Athena Study status

Matteo Guainazzi (*Athena* Study Scientist)

NASA *Athena* Science Team

12 February 2021

Credit: IRAP, CNES, ESA & ACO

Outline

- Community structure
- Study Status and milestones to Adoption
- “Red Book” and Astronomy & Astrophysics Special Issue
  - More on the latter in the talk by R. Smith
- Optics development program and performance

Inputs by Mark Ayre (Athena Study Manager) and Paul McNamara (ESA Coordination Office) are gratefully acknowledged

Athena community news

NEW

Full community structure at: https://www.the-athena-x-ray-observatory.eu/community.html

ESA *Athena* Science Study Team (ASST)

M. Guainazzi (Chair), D. Barret (X-IFU PI), K. Nandra (WFI PI), M. Cappi, J. Croston, A. Decourchelle, J.W. den Herder, L. Piro, N. Rea, T. Reiprich, N. Werner, R. Smith (NASA), H. Matsumoto (JAXA).

SWG1
Hot Universe

New
Ettori, Fabian, Reiprich, Ota

SWG2
Energetic Universe

New
Aird, Brenneman, Cappi

SWG1.2
Astrophysics of galaxy group and clusters
Eckert, Mernier, Pratt
New

SWG1.3
AGN feedback in galaxy group and clusters
McNamara, Sanders, Simionescu
New

SWG2.1
Formation and growth of earliest SMBH
Buchner, Civano, Comastri
New

New
SWG3.6
***Athena* Multimessenger**
Piro

SWG3.7
Physics Beyond the Standard Model
Bulbul, Reynolds

The *Athena* community features 1000+ scientists!

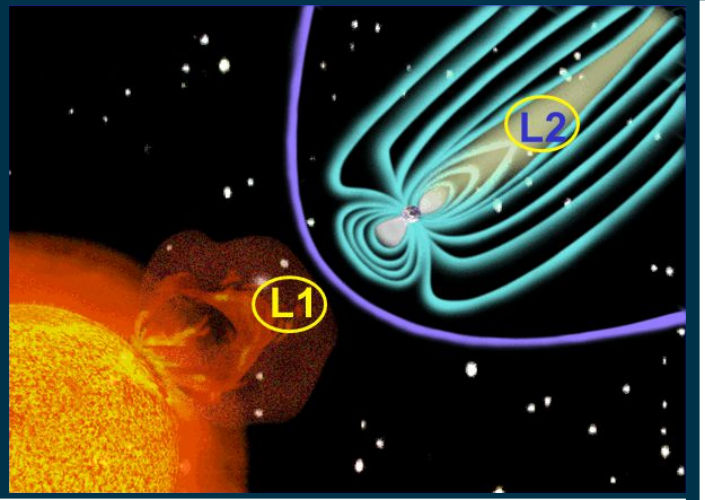
Study Status

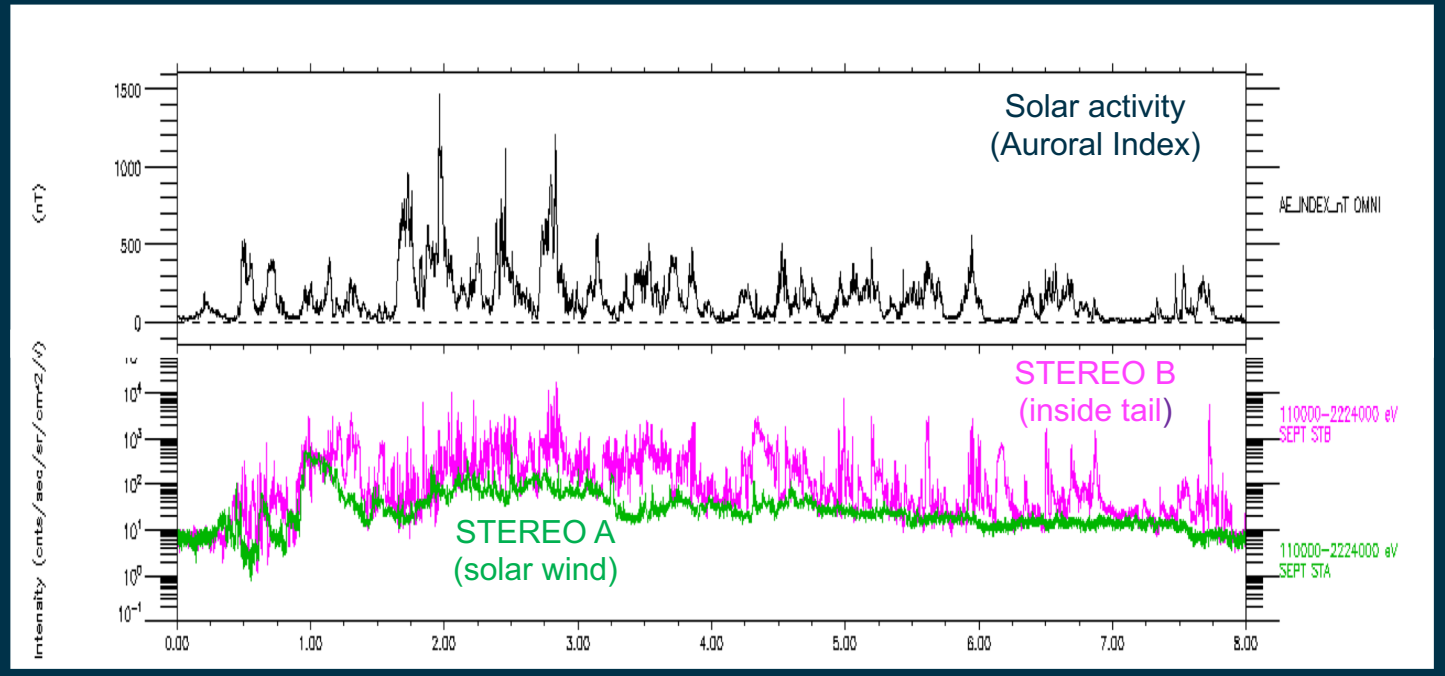
- Athena is in **Phase B1** – to be closed with the formal Adoption in the ESA Science Program (see later)
- Most recent event: **Spacecraft Interim Review** (almost closed on *January 27*)
  - S/C design similar between the two Industrial Primes and stable.
  - No major technical issue identified. Minor areas of attention
  - COVID-19 impact moderate so far
  - Mirror layout stable, pending demonstration (frozen in summer 2020: the “Phase B1 mirror”)
- **Orbit choice (L1 vs. L2) still open**
  - No showstopper identified for the switch to L1 (recommended by the ASST)
  - Better technical justification needed – Study Team working with AREMBES and Background WG
- **AHEPaM** (Athena High-Energy Particle Monitor)
  - Recognized as key to ensure the unfocused non-X-ray background reproducibility requirement
  - Technical and programmatic solution identified through a Consortium designing a similar instrument
  - ”Phase A”-like study initiated to mitigate risks – potential complexity in the thermal control identified
  - Assumption of the provision by ESA Member States to be confirmed

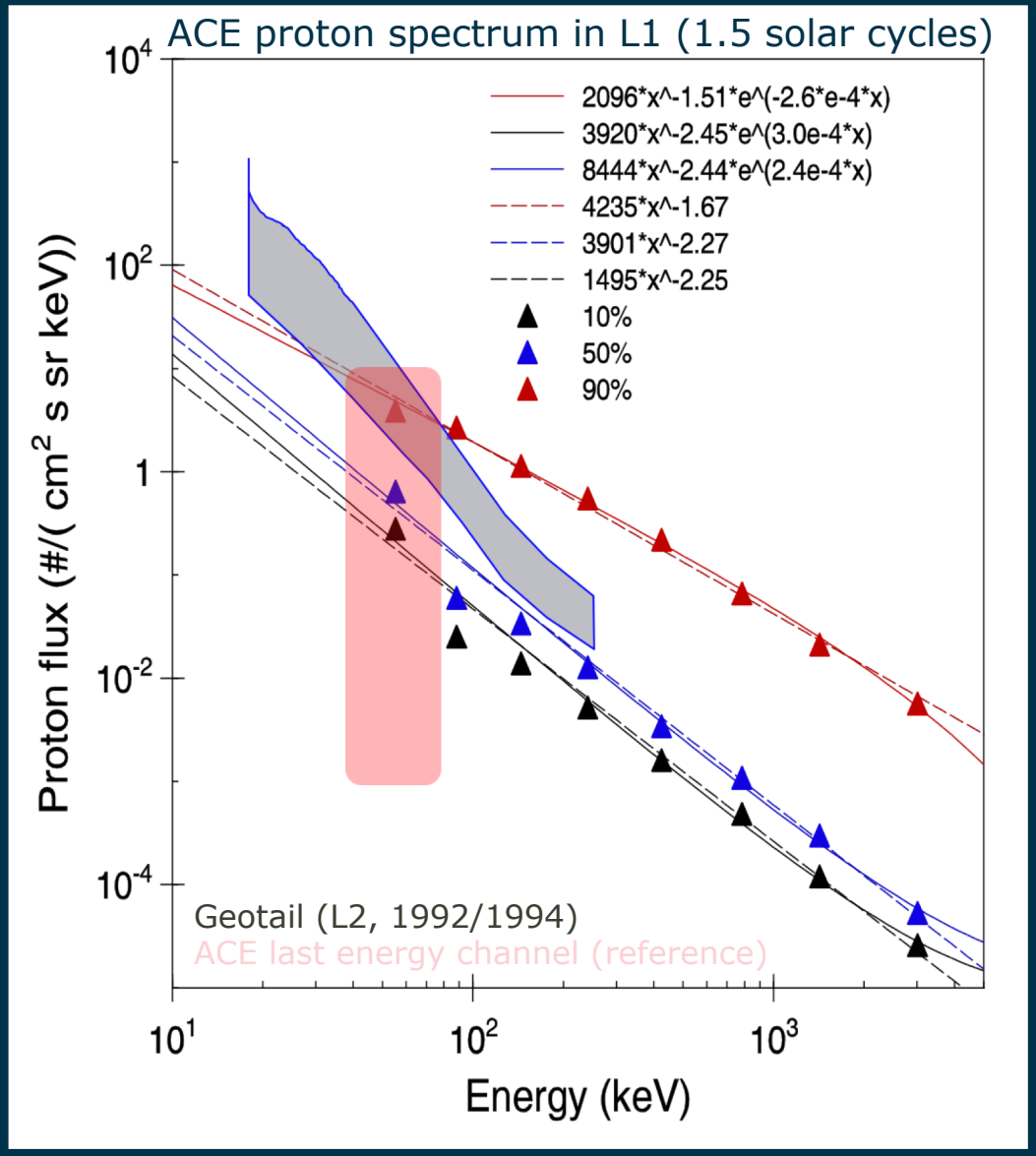
Athena orbit

L1 recommended for its better known and less variable soft proton environment

Credit: Luigi Piro (INAF/IASF) and the AREMBES Team





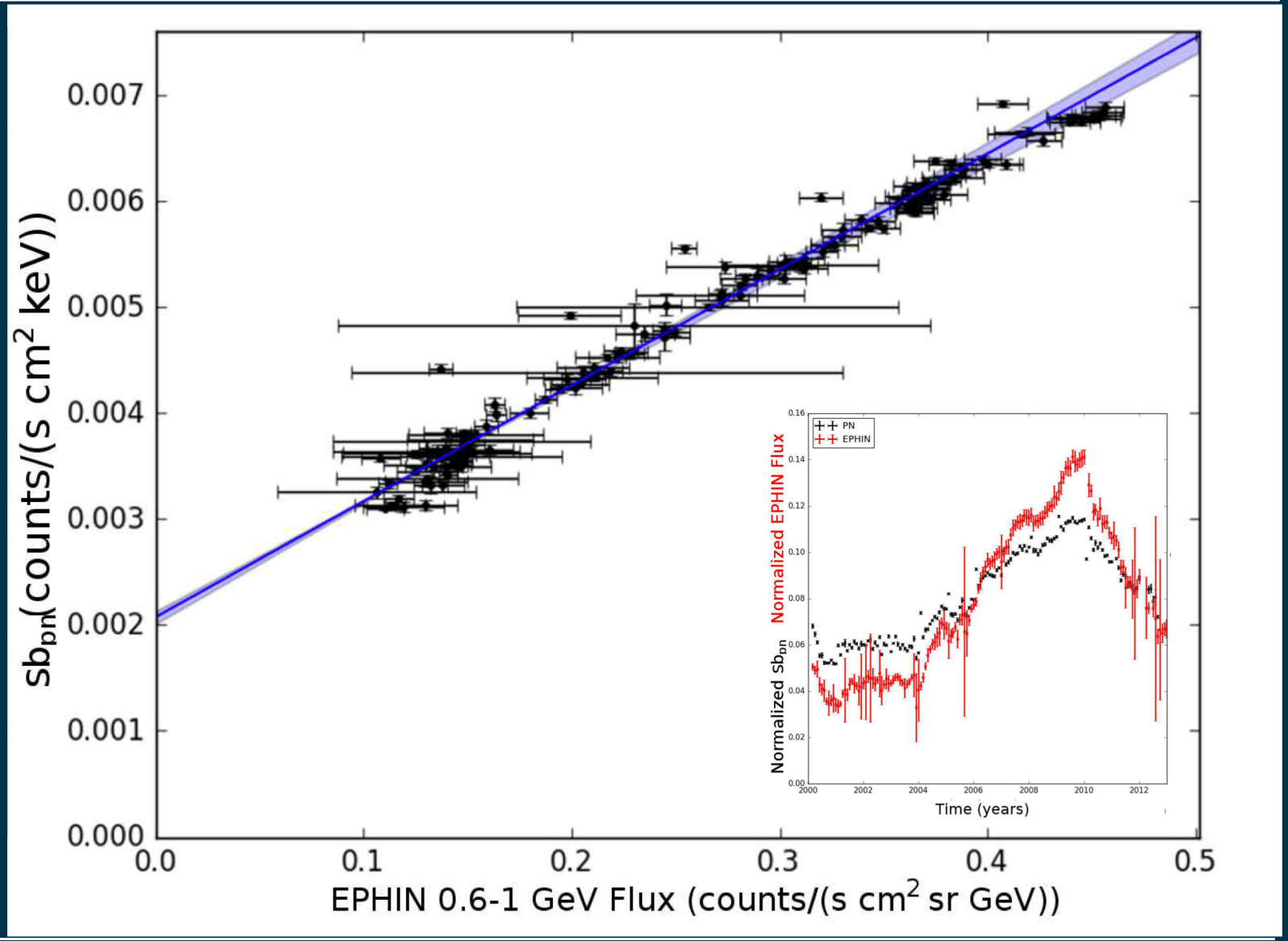


AHEPaM

Marelli et al., 2021, arXiv:2012.02071

- **NXB reproducibility** requirement **(~2%)** needed to ensure:
  - ≤20 km/s accuracy on turbulent velocities
  - ≤4% accuracy on temperature and metallicity
  - ≤25% accuracy on entropy profile of galaxy clusters
- Affected core SCIOBJs:
  - -112 (cluster bulk motion and turbulence; X-IFU)
  - -121 (cluster entropy profile evolution; WFI)
  - -122 (cluster chemical evolution; X-IFU)

- Key: **correlation between NXB and ~GeV particle flux** (based on XMM-Newton vs. SOHO)
- Hard to achieve otherwise (anti-coincidence; WFI vs. X-IFU, GEANT4 simulations …)



Athena Adoption and implementation

- Adoption scheduled to the **November 2022** Science Program Committee (SPC) meeting
- Prerequisites to **Adoption** (abridged):
  - Demonstration of Technology Readiness Level 5/6 for critical payload/platform technologies
    - X-IFU Detector Cooling System
      - Cool down of a representative 2K core in representative environment *must* occur priorly
    - Mirror performance (see later)
  - Successful Mission Adoption Review (MAR)
  - Definition Study Report (“Red Book”) – see later
  - Science Management Plan (to be presented to the ASST in ~Q3/2021)
  - Memorandum of Understanding (under discussion at Agencies’ level)
- Two-step **implementation** approach
  - First step for all the critical elements (up to mirror/instrument/SIM Critical Design Review)
  - Second step for all the other elements (mainly S/C)
  - Current estimate for the duration of the implementation phase: ~10.5 years (TBC)

Milestones to Adoption

- **Science Instrument Module (SIM) Interim Review** (Q3/2021, TBC)
  - Confirmation of the X-IFU cryostat design by the Primes after procurement responsibility CNES → ESA
- **Payload and SIM System Requirement Review** (SRR) (Q2/2022, TBC)
- **Mission and S/C SRR** (Q2-Q3/2022, TBC)
- **Technology Readiness Assessment** (Q2-Q3/2022, TBC)

- Mirror development program milestones:
  - Q1/2021: Angular resolution test results (Bessy) on oversized-and-cut 34-plates stacks (2x)
  - Q2/2021: Performance tests on a full Mirror Module in flight-like configuration
  - Q3/2021: Comprehensive tests on a stack of plates produced with Ion Beam Figuring (IBF)
    - Expected improvements to the angular resolution due to lower stress induced by thinner SiO layer
  - Q3/2021: Full performance tests on bi-layer coated plates (Ir+SiC and Ir+B_4C)
  - Q4/2021: definition of reference mirror performance for the Red Book (RB) (*i.e.*, extrapolation at Adoption)
    - Exact RB schedule to be confirmed by ASST#24 (March 2021)

The “Red Book”

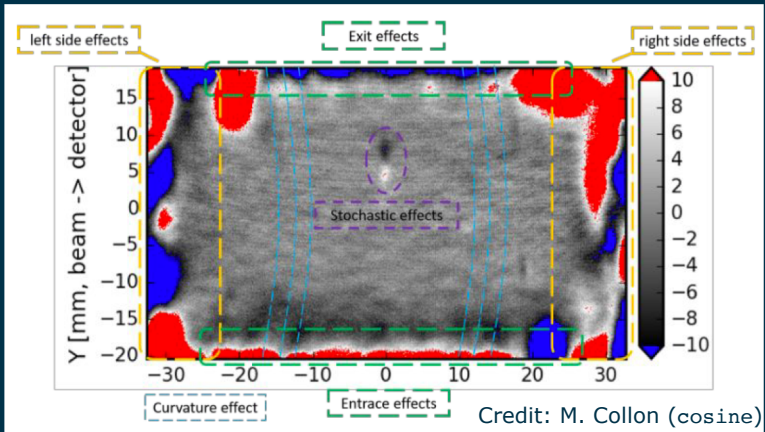
- For Adoption, Science Study Teams must submit an **Assessment Study Report** (a.k.a. *“Red Book”*)
- ESA Document, public
  - Main Editor is the **ESA Study Scientist**
  - Content is primary responsibility of the **ASST**
  - ASST set-up a **7-member Editorial Board**, and an **External Review Panel** (Chair: A. C. Fabian)
- Aiming at describing (primarily) the science (30-40%), as well as aspects of the mission implementation:

Adopted ESA mission Red Book	Executive summary	Science objectives	Science & mission requirements	Payload	Mission design	Performance & Observing modes	Ground segment & Data handling	Management
JUICE (118 pages)	5%	20%	9%	27%	12%	-	14%	1%
EUCLID (116 pages)	2%	20%	13%	14%	9%	11%	6%	5%
Solar Orbiter (107 pages)	4%	28%	14%	15%	21%	2%	7%	4%

- To be submitted by (late) **August 2022** (per SPC paper)
- Accompanied by an Astronomy & Astrophysics Special Issue on *Athena* mission & science (see Smith’s talk)

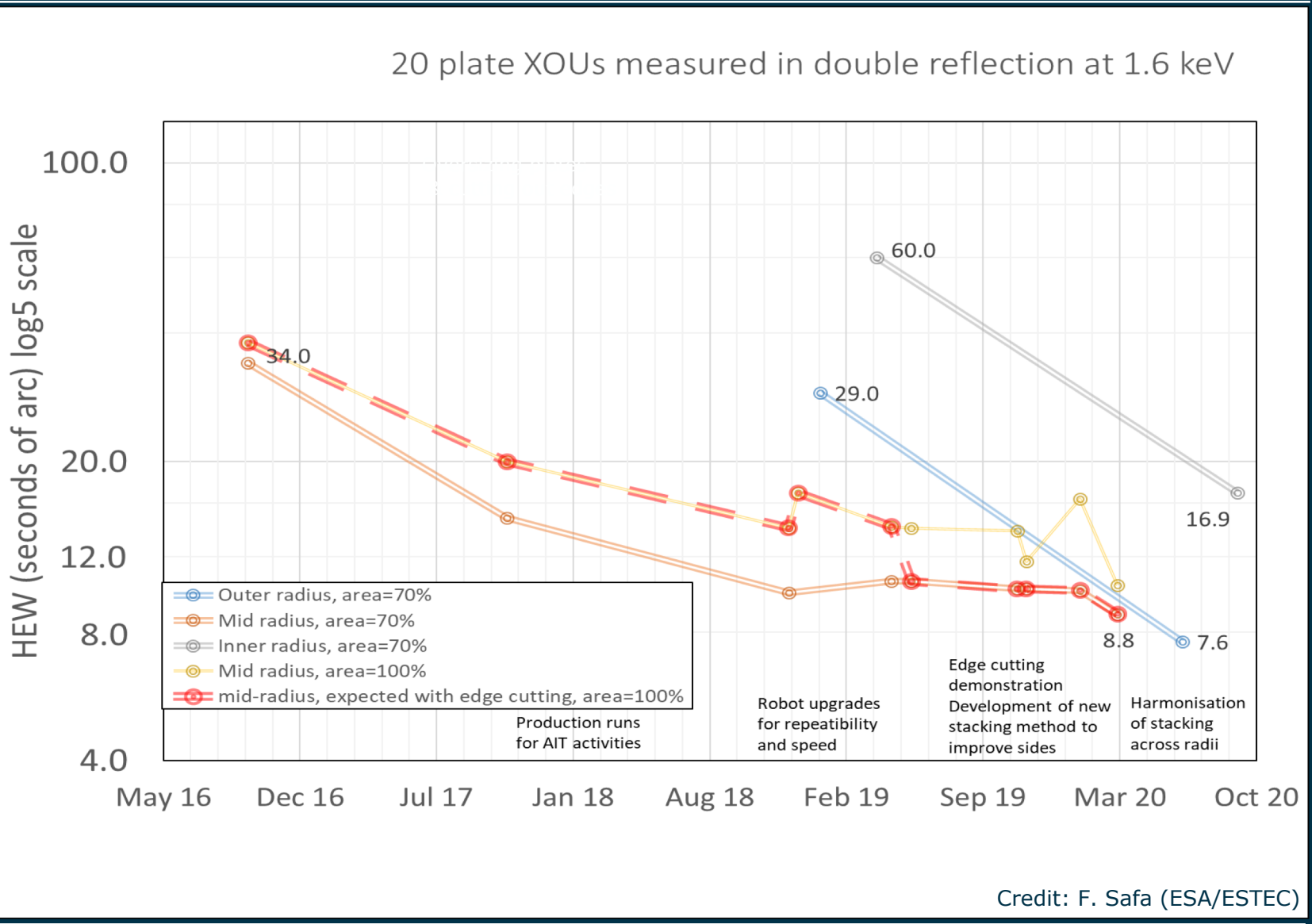
Optics performance: angular resolution (HEW)

- Demonstrated performance: ~8”/9.9” HEW on 20/34-stack plates (middle radius, “workhorse”)
- Similar HEW at outer radius; inner radius (high energies): ~2x worse
- Work continuing on all areas:



Credit: M. Collon (cosine)

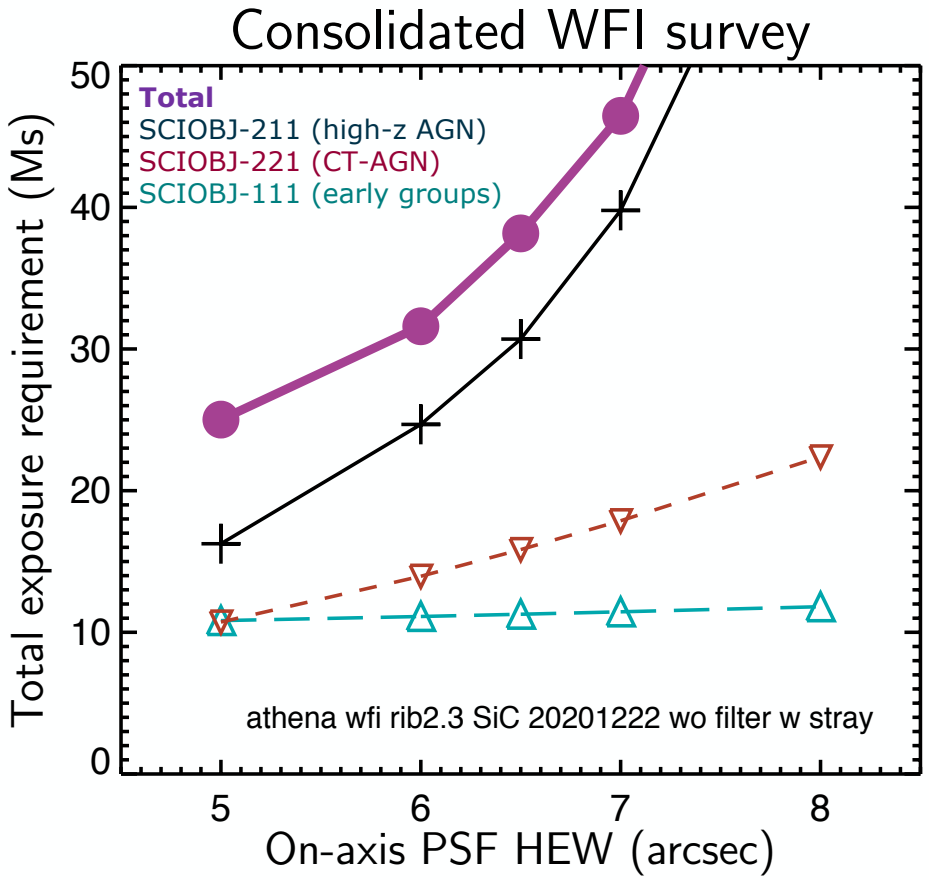
- IBF could give the next big jump (down)

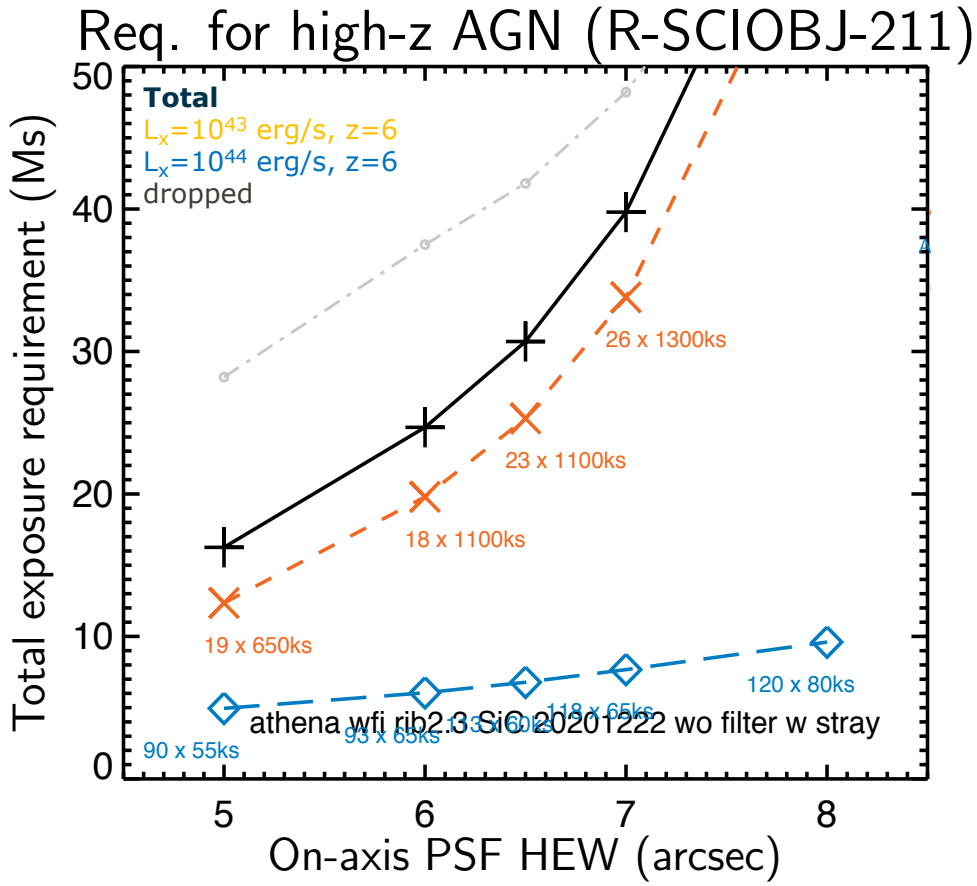


Credit: F. Safa (ESA/ESTEC)

Impact on the *Athena* science

Credit: J. Aird (IoA, Cambridge)





For HEW>8”, a few X-IFU science cases are also affected (TP#1.3)

Optics performance: effective area

Credit: F. Safa (ESA/ESTEC)

	Total A_{eff} requirement From SciRD (X-IFU/WFI) [m2]	Mirror A_{eff} Requirement Derived from SciRD [m^2]	Detection QE requirement From SciRD (X-IFU/WFI) [%]
1 keV	1.050 / 1.332	1.567	67% / 85%
7 keV	0.160 / 0.193	0.222	72% / 87%

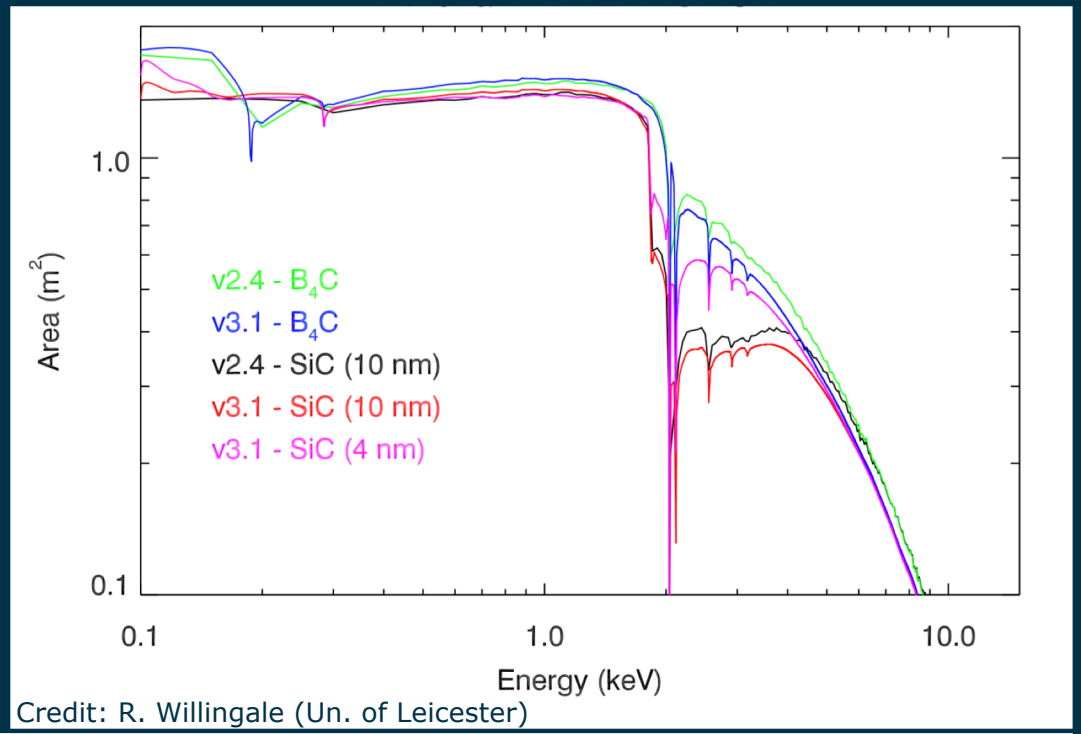
Mirror area

	Mirror A_{eff} Derived from SciRD [m^2]	Mirror A_{eff} Status 2018 [m^2 / % Δ wrt. SciRD]	Mirror A_{eff} Status 2020 [m^2 / % Δ wrt. SciRD]	Mirror A_{eff} Target by 2022 [m^2 / % Δ wrt. SciRD]
1 keV	1.567	1.235 / -21%	1.411 / -10%	1.708 / 9%
7 keV	0.222	0.125 / -44%	0.160 / -28%	0.194 / -13%

Instrument efficiency

	Detection QE From SciRD (X-IFU/WFI) [%]	Detection QE Status 2019 (IPRR) [%]
1 keV	67% / 85%	69% / 81%
7 keV	72% / 87%	73% / 95%

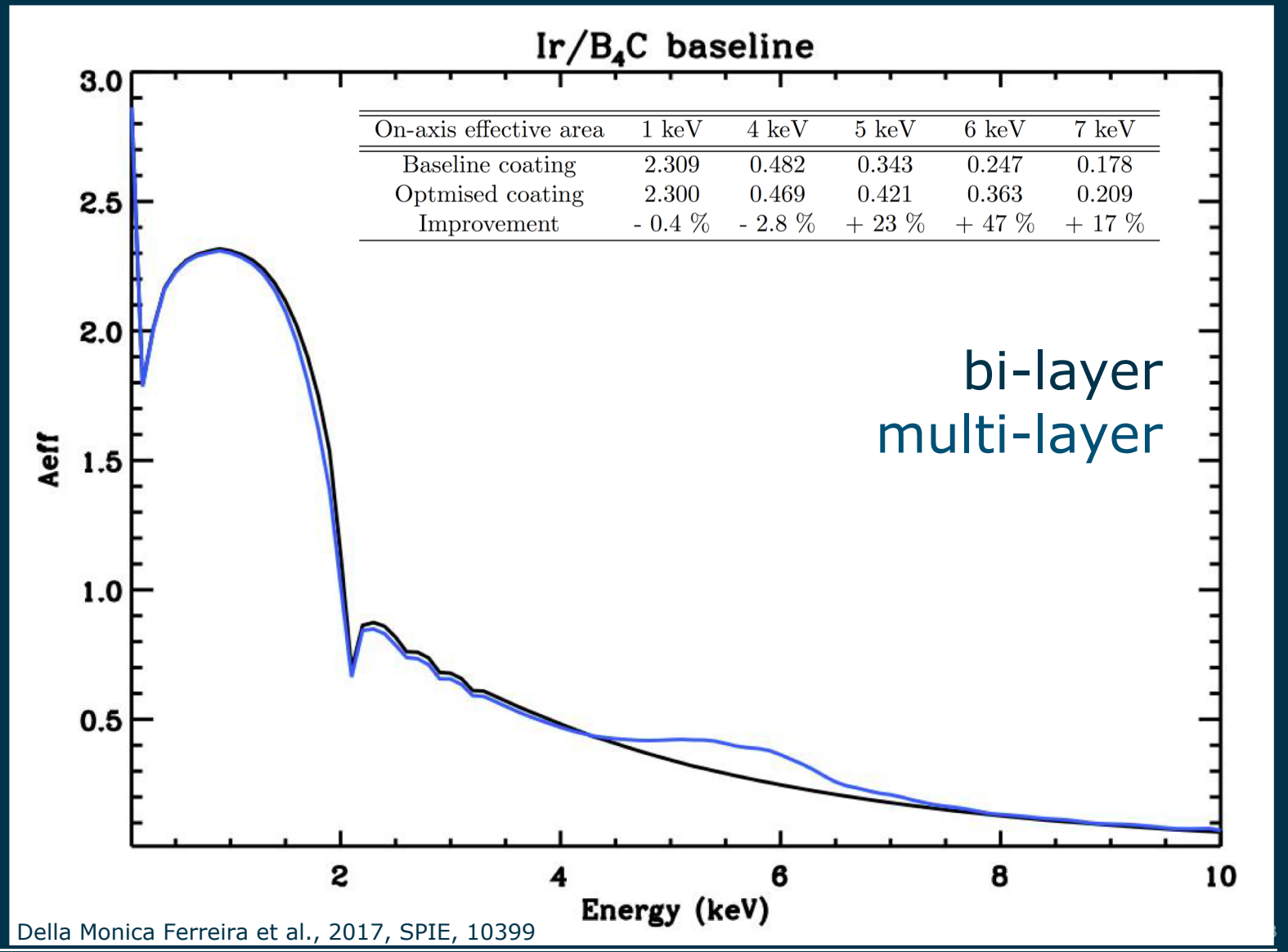
- Shortfall of mirror effective area w.r.t. SciRD:
  - **~10% at 1 keV, ~30% at 7 keV**
- Optimized SiC layer reduces area loss at 2-4 keV
- Unlikely to be recovered via instrument efficiency
- Avenues to recover mirror area:
  - Wedging scheme 0/+2 instead of +1/-1
  - Single 76-plate stacks in a Mirror Module
  - Resurrect Ir+B_4C



Credit: R. Willingale (Un. of Leicester)

Multi-layer coating: option to recover high-E area?

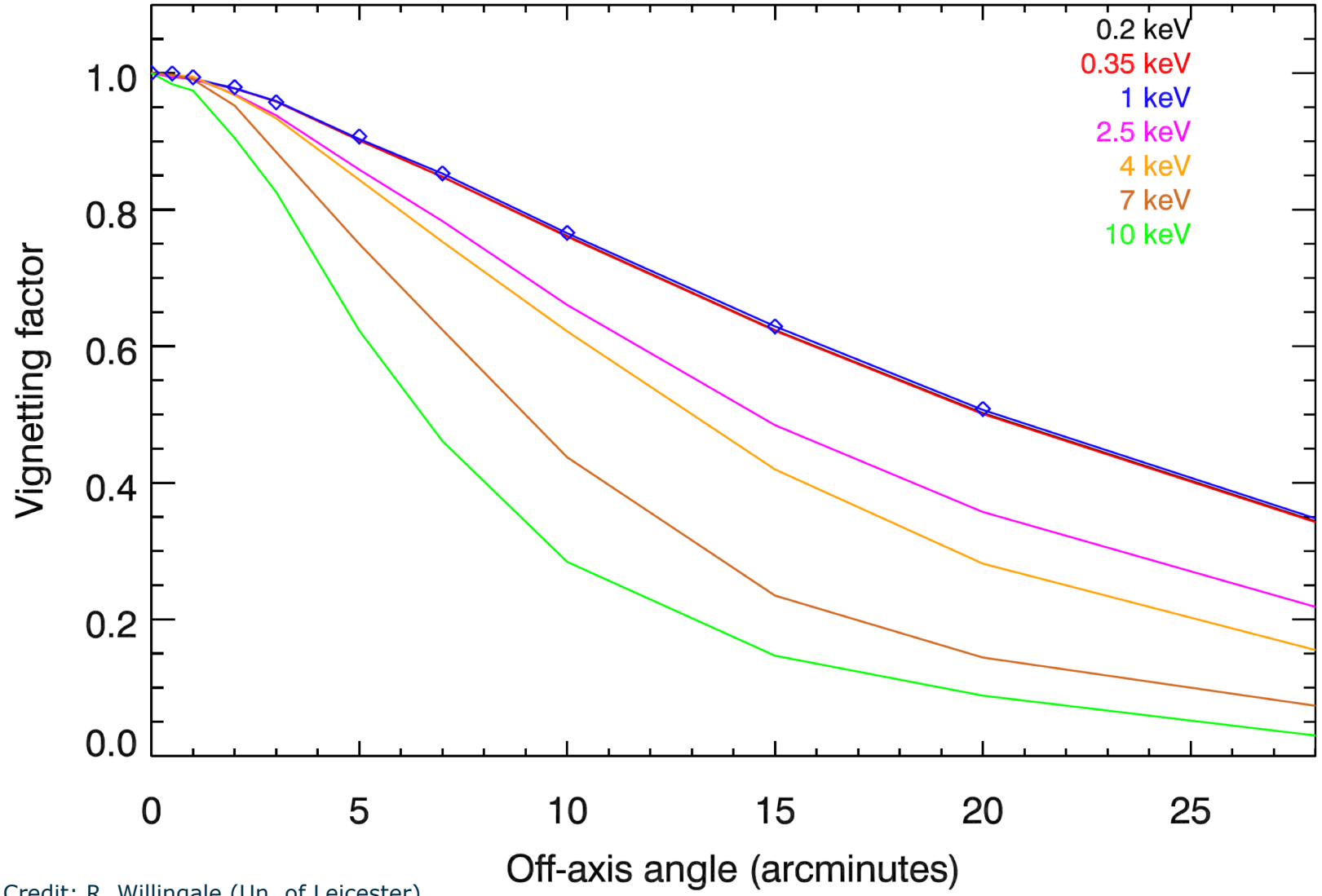
- Current ESA baseline is a **bi-layer coating**
- Suitable multi-layer coating can enhance A_{eff} in a small energy range, with penalty elsewhere
- Solution studied by ESA/DTU in the past, work now also at OAB and in Japan
- Supported by the coating machine installed at cosine
- Possible impact on calibration, HEW – no showstopper so far
- **ASST to consider a recommendation to ESA**



Della Monica Ferreira et al., 2017, SPIE, 10399

Optics performance: vignetting

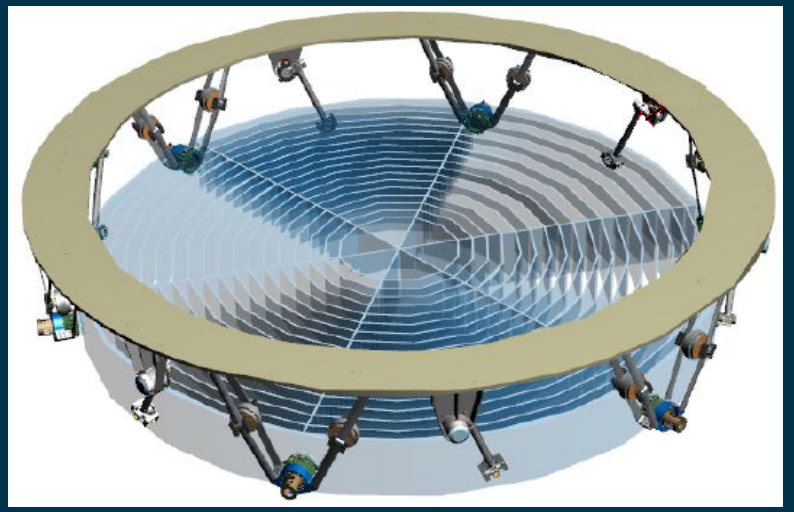
- Phase B1 mirror features a flatter vignetting
- Calculations assume a “wide” (2.3 mm) rib pitch
- Full pitch demonstration expected by Q2/2021
- *[1 mm pitch would imply ~60%/~400% less 1/7 keV area at 20’ off-axis angle]*

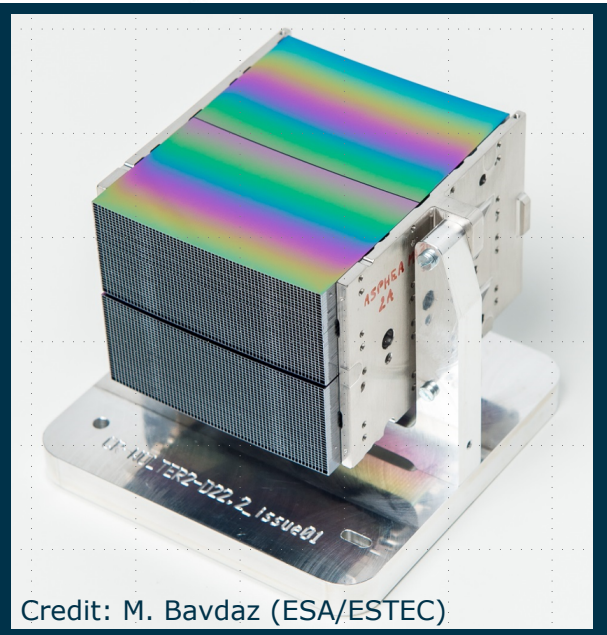


Credit: R. Willingale (Un. of Leicester)
Phase B1 mirror area, vignetting, PSF files available at: `https://www.cosmos.esa.int/web/athena/resources-by-esa`

Optics industrialization, environment, calibration

- **COATED**: coating process development and upgrading 2nd mirror plate supplier
- **SPORT**: SPO MM ruggedisation: successful vibration tests of medium- and inner-radii MMs completed
- **MAMD**: Mirror Assembly Module Demonstrator activity started with two contractors (parallel competitive)
  - Discussion on tests at NASA/XRCF proceeding well
- **AIT facility** implementation (Media-Lario) progressing well
  - Demonstrated performance exceeds requirements
- **VERT-X** (vertical scanning calibration facility) design completed, implementing critical elements (collimated X-ray source, scanning system)
- **ALBA** synchrotron beamline being implemented





Credit: M. Bavdaz (ESA/ESTEC)

Summary

- Mission Adoption targets the **November 2022 SPC meeting**
- Ultimate consolidation of the schedule to Adoption expected in summer 2021
- Definition of the mission profile for the RB at the beginning of 2022 (RB delivery: August 2022)
- ***My own expectation*: work on the RB starts early 2022**
  - Schedule to be formally discussed and approved by the ASST in March 2021
- *Athena* has survived a very long and complex Phase A/B1 with science by far and large preserved
- Residual performance risks (currently known):
  - **Mirror angular resolution**: current demonstrated HEW insufficient for SCIOBJ-211 (high-z AGN), large impact on consolidated WFI strategy, as well as minimal impact on X-IFU science
    - Work continuing to achieve the 5” HEW requirement by Adoption
  - **Effective area**: 10%/30% mirror area shortfall at 1/7 keV can be entirely recovered if technological avenues are all successful
    - Including a still TBD multi-layer coating, and assuming stable instrument efficiencies
  - Ultimate demonstration of the 2.3 mm rib pitch (**vignetting**) expected in Q2/2021

2021 EAS SS3: Black holes under the magnifying glass of XRISM and Athena

[28 Jan 2021]

https://www.the-athena-x-ray-observatory.eu/66-conferences-2/1113-eas-2021-special-session-3.html

The XRISM project, the *Athena* Science Study Team, and the *Athena* Community Office are organizing the Special Session "Black holes under the magnifying glass of XRISM and *Athena*" at the European Astronomical Society 2021 Meeting. The event will be entirely virtual on the 30th of June.

Please, note these important dates:

- Opening of registration and abstract submission: 18 January 2021.
- Abstract submission deadline: 2 March 2021.

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