Athena: mission concept, Study status, and optics development

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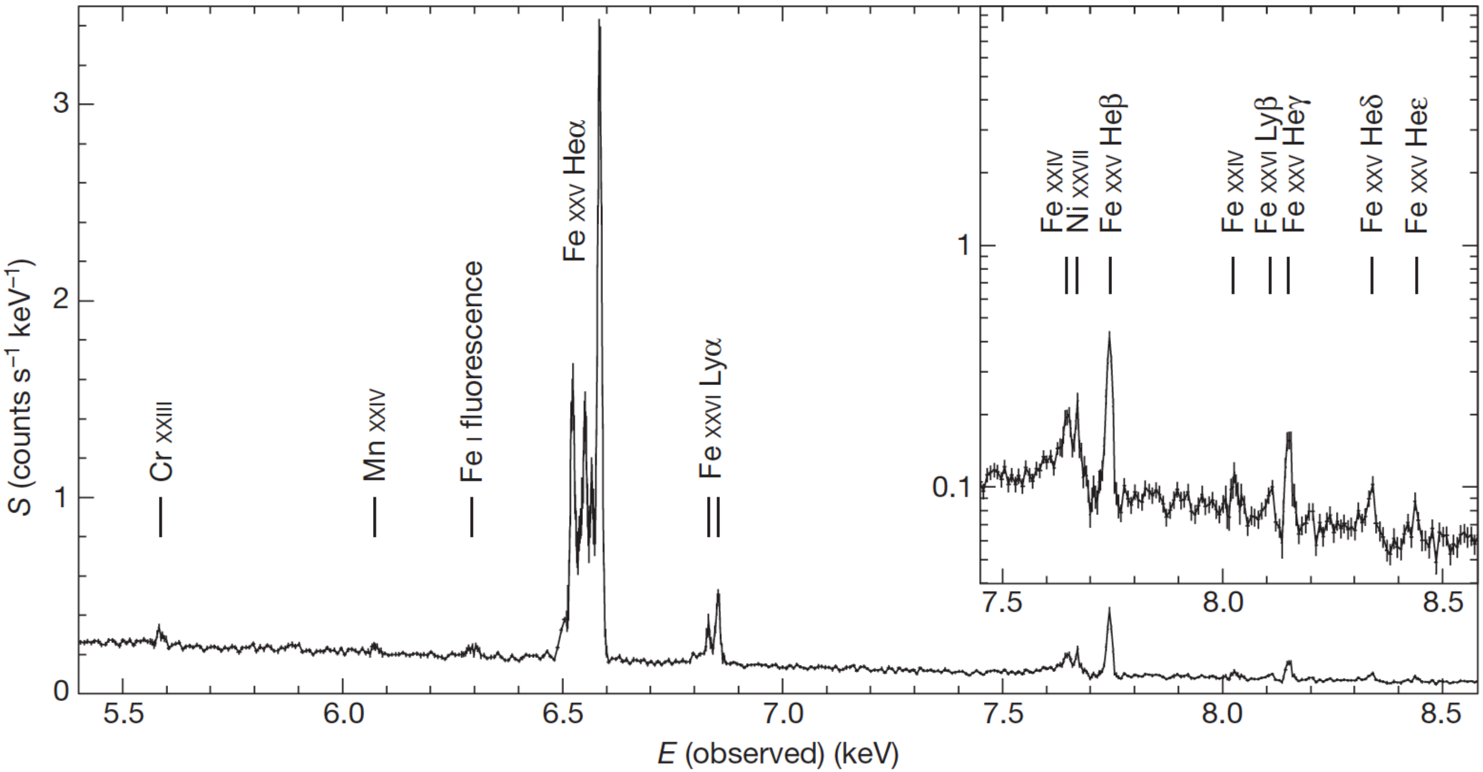
With extensive contributions by M.Ayre, M.Bavdaz, D.Lumb, J.de Bruijne, (ESA/ESTEC), M.Ehle (ESA/ESAC), and the whole ESA Study Team

Gold standard for X-ray spectroscopy



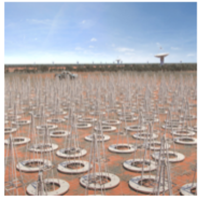
μ-calorimeter spectrum of the Perseus Cluster (*Hitomi*/SXS)

Talks by Ohashi, Gu, Ichinoe, Nakashima, Noda Sato

Hitomi collaboration, 2016, Nature, 535, 117

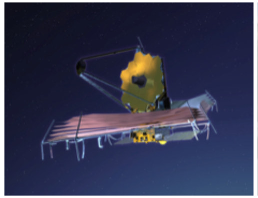
The 2020’s big observatories landscape

SKA

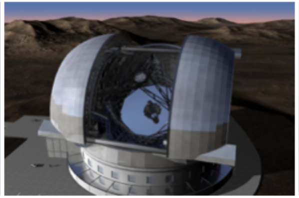


ALMA

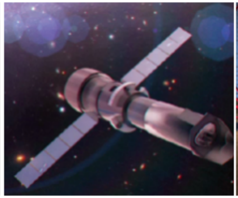
JWST



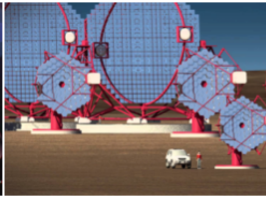
E-ELT

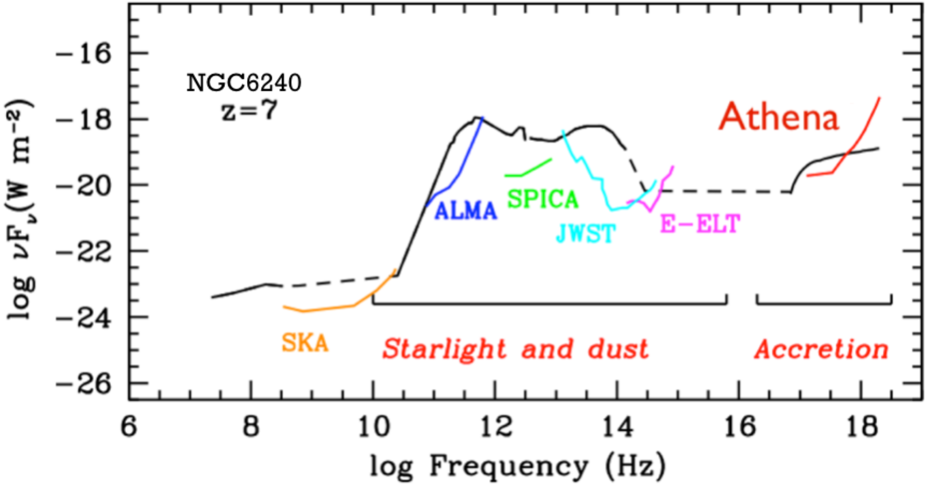


Athena



CTA

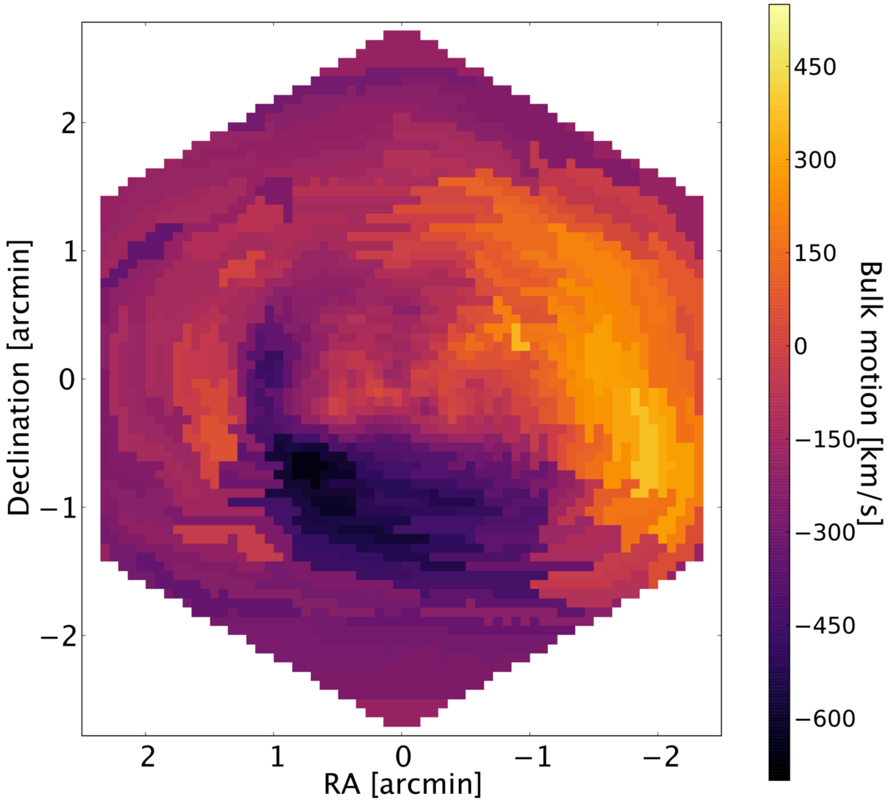


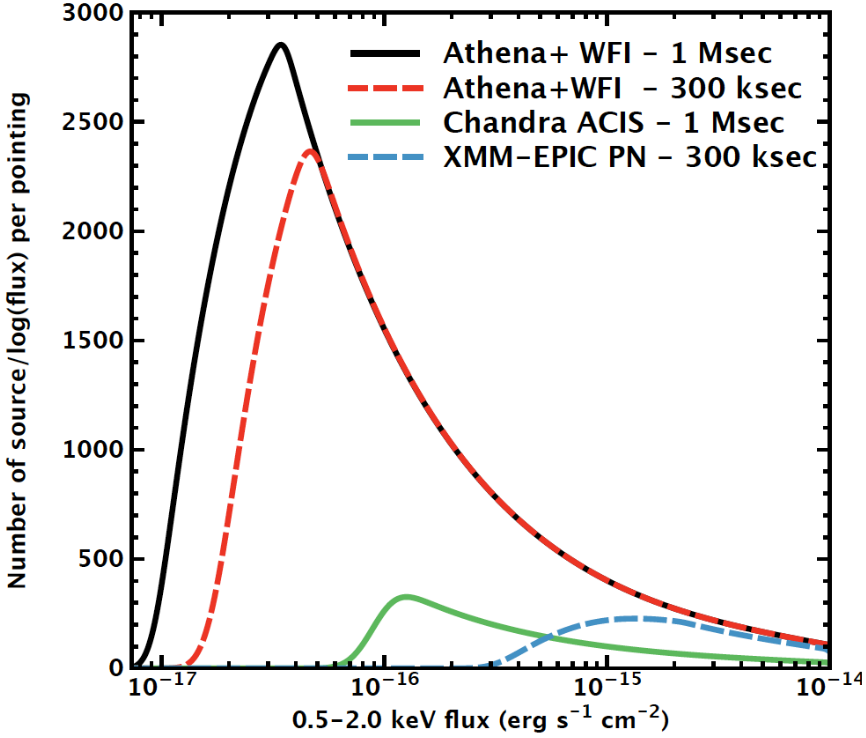


Athena is *the* contribution of the X-ray community to the new astrophysical frontiers of the 2020/30s

Courtesy of M.Türler (ISDC) and the Athena Science Study Team

A transformational mix of science performance





Barret et al., 2016, SPIE, 9905, 2; Nandra et al., 2013, arXiv:1306.2307

Outline

- Athena mission profile
- Athena Study status
- Athena optics development status

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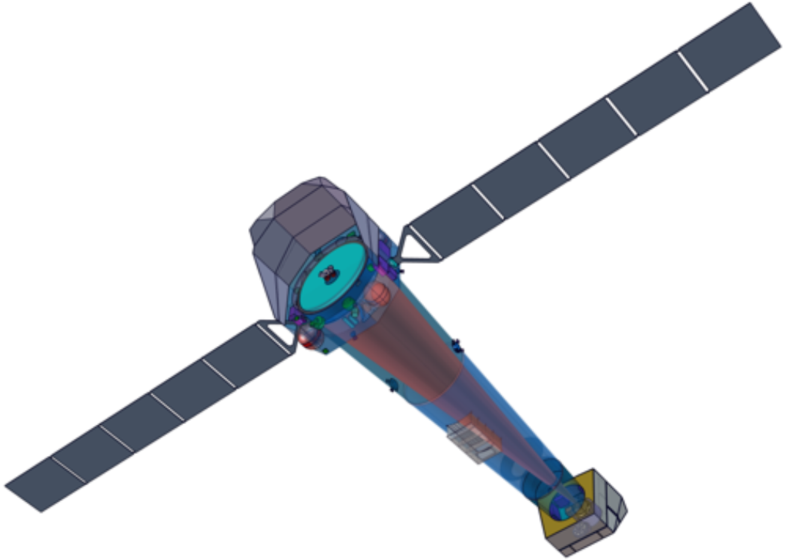
Athena mission profile



Athena concept, ESA CDF

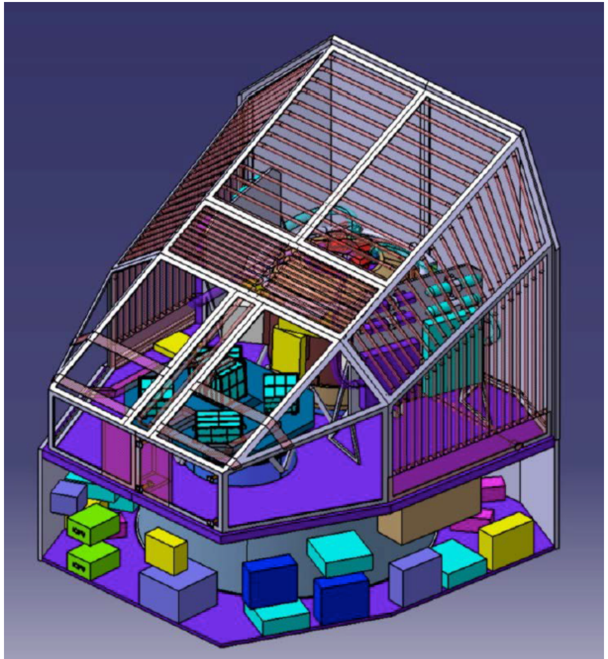
- Single telescope, Silicon Pore Optics (SPO) technology, 12 m focal length, 2 m^2 area (goal) @1 keV
- WFI (Active Pixel Sensor Si detector): wide-field (40'x40') spectral-imaging, CCD-like energy resolution (120-150 eV @6 keV) (A.Rau's talk)
- X-IFU (cryogenic imaging spectrometer): 2.5 eV energy resolution, 5'x5' field-of-view, ~5" pixel size (D.Barret's talk)
- Movable mirror assembly to switch between instruments in the focal plane
- Defocusing capability increases count rate dynamical range
- Metrology system to achieve a reconstructed astrometric error ≤1" (3σ)
- Launch 2028, Ariane 6.4, L2 halo orbit (TBC)
- Nominal life-time 5 years + extensions
- End-of-Life disposal in deep space

Athena key mission requirements

Parameter	Requirements
Effective Area	2 m^2 @ 1 keV 0.25 m^2 @ 6 keV
Angular Resolution	5″ on-axis 10” at 25’ radius
Energy Range	0.3-12 keV
Instrument Field of View	Wide-Field Imager: (WFI): 40’ X-ray Integral Field Unit: (X-IFU): 5’
Spectral Resolution	WFI: < 150 eV @ 6 keV X-IFU: 2.5 eV @ 6 keV
Count Rate Capability	> 1 Crab (WFI) 10 mCrab, point source (X-IFU) 1 Crab (30% throughput)
TOO Response	4 hours with a 50% efficiency to observe a TOO source in a random sky position

Adapted from Barret et al., 2013, SF2A-2013, 447

Science Instrument Module (SIM) design as of December 2016



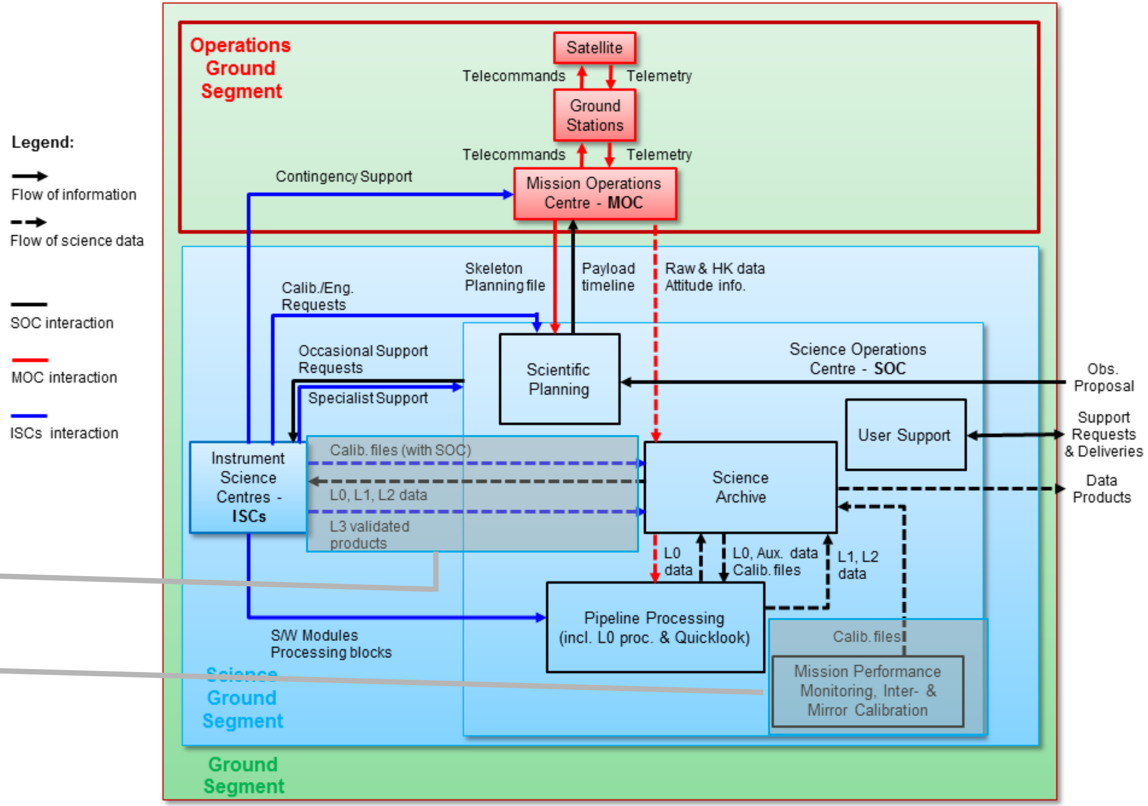
SIM (a.k.a. FPM) concept, ESA CDF

Athena Ground Segment

Mission Operations Centre (MOC): ESA/ESOC
Science Operations Centre (SOC): ESA/ESAC
Instrument Science Centres (ICSs)

Share of tasks between SOC/ ICSs under discussion:

- Data processing
- Telescope calibration, instrument cross-calibration and inter-calibration



Ehle, 2016, ATHENA-SA-Dc-0001

Athena Target of Opportunity (ToO) capabilities

- 3 hours daily downlink to New Norcia + additional uplink stations for ToO (New Norcia, Malargüe)
- [ToO alerts isotropic and random assumed hereafter:]
- Working hours reaction (MOC/SOC): 09:00-17:00, Monday-Friday
- Out-of-working hours reaction (MOC/SOC): 2 hours commutes twice per day
    - SOC staff able to perform trigger evaluation at home
- Agile spacecraft (4°/minutes slew & settle)
- 10 minutes instrument swap if the “wrong” instrument is observing
- 40 hours X-IFU cooling cycle, with 32 hours cool time and 8 hours regeneration time (main constraints on the ToO trigger response time and ToO exposure time)

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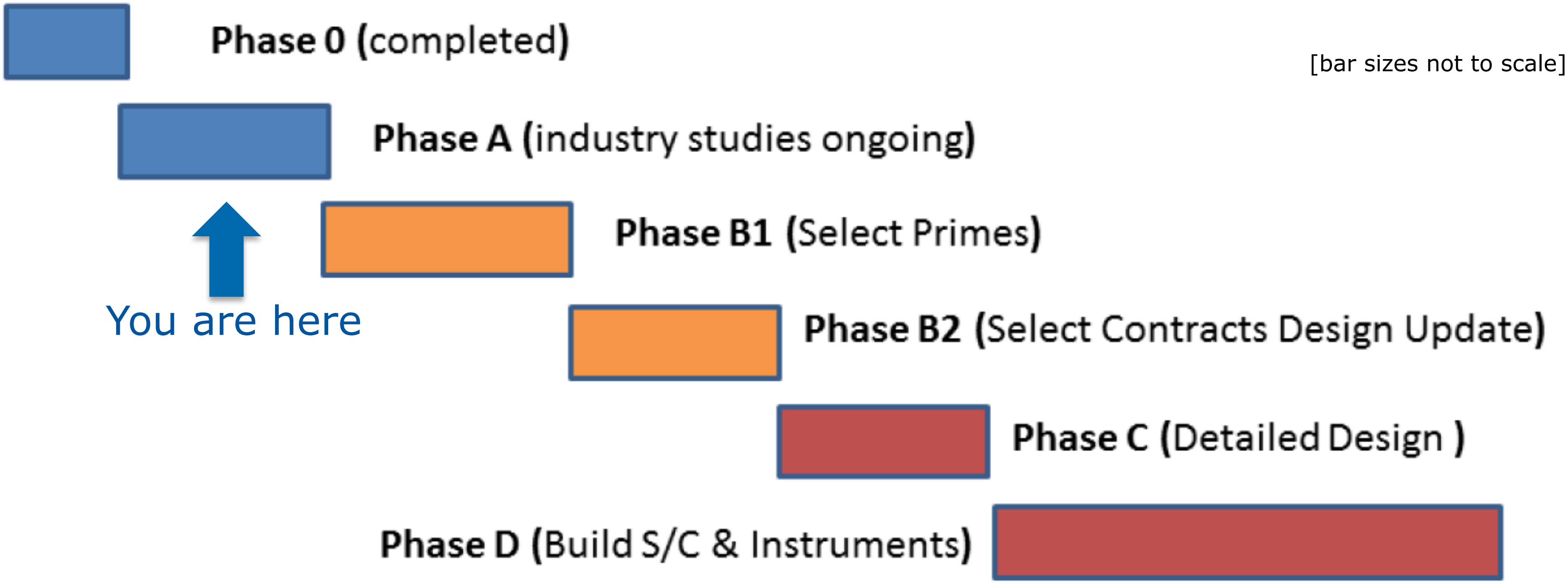
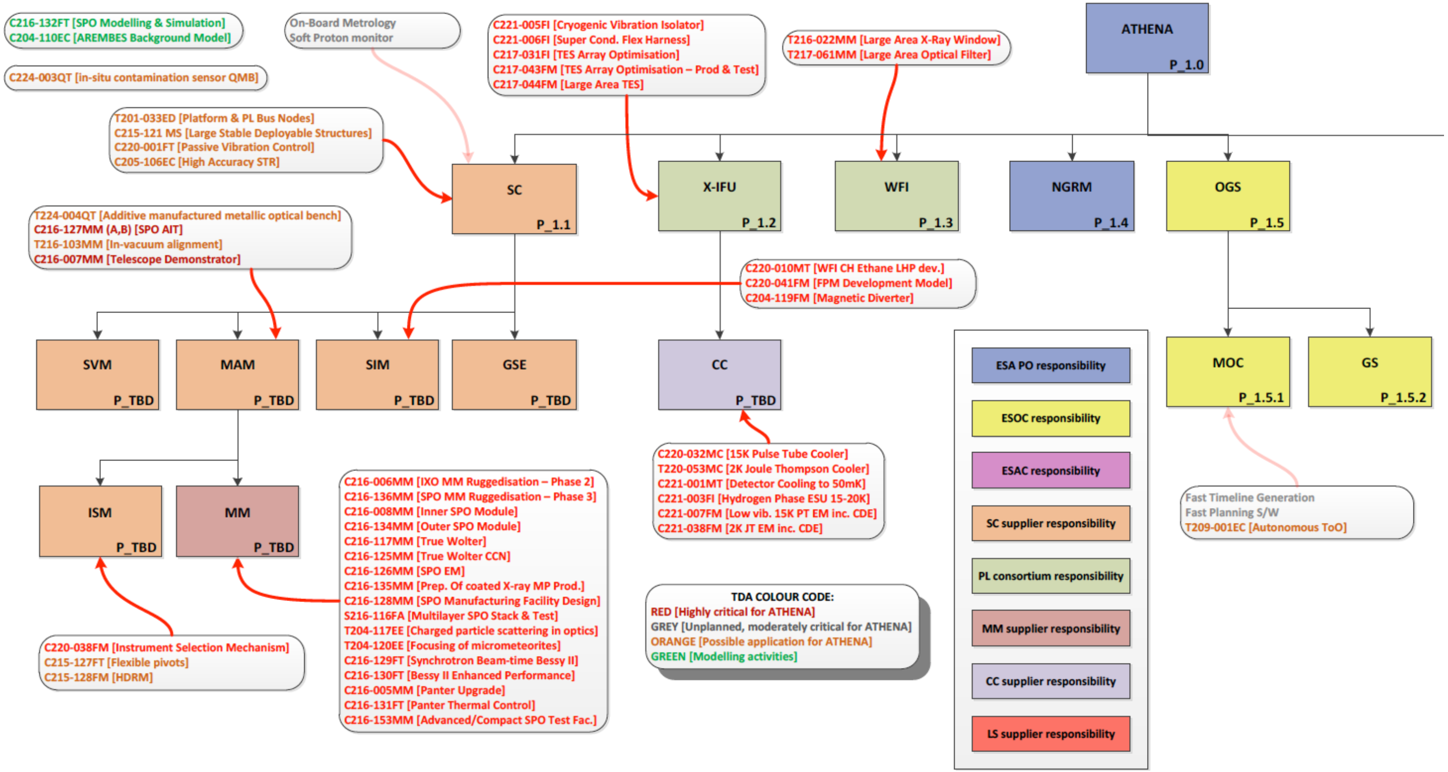
Athena overall schedule



Key date: adoption by the ESA Science Program Committee, **2020**

Athena-related technological activities



TRL* ≥5-6 before adoption

Key areas:

- Optics
- X-IFU Cryogenic Chain (CC)
- Background modeling
- Autonomous ToO

*Technical Readiness Level (scale 1-9: 5-6 is the level of “technology demonstration”)

MCR+ Delta (Δ) MCR – technical

Mission Consolidation Review (May 2016) + Delta MCR (February 2017)

Main **technical** conclusions:

- Mature mid-Phase A spacecraft design for all elements
- Mass constraint (7 tons) can be achieved with *at m*ost a minor reduction of the mirror diameter (corresponding to ~7% effective area @1 keV)
- High-load at the center of the mirror structure potential concern, but can be addressed with reliable technical solutions
- Complex SIM thermal control design, with high-level of dissipation (~3 kW) and ~no growth potential
- X-IFU thermal budget and instruments' mass budgets to be consolidated
- Launcher requirements still under definition (potential uncertainty)

MCR + ΔMCR - costs

ESA Cost-at-Completion (CaC) cap: **1.05×10^{9} €**

- Cost estimates systematically exceed the CaC cap over the whole Phase A
- Envelope of international contributions (JAXA/NASA) defined, unlikely to change
- The problem *must be addressed* ≤autumn 2017. Among the possible options:
    - More "aggressive" industrial cost policy
    - Transfer of SIM-related activities/responsibility ESA → others
    - Saving in operation (MOC/SOC) costs
    - Optimization of international contributions and/or new partners
    - Mission performance: mirror diameter/number of modules, field-of-regard, nominal operational life
        - Shared effort of the ESA Study Team and the Athena Science Study Team

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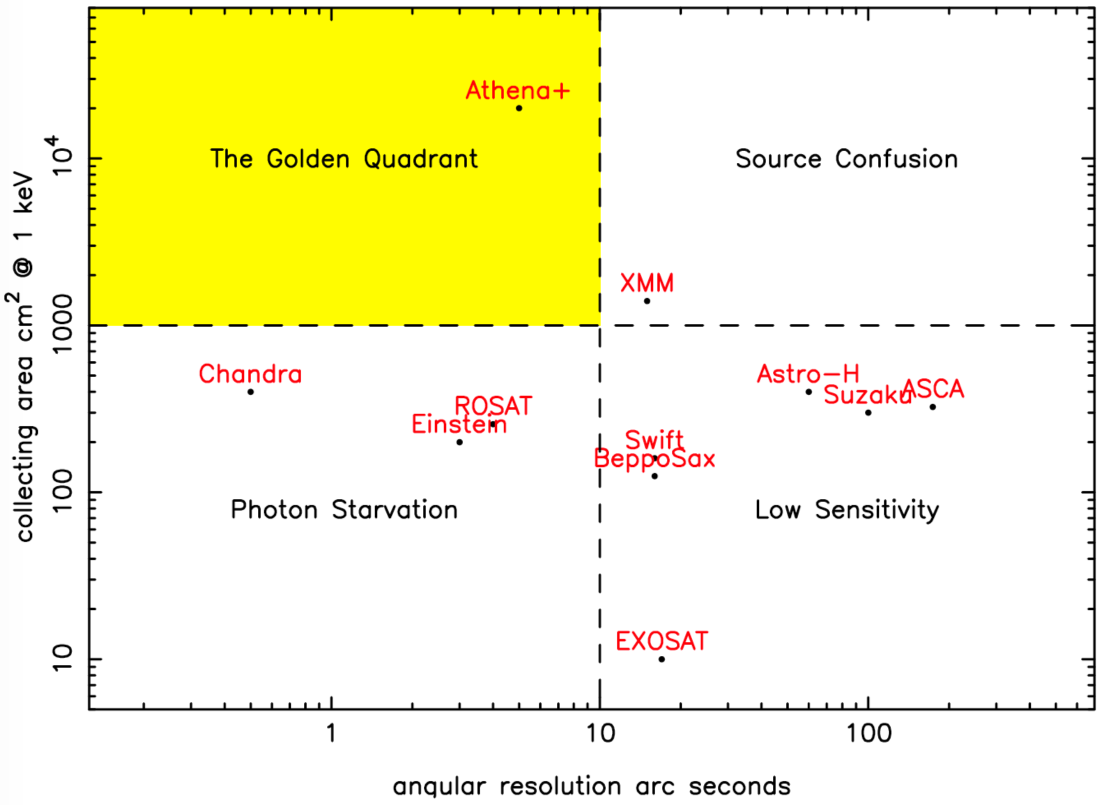
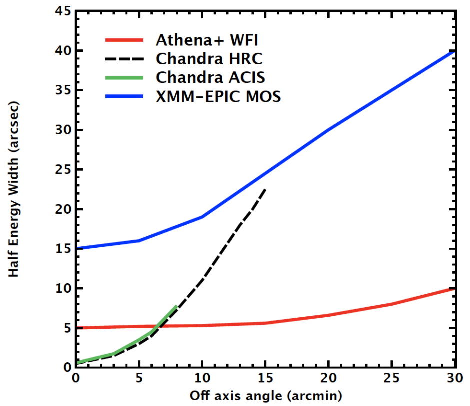
Athena mirror: a gold standard



Willingale et al, 2013, arXiv:1307.1709

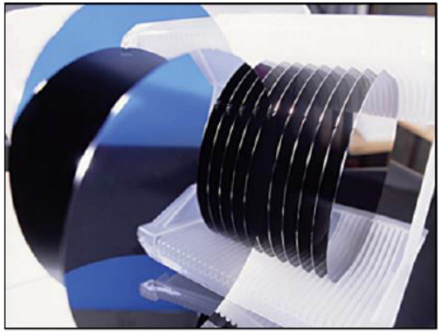
Key requirements:

- 1.4-2 m^2 area @1 keV
- 5″ HEW on-axis
- Graceful degradation off-axis (<10″ @20′)
- Limited vignetting @1 keV

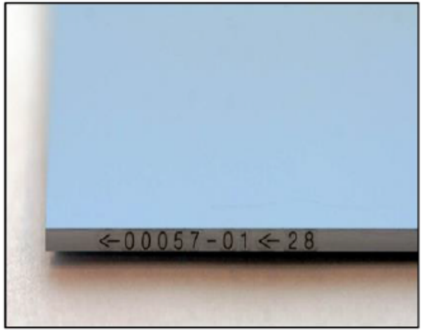


Silicon Pore Optics (SPOs)

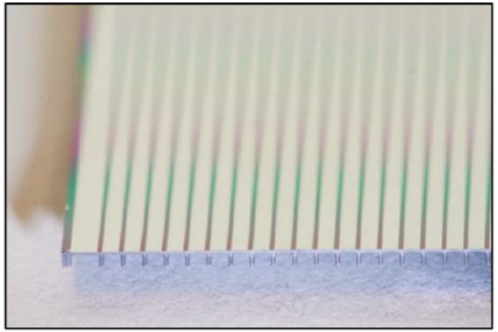
12" Si wafers



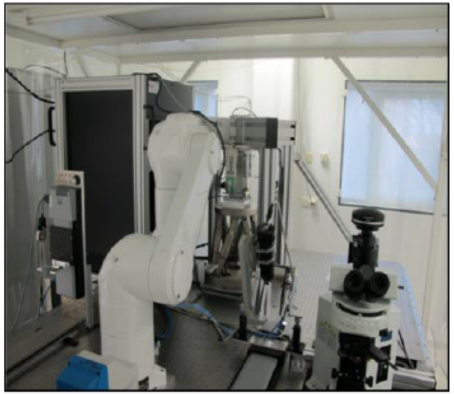
Dicing & Ribbing



Wedging & Coating

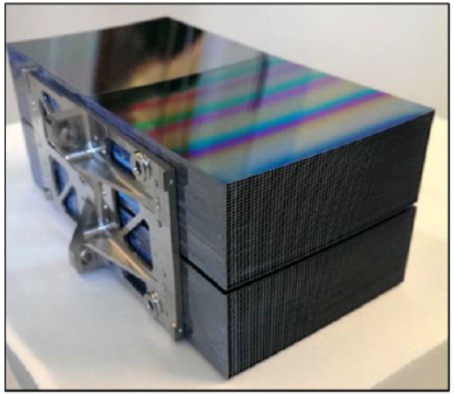


Edge-on zoom of a partial stack

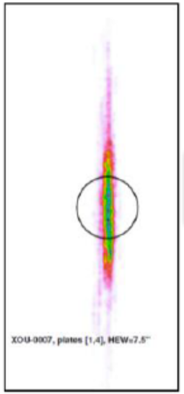


Automated stacking

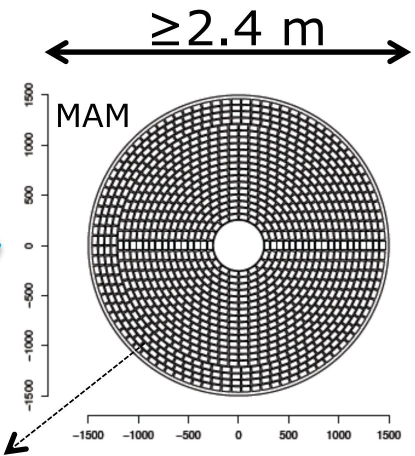
Stack



Mirror module



Testing

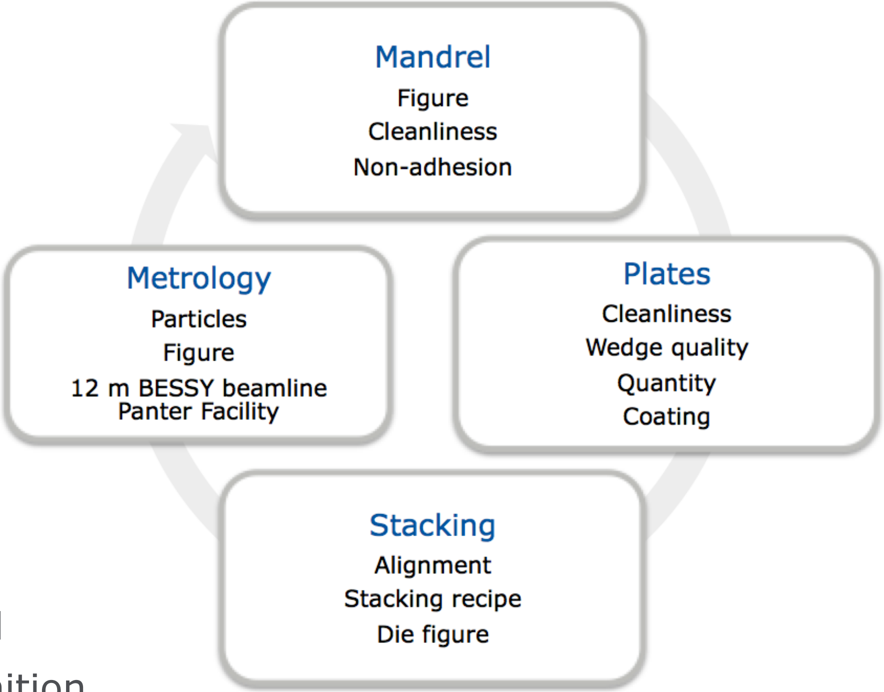


Mirror module (~10^3 in the MAM)

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

SPO development priority activities

1. **Improving the angular resolution**
   - Deposition of first and second plate
   - Optimized die design for different radii
   - Stacking recipe (pressure, duration)
2. **Increasing production rates**
   - Mirror plate production automation
   - Coating mass production
   - Stacking time reduction
3. **Environmental qualification**
   - Annealing of stacks
   - Shock and vibration testing on stack level
   - Qualification and acceptance criteria definition



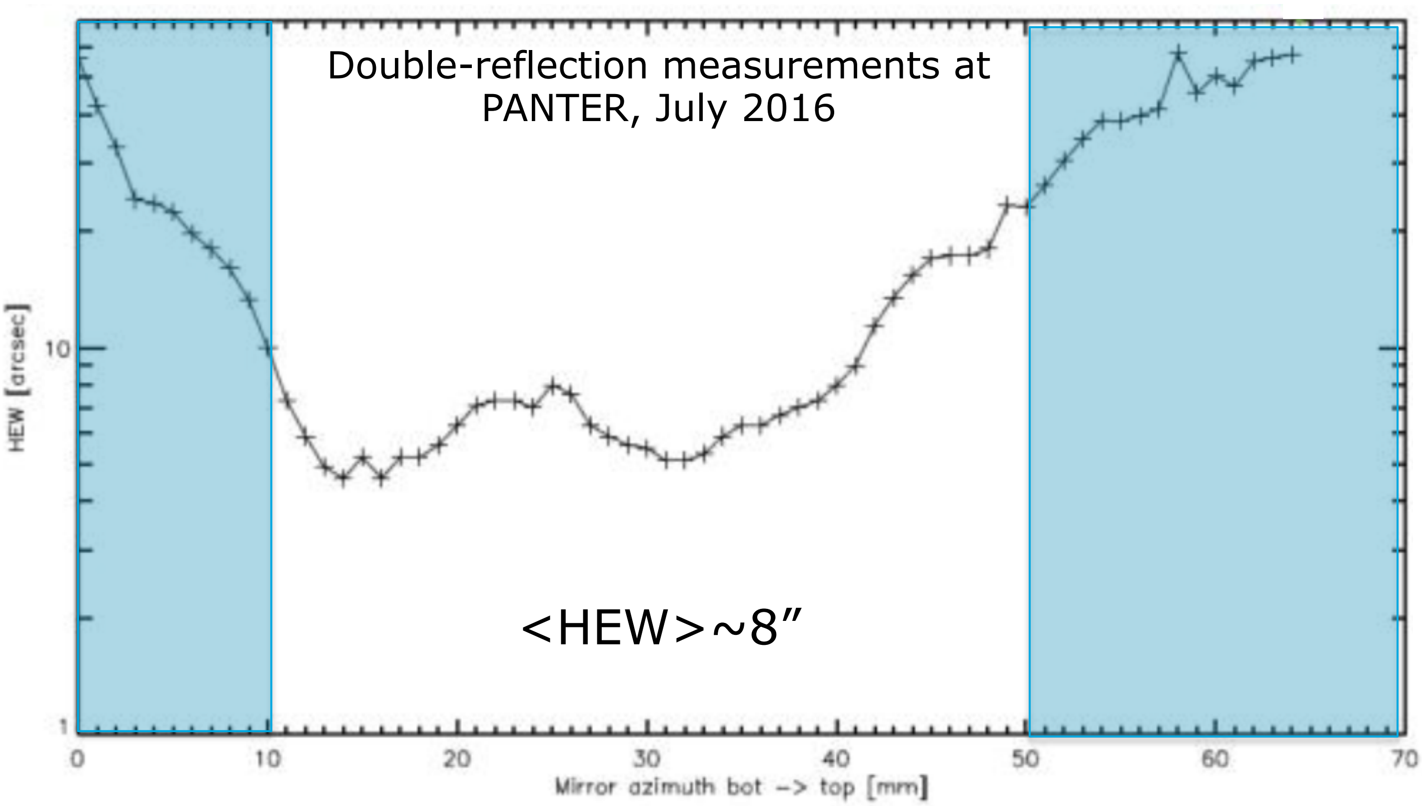
Bavdaz et al., 2016, SPIE, 9905, 27

Dedicated shock testing facility close to the stack production

Shaker facility

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

HEW per column (entire pair of stacks in ~Wolter I configuration)



<HEW>:~22″ in 2015 → 13.9″ in 2016

60% of the optics have a HEW of 8″

Best performance: ~5″

Consistent results at Bessy (2.8 keV) and Panter (1.49 keV)

→ J.De Bruijne's poster on the MAM calibration

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

Summary

- Athena is *the* contribution of the X-ray community to 2020s astrophysics
- It will represent a ≥order-of-magnitude performance improvement (in several parameter spaces) with respect to any existing or approved X-ray missions
- Unique combination of effective area, energy/spatial resolution, *and* FoV
- The Phase A study has confirmed the technical feasibility, with a maturity level adequate to the current Study phase
- Need to optimize the mission profile/performance/international contributions to fit the CaC cap – to be done *now*!
- Intense SPO optics development to: a) continue the current rate of performance improvement; b) achieve production rates and quality standards adequate for Flight Module production