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Status of the demonstration of the critical technologies of the ATHENA telescope

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ABSTRACT

The ATHENA (Advanced Telescope for High ENergy Astrophysics) mission is the current 2nd 'Large' mission (L2) in the ESA Cosmic Vision programme currently. It is currently at Phase B1 but the mission concept will now enter a reformulation phase that will follow a design-to-cost approach.

This paper describes the main technologies behind its reference X-ray telescope based on the modular Silicon Pore Optics (SPO) technology.
The large X-ray mirror is the mission enabler being specifically developed for ATHENA, in a joint effort by industry, research institutions and ESA. All aspects of the optics are being addressed, from the mirror plates and their coatings to the mirror modules and their assembly into the ATHENA telescope, as well as the facilities required to build and test the flight optics, demonstrating performance, robustness, and programmatic compliance.

An overview of the status of the design and demonstration of the telescope is given. The risks that have successfully been mitigated are made explicit and the remaining risks are identified.

Keywords: X-ray optics, X-ray astronomy, Athena, Silicon Pore Optics, X-ray telescopes

1. MISSION STATUS

The ATHENA mission preparation is ongoing since 2014 following the selection of the “Hot and Energetic Universe” as the theme for L2. Its study started with the selection and mission assessment done at ESA’s Concurrent Design Facility (CDF) in October 2014 [1] and, since then, continues with industrial studies and significant parallel technology developments. The description of the mission and corresponding spacecraft is well established [2].

The mission entered Phase B1 by mid-2020, after successfully passing the mission formulation review. At that point a major programmatic decision was made to transfer a significant part of the responsibilities in the instrument module towards ESA. These extra responsibilities were added on top of the ones included in the original proposal in 2014.
In response, ESA prepared and awarded 4 phase B1 contracts to industry (2 competing contracts for the continuation of the spacecraft studies, and 2 new competing contracts for the instrument module). The goal of these contracts was to better establish interfaces and programmatic constraints in preparation of the mission adoption and future implementation.

The industrial contracts reached a consolidated design at the beginning of 2022 but, during the preparation of the mission adoption, it became clear that there was considerable escalation of the mission cost to ESA due to the increased perimeter of responsibilities in the instrument module. In consultation with the ESA Science Advisory Structure and the Science Policy Committee (SPC) it was decided to initiate a reformulation phase of the mission by following a strict design-to-cost approach. This reformulation of ATHENA is needed to ensure that ESA’s Science Programme maintains its financial sustainability and diversity (which is of paramount important to ESA member states).

The new mission concept for ATHENA will need a considerable cost reduction. All stakeholders will be involved in this reformulation, including the scientific community, the Executive, the national funding agencies, and the international partners. This work is now beginning, and all stakeholders are evaluating different possibilities towards achieving a cost-feasible concept during 2023, to be further detailed during 2024.

Nevertheless, all the developments related with the critical enabling technologies such as the ones related to the X-ray mirror described in this paper, shall continue in parallel to the reformulation of the mission.

2. ATHENA SPACECRAFT AND MIRROR ASSEMBLY DESIGN OVERVIEW

The ATHENA spacecraft is, in first order, very similar to that of XMM-Newton or Chandra. It includes a Mirror Assembly Module (MAM) where optical elements are accommodated, and a Science Instruments Module (SIM) where the instruments are placed. The focal length of the X-ray telescope is 12 m so these 2 modules are separated by a large tube called Fixed Metering Structure (FMS) (Figure 1). The largest difference wrt. XMM-Newton/Chandra is that the Service Module (SVM) is placed about half-way on the FMS to minimise the torque due to solar radiation pressure (by minimising the distance between the centre of pressure and the centre of gravity).

The MAM is the 2.6 m diameter module accommodating the Silicon Pore Optics (SPO) Mirror Modules (MMs).
The SPO technology is the key enabler of the ATHENA mission which has been under ESA-led development for over a decade [3,4]. This technology exploits the exceptional surface finish of silicon plates produced for the semiconductor industry (spinning in developments in that field) to produce stacks of reflecting plates corresponding to an approximation of a Wolter type I geometry, integrated into a modular format held between Invar brackets – a so called Mirror Module (MM) (see Figure 5).

The modular approach is a key feature to maximise reusability and decrease complexity. The SPO MMs are aligned and glued to a Mirror Structure (MS) that has many pockets designed to accommodate the different geometries of the MMs, whose dimensions change from row to row to fully utilise the available area. The current reference telescope design [5] is stable and includes a total of 600 MMs distributed along 15 rows (see Figure 1).

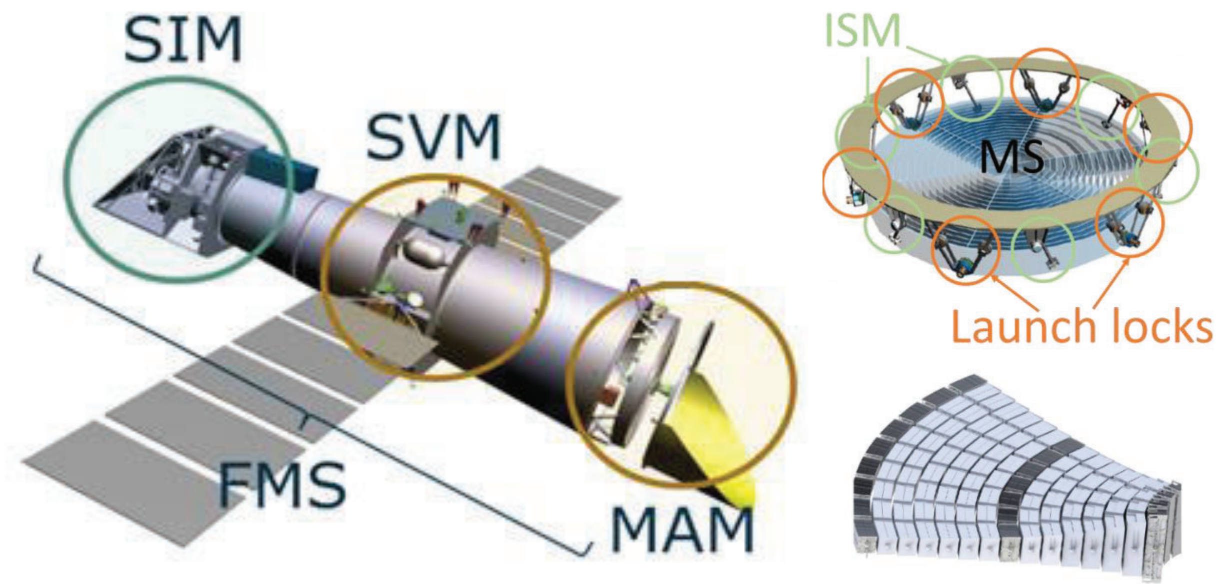

Figure 1: (Top left) Overview of the ATHENA spacecraft. (Top right) The MAM including the 2.6 m diameter aluminium alloy Mirror Structure (MS) with the 600 pockets where the MMs are placed, the launch locks and the Instrument Switching Mechanism (ISM). (Bottom right) Distribution of the SPO MMs along one of the sectors of the MAM.

The MS is machined from a monolithic blank and is expected to be done in an Aluminium alloy to facilitate manufacturability, cost, and mass.
The MS is essentially an optical bench that is thermally controlled with the help of hundreds of heaters placed inside the pockets and several tenths of thermistors. This thermal control system is needed to minimize the thermoelastic distortions (and the corresponding optical performance degradation), and to allow the MMs to be kept within their design temperature range (as close as possible to 20 ºC).
A thermally controlled baffle and/or a thermally controlled lower FMS, are also being considered to further optimise the thermal control system.

The MAM also includes 6 launch lock bipods, able to hold up to 60-100 kN each (Figure 1). The MS and the launch lock bipods work in tandem to provide the necessary damping of the structural loads expected during launch.
Once in space, these launch locks are released, and the MAM is then able to be tilted towards each of the instrument using a very accurate 6 degree of freedom mechanism (also relying on bipods) called Instrument Switching Mechanism (ISM).

Finally, at the centre of the MAM, as close as possible to the mirror node, there are several star trackers and other metrology elements to be able to achieve the required knowledge of the telescope line of sight.

3. ATHENA OPTICS CRITICAL TECHNOLOGIES AND THEIR DEMONSTRATION

The mission maturation approach defined by ESA establishes the need to pass through an adoption process. Adoption is the point at which the mission design is technically and programmatically scrutinised and is a gate to proceed towards the implementation phase. This occurs at the end of the Phase B1. The optics technologies remain fully on track to ensure compatibility with a mission adoption by end 2023 but the mission has now entered a reformulation phase.

One of the requirements for a successful mission adoption is to achieve a level of maturity for the critical technologies consistent with TRL5/6.
This means that breadboards need to be produced to verify the critical functions in a relevant environment [6].

The programmatic constraints of the ATHENA mission require a mass-production environment (the schedule allocation is around 2 years to produce the 600 MMs and align them into the MAM). Therefore, in addition to the demonstration by manufacturing and testing of the individual breadboards (performance and environmental), there is also the need to demonstrate the ability to achieve the required production rates.

The critical optics technologies that need to be demonstrated for ATHENA can be organized in areas shown in Figure 2.

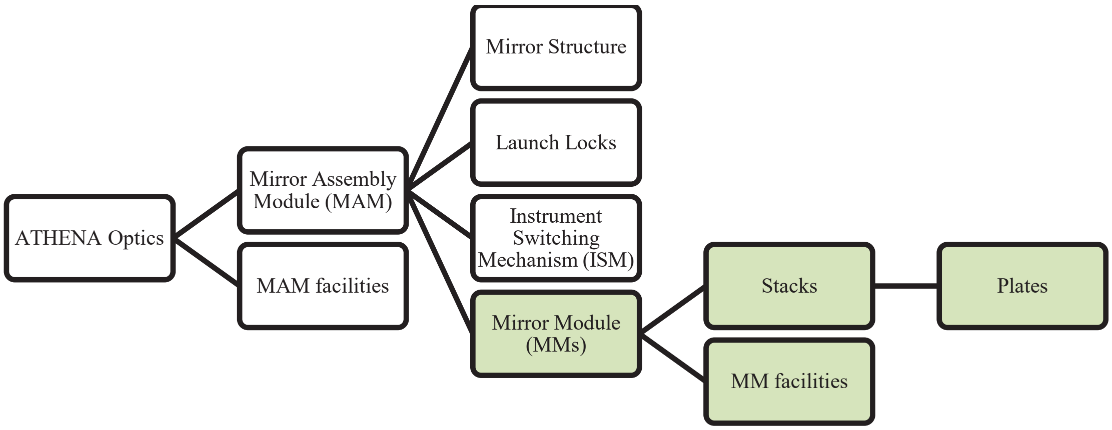

Figure 2: Areas of critical optics technologies for the ATHENA mission. The boxes in green have been assessed through a dedicated TRA (Technology Readiness Assessment) review.

The following sections briefly describe the design status of the technologies in each area, the verification approach, the status of the verification, the risks that have already been mitigated, and the remaining risks.

3.1 Mirror Assembly Module (MAM)

Design status

The MAM design is one of the most important parts of the overall spacecraft design. It is now considered stable as the result of several years of study, first by ESA and then by competitive parallel industrial studies.
Two detailed designs have been produced: one by the consortium led by Airbus Defence and Space (Friedrichshafen – Germany); and another by the consortium led by Thales Alenia Space (Torino - Italy) which itself is part of the OHB spacecraft consortium.

Verification approach

In addition to the detailed design reviews, dedicated activities were started in 2020 when ESA placed a tender for the design, development and testing of a demonstrator to allow the verification of some of the critical functions of the MAM prior to mission adoption – these activities are called the Mirror Assembly Module Demonstrators (MAMDs). The answers to this tender resulted in 2 parallel contracts awarded to the same consortia mentioned above.

The goal of the MAMDs is to allow the verification of the:
1. The ability to manufacture a full-sized MS (with a diameter of around 2.6 m with the selected Aluminium alloy),
2. The ability to accommodate the SPO MMs in the geometry prescribed by the reference telescope layout, ensuring the necessary geometric complexity can be machined without compromising the quality of the material,
3. The assurance that the materials and processes envisaged for the manufacture have the required maturity and quality,
4. The ability to provide environments for the SPO MMs that are within the range mentioned above.

For this purpose, the MAMDs to be manufactured needed to be fully representative of the MAM structural performance, using dummies to represent the SPO MMs and other elements, albeit with some compromises in terms of the manufacturing geometry (only fully representative in one of the sextants) and with only 1 releasable launch lock element.

The MAMDs needed to undergo vibration tests and launch lock release tests to check the sine, random and shock loads at the level of the MMs in different locations along the aperture. In addition to standard accelerometers, additional metrology was to be used to be able to check the alignment of the MM dummies before and after the different test loads to verify that slippages have not occurred in the glued interfaces between the MM dummies (mounted in the same way as real MMs) and the MS.

If at least one of the MAMD activities is successful, then the goals above would have been met and the MAM design would be demonstrated for the purposes of the mission adoption (TRL higher than 5).

Verification status

Both consortia have delivered representative sectors (one sixth) of the MS including some coated rows.
These representative sectors have been populated with heaters and 3 real row 8 MMs for thermal/X-ray tests at the Panter facility from MPE in Munich [7].
The sectors were placed vertically with the help of a jig and thermally stressed with the help of shrouds and the heaters. The tests were done by ESA and MPE, subjecting the sectors to several thermal cases while monitoring the centroid of the PSF of each of the 3 MMs. The goal is to infer the thermoelastic properties of the sectors by monitoring the misalignments of the MMs during the different thermal loads.
These tests occurred during July to September 2022 and the results are currently being compared with the predictions. Dedicated thermal and finite element analyses are being used for this purpose.

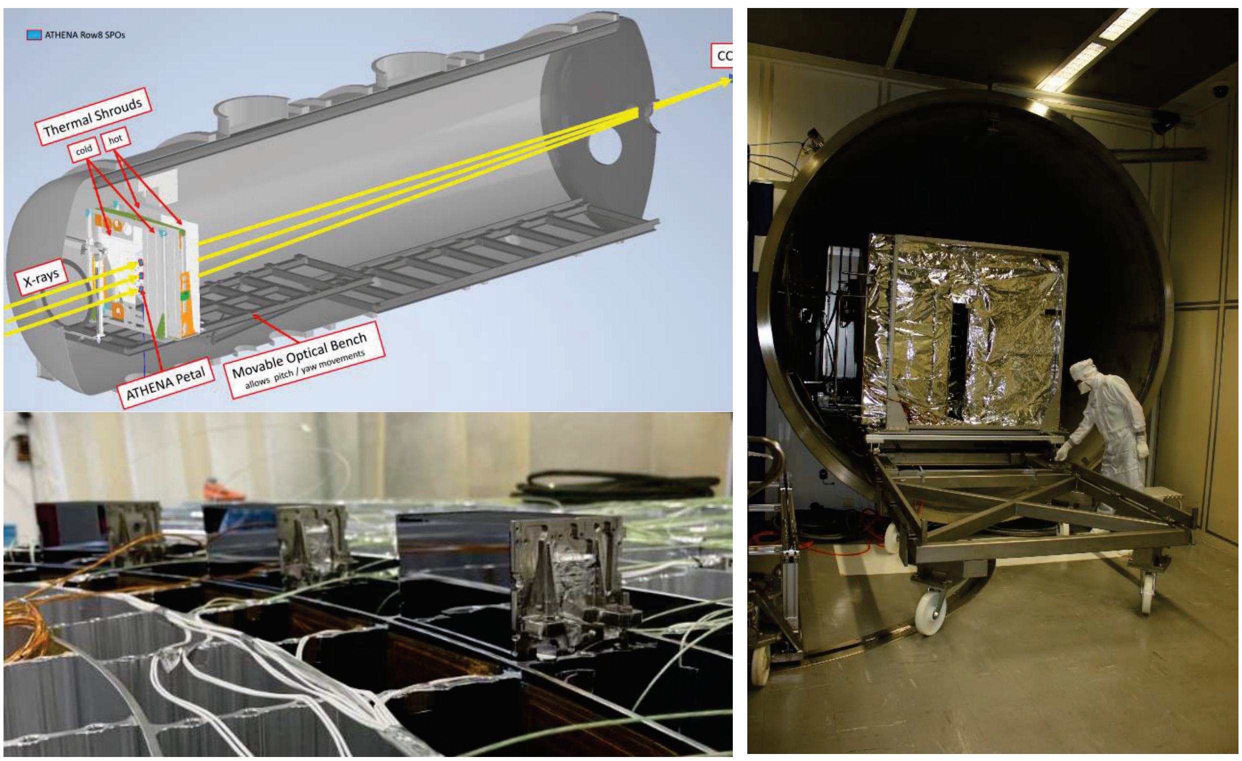

Figure 3: (Top left) CAD model of the setup for the sector tests performed at Panter; X-rays arrive from a source placed around 128 m away, each sector is placed between 2 shrouds (one hot shroud on the detector side able to go up to 40ºC, and a cold shroud in the source/space side able to go down to -40ºC). The detector was placed around 13.2 m away in an extension chamber (FL=12 m with a thin lens in a divergent beam). Different thermal cases were defined to thermally stress the sectors and monitor the centroids of the PSFs of the MMs (Bottom left): Details of the installation of the 3 row 8 MMs in one of the sectors, also showing the coating and the heaters in adjacent pockets. (Right) Assembly consisting of the 2 shrouds, jig, and one of the sectors, being placed in the large vacuum vessel at Panter.

One consortium has successfully finalised the manufacturing of all the MAMD parts, completed the assembly, and performed the environmental tests during the Summer of 2022.
The other consortium is completing the manufacture of the MS. Most of the other elements (dummies, launch locks, etc…) have successfully been manufactured.

Due to the competitive nature of these contracts and their importance for the future selection of the spacecraft prime, only limited information is provided in this paper.

Mitigated risks

Manufacturability of the MS (to the required tolerance and finishing standard – including coating) and the other elements of the MAM.
Structural integrity.
Cost.

Remaining risks

The data of the vibration and sector thermal tests is still being analysed at the time of writing this paper, but the initial analyses performed with the gathered data during the tests show encouraging results.
There are still some remaining risks to be addressed in the MAM thermal control (a thermal baffle has recently been introduced), straylight, and contamination mitigation.

3.2 Mirror Structure (MS)

Design status

There are 2 detailed designs of the MS from the 2 MAM consortia mentioned before. Both designs are based on Aluminium alloys but are different in terms of material, geometry, and manufacturing process. Nevertheless, both designs are fully compatible with the reference telescope defined by ESA.

Verification approach

To be verified as part of the MAMD activities mentioned before.

Verification status/ Mitigated risks/Remaining risks

Same as mentioned before for MAM.

3.3 Launch locks and Instrument Switching Mechanism (ISM)

Design status

There are 2 different designs for the launch locks from the 2 MAM consortia mentioned before.
The first one was designed by SENER Poland (part of the TAS consortium) and is being developed through a dedicated activity funded by ESA. The second one was designed by Airbus Defence and Space (Friedrichshafen – Germany) and manufactured for the MAMD activity directly.
Both designs are mature.

The are also 2 different designs for the ISM. The first one was designed by SENER Poland, design and developed in tandem to the launch locks. The second one is being developed by Airbus Defence and Space (Friedrichshafen – Germany) and Astronika Poland.

Verification approach

For the launch locks, the verification approach is to have standalone environmental tests and afterwards have the 6 launch locks as part of the MAMD activities mentioned before.

Figure 4: (Left) Test configuration of the ISM hexapod configuration developed by SENER Poland used to verify the required positioning accuracy performance. A dummy is used for representing the inertia of the MS. This concept demonstrated all the requirements in terms of accuracy and stability (around 10 µm over 1 day). (Right) Test configuration of 1 launch lock and 1 ISM actuator, used to verify the structural integrity, damping and shock from the release as a standalone item. The full verification will be completed once the MAMD environmental tests are completed (where the 6 launch lock systems are included).

For the ISM the verification approach is to use laser tracker metrology to measure the accuracy and the stability of the mechanism for the complete range of motion under different thermal cases.

Verification status

For the SENER Poland launch lock concept, the standalone environmental tests have successfully been performed. For the Airbus Defence and Space launch lock concept it has been tested as part of the MAMD environmental tests. For both concepts the MAMD environmental test with the 6 launch locks will be the final verification.

For the ISM, the SENER Poland concept has successfully been demonstrated. The ADS/Astronika concept shall be demonstrated during 2023 through a dedicated activity funded by ESA.

Mitigated risks

For the SENER Poland launch lock concept, the structural integrity (stiffness) and damping have been verified but for just one of the 6 elements. The SENER Poland ISM has the required accuracy and stability.

Remaining risks

The environmental tests of one of the MAMDs have been conducted but the results were not yet fully analysed at the time of writing this paper.

3.4 Mirror Modules (MMs) including stacks, plates and MM facilities

Design status

The design of the SPO technology is now considered to be mature for the purposes of ATHENA. The design of the SPO MMs is consistent with the configuration of the ATHENA MAM (itself based in the reference telescope design [5]), requiring 15 different designs for the different rows using the specified interface points (3 dowel pins per MM). Figure 5 shows the differences in design between MMs for inner and outer rows.

It is based on commercially available monocrystalline double-sided super-polished silicon wafers. These wafers are used as a basis to produce plates. SPO mirror plates are produced by carving pores on one of the sides of the wafers. The plates are bonded on top of each other thanks to direct silicon bonding, which requires no adhesives [8].

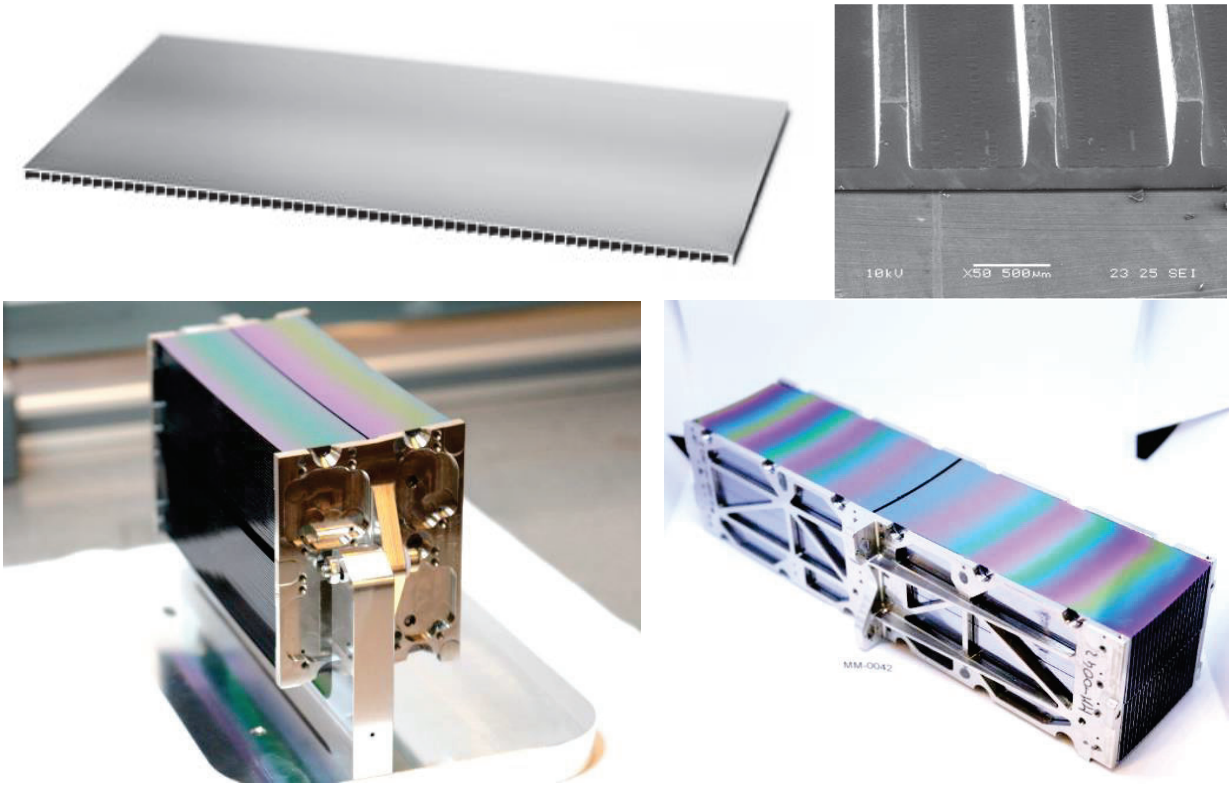

Figure 5: (Top left) Example of a SPO mirror plate with its reflective side on top, and ribbed side facing down. (Top right) Scanning electron microscope image of the ribs of a SPO mirror plate .(Bottom left) Photo of a SPO MM for the outer rows with wide and short plates. (Bottom right) Photo of SPO MM for the inner rows with narrow and long plates.

Plate production

The processes for plate production have been developed over the years, harnessing standard semicon processes and tools as much as possible, particularly the ones for 300 mm wafer processing [9].
Examples of these are the use of dicing machines, wetbenches with stardard cleaning and drying processes, or high purity clemical cleanliness systems. However, a number of them had to be developed/customised for the SPO application such as: methods for accurately measuring and improving the starting TTV (Total Thickness Variation) of the wafers, optimising the etching and cleaning processes, wedging of the necessary angle for confocality, thick silicon oxide deposition, laser marking of the plates, lithography optimisation, or even packaging.

Funded by ESA contracts and under the guidance of cosine, two companies have developed the necessary capabilties to produce plates for the SPO application: Micronit Micro Technologies B.V. in The Netherlands, and Teledyne e2V in the United Kingdom. The scalability of the processes is ensured as well as the programmatic redundancy for the implementation phase.

The main recent changes in the plate production process relate to: (1) the introduction of sacrificial areas for later removal to improve the figure degradation at the side edges, (2) the establishment of the use of Ion Beam Figuring (IBF) to reduce both the starting TTV of the wafer, and improve the quality of the necessary wedging (which was previously done chemically requiring thick silicon oxide that increased the stress in the plates).

Plate coating

SPO plates are coated with a thin film to improve their reflectivity and therefore effective area (a key parameter for the mission). Direct current magnetron sputter deposition is used with an industrial grade machine where the plates are supported by a carrier in a rotating drum [10-12].
High-z materials are used to enhance high energy reflectivity, and low-Z materials to improve low energy reflectivity.

Optimal coating recipes have been studies by the Danish Technical University (DTU). The current baseline is to have layers of Iridium as the high-Z material and Carbon as the low-Z material. The goal is to develop multilayer coatings consisting of superimposed bilayers of high-Z/low-Z material to optimise the effective area at given point of the energy spectrum (such as the Fe-line). The multilayer developments will start at the end of 2022 with (1) study of different coating recipes, (2) verification of the compatibility with all SPO process steps (by checking possible changes in reflectivity using PTB beamlines at BESSY II and a dedicated facility at DTU), and (3) verification of the repeatability.

Stacking

The current baseline consists of stacking 38 plates + 1 baseplate (special starting plate) on top of each other.
This is done in a completely automated way. Cosine has developed 4 stacking robots that are currently targetting stacks for different radii, some of these are used in a development mode and the others in a production mode.
Once the stacking is completed, the sacrifical side edges are removed with a laser microjet (LMJ) process, removing the areas with the worst figure.

Most of the development effort is now spent on optimising the deposition of the plates, and on the design of the mandrels and dies. The goal is to achieve 5 arcsec Half Energy Width (HEW) angular resolution for the complete MM. Accurate metrology is used to learn and iterate on the design to improve edge effects, which currently are the largest sources of HEW degradation [13].
As for the production mode, stacks are now done by operators with standardised procedures. Data is gathered at each step for traceability and quality control.

MM assembly

MMs are assembled by securing four stacks in their relative positions by two lateral brackets. Different types of glue are used during this process and the alignment of the stacks is checked by monitoring real-time the position of the PSF using synchrotron radiation. Laser-trackers and other metrology is used to ensure the required accuracy is achieved in co-aligning the four stacks to produce a single focus [14].
Currently the MM assembly is done in a dedicated beamline - XPBF 2 - at the BESSY II synchrotron radiation facility in the laboratories of the Physikalisch-Technische Bundesanstalt (PTB) in Berlin, Germany [15-16]. Another beamline is being developed for the same application at the ALBA synchrotron facility in Barcelona, Spain [17]. For the implementation phase, 2 more beamlines at BESSY II are planned to improve the production rate and provide programmatic redundancy.

Verification approach

The performance of the MMs is currently checked under X-ray illumination using (1) a raster scan of a collimated pencil beam at XPBF2, (2) full area illumination at the Panter facility in Munich, Germany, or (3) full area illumination using the newly commissioned BEaTriX facility (compact design with a crystal beam expander) [18]. The XPBF 2 and Panter measurements generally agree to better than 5-10% in terms of angular resolution (HEW) and effective area. The measurements at the BEaTriX facility have recently been initiated and the agreement wrt. to the other facilities will be done as part of its commissioning.

The MMs are also environmentally tested. Vibration, shock, and thermal tests have regularly been done. Dedicated jigs are used to simulate the MAM mounting concept (using Titanium dowel pins) [19].

Verification status

The development of the SPO MMs, from mirror plates to the MM assembly, is progressing firmly. A Technology Readiness Assessment (TRA) has been performed at the beginning of 2022, showing that the level of maturity of the SPO technology is consistent with TRL5 according to the ISO scale [6].

Compatibility checks with the SPO cleaning process, thermal annelaling and stability over time have allowed the verification of the (Ir/C) baseline coating recipe.

The angular resolution performance of the optics is steadily improving. Since November 2021 the SPO samples have regularly a HEW of less than 10”, measured over 100% of the area, with 3 or 4 samples showing around 8 arcsec over 100% of the area. When masking off the left and right 10 mm of the optics width, the measured HEW drops to 6.5 arcsec.
The majority of the environmental tests have been sucessful, with the exception of the shock failure in a few outer row MMs and the shift of mechanical properties before and after the TVAC test for a particular MM. Both of these issues are currently being investigated. The recent MAMD environmental tests allowed the measurement of the actual loads at the level of the MMs and will allow a relaxation of the requirements.

The necessary production rate for plates and stacks has been demonstrated with production runs done by operators. The current bottleneck for the overall process is the assembly process that occurs at the BESSY II synchrotron beamline; currently it takes around 40 hours to assemble a MM. Several improvements have been identified such as changing the MM design to only have 2 stacks instead of 4 to reduce this duration. In addition, the ALBA facility shall have its first light at the end of 2022, and as mentioned earlier, 2 other beamlines are foreseen at BESSY II during the implementation phase.

Mitigated risks

Achieving the necessary low energy effective area requirements.
Achieving the necessary production rate for plates and stacks.
Compatibility with the MAM interfaces.
Repeatability, quality control, and cost.

Remaining risks

Not achieving the high energy effective area requirements (study of multilayer coatings will be initiated at the end of 2022).
Shock compatibility (particularly for outer row MMs) and glue stability.
Not achieving the 5 arcsec angular resolution HEW in a repeatable way.

3.5 MAM facilities

Design status

MM alignment into the MAM (SPO AIT facility)

To achieve the 5 arcsec HEW angular resolution for the ATHENA MAM a novel method was developed to enable the alignment of the MMs into the MS with an accuracy of at least 1.5 arcsec (1 arcsec as a goal).
The MM alignment concept was developed at Medialario Technologies (Bosisio Parini, Italy) [19]. It consists in using a vertical optical bench to capture the focal plane image of each SPO MM while illuminated by a reference plane wave at a wavelength of 218 nm (UV). This is possible because it has been confirmed by simulations and experimentally that the centroid of the PSF is at the same location in UV and X-rays [19]. Working with UV illumination simplifies the alignment operation and allows the use of space-qualified gluing processes in air (Figure 6).

The light emitted by the UV source is reflected by a parabolic mirror to generate a beam collimated to better than 95 km, thus simulating illumination from a source at infinity. Each MM focuses the collimated beam onto a CCD camera placed at the focal position and the acquired PSF is processed in real time to calculate the PSF centroid position and intensity parameters. This information is then used to guide the robot-assisted alignment sequence, which makes use of a manipulator providing six degrees of freedom.

The implementation of this concept is done in a building at Medialatio called SPO AIT facility, where an UV collimator is placed around 6.5 m below ground floor, the robotic integration, and glue injection occurs at the level of the ground floor, and the detector is placed 12 m away (total building height of 17 m to accommodate other necessary equipment) (Figure 6).

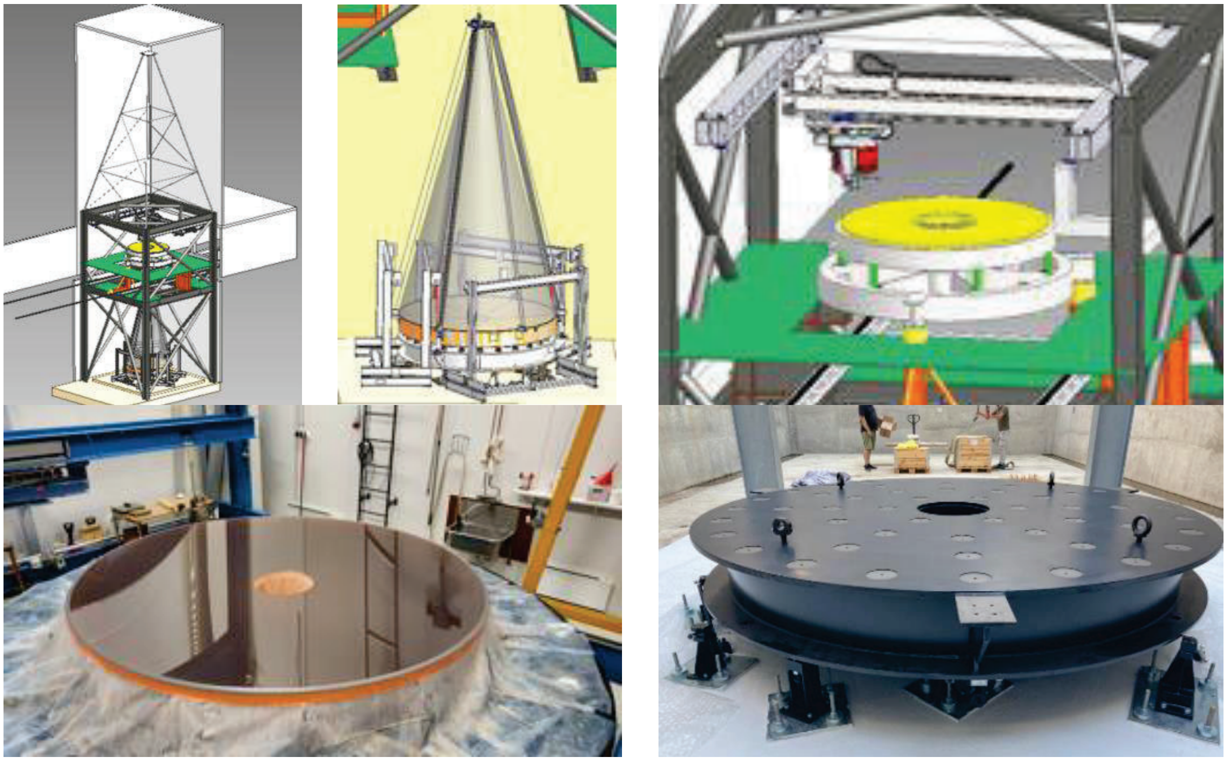

Figure 6: (Top left) CAD of the SPO AIT facility. UV collimator assembly on the bottom (6.5 m below ground floor), MAM on the ground floor, and detector 12 m away. (Top middle) The UV collimator assembly that sits on the bottom of the facility (with UV source fibre mounted on CFRP struts and 3 pentaprism systems to monitor the position of the source at all times. (Top right) The assembly where the MAM is mounted on the ground floor including the MAM gravity offloading device and the gantry for the alignment robot. (Bottom left) The polished zerodur UVcollimator. (Bottom right). (Bottom right) The mirror cell that is part of the UV collimator assembly onto which the UV collimator is mounted.

MAM X-ray verification (VERT-X)

The need to comply with the tight verification/calibration requirements for the size of the ATHENA MAM is a major challenge, keeping the beam divergence as low as possible is of paramount importance to be able to verify the alignment and calibrate the mirror performance. A new concept of X-ray facility called VERT-X is being developed by a consortium led by the Osservatorio Astronomico di Brera (OAB-INAF) and EIE from Italy [20]. In this type of facility, the MAM can be kept horizontal to minimise sagging and a small highly collimated X-ray beam is used to raster-scan the MAM aperture, an X-ray detector is placed 12 m away and the quality of the MAM performance is verified by aggregating the exposures gathered during the scan.

The critical items of this facility are being implemented at the time of writing: the X-ray tube and the raster scan mechanism. The plan is to build the whole facility next to the SPO AIT facility at Medialario. This will significantly facilitate the logistics of the X-ray verification particularly for intermediate alignment checks in X-ray.

Verification approach

Due to the novelty of both facilities, the verfication approach is to build them and verifying their performance using the MAMDs. For the case of the SPO AIT facility, the complete facility is expected to be finalised by mid 2023. For VERT-X, only the critical items are being implemented now and will be tested in 3 dedicated Panter campaigns; the rest of the facility will likely only be implemented after adoption.

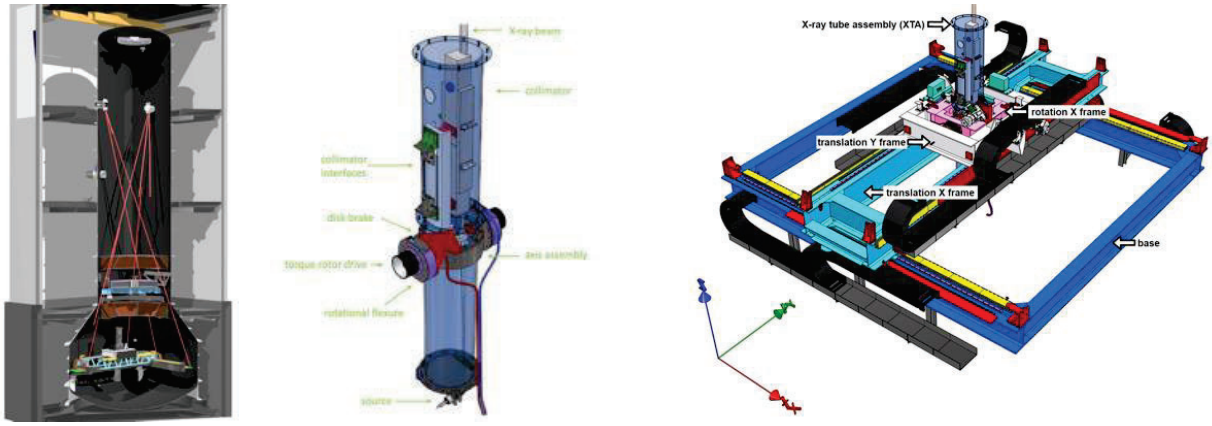

Figure 7: The VERT-X facility consisting of a vacuum vessel with a height of around 18 m. This facility shall be placed next to the SPO AIT facility. (Center) X-ray tube able to generate a small X-ray beam collimated to better than 1 arcsec consisting of a microfocus X-ray source held together to a fused silica Wolter I mirror. (Right) The raster-scan mechanism used to scan the X-ray tube along the MA aperture, consisting of 2 linear stages and 2 alt-stages. This element is mounted at the ground level of the vacuum vessel - shown on the left.

Verification status

The foundations for SPO AIT facility have been completed, the UV collimator is currently about to be accepted for coating and recently, and the mirror cell where the UV collimator will be mounted has been installed in on top of the foundations. The rest of the elements of the UV collimator assembly are available to finish the assembly in September 2022. The UV collimator shall be mounted on top of the cell by end October 2022 and then the rest of the building will be finalised.

For the VERT-X facility, manufacturing of the critical items is ongoing. The mirrors are being polished and most of the equipment necessary for the raster scanning mechanism is already available. The verification of these critical items is expected by Q3 2023.

Mitigated risks

Use of UV for the MM alignment. This has been verified with a precursor activity.

Remaining risks

Compatibility with the necessary production rate.
Finalisation of the facilities. Particularly VERT-X will likely only be finalised after adoption.
Accuracy of the raster scanning mechanism for VERT-X. Shall be verified by Q3 2023.

4. CONCLUSION

All the technologies required to implement the ATHENA mirror are being addressed through dedicated activities that have been put in place to mitigate the identified risks due to (1) the novelty of the Silicon Pore Optics technology, and (2) the need to have the large X-ray telescope built with the required performance within the established programmatic boundaries.

The entities involved in the development and production of the core element of the optics, the mirror modules, are being consolidated, and a consortium is being formed in preparation of the future flight implementation phase.
Most of the risks have now been mitigated and the level of maturity has been assessed as TRL5 with a Technology Readiness Assessment done during 2022.

There are plans in place to address the remaining risks in the next years, focussing on the further improvement of the angular resolution, the optimisation of the reflective coating for the plates, the finalisation of the demonstration of the mirror assembly, and the implementation of the novel parts of the new facilities needed.
The SPO technology remains the baseline in the current reformulation phase of ATHENA. This reformulation shall preserve the investments already made, and in parallel ensure that the momentum is kept guaranteeing that the remaining risks are addressed.

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