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A vertical facility based on raster scan configuration for the X-ray scientific calibrations of the ATHENA optics

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ABSTRACT

The ATHENA X-ray observatory is a large-class ESA approved mission, with launch scheduled in 2028. The technology of Silicon Pore Optics (SPO) was selected since 2004 as the baseline for making the X-ray Mirror Assembly. Up to 700 mirror modules to obtain a nested Wolter like optics. The maximum diameter of the shells will be 2.5 m while the focal length is 12 m. The requirements for on-axis angular resolution and effective area at 1 keV are 5 arcsec HEW and 1.4 m^2, while the field of view will be 40 arcmin in diameter (50 % vignetting). While in this moment there an on-going effort aiming at demonstrating the feasibility of a so large optics with so stringent scientific requirements, an important aspect to be considered regards the scientific calibrations of the X-ray optics. In this respect, the Point Spread Function and effective area have to be correctly measured and calibrated on-ground at different energies across the entire field of view, with a low vignetting. The approach considered so far foresees the use of a long (several hundreds of meters) facility to allow a full illumination with low divergence of the entire optics module (or at least of large sections of it). The implementation of similar configurations in a completely new facility to be realized in Europe (friendly called "super Panter") or the retrofitting existing facilities like the XRCF at NASA/MSFC are being considered. In both cases the costs and the programmatic risks related to the implementation of these huge facilities, with their special jigs for the alignment of the ATHENA optics, represent important aspects to be considered. Moreover, the horizontal position of the optics to be used in full illumination facilities would determine gravitational deformations, not easy to be removed with actuators or by modeling. In this talk we will discuss a completely different concept, based on the mount of the optics in vertical position and the use of a raster scan of the ATHENA optics with a small (a few cm^2 wide) highly collimated (1 arcsec or so) white beam X-ray. This system will allow us to operate a much compact system. The use of a vertical configuration will imply smaller gravitational deformations, that can be controlled with actuators able to compensate them. A proper camera system with a sufficient energy resolution will be able to grant a correct measurement of both PSF and effective area of the Mirror Assembly within the calibration requirements and in a reasonable integration time. Moreover, it may allow us also to perform end-to-end tests using the two flight focal plane instruments of ATHENA. The cost and risks for the implementation would be much lower than for the full illumination systems. The conceptual configuration and preliminary expected performance of the facility will be discussed.

Keywords: X-ray Telescopes, ATHENA Mission, X-ray calibrations, calibration facilities

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1. INTRODUCTION

The Advanced Telescope for High-Energy Astrophysics (ATHENA) is an X-ray telescope designed to address the Cosmic Vision science theme 'The Hot and Energetic Universe' [1]. The primary goals are of the mission concern the mapping of the hot-gas structures of our Universe and determining their physical properties in view to understand how ordinary matter assemble into the large-scale structures we see today and the search for supermassive black holes at very high redshift (up to 7). By combining a large X-ray telescope with state-of-the-art scientific instruments, ATHENA will be able to make an important contribution to get these scientific goals. On 27 June 2014, ATHENA was selected as the second L-class mission in ESA's Cosmic Vision 2015–25 plan. The mission has now entered the advanced study phase [2,3,4]. The telescope 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). After a trade off study, the initial design of the optics has been slightly modified with respect to the proposal [5] based on 3 m diameter optics system with a 2 m^2 on-axis effective area at 1 keV. In the modified design, the telescope consists in a 2.5 m circular supporting structure on which about 700 Silicon pore optics (SPO) mirror modules (MM) are integrated, bringing to an on-axis effective area of 1.4 m^2 at 1 keV [6]. The total weight of the optics module is about 1 tons [7].

The telescope focuses X-ray photons onto one of two instruments, which can be put in and out of the focal plane using a movable mirror assembly. One instrument, the X-Ray Integral Field Unit (X-IFU) [8], provides spatially-resolved high resolution spectroscopy. The instrument is a cryogenic X-ray spectrometer, based on a large array of Transition Edge Sensors (TES), offering 2.5 eV spectral resolution, with 5'' pixels, over a field of view of 5 arc minutes in equivalent diameter. The other instrument, the Wide Field Imager (WFI), is a Silicon-based detector using DEPFET Active Pixel Sensor (APS) technology. The WFI will provide imaging in the 0.2-15 keV energy band over a wide field, simultaneously with spectrally and time-resolved photon counting. The instrument is designed to make optimal use of the grasp (product of collecting area and solid angle) provided by the optical design of the ATHENA mirror system, by combining a sensitive approximately 40'x40' field of view DEPFET detector with a pixel size properly sampling the angular resolution of 5'' on-axis (half energy width) [9]. The two X-IFU and WFI instruments are assembled together into the Science Instrument Module (SIM) [10], an important system also in terms of mass and size with its weight slightly less than 2 tons, a diameter of and a height of about 2.8 m and 3.5 m respectively.

The alignment, testing and scientific X-ray calibrations of the designed ATHENA X-ray Mirror, in its fully or partial assembly, will require a check of the overall mirror performance in X-rays. The tests in X-rays of the single SPO mirror modules will be done using monochromatic X-ray pencil-beams with raster scans at the BESSY synchrotron facility [11] and using the BEATRIX testing facility in full illumination mode [12]. The integration and alignment tests of the mirror modules into the Mirror Assembly will be done using a large collimated UV beam, with a vertical facility that will be implemented ad hoc [13]. The main X-ray scientific calibration requirements for the Mirror Assembly are listed in Tab. 1 (see Ref. [14] for details) and a special facility for this key activity still need to be implemented.

Tab.1: Scientific X-ray calibration requirements.

HEW core/wings/halo	0.1"/0.1"/0.5"
PSF 2D shape	0.1"
Absolute eff. area on-axis	6%
Relative eff. area. on-axis	2%
Relative eff. area. on-axis	4%
Relative eff. area. fine structure	1%

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Taking into account these parameters, the ground calibration of the ATHENA optics raises significant difficulties due to the unprecedented size and mass of the system. The conclusions of the ATHENA's Telescope & Calibrations Working (TCWG) Group are that, while for full illumination, an 800 m beam is required [15]. At this distance calibration can be performed in full illumination regime with area losses lower than 10%; the focal length systematic error can be kept within the 1 mm and the PSF aberration remains within 1 arc seconds However, such a configuration has a large cost impact on the mission since it would require building a new large facility in Europe. The low divergence of the beam is needed to guarantee that the Half Energy Width (HEW) errors introduced by the divergence of the beam are kept to a low value. And the beam size needs to be large enough to guarantee that the calibration plan can be achieved within the allocated six (6) months for performing the calibrations. The high costs and significant programmatic issues of this beam facility prompt to look for alternative configurations.

Given that such a long beam facility does not yet exist and the resource constraint might prevent from building it, the ATHENA TCWG explored also the possibility of carrying out the Mirror Assembly calibrations in partial illumination. The conclusion is that in partial illumination regime a minimum length of at least 300 m is in any case required in order to keep the area losses ≤10% and the PSF aberration ≤0.5 arc seconds. An attractive solution that is being considered is the use of the already existing X-ray Calibration Facility operated at NASA/MSFC [16], already used for the calibration of the Chandra Observatory. In this case the length of the facility is 600 m and the useful aperture about 1 m. For allowing to pursue the ATHENA's optics X-ray calibrations then it would be necessary the retrofitting of the calibration chamber, in order to host the ATHENA Mirror Assembly (much bigger than Chandra) and to implement a special jig (whose implementation is expensive wand presents some challenging aspects) able to rotate and corrected the tilt of the ATHENA optics in order to ensure the ideal alignment with respect the X-ray source of each sector of the optics illuminated.

In both above-mentioned configurations, the calibrations will be carried out with the optical axis positioned in horizontal direction. This entails two main drawbacks: a) a deformation of the optics due to the gravity force on ground that can't be totally compensated with the use of actuators, causing an inherent error in the PSF measurement of a few arcsec; b) the impossibility to perform an end-to-end (hereafter E2E) test using also the ATHENA's focal plane instruments, since the SIM module can be mounted just in vertical position in order to grant a correct behavior of the cryostat.

On the other hand, another alternative possibility, which is the subject of this paper, is to develop and use a testing and calibration facility able to create a small-aperture collimated X-ray beam that can be moved to raster scan the whole Mirror Assembly (MA), sufficiently fast. Such a configuration would require an X-ray mirror to generate a highly collimated beam (with divergence ~ 1 arcsec), and highly accurate translation and metrology systems to be able to effectively produce a raster scan of the Mirror Assembly. In addition to the lower cost and lower beam divergence, such a configuration would have the advantages of allowing local measurements of some of the Mirror Modules (hereafter MMs) and could potentially allow end-to-end testing of the integrated system MA-Science Instrument Module (SIM), since the MA can be placed with the optical axis in a vertical configuration. Moreover with the ATHENA Mirror Assembly mounted in vertical, the deformations due to gravity can be easily compensated by the use of proper actuators, bringing the residual error to less than 1 arcsec. In this paper, we present the concept of a similar facility called VERTE-X, discussing a preliminary configuration and about the implementation of the main subsystems. This system has been proposed at conceptual level by G. Pareschi (INAF) during the ATHENA TCWG meeting of April 2018. Afterwards ESA decided to formalize an Intention to Tender [17] devoted at performing a detailed study of this facility (September 2018).

2. VERTEX: A VERTICAL X-RAY CALIBRATION FACILITY FOR ATHENA

The vertical optical bench is schematically shown in Fig.1.

- ATHENA Mirror Assembly mounted in vertical position inside a vacuum chamber about 20 m high. The focus of the ATHENA optics is placed at the upper end of the chamber. The support of the optics will make use of actuators, in order to subtract the contribution of gravity that would deform the ATHENA Mirror Assembly;
- an X-ray source, with micrometric target and high flux is placed onto a movable X-Y translation stage at a distance of 2-4 m from the optics, in the lower part of the facility. The X-ray source produces a polychromatic isotropic beam via "bremsstrahlung" in the 0.1 – 15 keV range, with the possibility to play with different

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targets, filters and bias voltage in order to tailor the emission spectra depending on the needs for the calibrations;

- a good quality X-ray optics is used to collimate and widen the X-ray beam. It is based on a parabolic grazing incidence mirror fabricated using a thick substrate (a few cm) in Silicon or glass-ceramic (similar to the grazing incidence systems used to condition the X-ray beams in synchrotron light beam-lines) with a focus of 2-5 m, able to produce at the exit of the pupil a few cm^2 large polychromatic flux with low divergence (1 arcsec). The focus of the X-ray optics corresponds to the position of the X-ray generator target. It should be noted that EUV/X-ray optics to widen and collimate the beam for the calibration of X-ray telescopes have been already studied [18,19] and will be also used in the context of the BEATRIX facility;
- a mechanical system stable and precise, with a good metrological feedback, in order to perform the raster scan with the X-ray beam emitted by the X-ray source and collimated and widened by the grazing incidence parabolic "collimator" mirror with proper accuracy;
- an X-ray detection camera system. It should be noted that a first phase of the calibration of the ATHENA optics will be done using a service camera to be procured ad hoc, having a pixel size at least a factor 3 times lower than the PSF Half Energy Width (5 arcsec) and with a spectral resolution of the order of about 150 eV. In ascend phase a true E2E calibration will be performed with both flight instruments of ATHENA (X-IFU and WFI). In this case the SIM module will be installed at the upper end of the vacuum chamber.

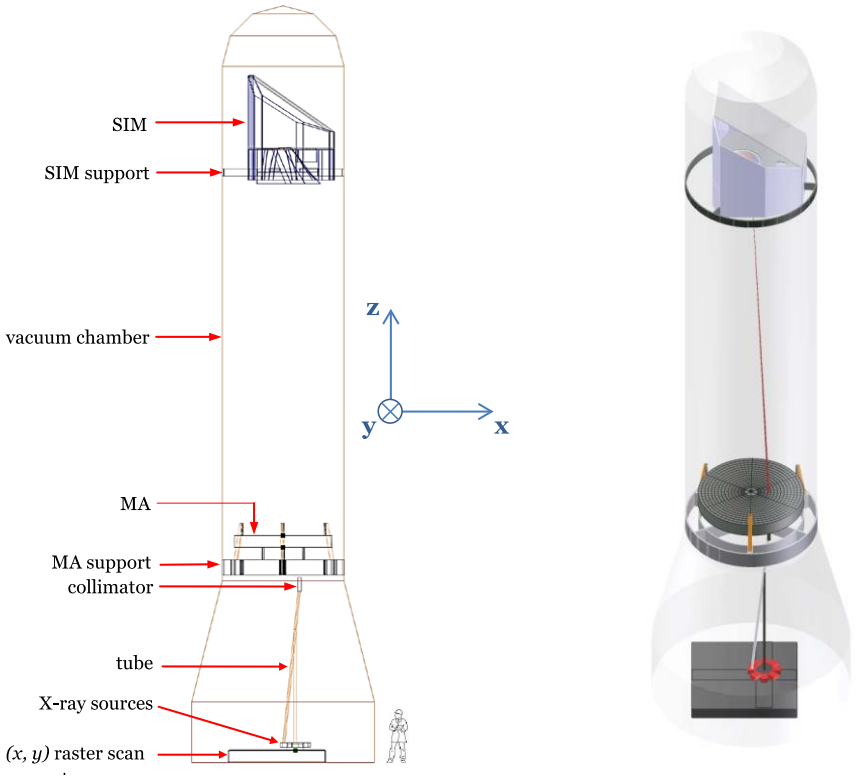

Fig. 1. 2D frame sketch and 3D conceptual model of the vacuum chamber of the X-ray Vertical Facility (VERTEX), containing the X-ray source, collimator and x-y raster scan stage, the ATHENA Mirror Assembly and the SIM (or the service camera) with respective interface to the vacuum chamber (CREDITS: ESA).

2.1 The X-ray Source

The X-ray source is a X-ray tube to be of micro-focus type, able to produce a polychromatic Bremsstrahlung spectrum in the 0.1 – 12 keV. The acceptable maximum size of the target will depend on the plate scale of the collimator mirror (and then, from the average distance of the mirror from the X-ray source focus), order not to exceed a divergence larger than 1

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arcsec. Since the average distance of the focus from the X-ray source will be in the range between 2 m and 3.5 m, the size of the X-ray target has to be in the 1 – 10 μm range. There are already different commercial sources that can fit this requirement. For example the Incoatec GmBh company (https://www.incoatec.de/), already produces a micro-focus source with a spot size not of 30 μm FWHM (circular – can be reduced with a pin-hole up to 1 micron in diameter), that is foreseen to be used e.g. in the BEATRIX X-ray facility (see Fig.2). The source has to be diverging and with an emittance of 10^{11} - 10^{12} photons/sec/sr. The source shall withstand at least 10000 h of operation time, and dissipate a power not higher than 20 W. Anodes: Cu, Ti, Mo, W…). Also the SIGRAY company in USA produces a very attractive source at high brilliance with a spot of just 7 μm in diameter (http://www.sigray.com/xcite-microbeam-source-optic/).

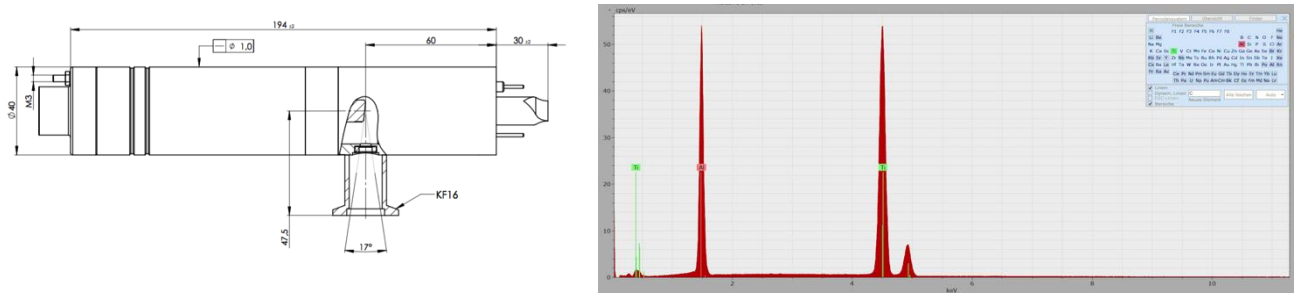

Fig. 2. : Left: scheme of the Incoatec X-ray microfocus source. Right: measured polychromatic spectrum of the hybrid X-ray micro-focus source with the anode in Ti-Al alloy (50% Al and 50% Ti), showing the X-ray fluorescence lines of both elements (courtesy by Incoatec). The source can mount targets of different materials.

2.2 The X-Y translation Stage and the collimator mount

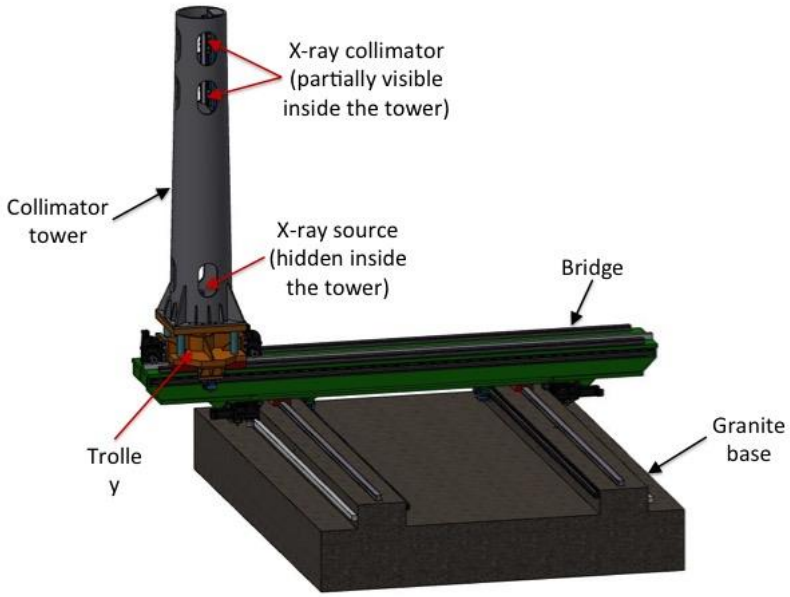

Fig. 3. X-Y translation stage of the pantograph, including the tower hosting the X-ray source and the X-ray parabolic mirror that will widen and collimate the X-ray beam, mounted onto a granite basement.

In Fig. 3 it is sketched the conceptual design of the high precision pantograph with X-Y translation of the tower supporting the collimator of the Athena testing facility and including the X-ray sources. During the assembling phase,

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the support structure allows the alignment of the collimator along five degrees of freedom (X, Y, Z translation, X and Y rotation).

Fine regulation is obtained through dedicated pushing screws. The trolley that bears the collimator tower stands on a granite base. Since the attitude of the platform changes during the motion, piezo-actuators will be used in order to recover the tip-tilt alignment. In this respect the tiltmeter probes for the metrological feedback will have to fulfill the following requirements: i) Pitch / Roll detection with two independent single axis tiltmeter; ii) Low noise (<0.02 arcsec RMS); iii) Fast response (few seconds); iv) Range ±2 arcsec. In this respect, we envisage these two alternative approaches: a) tilt-meter developed for the ALMA Antennas (currently operating) [20]; b) COTS (Commercial Off-The-Shelf) sensors.
The tilt-meter measurement concept developed for ALMA (see Fig. 4-a) is based on an inverted pendulum m kept in position by means of electromagnetic motors with a position feedback based on capacitive sensors. Each component is vacuum compatible, allowing us to achieve a noise <0.02 arcsec, a tilt-meter linearity of ±1.63, a temperature dependence of -3.52 mrad / °C. COTS sensors (e.g. from the Geomechanics company, http://www.geomechanics.com, see Fig. 4-b) have also similar characteristics.

Concerning the actuators, the proposed solution includes two stages (coarse and fine) for each axis. The error budget allocates 0.05 arcsec rms to the mirror positioning accuracy. Vacuum Compatible Piezo Actuators can provide ultra-high accuracy (<< 0.001 arcsec) and high force (800 N) to control the attitude of the platform (see Fig. 4-c).

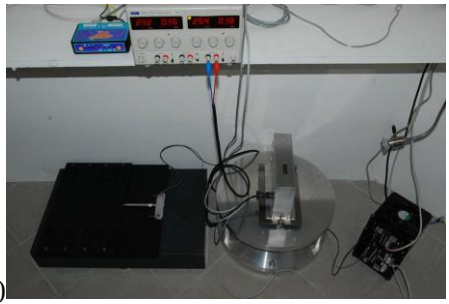
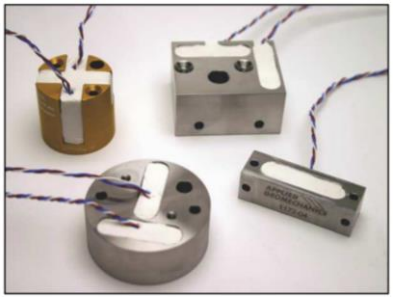
A)  B)  C) 

Figure 4. a) Tiltmeter sensors developed and used in ALMA; b) example of titltmeter COTS sensors; c) example of piezo actuators of the kind will be used for VERTEX.

2.3 Mirror collimator

A parabolic grazing-incidence mirror will be used just after the source to obtain a collimated beam. A parabolic mirror is a perfectly focusing optics: when a point-like source is placed in the parabolic mirror focus the produced beam would be completely free of divergence. The photons reaching the optics to be tested will be deflected only by the collimator surface local errors. The parabolic mirror makes the beam parallel, defines the vertical dimension of the final beam, and determines the horizontal size of the beam. For a parabolic mirror with geometrical parameters shown in Fig. 5, the beam at the exit pupil, to be considered as the rectangle inscribed in the beam, is as large as 60 mm × 4 mm. In Fig. 6 it is shown a mirror similar to the one to be used in VERTEX (the one being precisely figured for BEATRIX), while in Fig. 7 there is a sketch of the mirror mounted on the tower.

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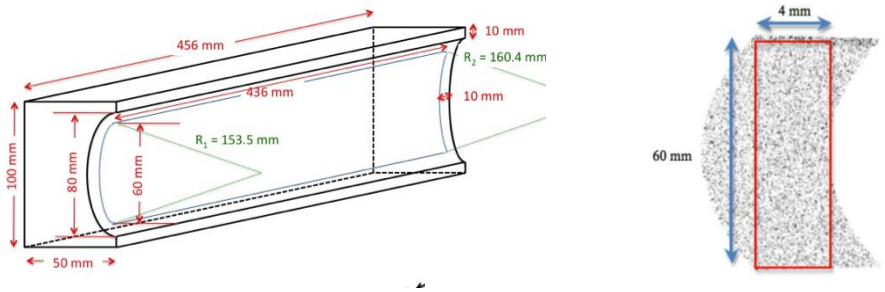

Fig. 5. Left: example of design of the paraboloidal mirror to be used in order to widen and collimate the pencil beam (in this case the average distance from the X-ray source is about 4.5 m. Right: the expected beam at the exit pupil of the mirror.



Fig. 6. Segmented parabolic mirror in fused quartz HOQ 310 being developed for the BEATRIX facility, similar to the one that will be used in VERTEX.

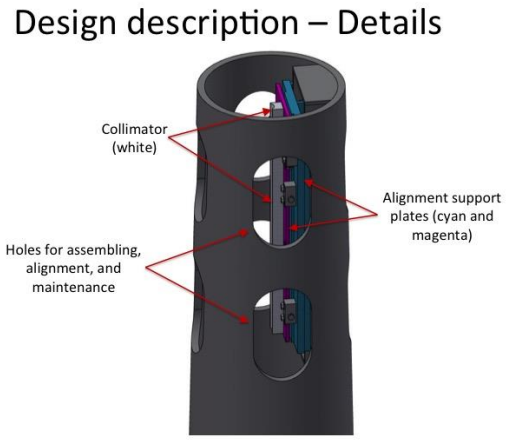

Fig. 7. Sketch of the parabolic segmented grazing-incidence mirror mounted on the tower.

2.4 The service camera for the optics calibration

The service camera should be able to sample the PSF with a proper spatial accuracy, large area (in order to make flat fields onto a large and representative detection section), a sufficient energy resolution (150 eV or so) and able to operate in photon counting mode. In this respect, e.g. the Sydor Fast CCD X-ray Detector appears as a very attractive solution. It is a complete direct detection based on a split frame transfer architecture, X-ray imaging system that combines a custom, Lawrence Berkeley National Laboratory developed [21], in vacuum sensor module with a commercial-off-the-shelf data acquisition system. The camera head is an in-vacuum, 960 x 960 pixel (1 pixel is 30 μm x 30 μm, the total area is almost 30 mm x 30 mm), frame store, fast CCD sensor with a maximum frame readout rate of at least 120 frames per second. The readout system is implemented on an ATCA backbone and is used to control and readout the camera head, store raw camera data to hard disk, perform simple signal processing tasks and provide a simple user interface.

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3. OPERATING MODE AND EXPECTED PERFORMANCE

The facility will operate translating in X and Y the system of the X-ray source and mirror for collimation in order to scan the Athena optics. The flat field will be taken at the center of the ATHENA Mirror Assembly, where there is a hole that allows to register on the detection camera the X-ray beam without being reflected by the mirror shells of the telescope. The cameras will operate in photon counting mode, allowing to couple via time-stamp the detection time to the position of the X-ray source. Proper metrological and feedback systems will be installed on the tower hosting the X-ray source and parabolic mirror.

A preliminary exercise was performed assuming the following parameters per the X-ray parabolic mirror:

- Length: 688 mm
- Distance from the X-ray source: 229 mm
- Min and Max diameters: 16 mm and 32 mm
- PSF /HEW < 1 arcsec
- Resulting collimated beam: half-a-moon with internal radius of 8 mm and external radius of 16 mm.
- Average reflectivity between 0.2 keV and 10 kev: 50 %
-

We assumed a flux of 4 x 10^{11} ph/sec/ster from a 30 microns x 30 microns source like the one produced Incoatec GmBh (and including the geometrical reduction due to the 1 micron pin-hole). Supposing on the focal detector we need a detection of 20000 ph for each of the 700 mirror units, an integration time of just a few hours is expected for making the full calibration excluding the dead-time periods. A much better performance is expected using a larger size and larger focal length mirror.

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REFERENCES

[1] Nandra, K., Barret, D., Barcons, X., et al., “The Hot and Energetic Universe: A White Paper presenting the science theme motivating the *Athena* mission”, http://arxiv.org/abs/1306.2307 (2013)
[2] ESA, 2ATHENA: Assessment of an X-Ray telescope for ESA Cosmic Vision Program,” CDF-150(A) (2014).
[3] http://www.the-athena-x-ray-observatory.eu
[4] http://sci.esa.int/cosmic-vision/54517-athena
[5] Willingale, R., Pareschi, G., Christensen, et al., “Science requirements and optimization of the silicon pore optics design for the Athena mirror,” Proc. SPIE 9144, 91442E (2014)
[6] Bavdaz, M., Wille, E., Ayre, M., Ferreira, I., Shortt, B., et al., “Development of the ATHENA mirror”, Proc. SPIE 10699, 106990X (2018)
[7] Ayre, M.; Bavdaz, M.; Ferreira, I.; Wille, E.; Fransen, S.; Stefanescu, A.; Linder, M., ATHENA: system studies and optics accommodation, Proceedings of the SPIE, Volume 10699, id. 106991E 16 pp. (2018).
[8] Barret, D., et al., The ATHENA X-ray Integral Field Unit (X-IFU), Proceedings of the SPIE, Volume 10699, id. 106991G 15 pp. (2018).
[9] Meidinger, N., et al.,, The Wide Field Imager instrument for Athena, Proceedings of the SPIE, Volume 10397, id. 103970V 12 pp. (2017).
[10] ATHENA - SIM-System Concept Report, ESA-ATHENA-ESTEC-SYS-DD-0001 (2018)

[11] Krumrey, M., Muller, P. et al., "New X-ray parallel beam facility XPBF 2.0 for the characterization of the silicon pore optics," Proc. SPIE 9905, 99055N (2016)

[12] Salmaso, B., Spiga, D., Basso. S., Ghigo, M., Giro, E., Pareschi, G., Tagliaferri, G., Vecchi, G., Pelliciare, C.,

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Burwitz, V., Sanchez del Rio, M., Ferrari, C., Zappettini, A., Uslenghi, M., Fiorini, M., Parodi, G., Ferreira, I., Bavdaz, M., "Progress in the realization of the beam expander testing x-ray facility (BEaTriX) for testing ATHENA's SPO modules", Proc. SPIE 10699, 1069931 (2018)

[13] Valsecchi, G., Bianucci, G., et al., "Results of SPO mirror modules optical integration in the ATHENA telescope", Proc. SPIE 10699, 106990Z (2018)
[14] Guainazzi, M., den Herder J.W. et al.; *CALIBRATION REQUIREMENTS*, ESA-ATH-SP-2016-001
[15] Burwitz, V., Willingale, R., Pelliciari, C., et al., "Developing, testing, and calibrating the ATHENA optics at PANTER", Proc. SPIE 10399, 103990O (2017)
[16] O'dell, S. L.; Weisskopf, M. C., "Calibration of the AXAF observatory: overview", Proc. SPIE Vol. 3113, p. 2-17 (1997)
[17] ESA- EMITS ao9549, "X-ray Raster Scan Facility for the ATHENA Mirror Assembly ", September 2018.
[18] Maeda, Y., et al, An X-ray calibration facility with a dynamical pencil beam for the post-Astro-E2 telescopes, Proceedings of the SPIE, Volume 4851, pp. 734-741 (2003)
[19] Menz, B., Brauninger, H., Burwitz, V., Hartner, G., Predehl, P., "Studying ATHENA optics with divergent and collimated x-ray beams," Proc. SPIE 9144, 91445J (2014)
[20] Marchiori, G., and Rampini, F., "Final tests and performances verification of the European ALMA antennas",. Proceedings of the SPIE, Volume 8444, article id. 84442J, 11 pp. (2012).
[21] C. J. Bebek, et al. "CCD research and development at Lawrence Berkeley National Laboratory", Proc. SPIE 8453, High Energy, Optical, and Infrared Detectors for Astronomy V, 845305 (2012)

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