Athena optics calibration plan

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With contributions by:
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(Chairs: R.Willingale, G.Pareschi)

Scientific goals of *Athena*

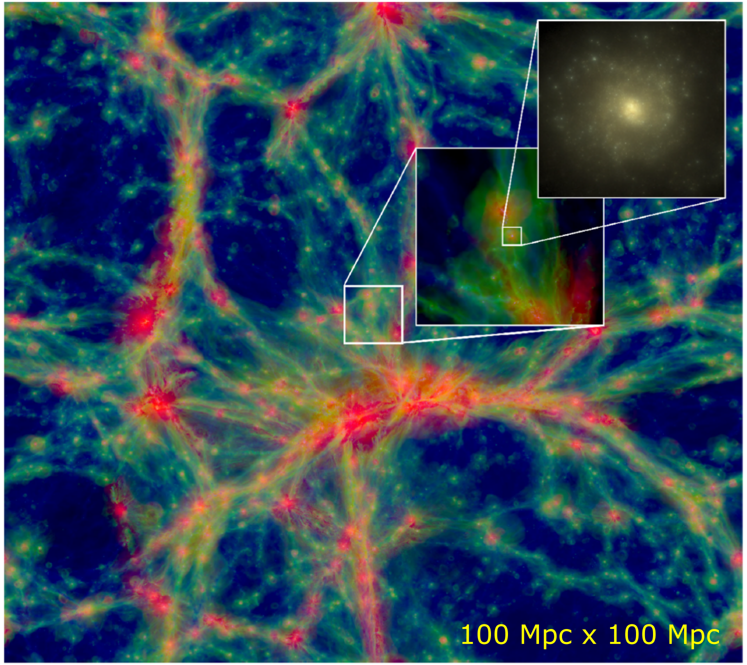
Science theme: **The Hot and Energetic Universe**

- The Hot Universe: How does baryonic matter assemble in the large-scale structures? How do they evolve from the formation epoch to the present day?
- The Energetic Universe: How do black holes grow and shape galaxies?
- The Observatory and Discovery science:
  - Observatory science across *all corners of astrophysics*
  - Fast response (≤4 hours) capability to study transient sources

The “Hot Universe” with *Athena*

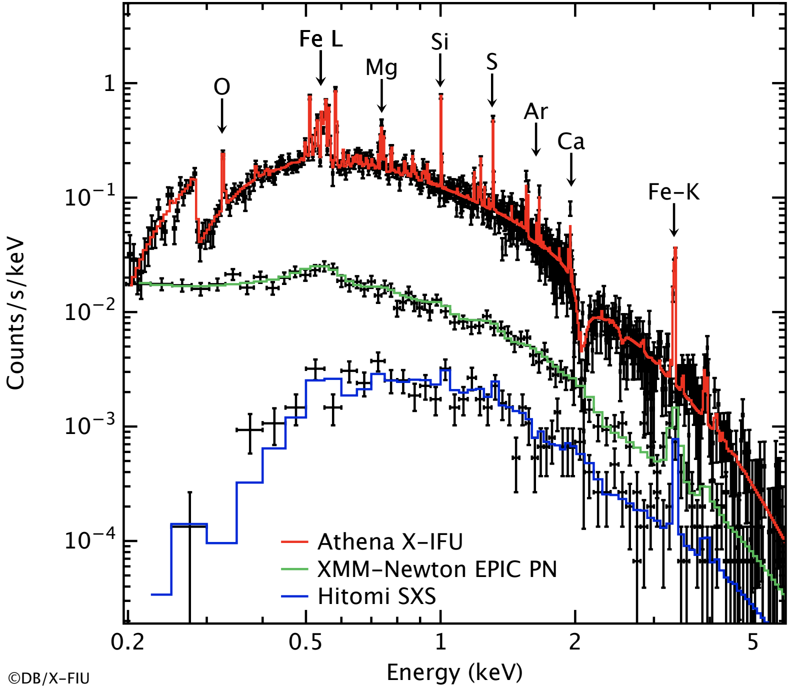
EAGLE cosmological simulation

$T<10^{4.5}$ K $10^{4.5} \leq T \leq 10^{5.5}$ K $T>10^{5.5}$ K



Schaye et al. 2015, MNRAS, 446, 521

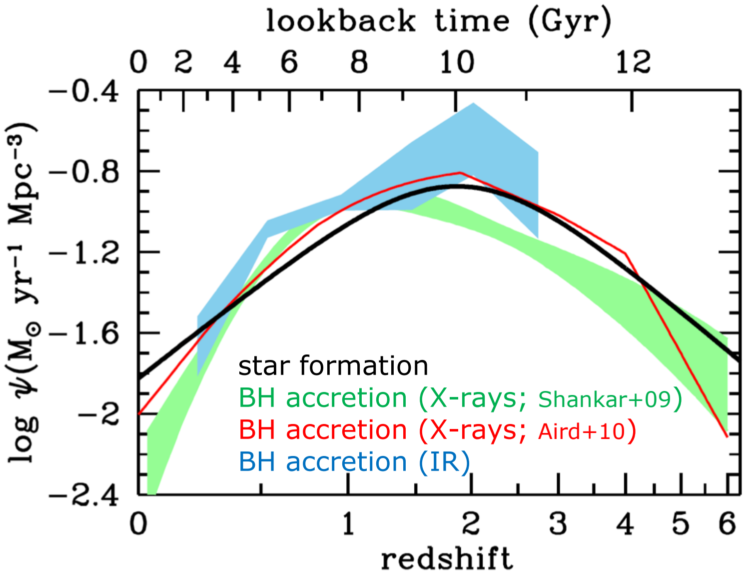
z=1 galaxy cluster (*Athena* vs. XMM/*Hitomi*)



Athena will trace the evolution of heavy elements from z~2 to the local Universe

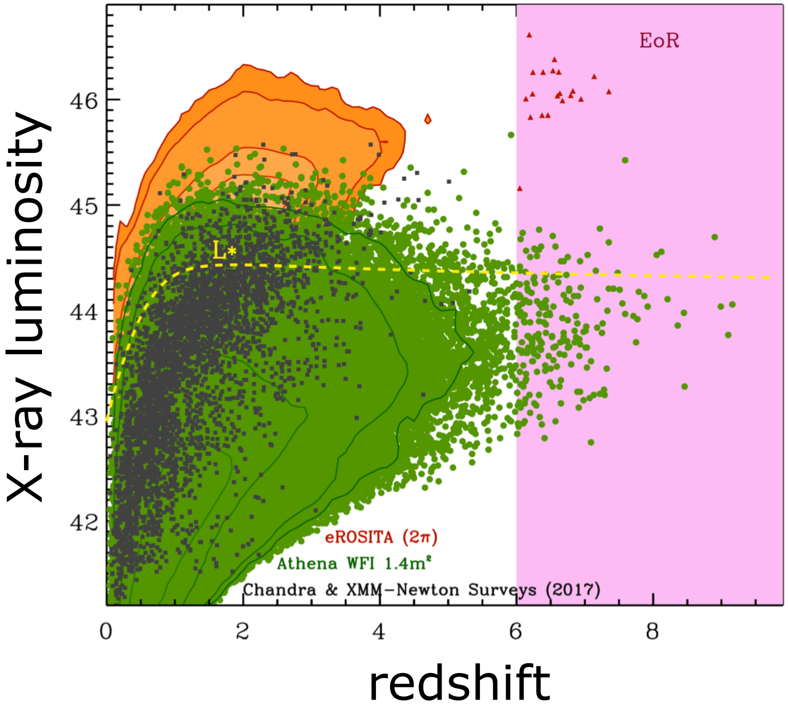
Pointecouteau et al., 2013, arXiv:1306.2319

The "Energetic Universe" with *Athena*



The cosmological history of black hole accretion is **uncertain** at z>3, **unknown** at z>6

AGN L_X versus z plane



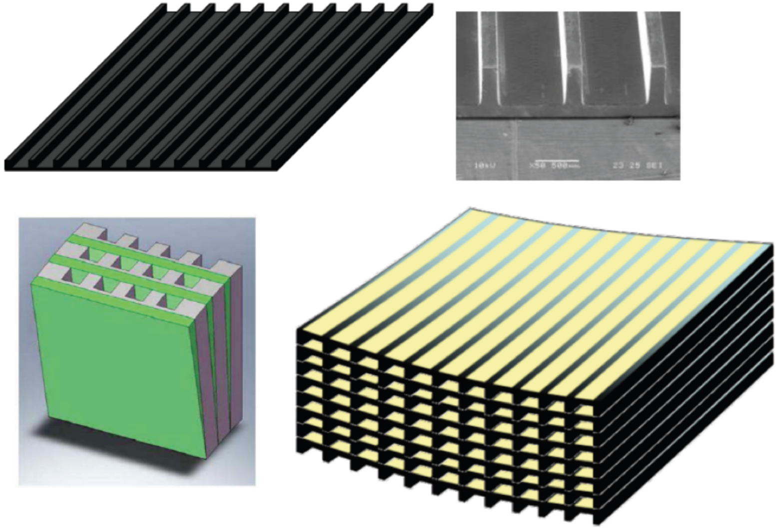
Madau & Dickinson, ARA&A, 52, 415

Aird et al., 2013, arXiv:1306.2325. Courtesy A.Rau (MPE)

Mission profile

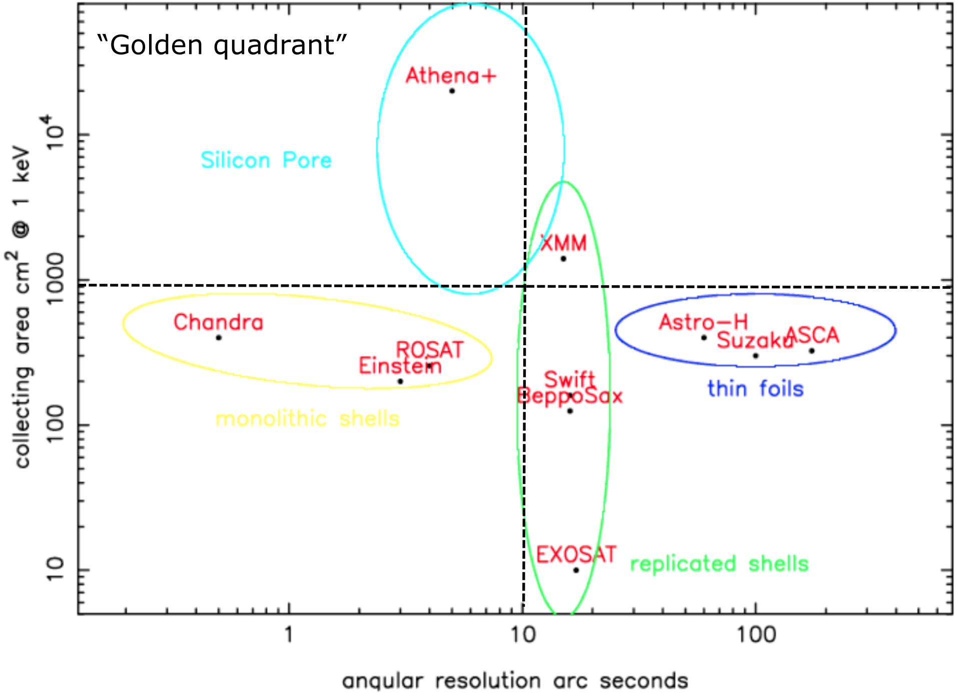
- **Single telescope**, Silicon Pore Optics (SPO) technology, 12 m focal length (f.l.), ≥1.4 m^2 area @1 keV, 0.25 m^2 @6 keV
- **WFI** (Active Pixel Sensor Si detector): wide-field (40′x40′) spectral-imaging, CCD-like energy resolution (120-150 eV @6 keV)
- **X-IFU** (cryogenic imaging spectrometer): 2.5 eV energy resolution, 5′ diameter effective field-of-view, ~5″ pixel size
- Count rates capabilities: >1 Crab (WFI)/~1 Crab (X-IFU; 30% throughput)
- ≤4 hours response with a ~50% efficiency to observe a Target of Opportunity (ToO) in a random position in the sky
- Launch early 2030s, Ariane 6.4, L2 halo orbit (TBC)

Silicon Pore Optics technology



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

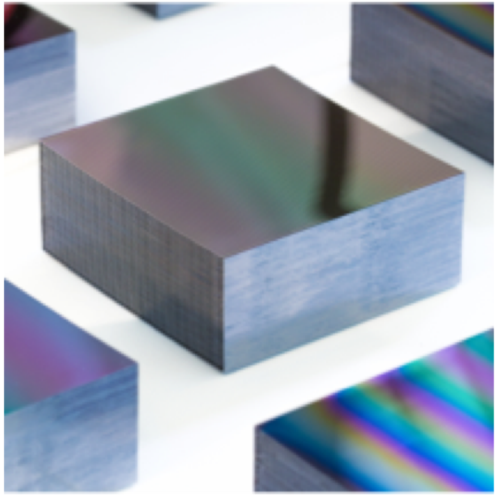
Courtesy M.Bavdaz (ESA/ESTEC), M.Collon (Cosine)



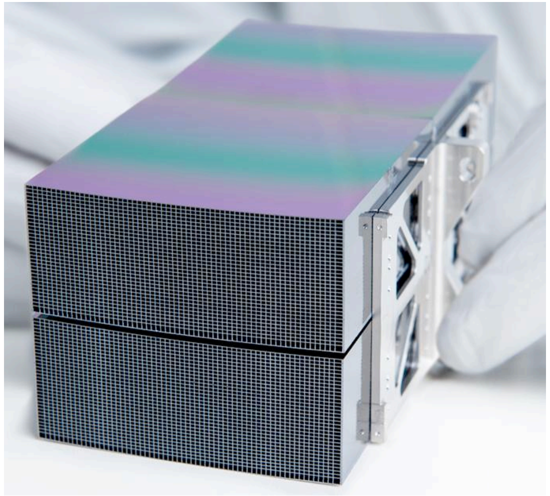
Willingale et al., 2013, arXiv:1307.1709

SPO terminology

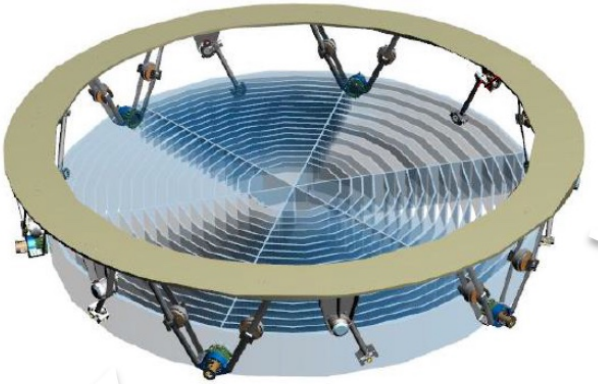
Collon et al., 2016, SPIE, 9905, 28



SPO mirror stack
(35 plates)



Mirror Module (MM)

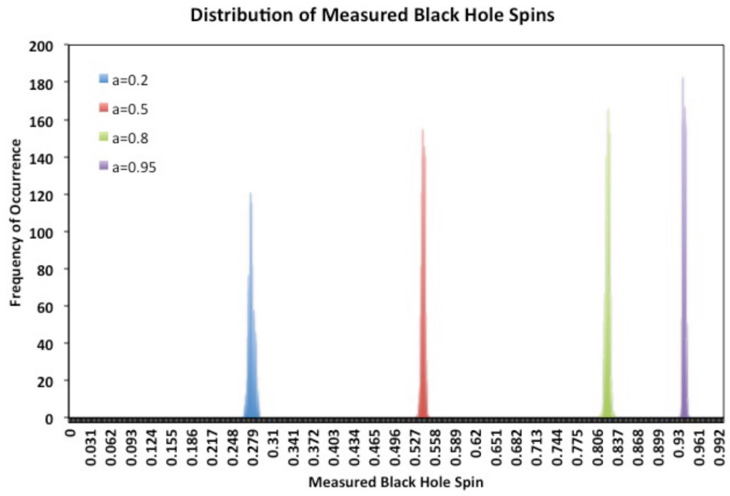


Mirror Assembly
Module (MAM)
~600 MMs

Optics calibration requirements

Ref. number	Requirement	Total value	MA value
AST-R-02	Focal length (on-ground)	1 mm	1 mm
AST-R-03	Focal length (in-flight)	1 mm	1 mm
AST-R-05	Optical axis (w.r.t. MA_PCS)	10″	10″
AST-R-06	Optical axis (w.r.t. SC_PCS)	10″	10″
AST-R-07	Position of the detector w.r.t mirror	0.25 mm	0.25 mm
PSF-R-01	PSF HEW	0.1″/0.1″/0.5″	0.1″/0.1″/0.5″
PSF-R-02	PSF 2-D shape	0.1″	0.1″
EFF-R-01	Absolute effective area on-axis	12% (WFI) 10% (X-IFU)	6%
EFF-R-03	Relative effective area on-axis	5% (X-IFU) 3% (WFI)	2%
EFF-R-04	Relative effective area off-axis[4]	5%	4%
EFF-R-05	Relative effective area, fine structure	4%	1%
BKG-R-03	Stray light	5%	5%

Validated against science requirements

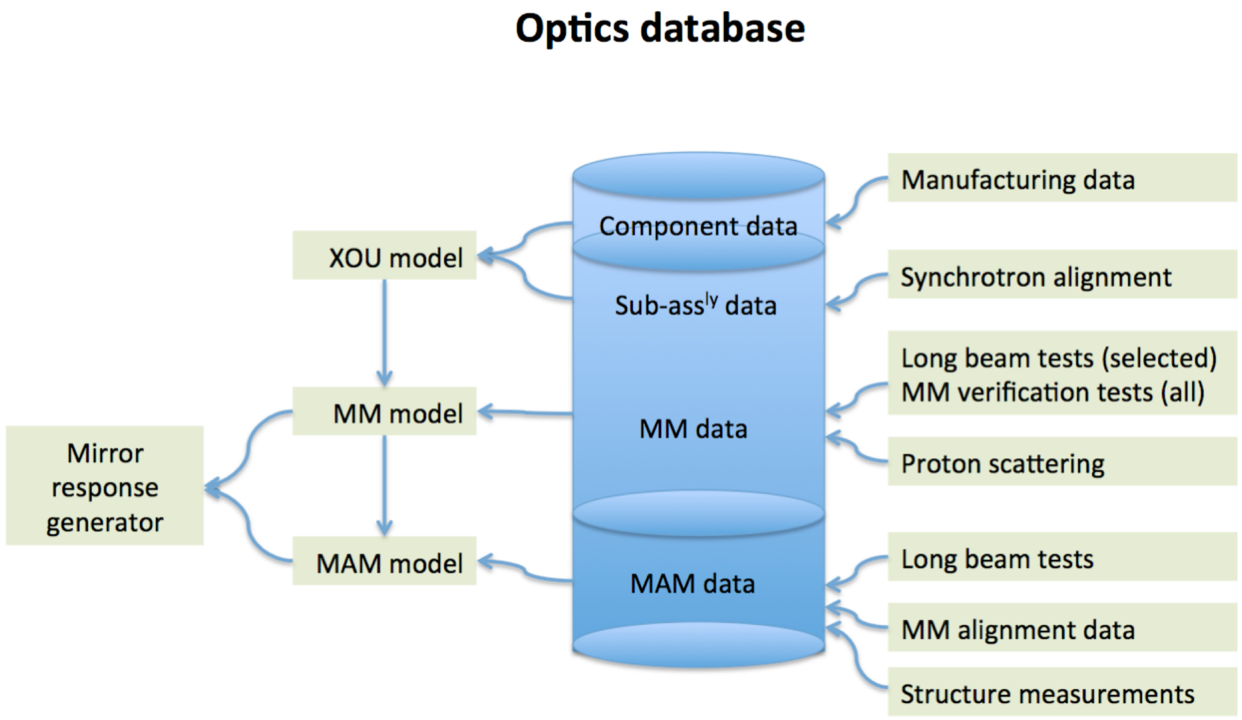


AGN black hole spin distributions due to relative effective area uncertainties

Telescope calibration: assumptions

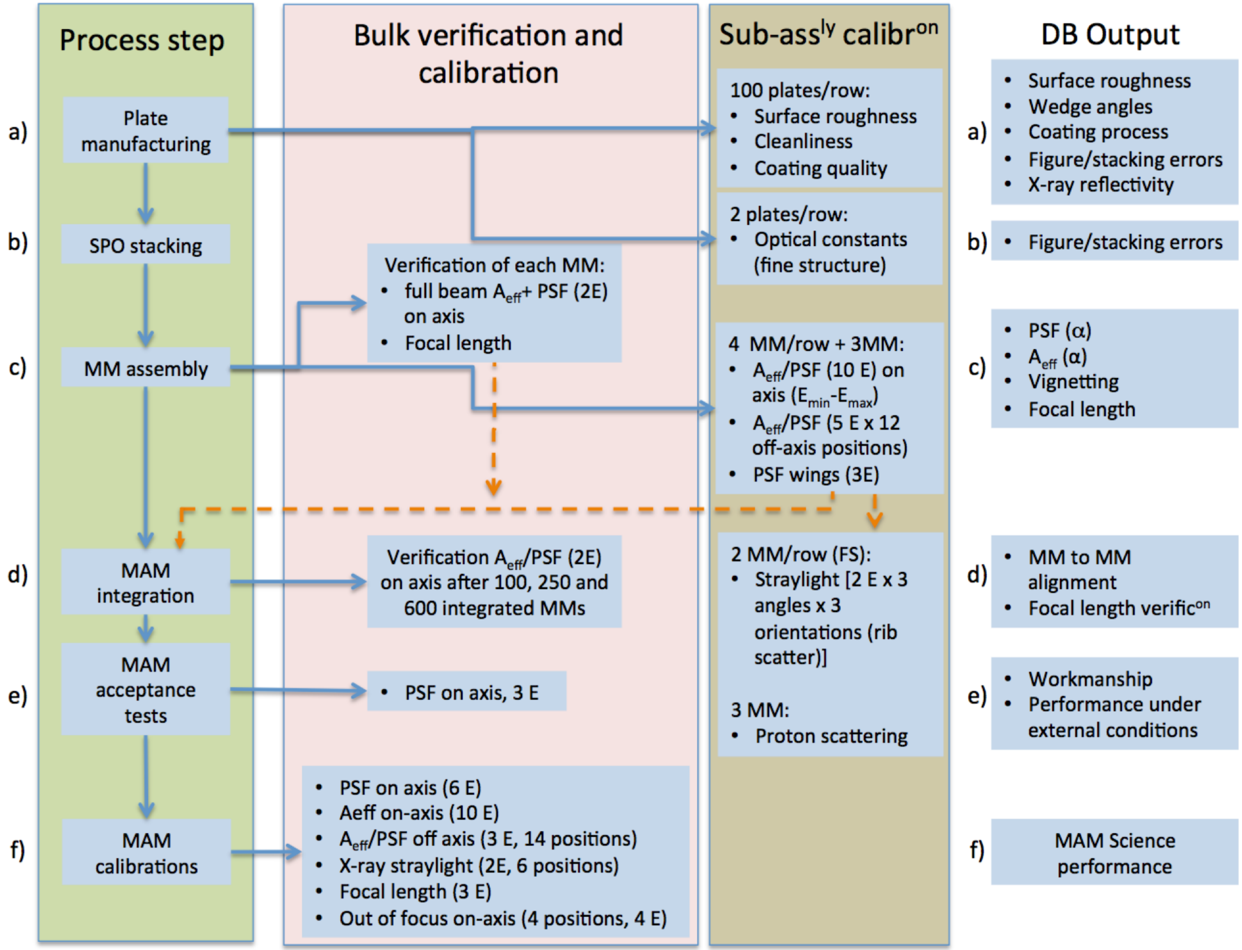
- A physical model of the telescope plays a crucial role, based on a common open-access database and validated by experimental data
- No resources available to cover the whole calibration parameter space for each and all MMs – multi-tier, flexible approach required
- [implying careful control on the 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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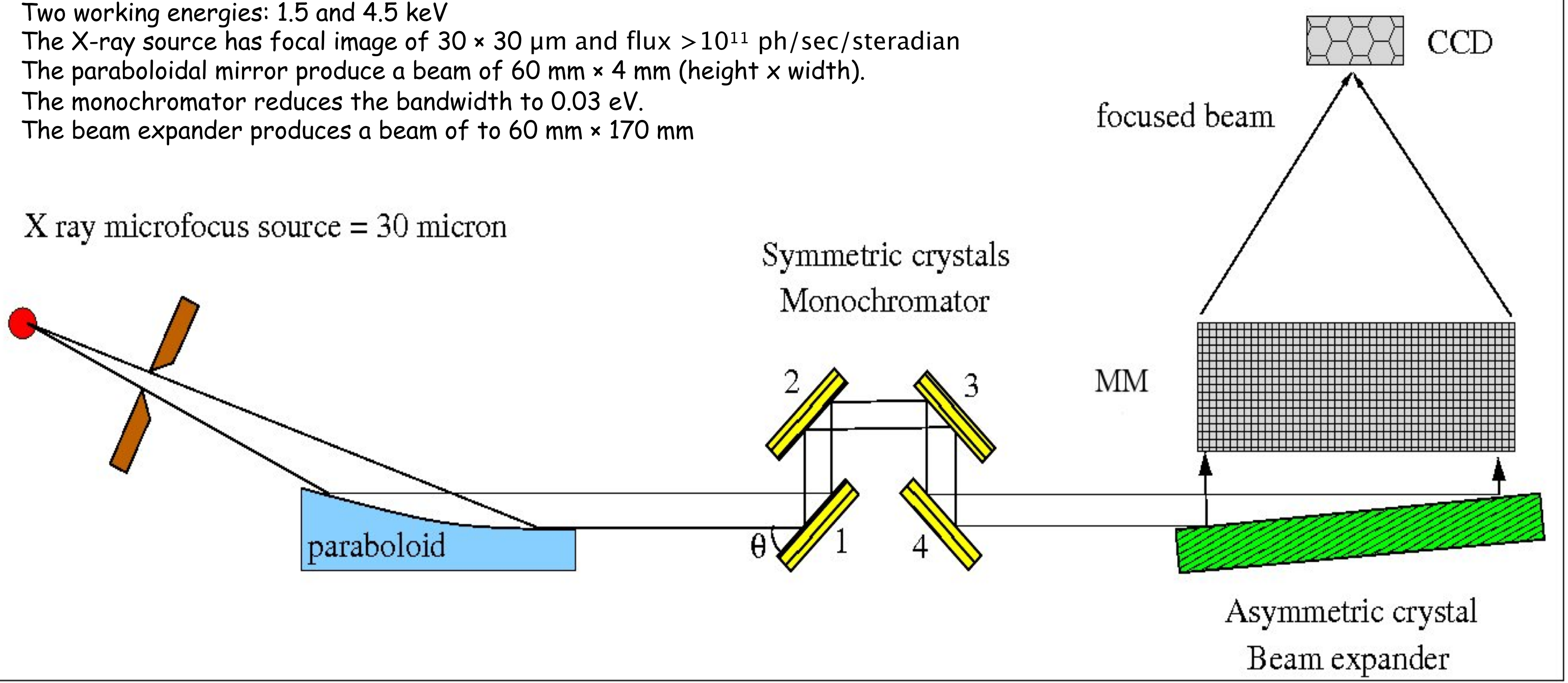
BEaTriX facility

Courtesy G,Pareschi (OAB/INAF)

Two working energies: 1.5 and 4.5 keV
The X-ray source has focal image of 30 × 30 μm and flux >10^{11} ph/sec/steradian
The paraboloidal mirror produce a beam of 60 mm × 4 mm (height x width).
The monochromator reduces the bandwidth to 0.03 eV.
The beam expander produces a beam of to 60 mm × 170 mm



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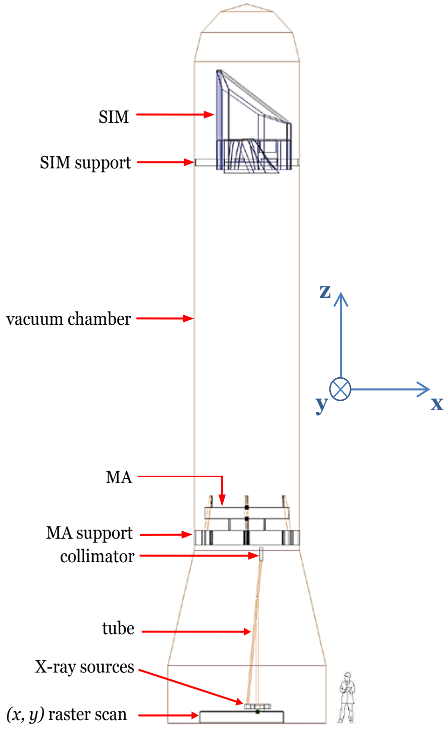
A vertical facility for MAM calibration



- Micro-focused X-ray sources
- Collimator able to produce a 1” parallel beam
- The mechanical system performs the raster scan in ~4 hours
- 20m high Vacuum Vessel
- Able to calibrate area and PSF of each MM
- Off-axis angle up to 3 degrees possible (by off-setting the source+collimator system
- Design funded by ESA
- Preliminary design 12/2019; final design 6/2020

Courtesy A.Moretti (OAB/INAF)

Summary

- Athena Study in Phase A
- Next milestone: Mission Formulation Review (Q3/2019)
  - Calibration requirement flow from science requirements
  - Payload calibration plans
- Comprehensive ground-based calibration plan. How much we can afford is a potential issue – e.g., end-to-end test?
- Adoption: 2021. Launch early 2030s