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ATHENA Telescope: Alignment Integration and Testing of the SPO Mirror Modules

G. Valsecchi, G. Bianucci, F. Marioni, D. Vernani, F. E. Zocchi

T. Korhonen[a], G. Pareschi[b], I. Ferreira[c], M. Bavdaz[c]

Media Lario S.r.l., Località Pascolo, 23842 Bosisio Parini (LC), Italy
[a]OPTEON Oy -Väisäläntie 20, FI-21500 PIIKKIÖ, Finland
[b]INAF Osservatorio Astronomico di Brera, Via E. Bianchi 46, 23807 Merate, Italy
[c]European Space Agency, ESTEC, Keplerlaan 1, NL-2200 AG Noordwijk, The Netherlands

ABSTRACT

Several hundreds of Silicon Pore Optics (SPO) mirror modules need to be integrated and co-aligned onto the ATHENA (Advanced Telescope for High-ENergy Astrophysics) Mirror Assembly Module (MAM). The selected integration process, developed by Media Lario, exploits a full-size optical bench to capture the focal plane image of each mirror module when illuminated by a collimated UV wavefront at 218 nm. Each mirror module, handled by a manipulator, focuses the collimated beam onto a CCD camera placed at the 12 m focal position of the ATHENA telescope. The image is processed in real time to calculate the centroid position and overlap it to the centroid of the already integrated Mirror modules. The 600 mirror modules must be accurately aligned on the ATHENA optical bench, with tolerances of few micrometers and arcseconds. The concept has been demonstrated in a preceding competitive technology development activity.

This Assembly Integration and Test (AIT) facility is a vertical optical bench with a collimated UV beam, generated by a 2.6 m Zerodur® parabolic mirror. This UV collimator mirror is already completed and ready to be delivered to Calar Alto Observatory (CAHA, Sierra de Los Filabres, Spain) for the deposition of the reflective coating.

In the AIT facility, the ATHENA telescope structure is positioned horizontally on a rigid mechanical structure, called MAIS, and supported by 9 actuators to minimize the gravity effects. One by one, the mirror modules are aligned under the UV beam, ensuring that they all focus into a common point and glued to the dowel pins connecting them to the mirror structure.

The building housing the AIT facility is under construction at Media Lario premises near Milan, Italy, and extends 6.5 m below and 17 m above ground. The building is dimensioned to also accommodate the vertical X-ray test facility (Vert-X). The co-location of these two facilities is strategic for the project and will permit regular checks of the mirror module alignment while the MAM is populated. A rail system connects the two facilities.

1. INTRODUCTION

The ATHENA (Advanced Telescope for High-ENergy Astrophysics) mission [1] of the European Space Agency is based on an X-ray telescope with a focal length of 12 m and an angular resolution of 5 arcsec half energy width (HEW). The telescope consists in a 2.6 m circular supporting structure on which about 600 Silicon pore optics (SPO) mirror modules (MM) [4] are integrated. Media Lario has developed the process for the alignment and assembly of the MMs into the ATHENA MAM (Mirror Assembly Module) within the 1.0 arcsec, [5] error budget allocated for integration.

The alignment and integration concepts consist in using a vertical optical bench (VOB) to capture the focal plane image of each SPO MM while illuminated by a reference plane wave at a wavelength of 218 nm. The light emitted by the UV source is reflected by a parabolic mirror, named UV collimator, to generate a collimated beam, thus simulating illumination from deep space. The Mirror Module focuses the collimated beam onto a CCD camera placed at the focal position and the acquired point spread function (PSF) is processed in real time to calculate, by means of image analysis, the centroid position with very high accuracy. This information is then used to guide the robot-assisted alignment sequence.

As series of test have been performed both in UV and in X ray wavelengths to demonstrate the one-to-one correspondence of the centroid positions, also confirmed by X-ray measurements at the PANTER test facility [6] in Münich.

The process is implemented in standard ISO 5 cleanroom and is designed to integrate 2 MMs per day, equivalent to 2-year total integration time for the entire telescope. The integration sequence of the 600 SPO MMs is adaptable to the SPO MM manufacturing, there are no limitations. Thanks to the full-telescope illumination, the optical performance of the telescope is daily monitored.

The used of an optical vertical bench has been developed and optimized in the last 30 years by Media Lario team. This technique has been successfully used for the integration of many X-Ray telescopes such as Beppo-SAX, SWIFT, XMM-Newton, eROSITA and recently Einstein Probe [7].

2. ATHENA BUILDING

ATHENA building is currently in construction at Media Lario premises. The building contains the assembly and integration facility for the integration and alignment of the SPO MM into the MAM, as well as the VERT X facility. The latter is the ATHENA X-Ray calibration instrument (see Figure 1).

The ATHENA building comprises two main parts: one in the ground, 6.5 m deep, and one above the ground, which is 17 m high.

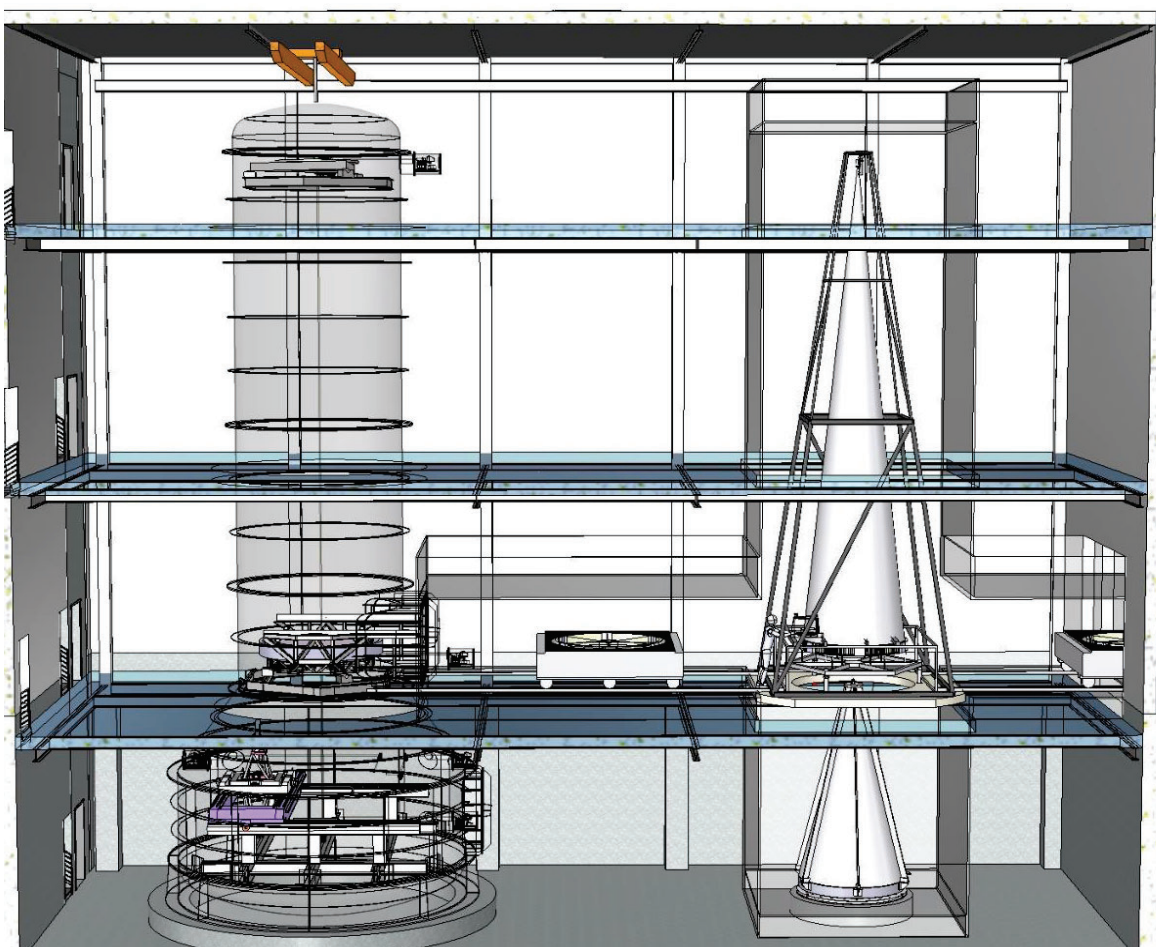

Figure 1. ATHENA building with VERT X (left) and ATHENA AIT (right)

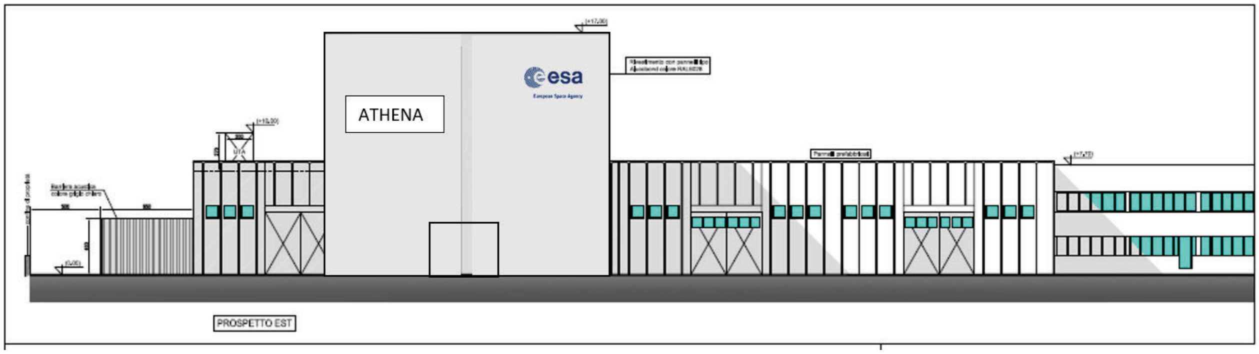

Figure 2. ATHENA building and Media Lario workshop

From the structural point of view, the underground area consists in a rectangular well 10 m x 20 m with a large watertight reinforced wall made of a series of concrete diaphragms. The lateral walls and the bottom slab are made of concrete, practically e double wall with waterproof materials inserted in between. The concrete bottom slab is also supported by underground layer of soil that is treated by Jet Grouting technique. This approach improves mechanical and permeability properties of the soil by using high-speed jets of water/cement mixtures injected at high pression into the soil. This treatment is applied to the soil to reach a depth of -13.5 m. Every single concrete diaphragms of the lateral walls is equipped with one tie rods 15 m long to firmly fix the well to the soil.

The well has been designed and structured to balance the mass of the Vert.X and AIT facilities and the Archimedean thrust of the ground.

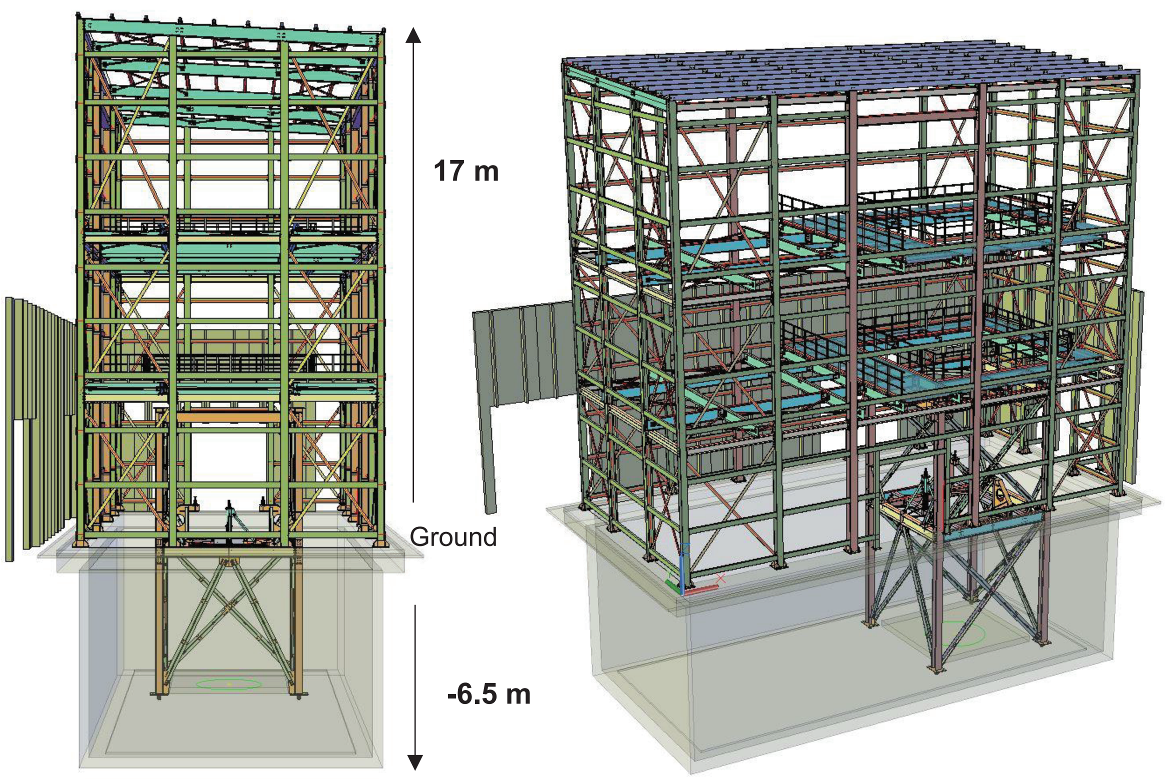

Figure 3. ATHENA building structure

Figure 4. ATHENA building

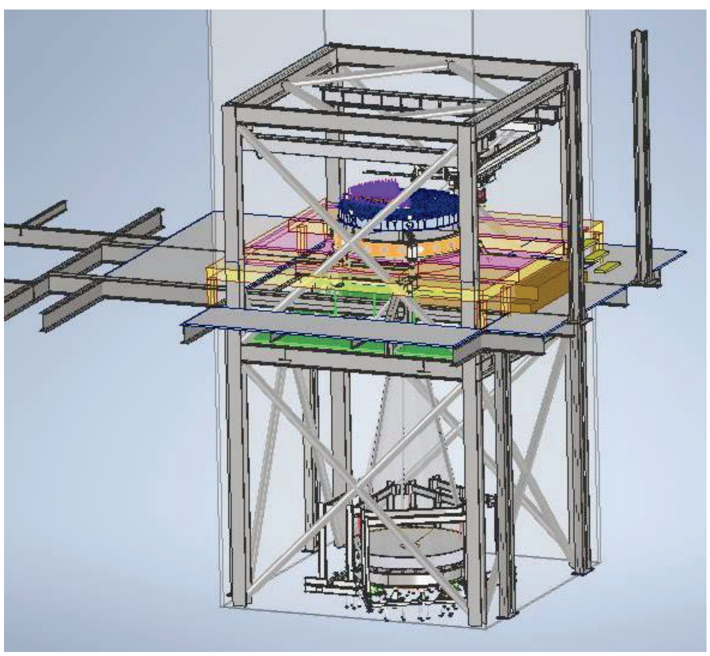

Figure 5. UVOB Cross section.

3. INTEGRATION FACILITY

The ATHENA assembly and integration facility is shown Figure 5. It consists of:

- UV parabolic collimator mirror.
- Carbon Steel Mirror-Cell supporting the UV parabolic collimator mirror.
- Three actuators and lateral constraints for the UV collimator alignment with respect to gravity
- CFRP frame to maintain the UV fiber source in the focus position of the UV parabolic collimator.
- XYZ stage for fine tuning of the UV focusing.
- Steel base frame supporting the ATHENA Mirror Assembly Module (MAM).
- Three actuators to support and align the ATHENA MAM gravity release system.
- Gravity release system for the ATHENA MAM with 9 actuators, force and position.
- CCD detector positioner, XYZ stage on top of the tower.
- Handling and Alignment Devices (HAD) with their XYZ mechanism for the integration of the SPO MM.

The UVOB is contained in an ISO 5 clean room, with an area of 6 x 6 m^2, extending down to the parabolic collimator and up to the detector. Requirements of position stability allow a maximum total focal length variation of 0.096 mm; therefore, the temperature inside the tower must be maintained within ±1 °C.

A CCD is suspended at the focus of the ATHENA telescope by means of a CFRP tower. The CCD is mounted on the tower by means of X, Y, Z translating stages for its fine positioning.

Laser trackers will routinely monitor the positions of the CCD, as well as the ATHENA telescope, the UV collimator mirror, and the UV source. To this purpose, retroreflectors are mounted on each component. Tiltmeters are also foreseen to verify the stability of the entire system and to maintain its optical axis parallel to the local gravity direction.

Figure 6. UVOB configuration

4. DESIGN OF THE INTEGRATION FACILITY

The conceptual scheme of the UVOB is shown in Fig. 5. It is composed by four sub-systems:

1. Collimator sub-system
2. Steel base frame sub-system
3. CCD assembly sub-system
4. Complementary items.

Each sub-system is composed of many parts according to the scheme reported hereafter.

1. The **Collimator sub-system** is shown in Figure **7** and Figure **8**. It is composed of the following parts:
    - Reinforced concrete foundation + steel plates interfacing to the collimator cell supports/constraints.
    - 3 collimator cell axial supports (motorised and adjustable from remote).
    - 3 collimator cell tangent constraints.
    - 2 tiltmeters and their supports.
    - Red Ring Reflectors for laser tracker and their supports.
    - 3 pentaprisms profilometers.
    - Collimator cell.
    - 54 collimator elastomeric supports.
    - Parabolic collimator.
    - UV source alignment supports and UV source.
    - XYZ stage for the fine tuning of the UV focusing.

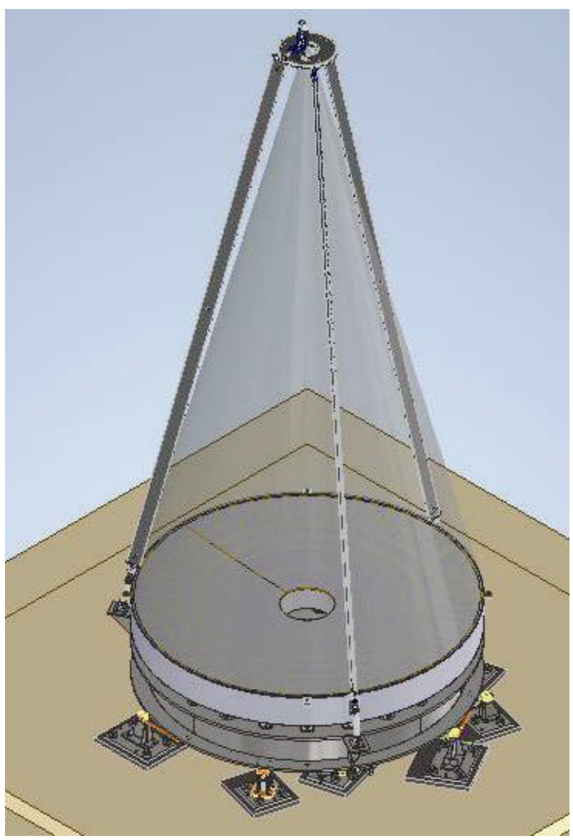

Figure 7. The Collimator sub-system

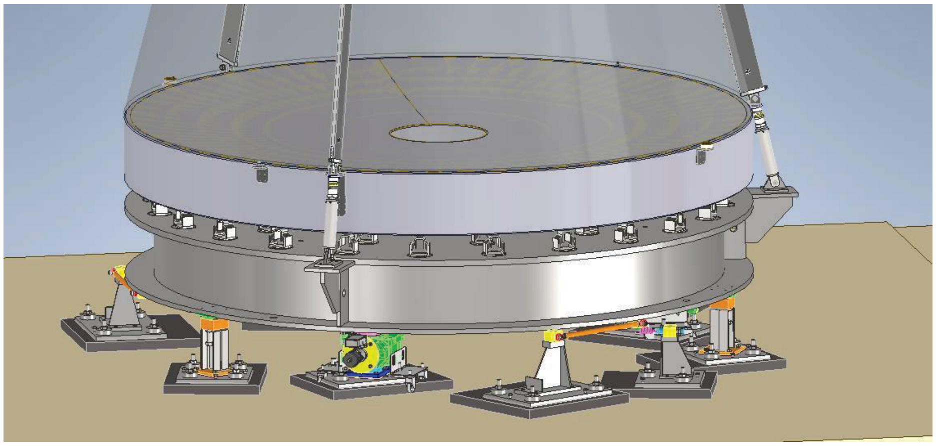

Figure 8. The backside parts of the Collimator sub-system

2. The **Steel base frame sub-system** is a two levels square tower as shown in Figure 9 and Figure 10. The two levels are composed by the following parts:
    - At lower level:
        - 2 permanent MAIS supports (adjustable actuators).
        - 1 removable MAIS support (adjustable screw).
        - Service deck at elevation -0.750 m to operate on MAIS supports.
    - At upper level:
        - Interfaces to CCD tower (if any).
        - 2 beams for gantry positioning.
        - 1 gantry systems to support the HAD.
        - 1 HAD with XYZ stages for fine positioning.

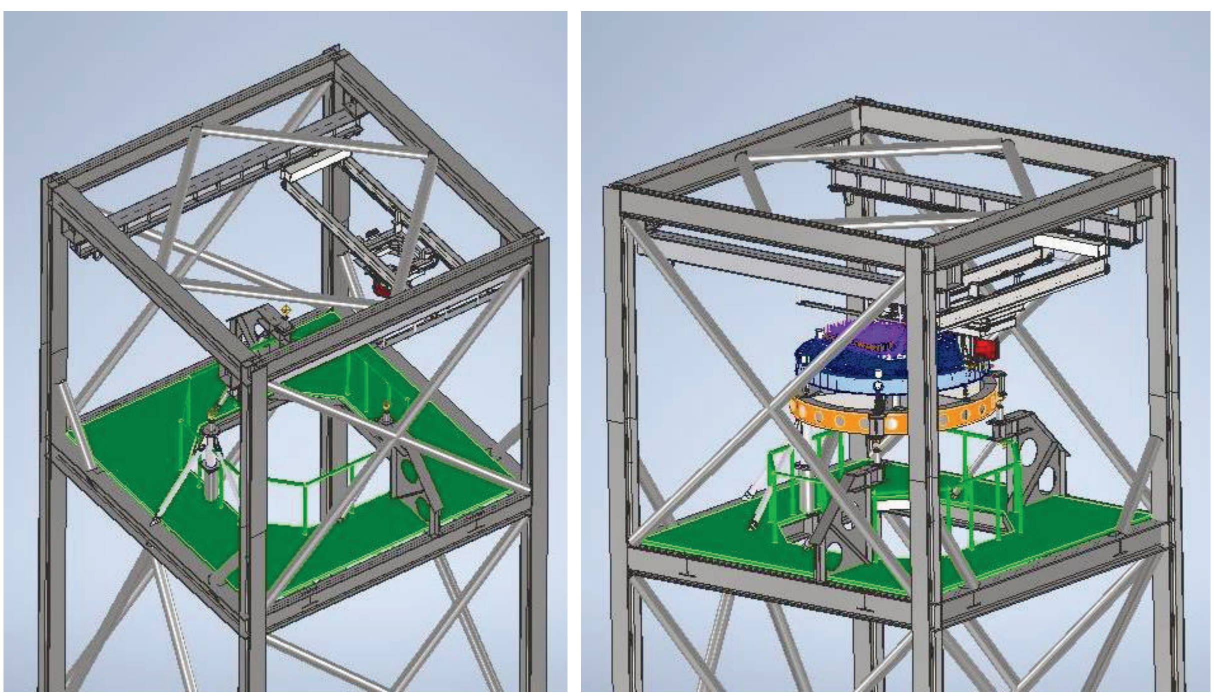

Figure 9. Steel base frame

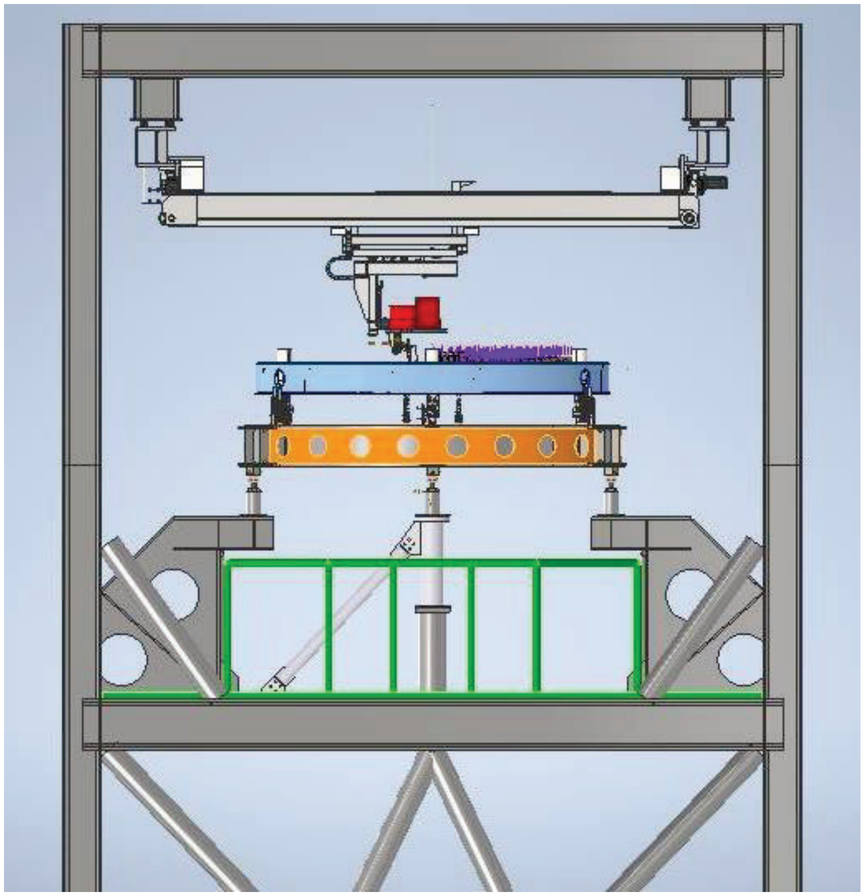

Figure 10. Devices on board to the base frame

3. The **CCD assembly sub-system** is composed of the following parts:
    - CCD tower (currently not envisaged).
    - CCD positioner, hexapods or XYZ stage on top of the tower.
    - CCD and UV filters.

4. **Complementary items** are also present; they are not properly part of the UVOB but represent the UVOB service equipment. They are:
    - Mirror Assembly Interface Structure (MAIS). According to current operational plan the MAM will be placed on the MAIS at the start of the activities. It will rest on the MAIS throughout the activities of alignment, integration, calibration and testing. The MAIS will be the sole interface with all handling devices (trolley) and all integration/testing equipment (AIV UVOB / Vert-X).
    - Service deck at +0.950 m elevation.
    - Trolley to transport MAIS + MAM assembly.
    - Rails for trolley.

The MAIS + MAM assembly rests on the UVOB structure which is a structure completely independent form the ATHENA Building structure.

Service deck, trolley, rails and operators gravitate on the ATHENA building structure in such a way that no vibrations are introduced by the movement of the operators or by the building itself.

5. THE UVOB COLLIMATOR

The 2.6 m collimator mirror is placed in the AIT tower at 6 m under ground level. The area provides a dry, water-tight, and vibration-isolated accommodation for the collimator supporting cell.

The latter consists in a carbon steel, ribbed structure, resting on the foundation slab of the well. The collimator mirror is equipped with 54 pads in metal with elastomeric parts. The collimator cell allows adjusting the collimator with respect to the gravity direction by three tip/tilt mechanisms. On the collimator side, a series of Invar pads are bonded to interface the CFRP structure that supports the UV source.

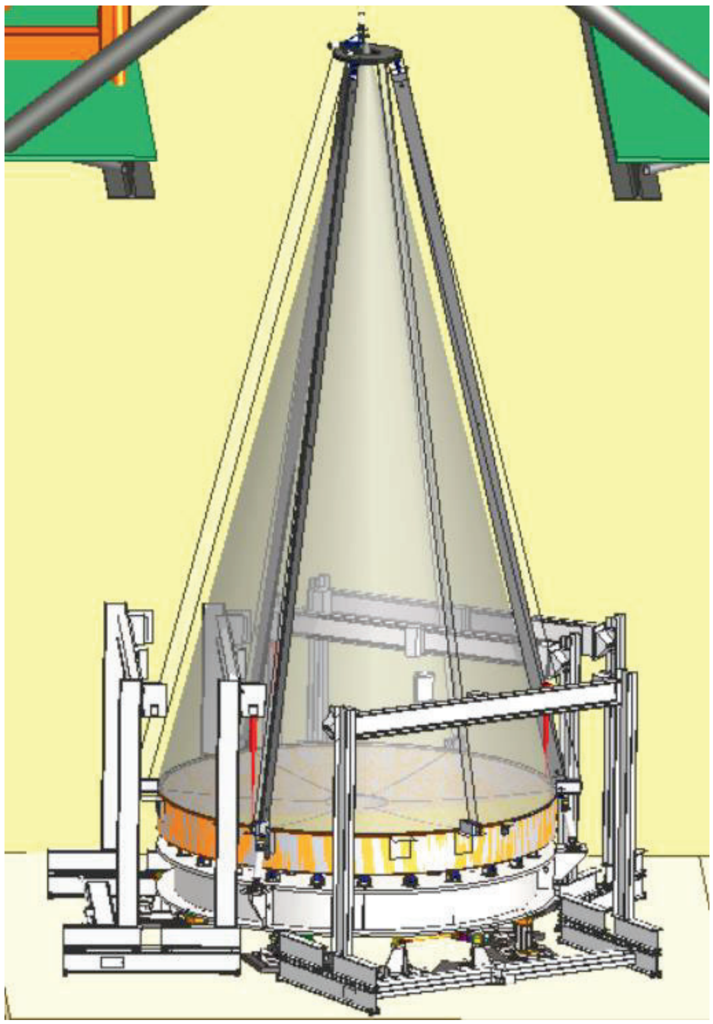

Figure 11. UV source supporting structure (above the mirror) and the 54 pads below the mirror.

At the top of the CRFP structure, X, Y, Z translating stages are mounted to hold the fiber optics of UV source. The design of the CFRP structure allows a good circulation to the air of the conditioning system.

The weight of the CRFP beams and structure itself is compensated by three actuators, which load the cell without inducing any deformation on the collimator mirror surface.

Since the collimator mirror has been polished while resting on the same 54 pads mentioned above, the deformation under gravity is absorbed by the polishing error budget. When installed on the UVOB cell, the surface error should be the same obtained in the polishing configuration.

A picture of the 2.6 m collimator mirror at Opteon Oy is shown in Figure 12. Polishing phase is completed. Aluminum coating is planned at the Calar Alto Observatory in October 2022.

The final surface shape of the collimator mirror is shown in the error map in Figure 13. The progress of the surface accuracy of the collimator versus time is shown in Figure 14.

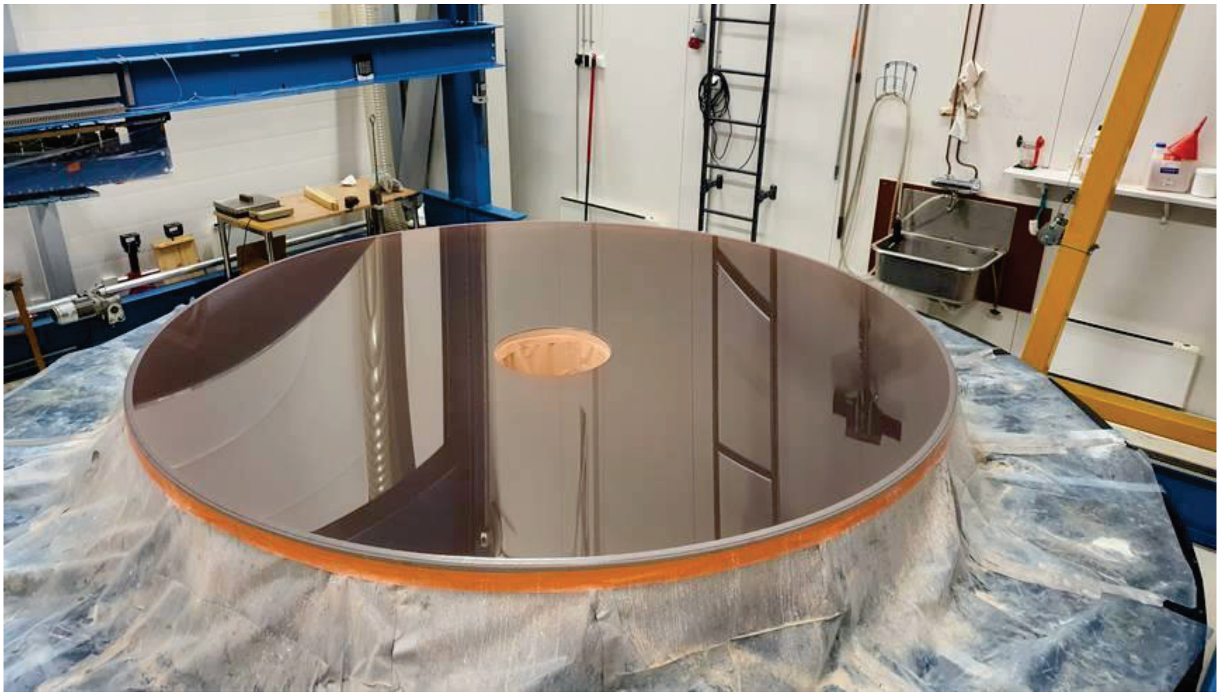

Figure 12. 2.6 m UV collimator at OPTEON Oy after polishing.

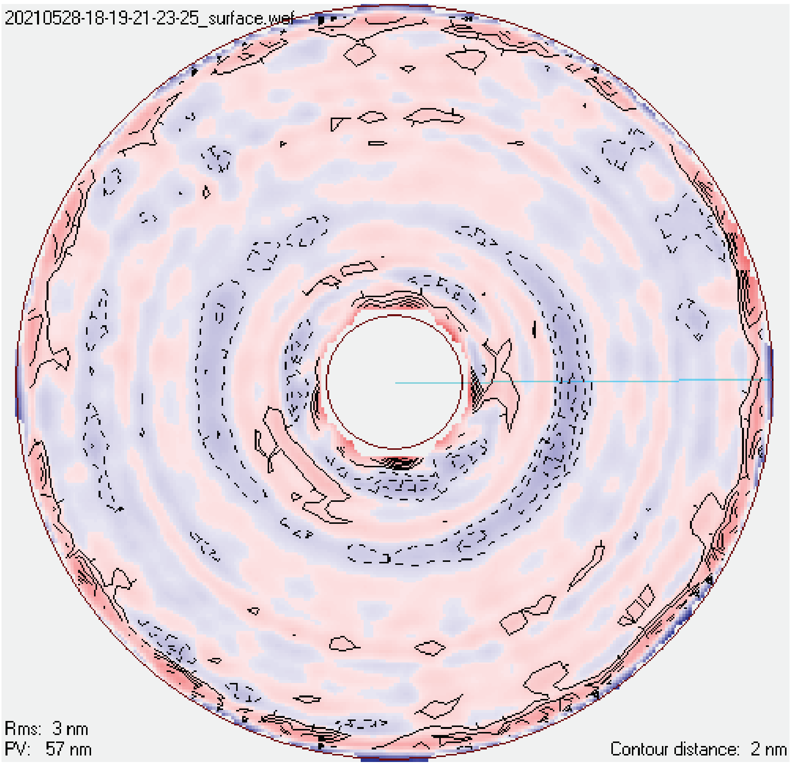

Figure 13. Latest surface accuracy measurement performed at OPTEON.

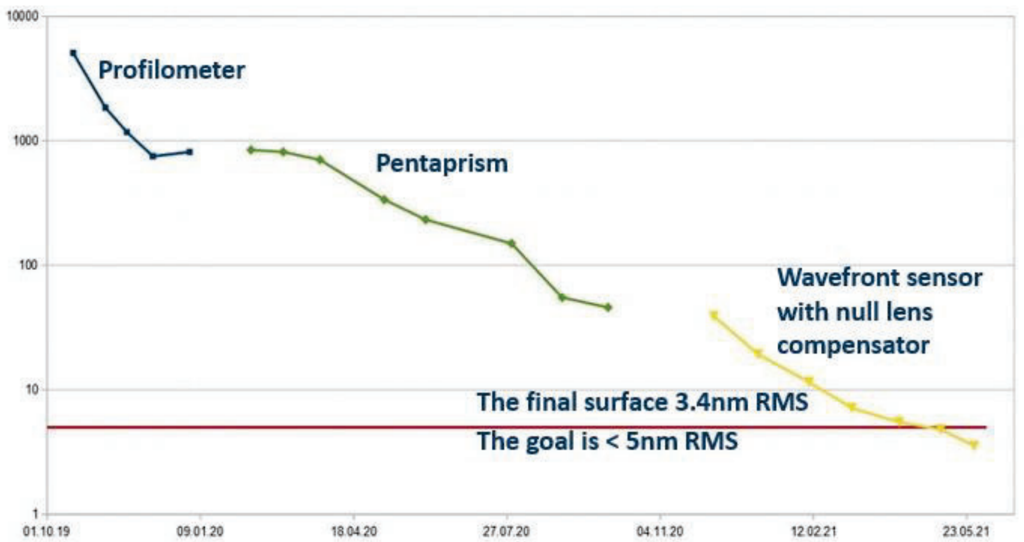

Figure 14. Surface accuracy of the Collimator mirror versus time

6. ATHENA MAM STRUCTURE SUPPORT

The steel structure supporting the ATHENA Mirror Assembly Module (MAM) is fixed to the concrete well slab by means of pre-stressed anchor bolts. It consists in a structure made of standard carbon steel, painted against corrosion.

On top of this structure the ATHENA MAM rests on nine actuators, three fix points and six spring-loaded interfaces. This configuration allows minimizing the gravity deformation. The MAIS design and force actuator to be adopted in the Gravity release system is reported in Figure 15.

The Handling and Alignment Device (HAD) system, for the positioning and integration of the Silicon Pore optics Mirror Modules, is mounted on top of the MAM as shown in Figure 16.

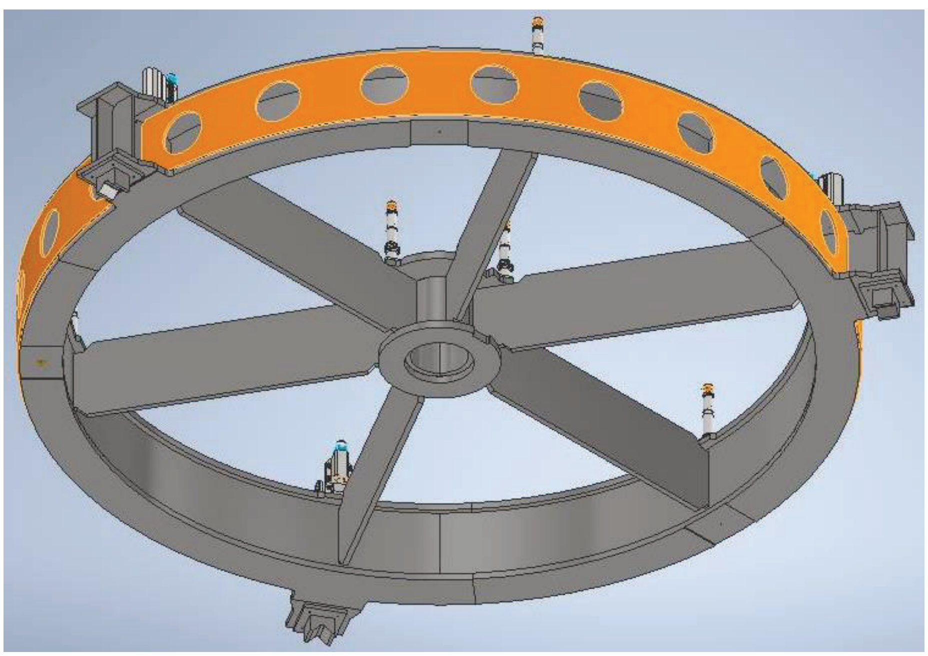
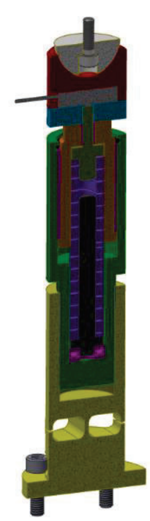

Figure 15. ATHENA MAM Interface Structure (left), Force Actuator (right)

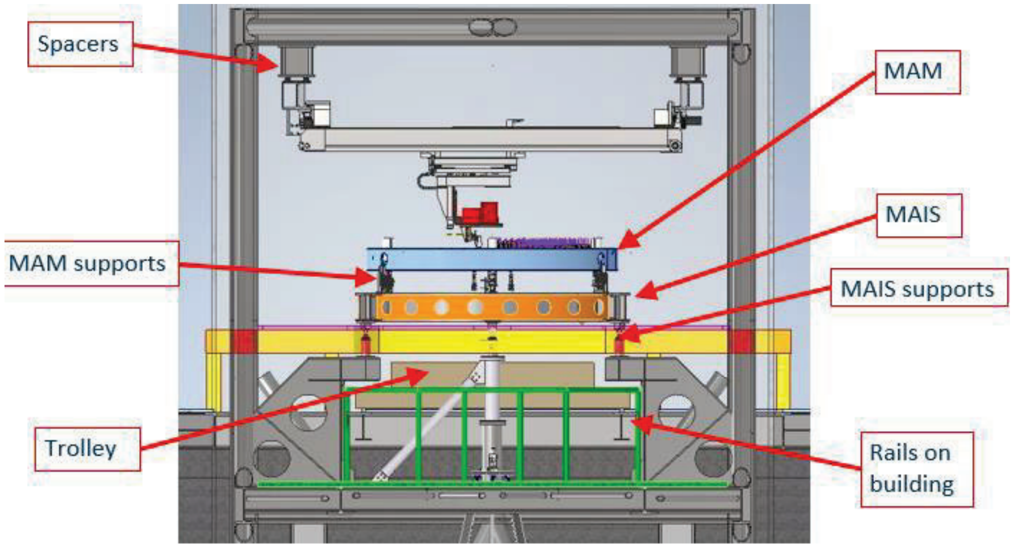

Figure 16. ATHENA MAM structure and Handling and Alignment Device

7. CONCLUSIONS

Media Lario and the team of scientific and industrial partners have developed and demonstrated the process for the alignment and integration of the silicon pore optics mirror modules in the structure of the x-ray ATHENA telescope. The AIT facility with its own UV optical bench (UVOB) and the VERT-X facility are under contraction. The ATHENA building at Media Lario premises will accommodate both facilities. The ATHENA Building and the UVOB will be completed in Q3 2022.

ACKNOWLEDGMENT

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