Athena calibration plans

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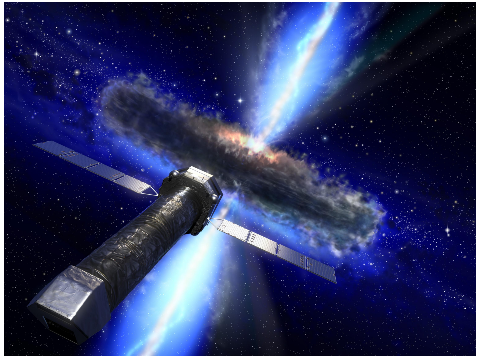
ATHENA Advanced Telescope for High-ENergy Astrophysics Spatially-resolved X-ray spectroscopy and deep, wide-field X-ray spectral imaging	
Cosmic Vision Themes	The Hot and Energetic Universe
Primary goals	Mapping hot gas structures and determining their physical properties Searching for supermassive black holes
Orbit	Halo orbit around L2, the second Lagrange point of the Sun-Earth system
Launch	2028
Lifetime	Five years, with possible five-year extension
Type	L-class mission



- Silicon Pore Optics (SPO) telescope with a focal length of 12 m and 2 m^2 effective area at 1 keV
- X-ray Integral Field Unit (X-IFU) for high-spectral resolution imaging
- Wide Field Imager (WFI) for high count rate, moderate resolution spectroscopy over a large field of view

(Barret et al., 2013, SF2A-2013, 447)

Parameter	Requirements	Enabling technology/comments
Effective Area	2 m^2 @ 1 keV (goal 2.5 m^2) 0.25 m^2 @ 6 keV (goal 0.3 m^2)	Silicon Pore Optics developed by ESA. Single telescope: 3 m outer diameter, 12 m fixed focal length.
Angular Resolution	5″ (goal 3”) on-axis 10” at 25’ radius	Detailed analysis of error budget confirms that a performance of 5” HEW is feasible.
Energy Range	0.3-12 keV	Grazing incidence optics.
Instrument Field of View	Wide-Field Imager: (WFI): 40’ (goal 50’) X-ray Integral Field Unit: (X-IFU): 5’ (goal 7’)	Large area DEPFET Active Pixel Sensors. Large array of multiplexed Transition Edge Sensors (TES) with 250 μm pixels.
Spectral Resolution	WFI: < 150 eV @ 6 keV X-IFU: 2.5 eV @ 6 keV (goal 1.5 eV @ 1 keV)	Large area DEPFET Active Pixel Sensors.
Count Rate Capability	> 1 Crab (WFI) 10 mCrab, point source (X-IFU) 1 Crab (30% throughput)	Fast Detector for high count rates without pile-up and with micro-second time resolution. Filters and beam diffuser enable higher count rate capability with reduced spectral resolution.
TOO Response	4 hours (goal 2 hours) for 50% of time	Slew times < 2 hours feasible; total response time dependent on ground system issues.

+ defocusing capability

Outline

- Athena mirror calibration plan
- X-IFU calibration plan
- WFI calibration plan

Primarily still ground-based plan.

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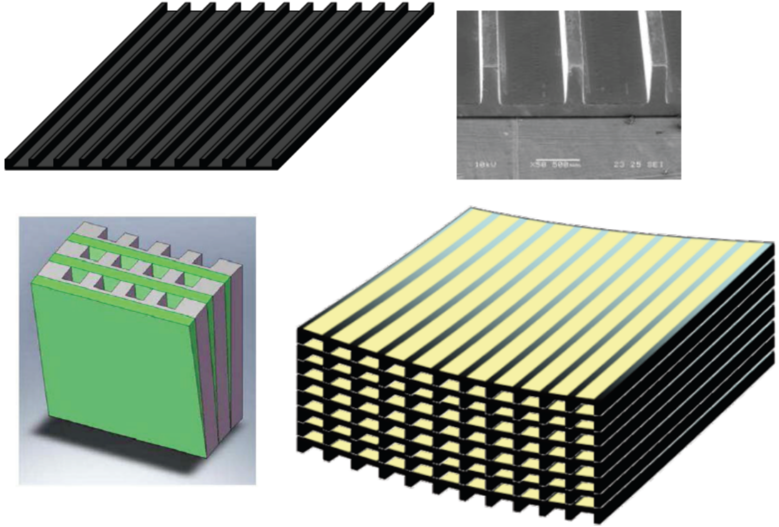
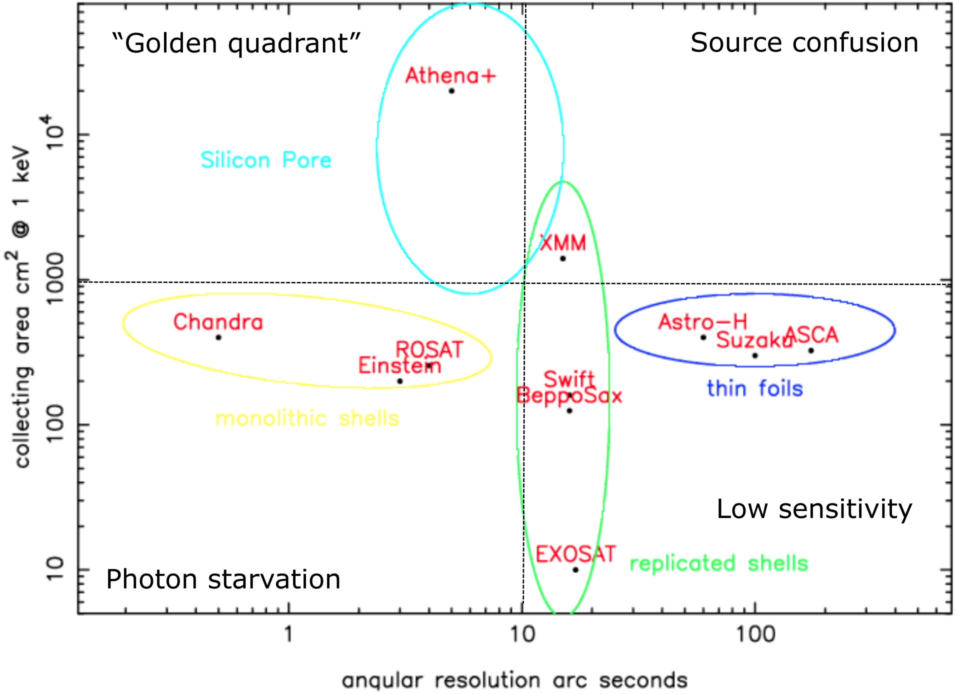
Silicon Pore Optics technology

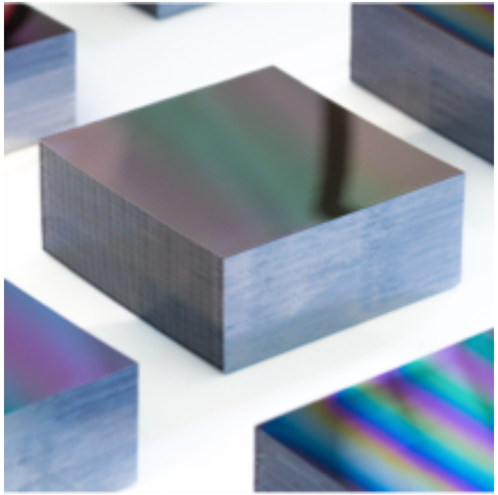


Developed by ESA and Cosine Measurement System (`cosine.nl`) over the last decade



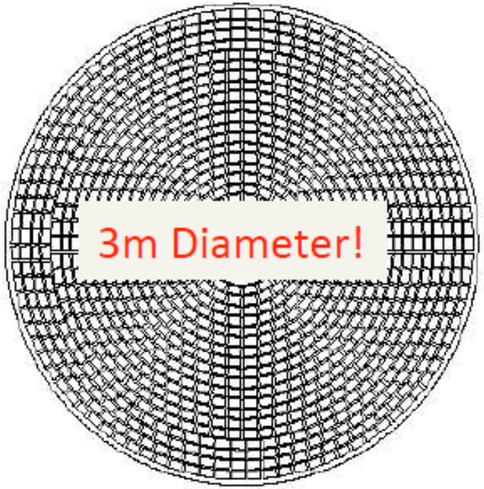
SPO terminology

Courtesy M.Bavdaz (ESA/ESTEC)



SPO mirror stack
(35 plates)

Mirror Module (MM)



Mirror Assembly
Module (MAM)
~10^3 MMs

Telescope calibration requirements

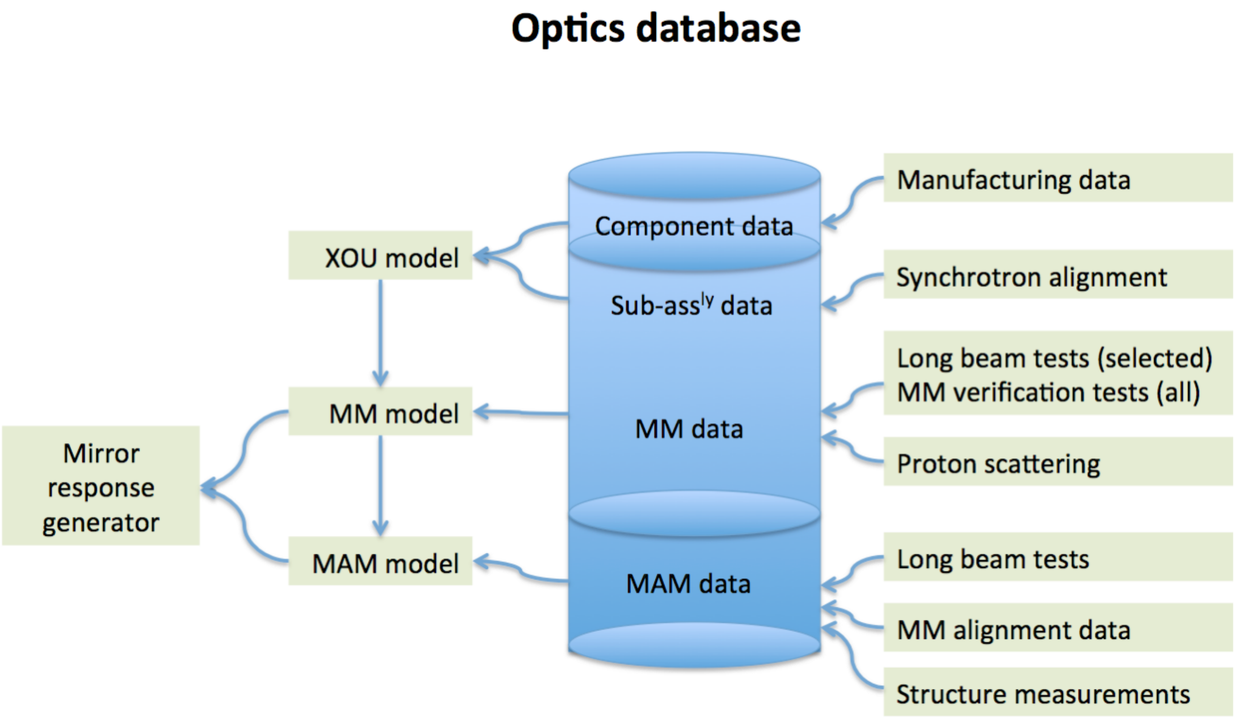
Requirement	Total value	MAM value
Focal length (on-ground)	10 mm	10 mm
Focal length (in-flight)	1 mm	1 mm
Platescale	0.2″	0.2″
Optical axis (w.r.t. MA_PCS)	30″	30″
Optical axis (w.r.t. SC_PCS)	30″	30″
PSF HEW	2/2/10%	2/2/10%
PSF 2-D shape	10″/2%	10″/2%
Absolute effective area on-axis	10%	6%
Absolute effective area off-axis	13%	9%
Relative effective area on-axis	5% (X-IFU) 3% (WFI)	2%
Relative effective area off-axis	5%	4%
Relative effective area, fine structure	1%+TBD	1%
Area stability with time (pre-launch)	2%	2%
Area stability with time (post-launch)	2%	2%
Stray light	5%	5%

- Preliminary …
- … but already intensively discussed!
- Stemming from the Science Requirement (Document) + Mission Budget (Document)
- Under review by the A. Science Study Team, the Telescope Working Group, and the Instrument Teams
- Aiming at a consolidated version by the Preliminary Requirements Review (≥Nov 2017)

Telescope calibration: assumptions

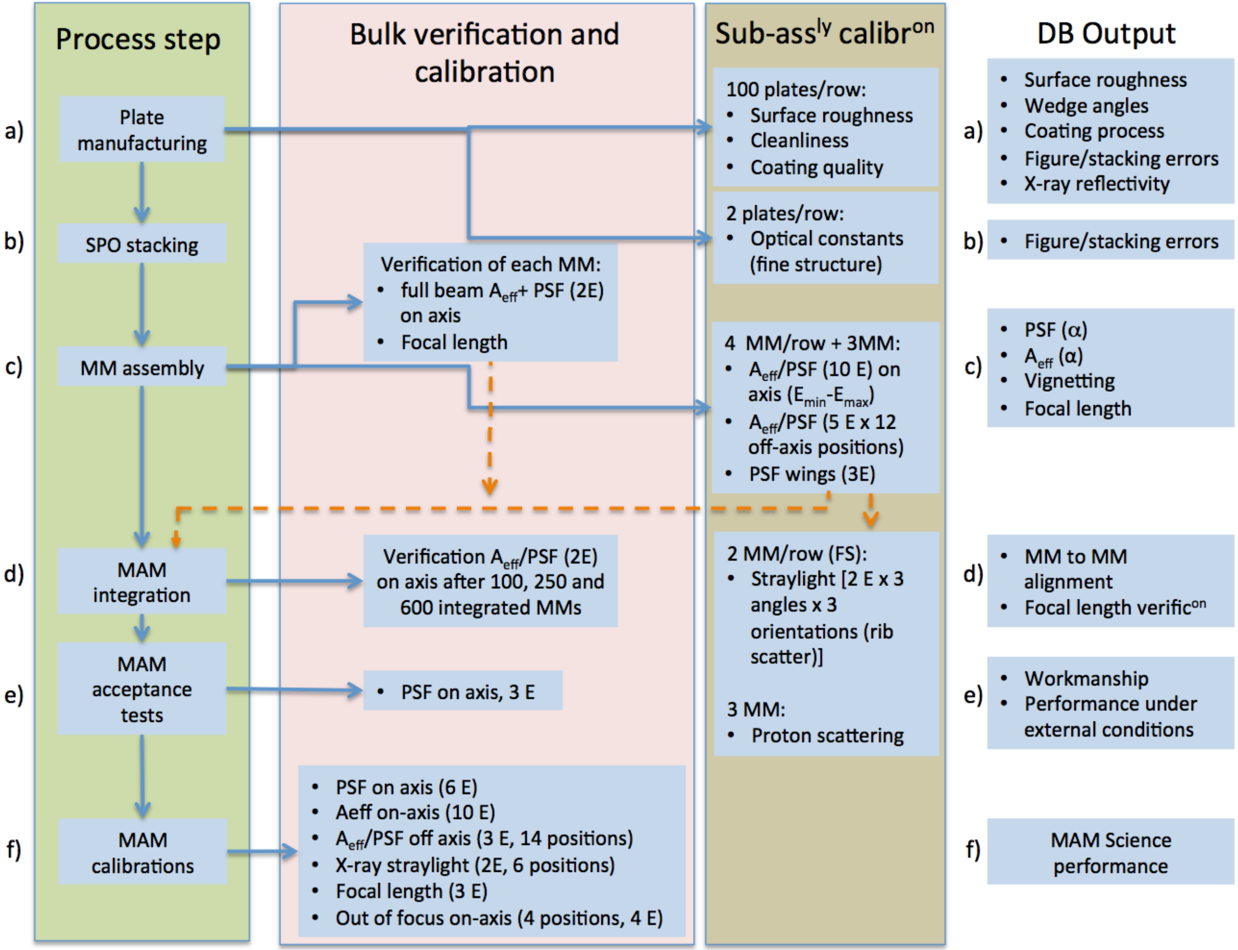
- A physical model of the telescope plays a crucial role, based on a common open-access database and validated by experimental data
- No resources available to cover the whole calibration parameter space for each and all MMs – multi-tier, flexible approach required
- [implying careful control on the performance homogeneity, and the sub-sample properties vis-à-vis the parent sample]
- Identify parameters to be calibrated on-ground (*e.g.*, PSF large-scale 2-D structure) vs. in-flight (*e.g.*, contamination)

Optics database



Calibration flow

- Process steps
- "Bulk verification/ calibration" = on all or a substantial fraction of MMs
- "Sub-assembly [detailed] calibration" = on some elements per row (~a few MMs)
- Integrated-MAM calibration for science performance assessment



Recommendations: flow & facilities

- **MM assembly, alignment**: synchrotron facility (*e.g.*, BessyII)
- **Fine structure**: long-baseline synchrotron beam with homogeneous full illumination with $\Delta E \leq 1$ eV resolution on ~2 plates/row at, *e.g.*, C, B, Si, Ir
- **MM verification**: A_{eff}, PSF, and FL measurements at 2 E on all MMs at a dedicated facility with good collimation, ~2 MM/day rate, close to MM production and/or MAM integration sites
- **MM [detailed] calibration**: A_{eff}, vignetting, PSF (on-/off-axis) at 5-10 E on ~4 MMs/row at long beam facility (2MMs/row spare; 2MMs/row back to flow)
- **MAM calibration**: Full characterization of science performance (A_{eff}, PSF in-/out-focus, vignetting, straylight, at ~2-10 E) at a long*er*-beam facility with ≥90% illumination (implying ≥800 m)

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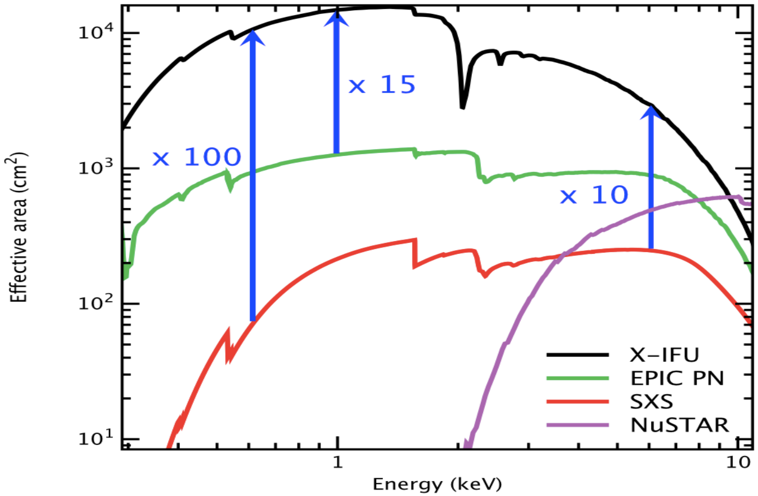
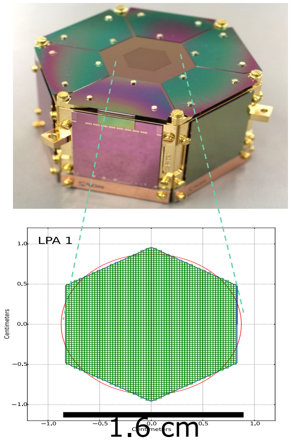
X-IFU calibration

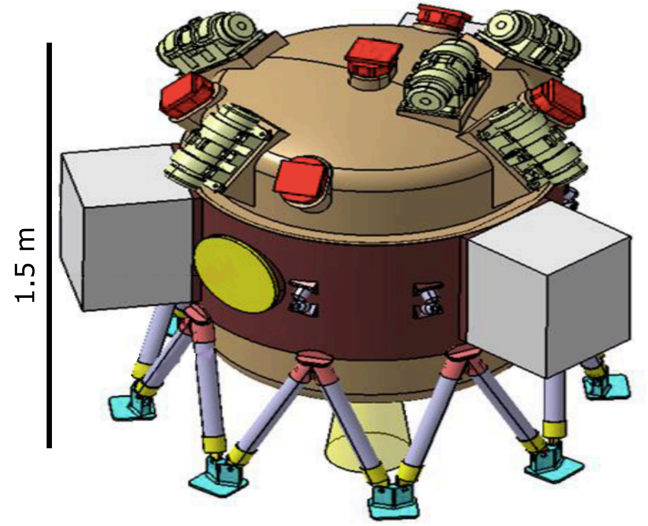
X-IFU is a very challenging instrument

- unprecedented energy resolution and large effective area requirements
  - ✓ 2.5 eV [1-7 KeV]
  - ✓ 0.1 m² [0.3 keV], 1.5 m² [1 keV], 0.17 m² [7 keV]
- 3840 micro-calorimeters
- cryogenic operations constraints





Detector assembly at 50 mK



X-IFU dewar

X-IFU calibration requirements

Energy scale :

- absolute: 0.4 eV [0.3 - 7keV]

Energy resolution (line spread function):

- energy resolution: 0.15 eV [0.3 - 7keV]

Effective area (QE)

- instrument QE: 4% [absolute, @1 keV]
- instrument QE: TBD% [relative over 0.5 - 10 keV]

Background

- non focused charged particle background: 2% TBC [100 ks, 9 arcmin^2, >1 keV]
- focused charged particle background: 10% TBC [100 ks, 9 arcmin^2, >1 keV]

Timing

- dead time knowledge (1%)

X-IFU calibration strategy

Parameter	When							
	Component level	Subsystem level	X-IFU on SIB or mock-up PF	X-IFU on SIM	Spacecraft before launch	X-IFU in flight	Sky sources	Fundamental physics
Energy scale		✓ FPA + readout	✓ (reference)	*check on MXS/^{55}Fe*	*check on MXS/^{55}Fe*	✓ (final) using MXS	TBD	TBD
Energy resolution	✓ detector array	✓ FPA + readout	✓ (reference)	*auto compatibility*	*compatibility w spacecraft*	✓ (final) on MXS/^{55}Fe	TBD	TBD
Energy redistribution	✓ detector array	✓ FPA + readout	✓ (final)	*health check on MXS/^{55}Fe*	*health check on MXS/^{55}Fe*	health check on MXS/^{55}Fe		
Quantum efficiency			*overall check TBC*				cross-calibration including mirror	
detectors	✓ (final)	*FPA level check TBC*						
filters/window	✓ (final)							
contamination	✓ initial reference			✓ reference before launch	✓ reference before launch		✓	
Background	irradiation TBC	irradiation TBC FPA including CryoAC	modeling irradiation TBC		modeling	✓		GEANT4 physics validation
Straylight					modeling		✓	
Timing		✓ Readout, MXS	✓ (final)				*check TBC*	

✓ means measurements on FM hardware (✓ when critical or final)

Italics indicates activities linked to AIT/AIV

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ATHENA WFI Calibration Plan: devices and facilities

- WFI DEPFET device
- with internal calibration source:
  conservative approach: based on Fe-55, with dedicated target material
- with external optics module:
  2 scientific instruments in focal plane and
  one large optics module $\rightarrow$ tilted
- camera at PUMA facility at MPE
- optics samples (+ camera) at PANTER facility at MPE
- additional measurements at synchrotron facility (e.g., BESSY)

ATHENA WFI Calibration Plan: subjects

- Gain of each pixel of the detectors
- Spectral resolution and redistribution matrix
- Pattern fractions
- Quantum efficiency (incl. on-chip light-blocking filter)
- External filter transmission
- Spatial homogeneity
- Offset and noise maps
- Determination of internal ("Closed") background
- Relative and absolute timing accuracy
- Spatial resolution (sub-pixel)
- Point-spread function and pile-up effects in camera
- beyond WFI: PSF as such, effective area, vignetting, stray-light, ...
- in-flight: CalPV, cross-calibration (X-IFU?), routine monitoring

Summary

- Athena Study Phase A ➔ achieve a consolidated set of calibration plans for the optics/instruments (requirement for PRR)
- Calibration requirements are in the definition phase
    - Ideally, based on "reverse engineering" the science requirements using extensive simulations (heritage of the Monte-Carlo perturbation approach discussed also at the IACHEC)
- We aim at a comprehensive ground-based calibration plan. How much we can afford is a potential issue – e.g., end-to-end test?
- Parallel effort to characterize the expected background conditions at L2 (vs. L1) is underway (see S.Molendi's presentation at the CCD WG)
- "*11 años no son nada*": now is the right time to bite the bullet!