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X-ray Testing at PANTER of Optics for the ATHENA and Arcus Missions

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ABSTRACT

Currently for the European Space Agency (ESA) ATHENA [1,2] mission Silicon Pore Optic (SPO) [3-8] Mirror Modules (MM) with a focal length of f = 12 m, are being developed and tested. The SPO MMs are also the baseline optic for the NASA medium explorer high-resolution spectroscopy mission Arcus [9-10] with f = 12 m that is currently undergoing a phase A study. SPOs are currently being tested at both the PTB laboratory of the BESSY synchrotron facility in Berlin using an X-ray pencil beam and the PANTER X-ray test facility in Neuried of the Max-Planck-Institut für extraterrestrische Physik, Garching using a long vacuum beamline (distance source to optic ~120 m). The different types of measurements performed at PANTER to characterise the ATHENA and Arcus optics will be discussed. This will be done on the level of an X-ray optical unit (XOU) composed of both a primary and secondary High Performance Optic (HPO) stack, a mirror module (MM) composed of two XOUs, small (<4 MMs) and large (< 25 MM) petals, and the complete integrated optic Athena (700-1000 MMs) and Arcus (4 petals each with 38 MMs). The main set of tests that are currently done at PANTER make full use the possibility to fully-illuminate single XOUs, MMs, and petals to determine their optical characteristics such as the half energy width of the point spread function as well as the effective area and the vignetting function at different energies. To ensure that the measurements, that are required to demonstrate the performance of ATHENA, are possible, a description of recent and upcoming upgrades to the PANTER X-ray test facility will be given. Finally, a status update on the progress on designing the new facility to be used to test and calibrate the complete ATHENA mirror will be presented.

Keywords: X-ray Optics, X-ray Telescopes, PANTER X-ray Test facility

1. INTRODUCTION

The PANTER X-ray test facility in Neuried of the Max-Planck-Institut für extraterrestrische Physik, Garching was designed and built at the end of the 70s for developing, testing, and calibrating the X-ray optics (focal length 2.4 m) and detectors for the ROSAT X-ray observatory. This included the setting up of a beamline with a long vacuum tube with (length 120 m and diameter 1 m) and a test chamber (length 6m and diameter 3.5 m). For testing the XMM-Newton optics (focal length 7.5 m) and detectors this chamber was enlarged (length 12 m but maintaining the same diameter). After XMM-Newton intra-focal tests on prototype modular optics for the proposed large new ESA X-ray observatories were performed at PANTER. This was done end of the 90s for XEUS [11] (focal length 50 m, effective area 6 m^2 (30 m^2 on ISS) at 1 keV) for Ni shells and starting in the mid 2000s for IXO [12] (focal length 20 m, effective area 3 m^2 at 1 keV). A new optics technology, the Silicon Pore Optics (SPO) [7-8] was developed by ESA in conjunction with the company Cosine to make it possible develop light weight modular optics that can be used in large collecting area missions. From 2012 and extension to PANTER [12] made it possible to obtain in-focus measurements of 20 m focal SPO Mirror modules. After the IXO project was discontinued ATHENA (focal length 12 m, effective area 2 m^2 at 1 keV, HEW 5”) was selected as the new ESA L2 mission. Since then developments and measurements have been going on.

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Furthermore the same SPO mirror technology that will be used in ATHENA has been set as the baseline optics for the proposed high resolution spectroscopy NASA MIDEX mission Arcus which has currently finalized its Phase A study and is awaiting a decision.

PANTER has played an important role in the development process of the SPOs as it is currently the only place in Europe that performs tests requiring a full illumination of the mirror modules.

2. TYPES OF OPTICS MEASURED AT PANTER FOR ATHENA

Optics modules (elements) for ATHENA and its predecessor missions IXO and XEUS mirror assemblies have been developed and most of them tested and measured at PANTER.
For many years slumped glass optics (SGO) were considered a possible optics solution for ATHENA, these were tested at PANTER in many different configurations from single layer primary + secondary shell modules to modules with many co-aligned layers. Currently the main development efforts for ATHENA from which Arcus also benefits are concentrated on the Silicon Pore Optics (SPO).
The plan is that a completed ATHENA mirror assembly (MA) will contain between 700 and 1000 SPO mirror modules, in the case of Arcus it would be 4 mirror modules each containing 38 SPO mirror modules [9,10].
Before a complete mirror assembly or petal can be tested the SPO mirror modules have to be individually assembled at BESSY. The SPOs are made up from two co-aligned X-ray optical units XOUs and each XOU is made up of a primary and secondary high performance optical (HPO) stack (i.e. a parabola and a hyperbola in the case of a Wolter type I X-ray optic). These HPOs are made of 35 layers of silicon wafers that are diced, wedged and grooved, coated and stacked on a high precision mandrel. The HPOs once stacked have many pores (i.e. opical channels) the give the optics their name.
In Figure 1 the process from Wafer to SPO Petal for ARCUS is shown.

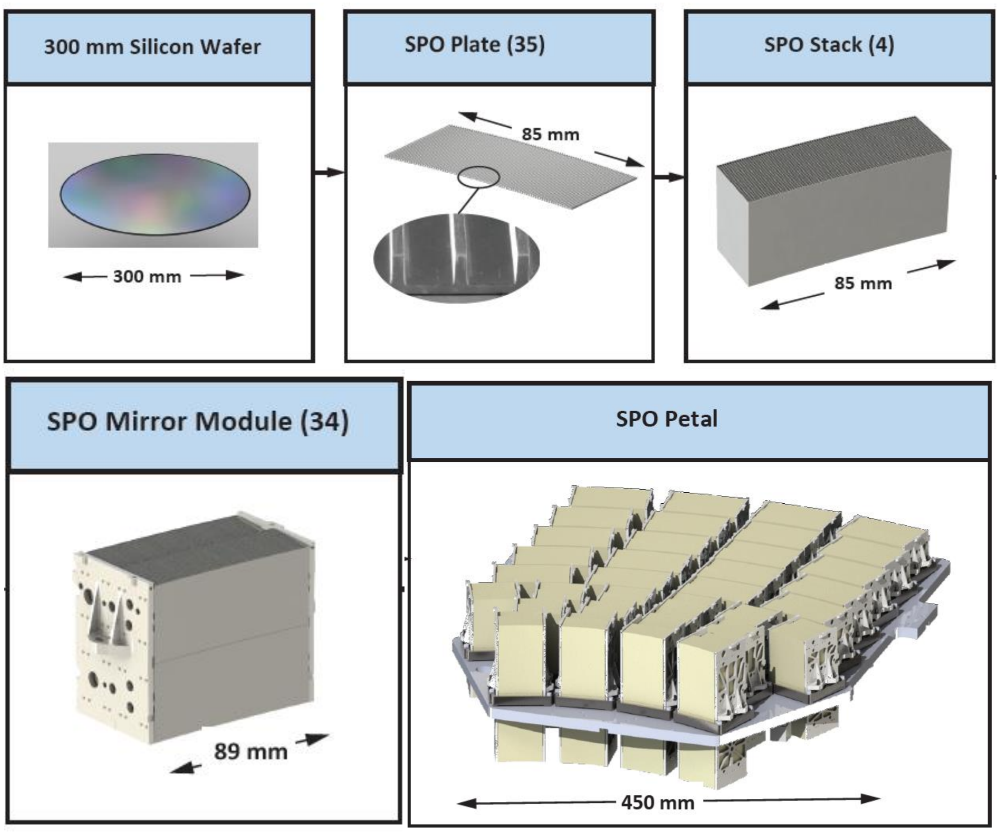

Figure 1 From top left to right to bottom right from the silicon wafer to the SPO petal for Arcus

3. MEASUREMENTS

To test X-ray optics and X-ray Telescopes in PANTER [13] a standard set of alignment and measurement sequences are performed to qualify the optics. These are adapted to conform with the needs and the status of the development of the different optics. Before the tests take place input from simulations [14] and if available measurements taken at other beamlines (i.e. BESSY) are used to prepare and optimize the measurement plan.

3.1 Laser Alignment of Optics Modules on Air

Once the optics are mounted in the large vacuum chamber either on the tip/tilt stage and rotary stage or the hexapods a laser beam that marks the geometric center of the beamline from the X-ray source to the center of the large vacuum chamber is used to do a preliminary alignment of the optic. This alignment entails checking that the optic is aligned in auto-collimation (sometimes using a reference mirror) and that the PSF is located on the detector. The separation of the X-ray detector to the intersection plane of the optic to the detector is set to value computed using the thin lense equation that takes into account that with a finite source distance, i.e. the image distance lies further from the optic than the true focal distance of the optic.

3.2 X-ray Alignment (pitch and yaw) under Vacuum

As a starting point in-vacuum alignment measurements are done using Al-K characteristic line at 1.49 keV as this is very efficient in producing X-rays that can also reflect nicely off uncoated glass and Si surfaces which are commonly used during the early development phases of X-ray optics. For optics modules such as the SPOs the best alignment reference we have is the self-shadowing by the SPO pores which produce nice quasi triangular (vignetting) functions of intensity vs. off axis angles.

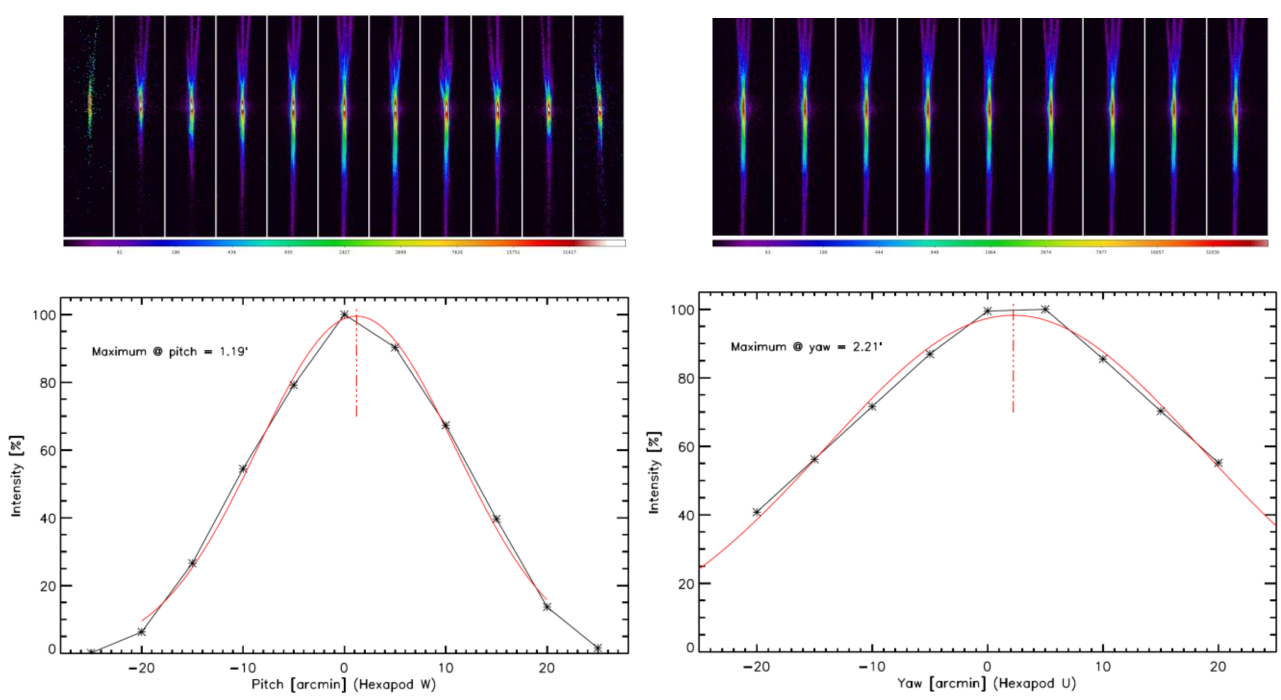

Figure 2 Top the PSF images corresponding to the individual pitch (left) and yaw (Right) scans of an f = 12 m SPO MM-0027 XOU-0048. The laser pre alignment in the chamber before pumping down is accurate to within a few arcminutes.

3.3 X-ray Focus Search

Following the X-ray alignment of the optic a focus search is performed in which the location of the best HEW (important for ATHENA) and the best transverse PSF (important for Arcus) is determined: See the focus search shown in Figure 3

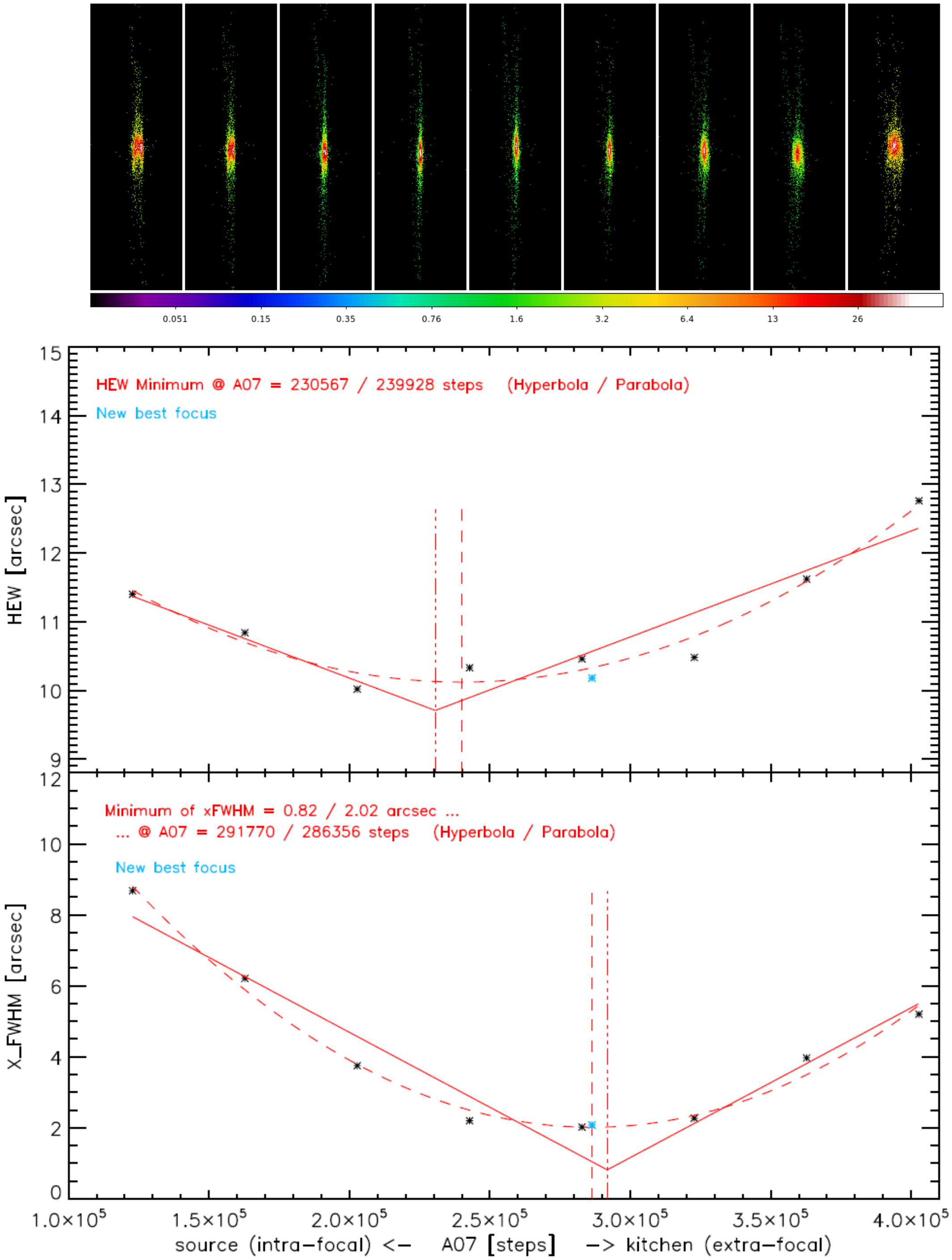

Figure 3 Focus search XOU-0060C: (Top) images of the measured PSFs, (center) the Half Energy Width HEW, and (bottom) transverse PSF FWHM as a function of focus position. The distance between the points corresponds to a shift of 50 mm. The best focus positions a determined by fitting both a hyperbola, and parabola function to the data points.

3.4 Hartmann Test

This test shows the quality of the mirror module as a function of azimuth. See Fig 4.

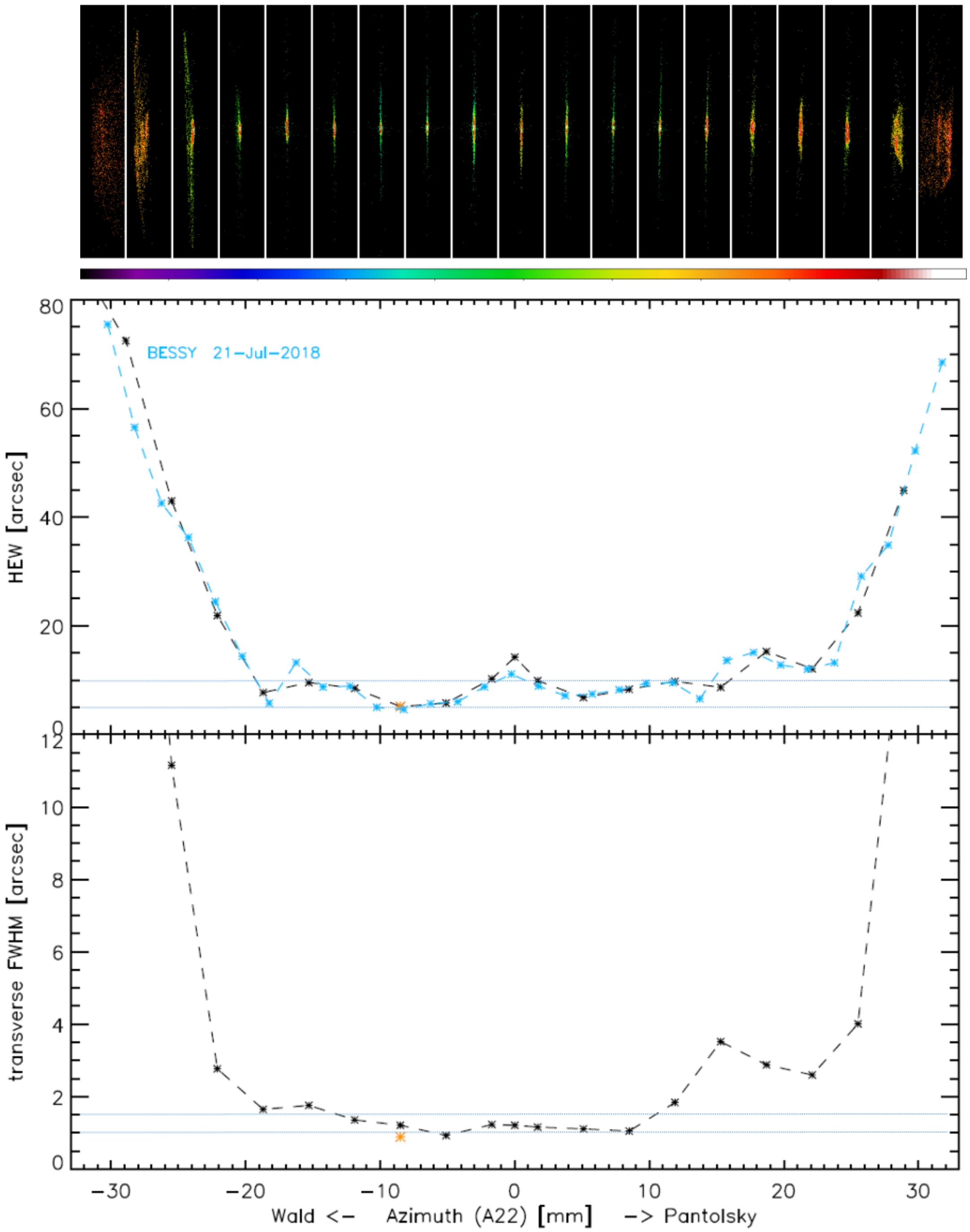

Figure 4 Hartmann test XOU-0060C: (Top) images of the measured PSFs, (center) the Half Energy Width HEW, and (bottom) transverse PSF FWHM as a function of azimuth. The distance between the points corresponds to a shift of 3.4 mm which is also the mask width. The top image shows a very good correspondence of the PANTER data (black)< and BESSY data (blue)

3.5 Point Spread function (PSF) Measurements

With these measurements the on and off-axis PSFs are characterized at different energies. The main parameter derived from these measurements is the Half Energy Width HEW (i.e. the 50% encircled energy). For ATHENA the requirement is that the average HEW for the SPO MMs is about 4.3 arcsec and 5 arcsec for the integrated Mirror Assembly.

For Mirror modules like the SPOs also the Full Width Half Maximum FWHM of the transverse PSF i.e. the waist of the bowtie shaped PSFs is measured. For the spectroscopic missions such as Arcus this important value should approach 1.5” so that the highest spectral resolution can be achieved.

3.6 Effective Area (EA) measurements

The best way of determining the effective area for the optics is done by measuring the countrate (cts/s) of the intrafocal image on the detector. Then without modifying the source settings that are a given energy you remove the optic from the beam and measure the flat field countrate per square cm (cts/s/cm^2) impinging on the detector of a known size (cm^2). The ratio of these two numbers corrected the distance between optic and detector gives the effective area (cm^2) of the optic.

4. RECENT ATHENA AND ARCUS RELATED TESTS

Recently at PANTER tests were done to check two competing Assembly Integration and Testing (AIT) methods to mount and co-align the SPO modules into the mirror assembly in this case two optics into a mini petal. One AIT approach (Media Lario) [15,16] uses UV light to check the alignment of the optics into the petal. The other approach (Thales-CH) [17,18] used a metrology characterization of the individual optics at BESSY and then co-aligned them based on the metrology in PANTER. Both methods provided results that were within the required accuracy needed for ATHENA in September 2018.

Currently we now have a setup running at PANTER that allows the mounting of two HPOs into a double hexapod support structure. This allows the testing of primary plus secondary HPO pairs that have not been glued into brackets. This allows PANTER to be even more involved in the development of the ATHENA optics. A very good matching between the BESSY and PANTER measurements can be seen in Figure 4 central panel.

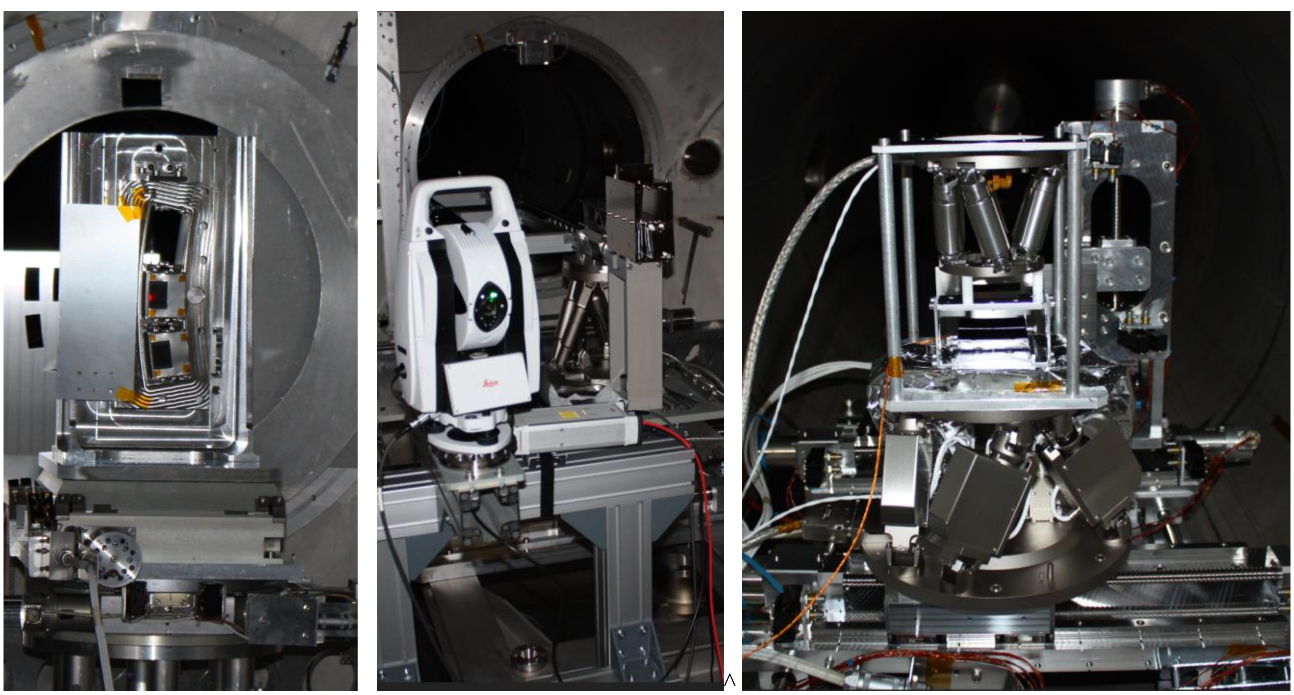

Figure 5 Test setups in PANTER: (left) Media Lario AIT Test setup, (center) Thales-CH AIT test setup, and (right) XOU double Hexapod alignment setup.

5. OUTLOOK

For ATHENA in the near future many more iterations of measurements at PANTER have to be performed on the XOU and SPO MM level to ensure that set HEW goal of 5 arcsec for mirror assembly can be achieved. Furthermore testing of ARCUS petals and later a 1/6 sector of an ATHENA mirror assembly can be tested at the existing PANTER X-ray test facility. To test and calibrate the complete mirror assembly a new facility will have to be built. The ATHENA [13] optics design requires an 800 m long beamline with an entrance aperture to the chamber between 2.8 m and 3.3 m depending on the final diameter of the Mirror assembly. A possible location of the new X-ray test facility at the Garching science campus is shown in Fig. 6.

Figure 6 Here the Garching science campus is shown with the possible location of the new “PANTER 2” X-ray test facility with its 800m long beamline and its location with respect to Max-Planck-Institut für extraterrestrische Physik (MPE).

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