M2) displacement. At -18µm M2 displacement, the tracking was reached but not maintained mainly because of a limitation of the test setup that could not guarantee all spots mainly at the same defocus , namely with 2 spots that were in practice more defocused than foreseen in the negative M2 direction (as can be seen in the Figure 5, spot N°2 appears more problematic having a "donut" shape instead of a central peak).

During the PLM TVAC test, it has been also characterized the CCD response at ambient by capturing dark ambient images of the four detectors with 0.1s and 1.6s of exposure (minimum and maximum exposure times during tracking) exploiting the FGS SW capability. This was the first time that the FGS CCD image was acquired by FGS SW at operative temperature (during FGS qualification and acceptance testing, the image was acquired by CCD using dedicated EGSE). In this test, it was confirmed the presence of few most energetic hot pixels and it was also discovered the presence of a small EMC effect at PEM level causing an increment or decrement in the reading of the signal (< 15DN, ~300 el) with a periodicity of 7 pixels. This was found to be stemming from the fact that the acquisition of the window composing the full-frame image was a multiple of 7 pixels and the effect aligned along the columns, but also thanks to the very low level of dark current at operative temperature. The impact on the FGS performance is a reduction of the detection probability for very faint stars (93% for stars mag > 18.4) and is deemed acceptable thanks to the good sky coverage guaranteed by the FGS Input Star Catalogue.

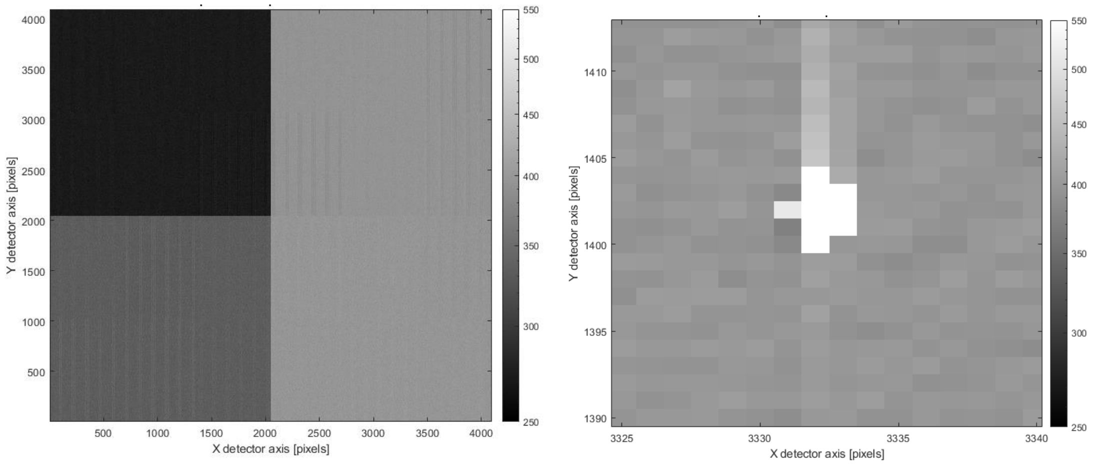



Figure 6. Example of full frame dark image (left). Different bias for each of the four quadrant is visible together with vertical stripes EMC effect. Example of high energy hot pixel (right).

## 4 THE SYSYEM TVTB TEST CAMPAIGN

### 4.1 Thermal Vacuum / Thermal Balance test overview

The EUCLID PFM thermal vacuum test consists of the combination of thermal cycling and thermal balance tests.

The main objective of the test is the system acceptance of the PFM spacecraft from a functional and thermal point of view under vacuum conditions and temperatures representative of the system-acceptance conditions (all unit temperatures are brought in between the worst-case flight predictions and the unit acceptance level).

Specifically, the objectives of the Thermal Cycling phases are:

- To verify the performance/functionality of all equipment's under vacuum and at extreme hot and cold temperature conditions
- To verify the functionality of the Thermal Control System (TCS), in particular of the main and redundant heater lines, including the heater-control software;
- To detect material, process and workmanship defects/errors.

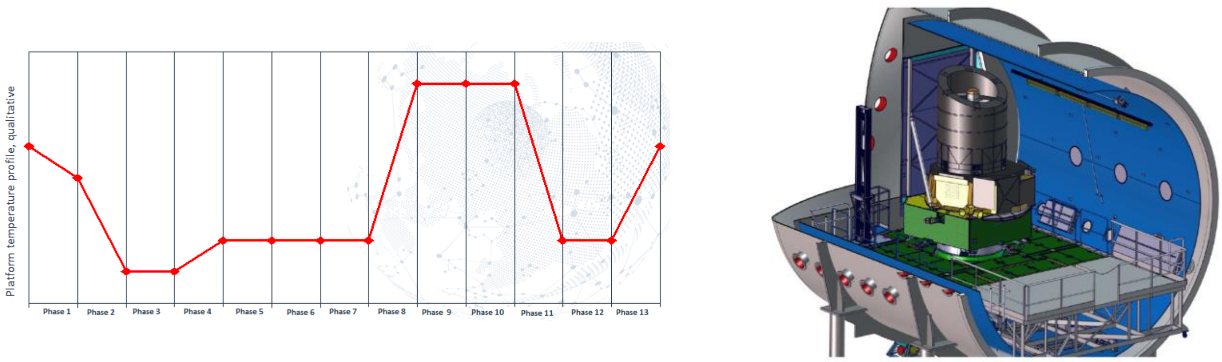


Figure 7. EUCLID PFM TV/TB Flow (left) and layout in the TVAC chamber (right)

The objectives of the Thermal Balance phases are:

- To confirm and complete the verification of the EUCLID thermal design performed within the Structural and Thermal Model (STM) campaign, in particular for those items/parts that were not present in the STM or for which a revision of the thermal design has been implemented after the STM test.
- To check and complete the validation of EUCLID Thermal Mathematical Model (TMM) performed during the STM campaign.

The test is subdivided in the following phases:

- Phase #1: Chamber Closure, Pump-down, Outgassing and Shroud Cool-down
- Phase #2: S/C Cool Down and transition to Not Operative Cold Condition
- Phase #3: Not Operative Cold Plateau
- Phase #4: Transition to Operative Cold Condition
- Phase #5: Operative Cold Plateau
- Phase #6: Cold Thermal Balance
- Phase #7: NISP Verification
- Phase #8: Transition to Operative Hot Condition
- Phase #9: Hot Thermal Balance
- Phase #10: Operative Hot Plateau
- Phase #11: Transition to Operative Cold Condition
- Phase #12: Operative Second Cold Plateau
- Phase #13: Return to Ambient Condition

During cold and hot phases of the TVTB, some AOCS closed loop tests were run, in particular relevant to the Science Mode (SCM) and representative of scientific observations.

### 4.2 Preparatory activities for AOCS closed loop tests in TVTB

The foreseen closed-loop test campaign for the TVTB has been prepared and tested before the entry of the spacecraft into the TVAC chamber, and this included a representative Science Mode (SCM) observation sequence ([1]) that was selected to be run during the thermal plateau.

Unexpectedly, the environmental noise of the facility created some problems for enabling a successful AOCS closed loop simulation. Indeed, such noise was sensed by the GYR and then fed into the attitude control, basically creating issues in the SCM sub-modes which use only the GYR (mainly the entry and the slew sub-phases). Figure 7 shows that the sensed GYR noise of the PFM presents a significantly higher energy in the frequency range from 1 to 10 Hz with respect to a situation where the GYR was in a clean room far from the TVAC facility (i.e. the AVM, which embeds one full spare channel of the GYR).

The workaround for mitigating this problem was to exploit the capability of the GYR to modify the cut-off frequency of its anti-aliasing filter, in order to reduce as much as possible the sensed noise contribution: the default value of this cut-off frequency was around 6Hz, which was chosen as the best compromise between performance and phase delay (also because such high level of noise in that frequency range is not expected in flight). In the end, a value of 1Hz has been used instead, which allowed a dramatic reduction of the noise (Figure 8) and a successful completion of SCM test campaign, with basically minor impacts in the obtained performance.

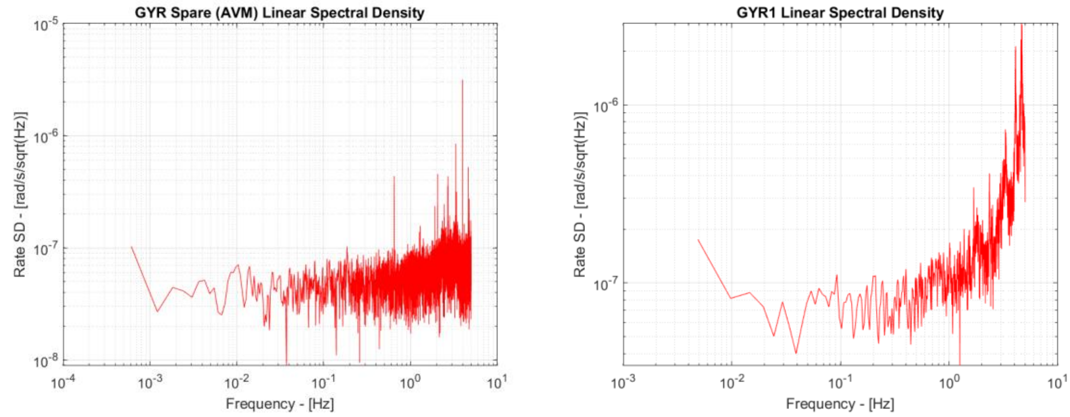


Figure 8. Comparison between sensed noise on AVM (left) and PFM close to TVAC facility (right)

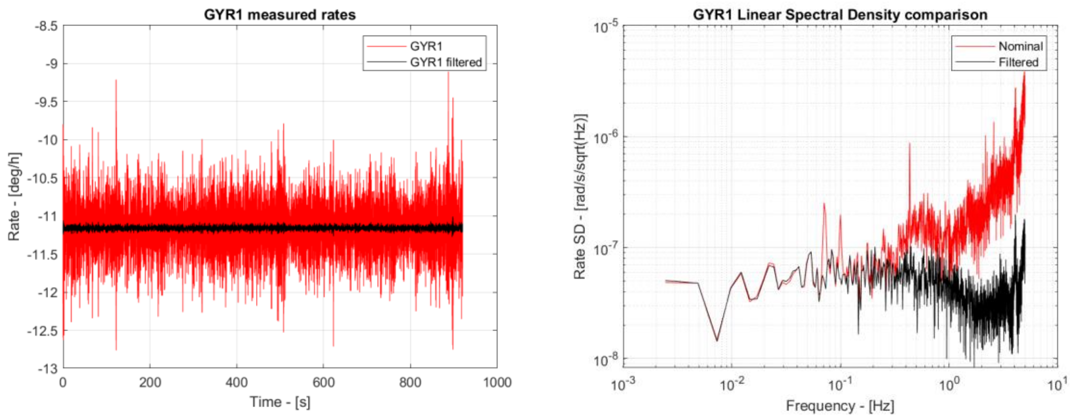


Figure 9. GYR unfiltered vs filtered measurements in the time (left) and frequency (right) domain.

### 4.3 Results of SCM simulation in TVTB

The workaround implemented for the GYR sensed noise allowed the simulation of a complete science observation sequence ([1]), including the implementation of the attitude slews using the Reaction wheels (RWL) in start-stop regime ([1], [2]), the simulated movements of the VIS shutter and the NISP Filter and Grism Wheel Assemblies (FWA, GWA) and contextual movements of the Compensation Mechanism Unit (CMU, [4]) which counteracts the induced disturbances.

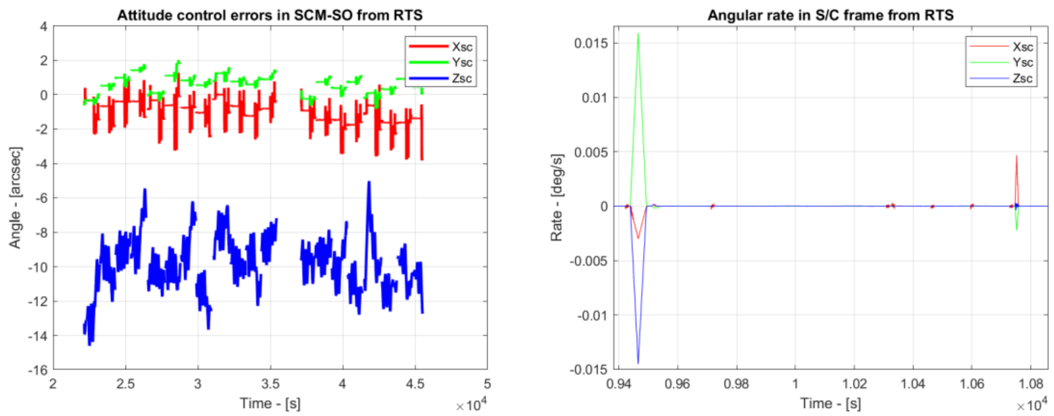


Figure 10. SCM Absolute Pointing Errors (left) and angular rates (right)

During the System TVAC, two FGS CCDs were connected to the PEM and Electronic Unit to allow the verification of the full FGS readout chain in Photo Mode and Checkout Mode at operative temperature. The other two CCDs were disconnected at SpW level and the ESG was connected to the Electronic Unit through SpW cable to allow closed loop testing.

Figure 10 shows the SCM Absolute Pointing Errors and the angular rates obtained during the SCM test, showing full compliance with the very stringent accuracy requirements defined in [1]. The high peak in the angular rates is due to the execution of the slews necessary to reach the adjacent observation field (about 0.7 deg amplitude), while the lower one to “dither” the current field (about 100 arcsec). Both the maneuvers are obtained with RWL start-stop approach, as showed in Figure 13.

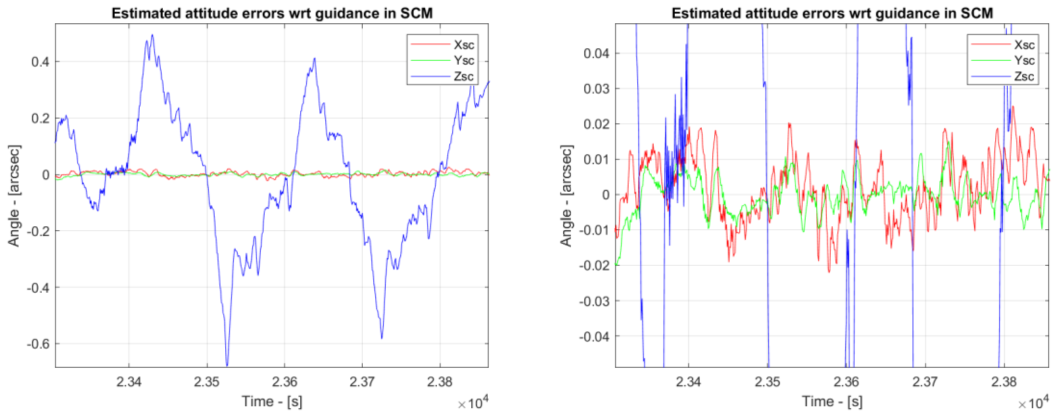


Figure 11. SCM Relative Pointing Errors overall (left) and zoomed (right)

Also the Relative Pointing Errors performance (Figure 11), fundamental to enable the requested image quality, is widely inside the requirements, especially looking at the most relevant axes (X and Y, the ones perpendicular to the telescope boresight).

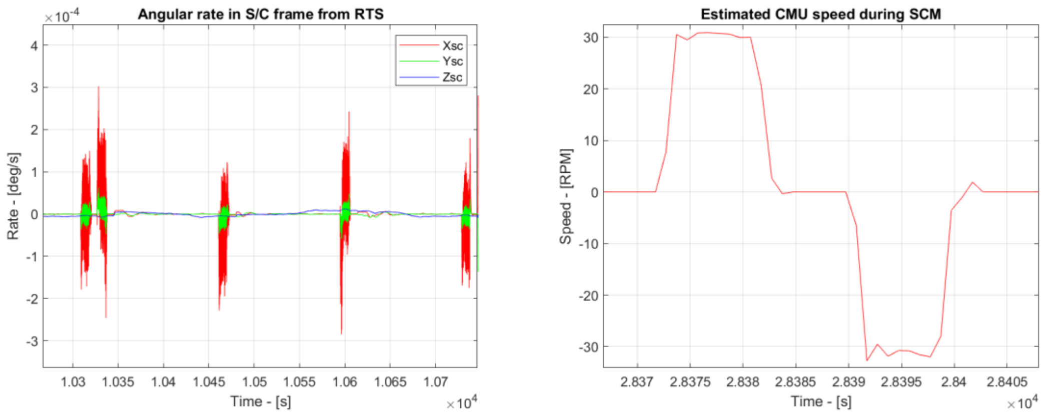


Figure 12. Angular rate (left) and CMU speed profile (right) during the NISP FWA/GWA actuation

Finally, Figure 12 shows a typical speed profile of the CMU and the corresponding residual angular rate on the S/C, which is kept low in order to guarantee that the FGS does not lose tracking during the movements of the NISP FWA/GWA.

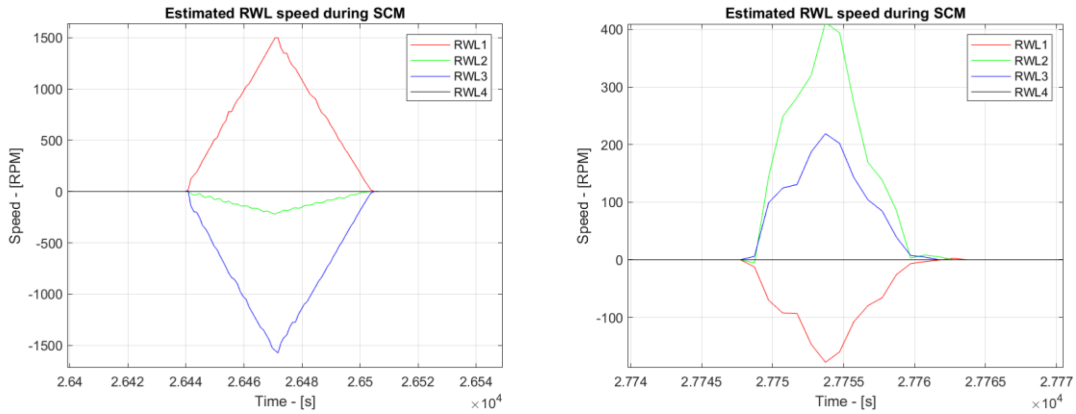


Figure 13. RWL speed profiled during field (left) and dither (right) slews.

## 5 CONCLUSIONS

The Euclid AOCS and FGS have undergone an extensive system-level testing campaign carried out by the Prime contractor (TAS-I). At Proto-Flight Model level, the AOCS has completed the full validation in a representative environment with the complete HardWare in the loop by performing closed-loop testing, also in thermal representative conditions and facilities.
In addition, the FGS validation campaign was carefully followed by TAS-I during the payload-level tests and during the subsequent system-level tests.
The results of this large test campaign showed very consistent performances under a large variety of testing conditions. As a result, the spacecraft was declared successfully qualified in 2022 and the Final Acceptance Review was achieved in May 2023.

The launch is currently scheduled at the beginning of July 2023. The LEOP and the subsequent commissioning will be conducted from the European Space Operations Centre in presence of TAS-I and will allow to confirm the in-orbit performances by the third quarter of 2023.

## 6 REFERENCES

[1] A. Bacchetta, M. Saponara, A. Torasso, G. Saavedra Criado, B. Girouart, *The EUCLID Science Mode Design*, 9th International ESA Conference on Guidance, Navigation & Control Systems, 2014, Porto, Portugal

[2] M. Saponara, A. Bosco, A. Bacchetta, S. Llorente, M. Oort,G. Saavedra Criado, *The EUCLID AOCS tasks at System level*, 10th International ESA Conference on Guidance, Navigation & Control Systems, 2017, Salzburg, Austria.

[3] A. Bosco, A. Bacchetta, M. Saponara, G. Saavedra Criado, *EUCLID pointing performance: operations for the Fine Guidance Sensor reference star catalogue*, SPACEOPS conference 2018, Marseille.

[4] M. Saponara, A. Bosco, S. Llorente, L. Meijer, C. Rosso, D. Huzel, *The EUCLID AOCS and FGS verification tasks at system level*, ESA Conference on Guidance, Navigation & Control Systems, 2020