

Integration and testing of the NewAthena mirror modules

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ABSTRACT

Several hundred Silicon Pore Optics (SPO) Mirror Modules (MMs) shall be integrated and co-aligned onto the telescope structure of the NewAthena (New Advanced Telescope for High ENergy Astrophysics). Supported by ESA, Media Lario is designing and developing dedicated innovative facilities, capable of aligning, integrating and testing the NewATHENA mirror module assembly. The preparation of the NewAthena building at Media Lario premises is quite advanced. The building extends 6.5 m below ground and 17 m above ground. The building is dimensioned to accommodate, beside the UVOB facility, the vertical X-ray (VERT-X) test facility. The co-location of these two facilities is strategic for the NewATHENA, permitting regular X-ray measurements of the SPO MMs aligned and integrated with the UV light. The building is designed with a rail system connecting the two facilities, allowing the transfer of the telescope structure from the UVOB to VERT-X and vice versa.

Keywords: NewATHENA mission, AIT, X-ray, telescope

1. INTRODUCTION

NewATHENA is the result of a re-formulation of the ATHENA (Advanced Telescope for High ENergy Astrophysics) mission [1,2,3] which was initiated in 2022, to reduce the total mission cost while preserving scientific excellence. The telescope still consists in a circular supporting structure on which hundreds Silicon pore optics (SPO) mirror modules (MM) [4] are integrated. For the optics, the re-formulation essentially reduces the number of mirror module rows of the telescope, from 15 to 13, and the associated number of mirror modules from 600 to 492. The performance requirements of NewATHENA have been re-defined, mainly by decreasing the energy resolution and number of pixels of the XIFU instrument, and requiring adjustments to the WFI instrument, and by accepting an angular resolution of 9 arcseconds Half-Energy Width (HEW).

Media Lario demonstrated the process for the alignment and assembly of the SPO MMs into the Mirror Assembly Module (MAM) within 1.0 arcsec [5], which is better with respect to the error budget allocation. The alignment and integration concepts consist in using a vertical optical bench (UVOB) 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 (the so-called), to generate a collimated beam, thus simulating illumination from deep space. The Mirror Module focuses the collimated UV beam onto a CCD camera placed at the focal position and the acquired point spread function (PSF) is processed in real time. This information is then used to guide the robot-assisted alignment sequence: to co-align the centroid position we act on 3 translation and 1 rotation, to maximize the effective area we act on the remaining 2 rotations. 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 Munich. The integration sequence of the 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 use 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.

The verification and test procedure can also take advantage of the proximity of the VERT-X facility. VERT-X is an innovative calibration facility designed to perform the ground calibration of the NewATHENA mirror assembly. It relies on an X-ray parallel beam, generated by a micro-focus source positioned at the focus of an X-ray collimator. A raster-scan mechanism enables the beam movement, covering all NewATHENA optics at varying off-axis angles. The compactness of the concept offers several benefits, including the vertical geometry which implies minimal PSF degradation due to lateral gravity. One of the most important features of VERT-X is its contiguity with the mirror AIT facility. The driving factor in the VERT-X design is to meet the NewATHENA calibration requirement for Half- Energy Width (HEW) accuracy at 0.1". Key contributors to the error budget in the VERT-X design include the source size, collimator error, and raster-scan pointing accuracy. The key element of the VERT-X facility is the calibration beam, produced by a point-like source positioned in the focus of a highly performing X-ray collimator [7]. The peculiar element of the VERT-X design is the raster-scan mechanism (RS), which enables the movement of the X-ray beam to cover the whole mirror assembly at different inclinations. The VERT-X will be located in the same building at Media Lario, adjacent to the NewATHENA UVOB integration facility. This strategic co-location allows multiple performance verification in X-ray during the integration phase, moving the MAM from one facility to the other by means of motorized ground support equipment. The design and manufacturing of the most critical element of the VERT-X, the X-ray Raster Scan XRS, is already started under a parallel ESA contract where the Italian astrophysics institute INAF is the prime contractor [8.9].

2. THE NEWATHENA BUILDING

The building that will host the two facilities is completed at Media Lario premises. The building is designed to contain 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 building comprises two main parts: one in the ground, 6.5 m deep, and one above the ground, which is 17 m high.

From the structural point of view, the underground area consists of a rectangular well 10 m $\times$ 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 a double wall with waterproof materials inserted in between. The concrete bottom slab is also supported by an 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 pressure into the soil. This treatment is applied to the soil to reach a depth of -13.5 m. Every single concrete diaphragm of the lateral walls is equipped with one tie rods 15 m long to firmly fix the well to the soil.



Figure 1. NewATHENA building Exterior (right) and the status of the Interior (left) at Media Lario

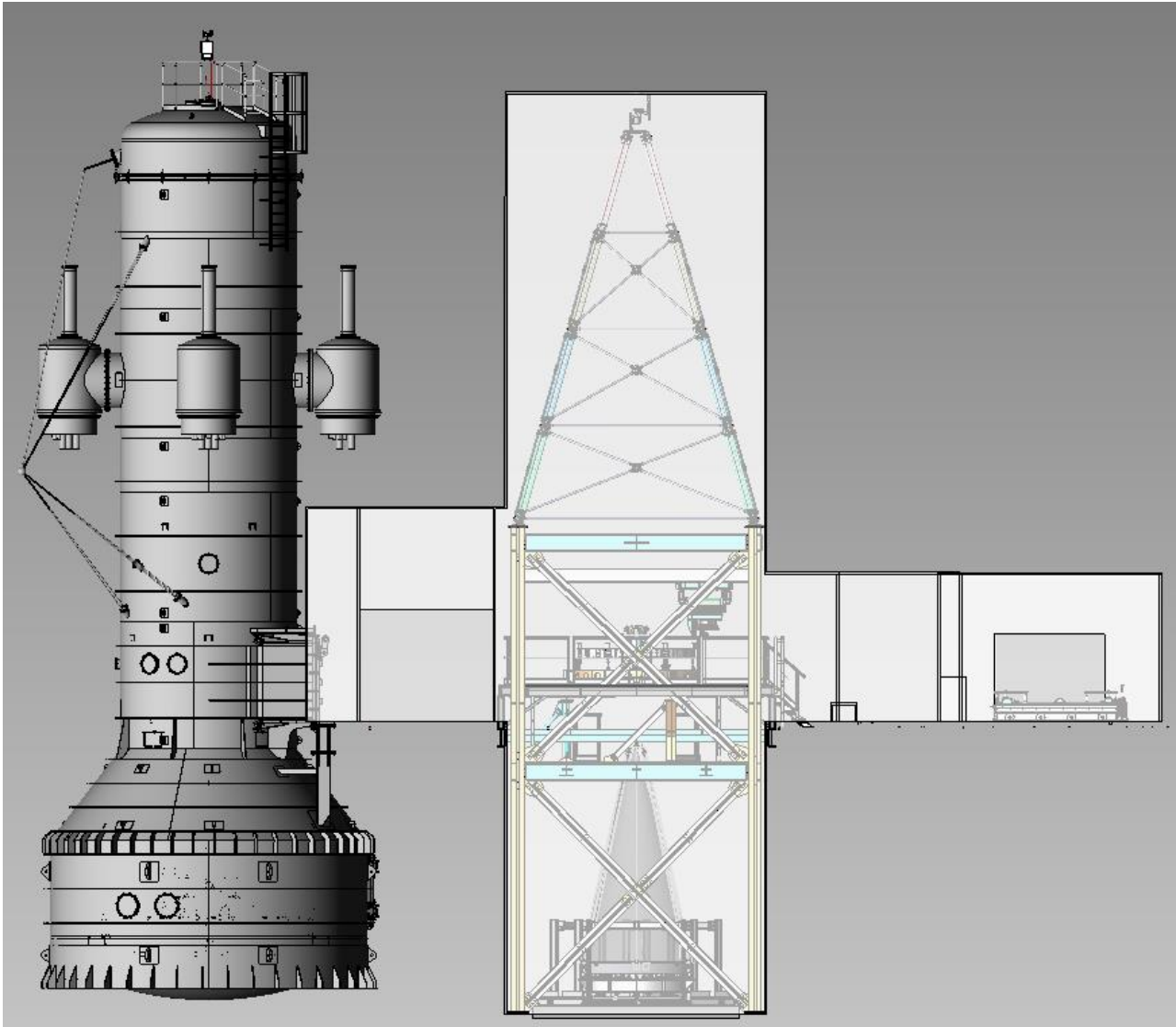


Figure 2. NewATHENA building with VERT-X (left) and UVOB (right) facilities

3. THE UVOB INTEGRATION FACILITY

The UVOB will operate in a cleanroom environment, with an area of $6 \times 6 \text{ m}^2$, extending down to the parabolic collimator and up to the detector.

A CCD is suspended at the focus of the telescope, mounted on the tower with X, Y, Z translating stages for its fine positioning. Laser trackers will routinely monitor the positions of the CCD, as well as the telescope, the UV collimator mirror, and the UV source. To this purpose, retroreflectors will be 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.

The conceptual scheme of the UVOB is shown in Figure 3. It is composed of four sub-systems:

1. UV Collimator sub-system (Figure 3. bottom right)
2. Steel base frame sub-system, including Mirror Module supports (Figure 3.top right)
3. CCD assembly sub-system (Figure 3. left)
4. Complementary items

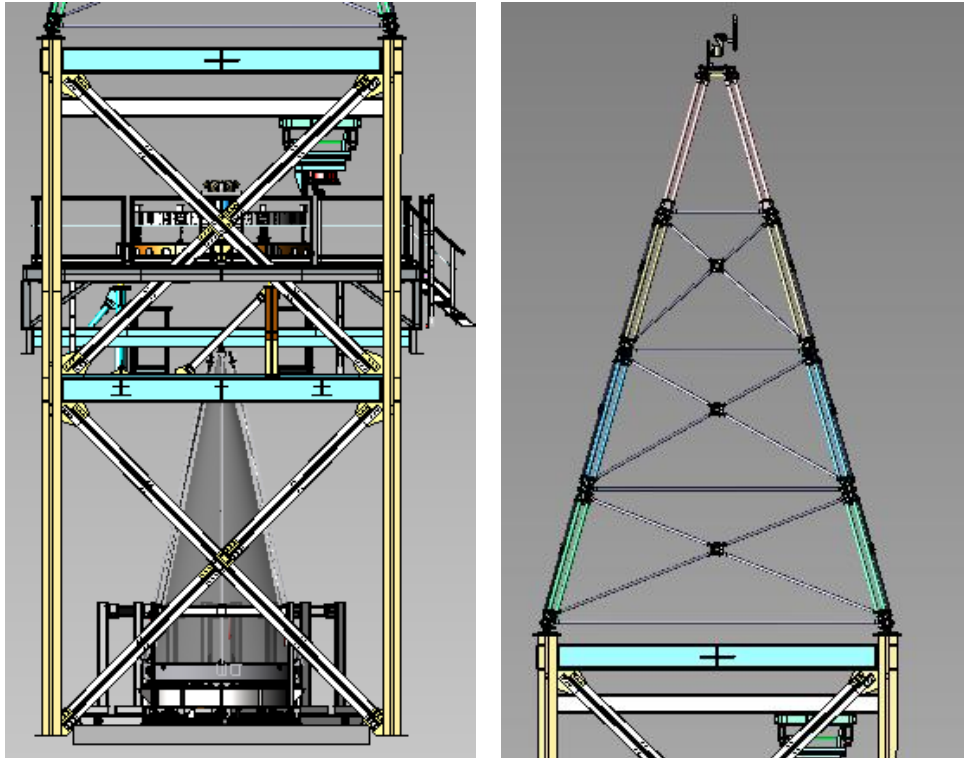


Figure 3. The UVOB with the UV Collimator sub-system (bottom right), the Mirror Module with the Handling and Alignment Device (top right) and the tower with the CCD system on top (left)

The UV Collimator sub-system:

- The collimator-cell
- 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
- 54 collimator elastomeric supports
- Parabolic collimator
- UV source alignment supports and UV source

The **Steel base frame sub-system** is a two levels square tower. the two levels are composed by the following parts:

- At lower level:
 - 2 permanent supports for the Mirror Assembly Interface Structure MAIS (adjustable actuators)
 - 1 removable support for the Mirror Assembly Interface Structure MAIS (adjustable screw)
- At upper level:
 - 2 beams for gantry positioning
 - 1 gantry systems to support the Alignment Device (HAD)
 - 1 Alignment Device (HAD) with XYZ stages for fine positioning

The **CCD assembly sub-system** is composed of the following parts:

- CCD positioner, hexapods or XYZ stage on top of the tower
- CCD and UV filters

Among the **Complementary items** there's the Mirror Assembly Interface Structure (MAIS). 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.

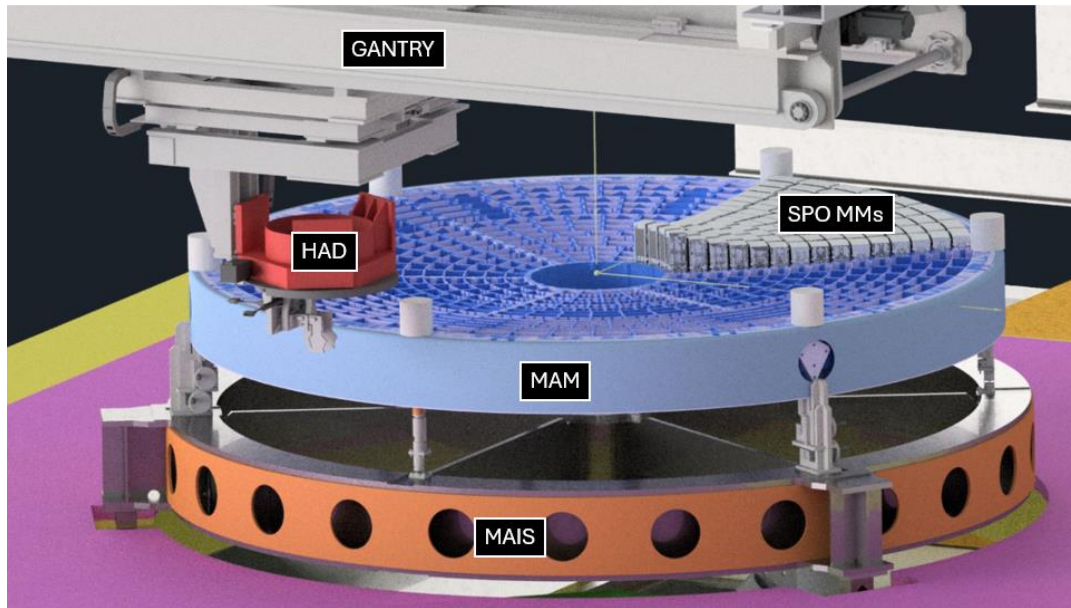


Figure 4. The MAIS, MAM, HAD

4. THE UV COLLIMATOR

The 2.6 m collimator mirror is placed in the AIT tower at 6 meters underground level. The area provides dry, water-tight, and vibration-isolated accommodation for the collimator supporting cell. The latter consists of 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.

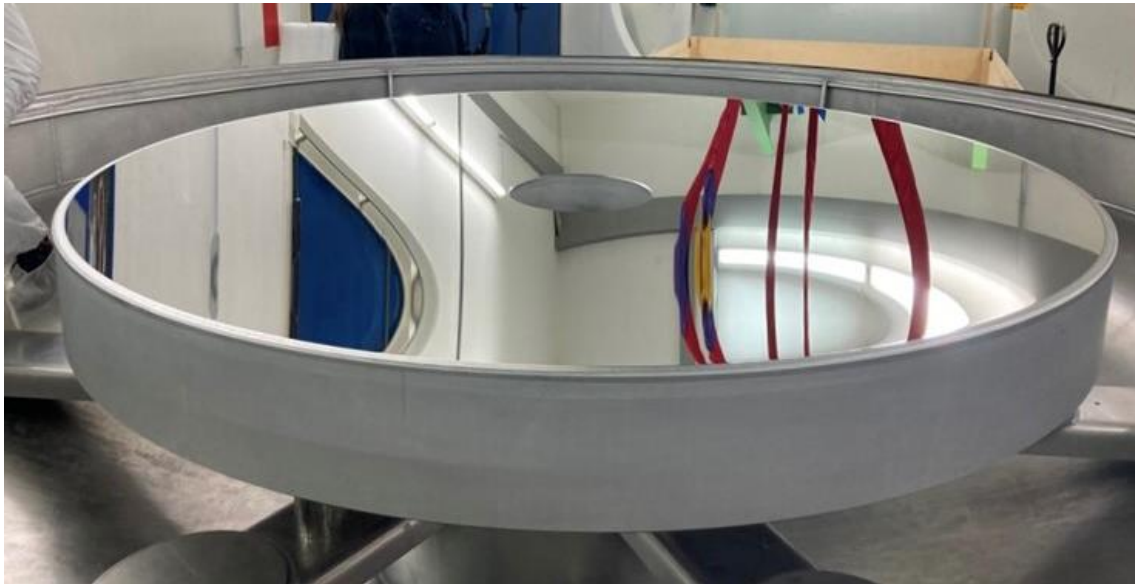


Figure 5. 2.6 m UV collimator after Aluminium coating at CAHA

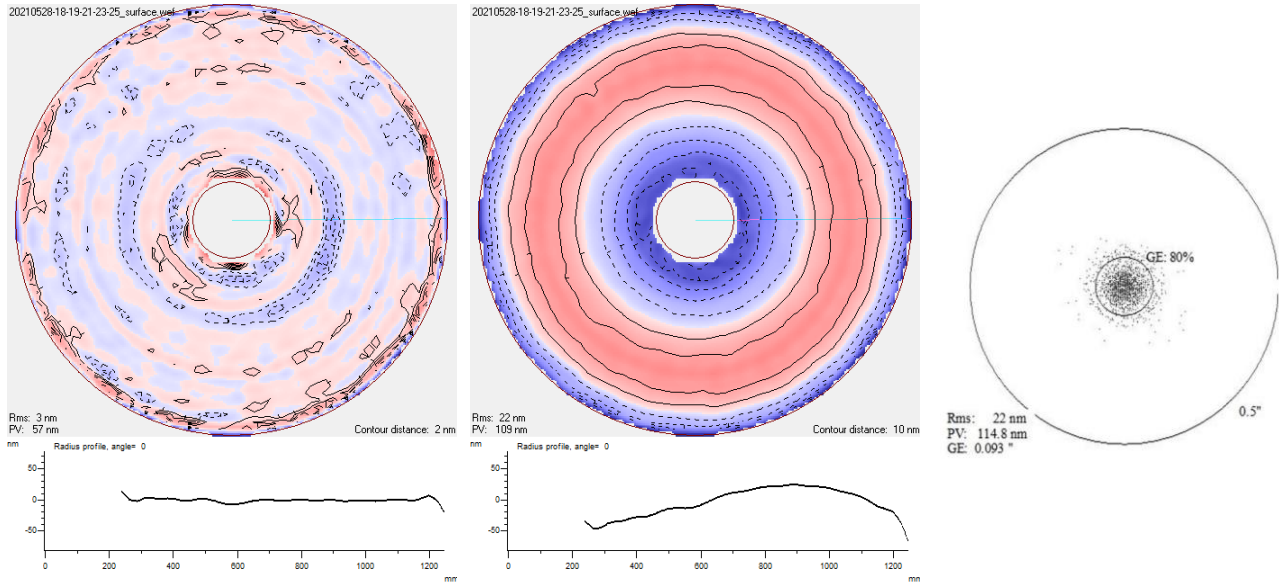


Figure 6. Collimator surface error: with wavefront sensor test and null lens compensator, spatial range 24 mm – 600 mm (left); with pentaprism test, low frequency errors (center); simulation of the optical image, 80 % of the rays are within a circle of radius 0.093'' (right)

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 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 cell, the surface error should be the same obtained in the polishing configuration.

The 2.6 m collimator mirror shown (in Figure 5) was polished in about 20 months at Opteon Oy and coated with Aluminium at the Calar Alto Observatory (CAHA). The mirror quality was specified by Media Lario in terms of Power Spectral Density (PSD) allocating a contribution of 0.2'' to the integration process. The overall surface error reached by Opteon Oy is 22 nm RMS and 115 nm PV, corresponding to a contribution of 0.093'', well within the 0.2'' specified. Looking to the mid-high frequency surface errors, namely in the spatial range 24 mm – 600 mm, the surface shape of the collimator mirror is 3.4 nm RSM (see maps in Figure 6).

5. VERT-X TESTING FACILITY

The ground verification and calibration of the NewATHENA Mirror Assembly Module (MAM) raises significant difficulties due to the unprecedented size, mass and focal length. VERT-X is an innovative calibration facility designed to tackle this exceptionally demanding task. It relies on an X-ray parallel beam, generated by a micro-focus source positioned at the focus of an X-ray collimator. A raster-scan mechanism enables the beam movement, covering all the MAM at varying off-axis angles. The compactness of the concept offers several benefits, including the vertical geometry which implies minimal PSF degradation due to lateral gravity. Furthermore, this allows for a flexible choice of location. Indeed, one of the most important features of VERT-X is its contiguity with the mirror integration facility.

The key element of the VERT-X facility is the calibration beam, produced by a point-like source positioned in the focus of a highly performing X-ray collimator. In the VERT-X design there's the raster-scan mechanism (RS), which enables the movement of the X-ray beam to cover the whole mirror assembly at different inclination. The implementation of this concept results in a vertical design (see Figure 7):

- the system is fully enclosed in a 20 m high cylindrical vacuum chamber, with the focal-plan on the top and the Mirror Assembly Module at the ground level;

- the raster-scan mechanism is positioned below that, at ~ 5 m underground, completely enclosed in the vacuum chamber, with the purposes of translating and rotating the vertical tube that hosts the X-ray source and the beam collimator.

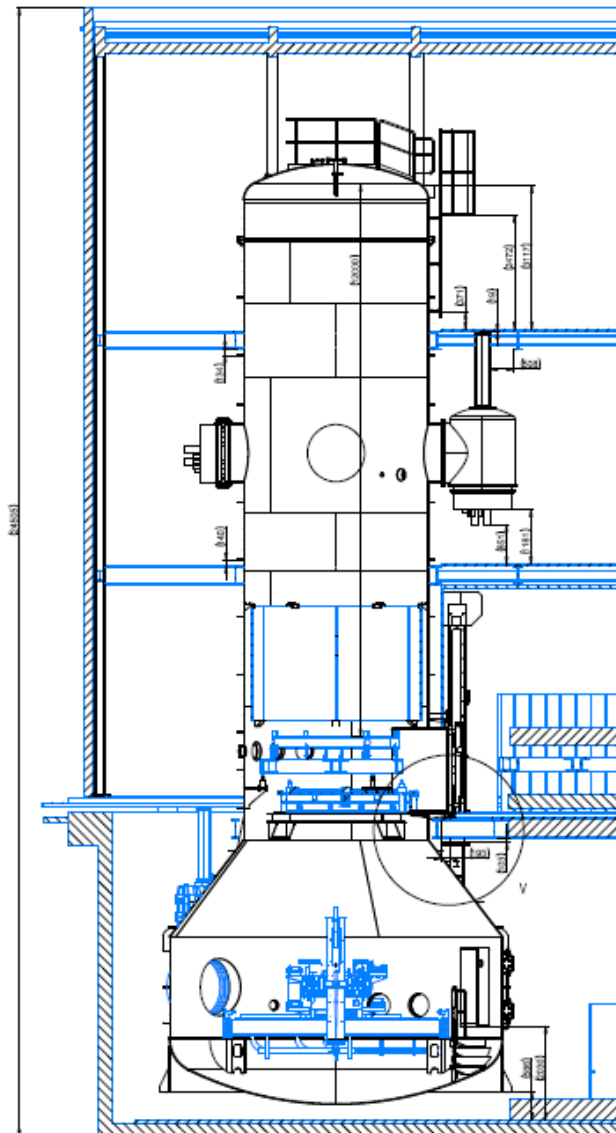


Figure 7. Section drawing of the VERT-X test facility showing the Raster Scan (in the bottom), the Mirror Assembly Module about 5 meters above the raster scan and the x-ray camera on top at about 12 meters from the MAM

The requirement analysis showed that the most critical aspect is the PSF calibration. According to the current calibration plan, an absolute knowledge error (AKE) of $0.1''$ at 68% confidence is required for the HEW at all energies in the 0.3-12.0 KeV energy band across the entire field of view. The error budget has two main components:

- the statistical error which depends on the number of X-ray photons collected;
- the systematic error primarily caused by the residual beam divergence.

The number of collected photons, of course, strongly depends on the pile-up limit (combination of HEW, pixel size and frame rate). Simulation by the working group of calibration measures showed that the statistical error can be kept as low

as 0.05", collecting the necessary number of photons in the required amount of time. Regarding the PSF systematics, the beam divergence results from the sum of the source size, the collimator error and the raster scan tracking error.

Assuming a HEW of the NewATHENA telescope of 9", a statistical error of 0.05" and a beam divergence of 1.5" (measured with an accuracy of 10%) results in a final error on the NewATHENA HEW measurement that complies with the cited requirement (0.1").



Figure 8. Vacuum Vessel under preparation at the Brinox facility

6. SUMMARY

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 NewATHENA telescope. The UV optical bench and the VERT-X facility are under advanced design and construction. The building at Media Lario premises is ready to accommodate both facilities.

ACKNOWLEDGEMENTS

Part of this work has been done in the framework of the European Space Agency contracts 4000126922/19/NL/IB/gg and 4000132680/20/NL/IB/gg. Calar Alto Observatory (CAHA) is acknowledged for the support on the coating of the UV collimator.

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