The Advanced Telescope for High Energy Astrophysics (Athena)

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On behalf of the Athena Science Study Team, the Athena Community, the X-IFU Consortium, and particularly CNES for taking the responsibility of delivering X-IFU

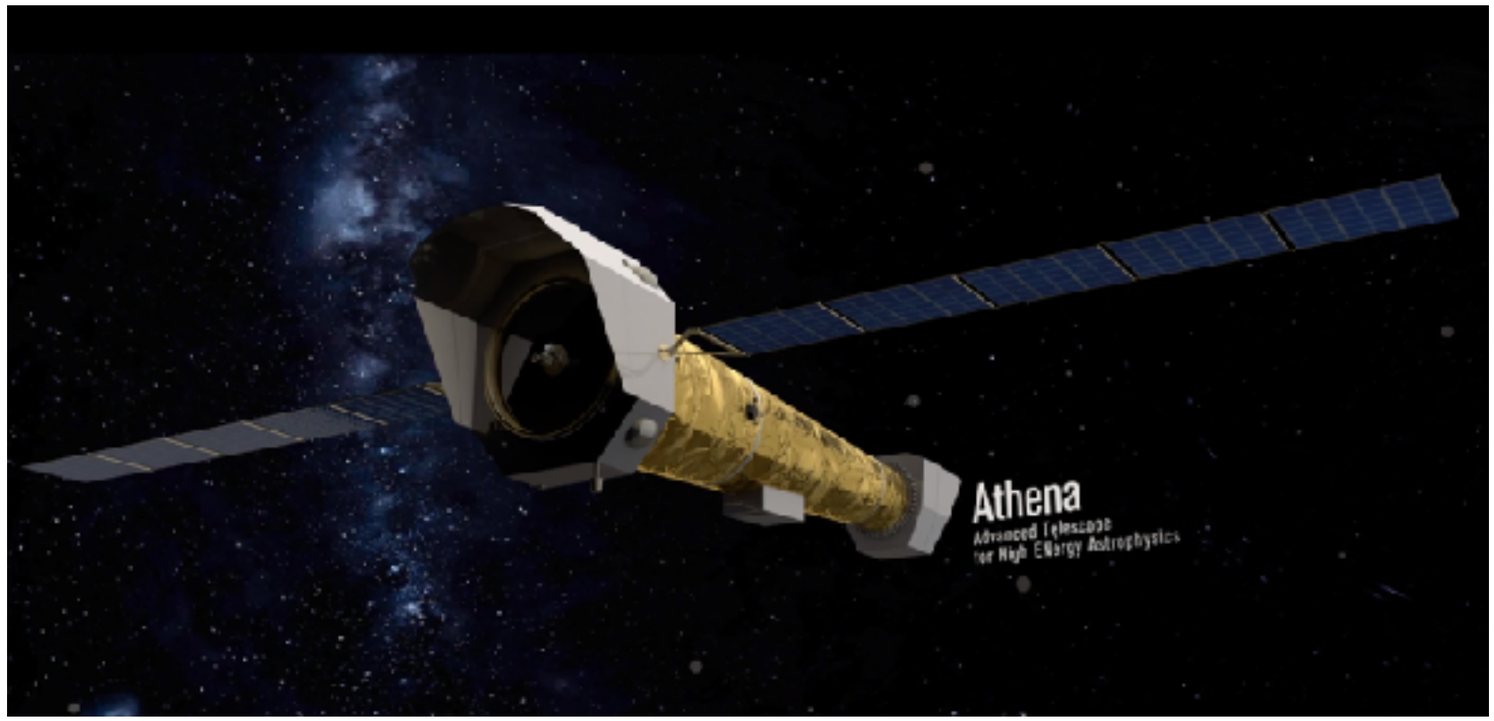
Atelier PNHE, September 15th, 2021

Conclusions to start

- Athena is your next large X-ray observatory: this is a flagship mission of ESA, with contributions from NASA and JAXA
  - XMM-Newton, Chandra and XRISM will fill the gap before Athena and keep the high energy community engaged
- Athena has revolutionary capabilities
  - Spatially resolved high resolution X-ray spectroscopy
  - Wide field X-ray imaging
  - Bright source capabilities up to 1/10 Crab with 10 eV/100 eV spectral resolution
  - Rapid response time for targets of opportunities
- Athena will operate simultaneously with large ground/space based facilities, e.g. CTA, ESO telescopes including ELT, KM3NET, GW/LISA, SKA, Rubin Observatory…
  - Synergies are being worked out and will likely lead to key programs
- Athena approaches its final adoption in the ESA Science Program, with the mission profile, including performance parameters, to be set for the "red book" (Q1/22)
- Thanks to PNHE for its unfailing support to Athena
  - A thematic school on the preparation of Athena, funded by CNRS, is being planned

Athena in a nutshell

- Athena: Advanced Telescope for High ENergy Astrophysics
  - The big X-ray observatory after the great XMM-Newton and Chandra, after XRISM
- Second Large mission of the European Space Agency Cosmic Vision Science program (before and possibly operating simultaneously with the LISA mission)
  - NASA and JAXA enabling contributions to the mission and the payload
- Dedicated to The Hot and Energetic Universe
  - With broad impacts in many corners of astrophysics: stars, galaxies, planets… which define the Observatory science of Athena

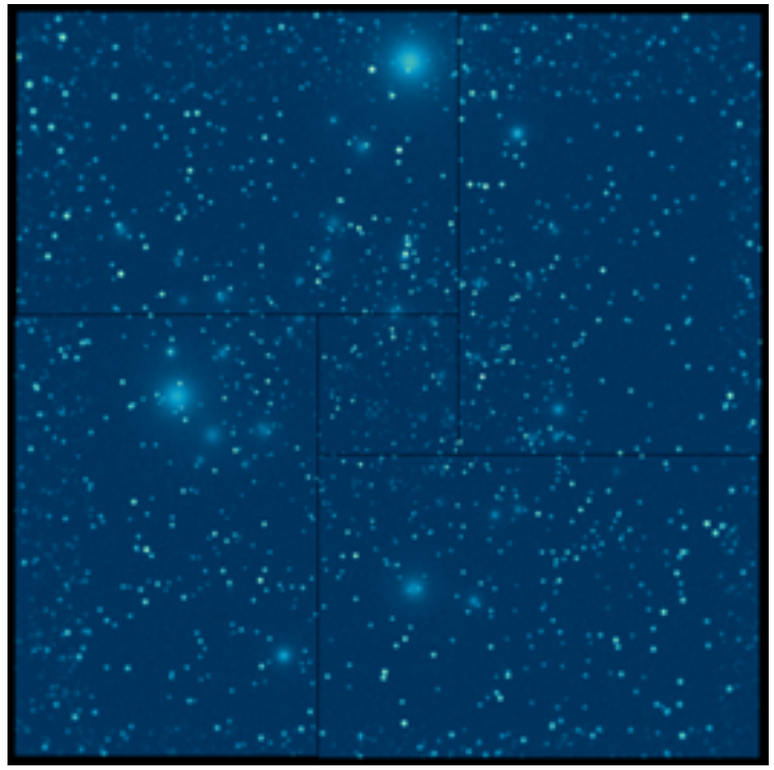


Athena in a nutshell

- A large aperture movable X-ray telescope (ESA)
- Two focal plane instruments
  - A **Wide Field Imager** (WFI, PI: K. Nandra, MPE, DE)
  - An **X-ray Integral Field Unit** (X-IFU, PI: D. Barret, IRAP, FR)
- Making up a very powerful observatory available to the world wide community through a Guest Observer program

WFI simulated image

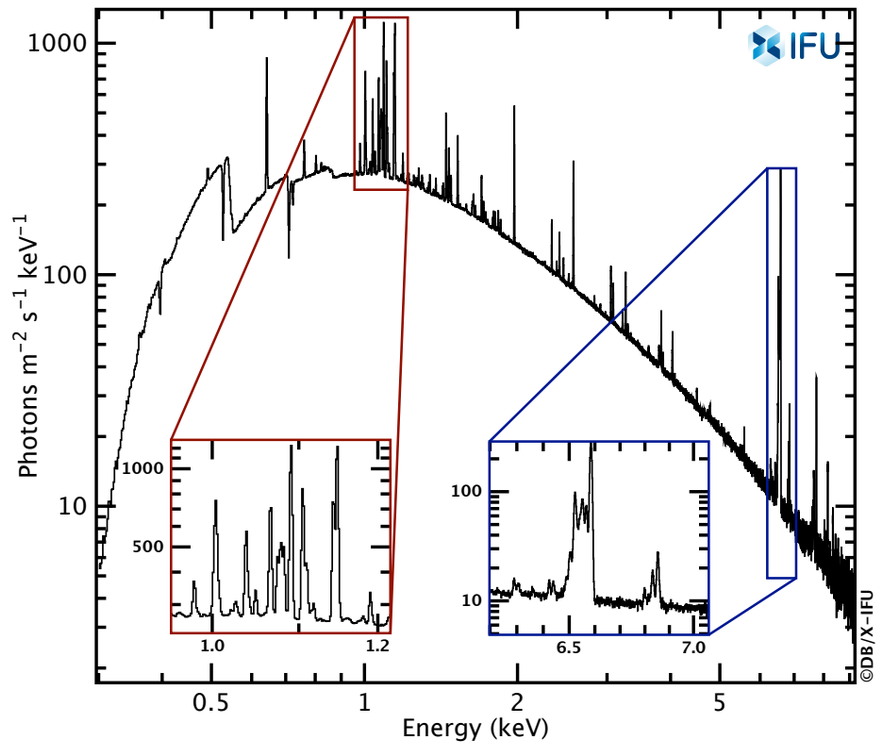
Hundreds of sources per image



Credits: WFI team

X-IFU simulated spectrum of a Perseus like galaxy cluster.

Hundreds of lines per spectrum

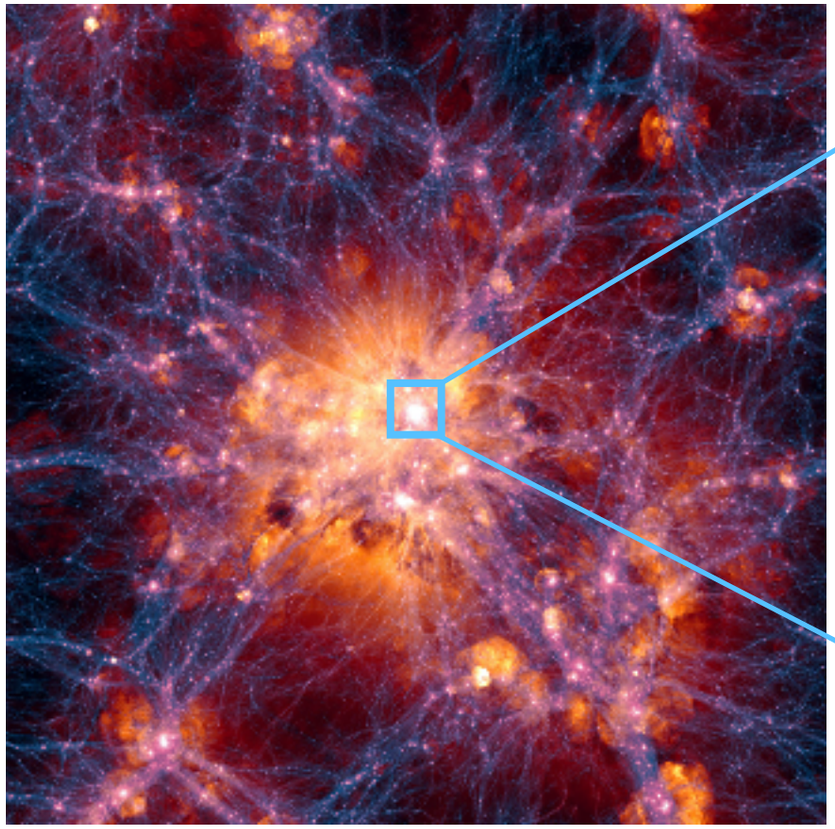


Credits: X-IFU team (data courtesy of C. Pinto and A.C. Fabian)

The Hot Universe

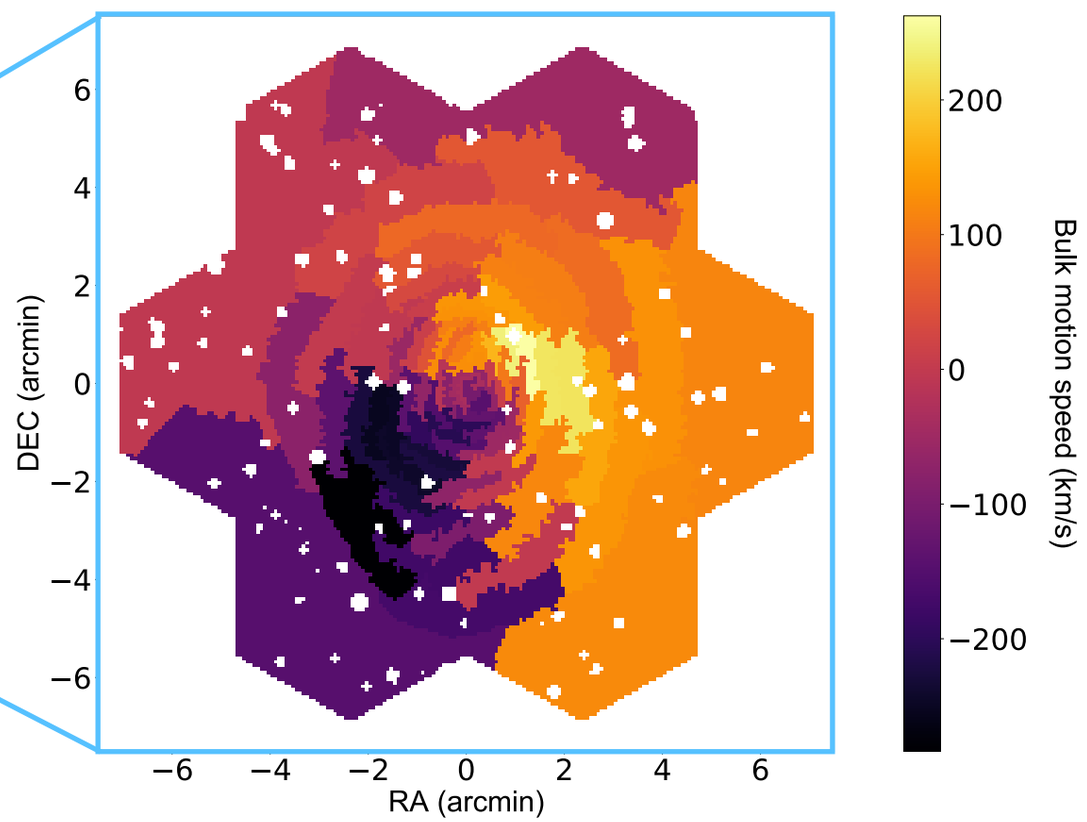
- How has the Universe evolved from the dark ages to today?
  - Tracking the formation, the dynamical and chemical evolution of the largest scale structures from the first galaxy groups to the massive clusters of the local Universe
    - ➡ X-ray probe : Hot X-ray emitting gas trapped in dark matter potential wells
  - Key parameters: Density, temperature, velocity, metal abundance, surface brightness,…

Cosmological simulations : the distribution of dark matter is shown in blue and the gas distribution in orange.



Credits Illustris Collaboration

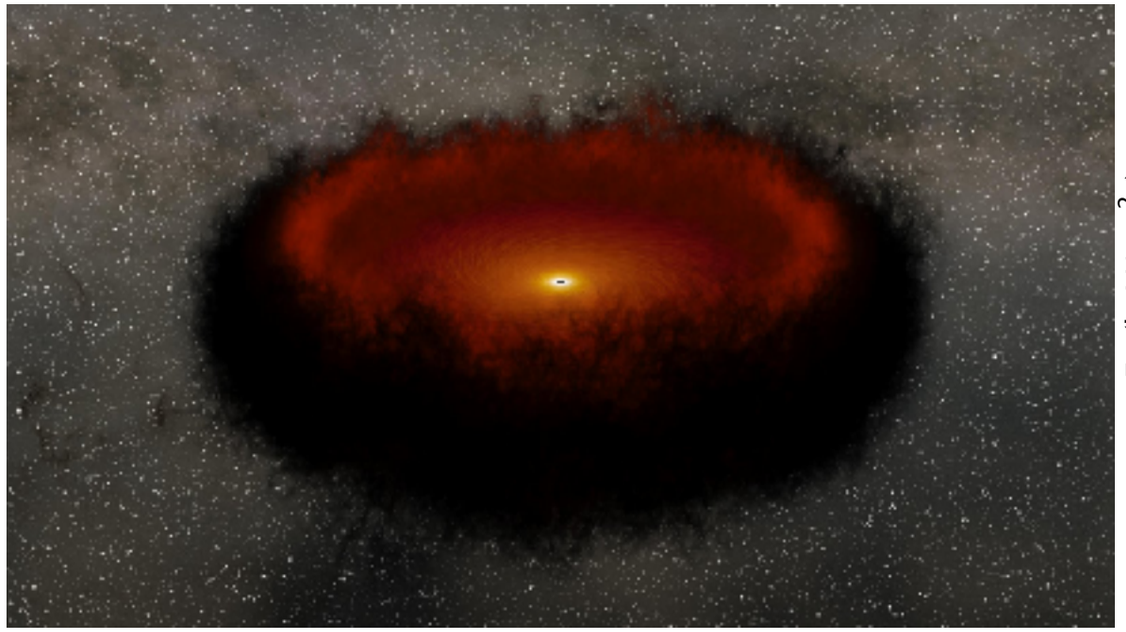
Bulk motion X-IFU map derived from cosmological simulations. White dots mask background AGN



Cucchetti et al. (2018, A&A)

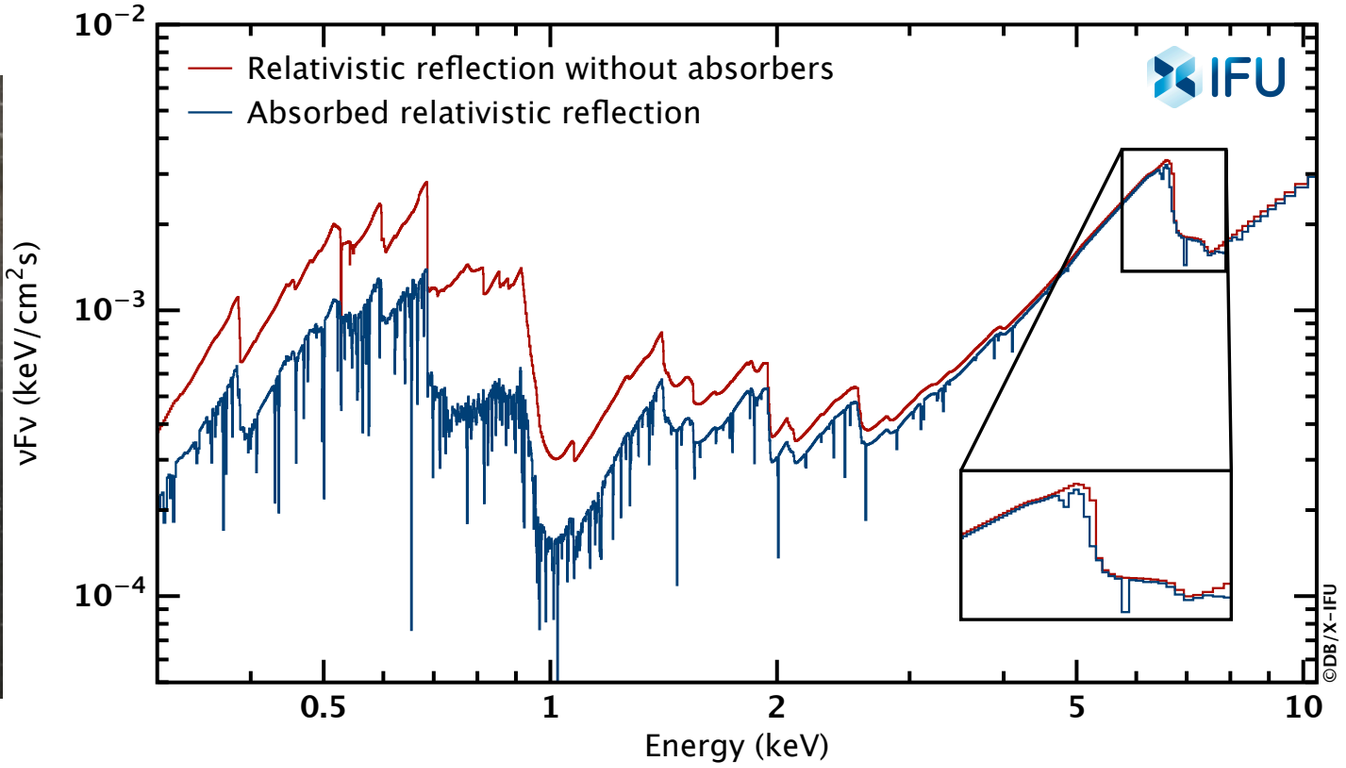
The Energetic Universe

- How do black holes work and shape the Universe at all scales?
  - Probing accretion/ejection processes & interactions with the surroundings
    - ➡ X-ray probes : Disturbed hot gas in clusters & Accretion powered X-rays generated around black holes at all redshifts, across the redshift, mass, luminosity scales
  - Key parameters: relativistic broadening, energetics, velocities, outflowing gas physical properties,…



Black Hole Accretion Disk and Torus

Image Credit: NASA/JPL-Caltech



Relativistic reflection in AGN spectra, as well as absorption by matter surrounding the black hole, e.g. torus

Barret & Cappi (2019, A&A)

Didier Barret (IRAP, Toulouse, France, @DidierBarret)

Additional breakthrough science — *for free*

- From solar system planets, stars, supernovae, binaires across the mass scales, up to new physics
  - Interaction of the Solar wind with the planets (auroral and disk emissions)
  - Ultra-fast outflows from the brightest X-ray sources of the sky

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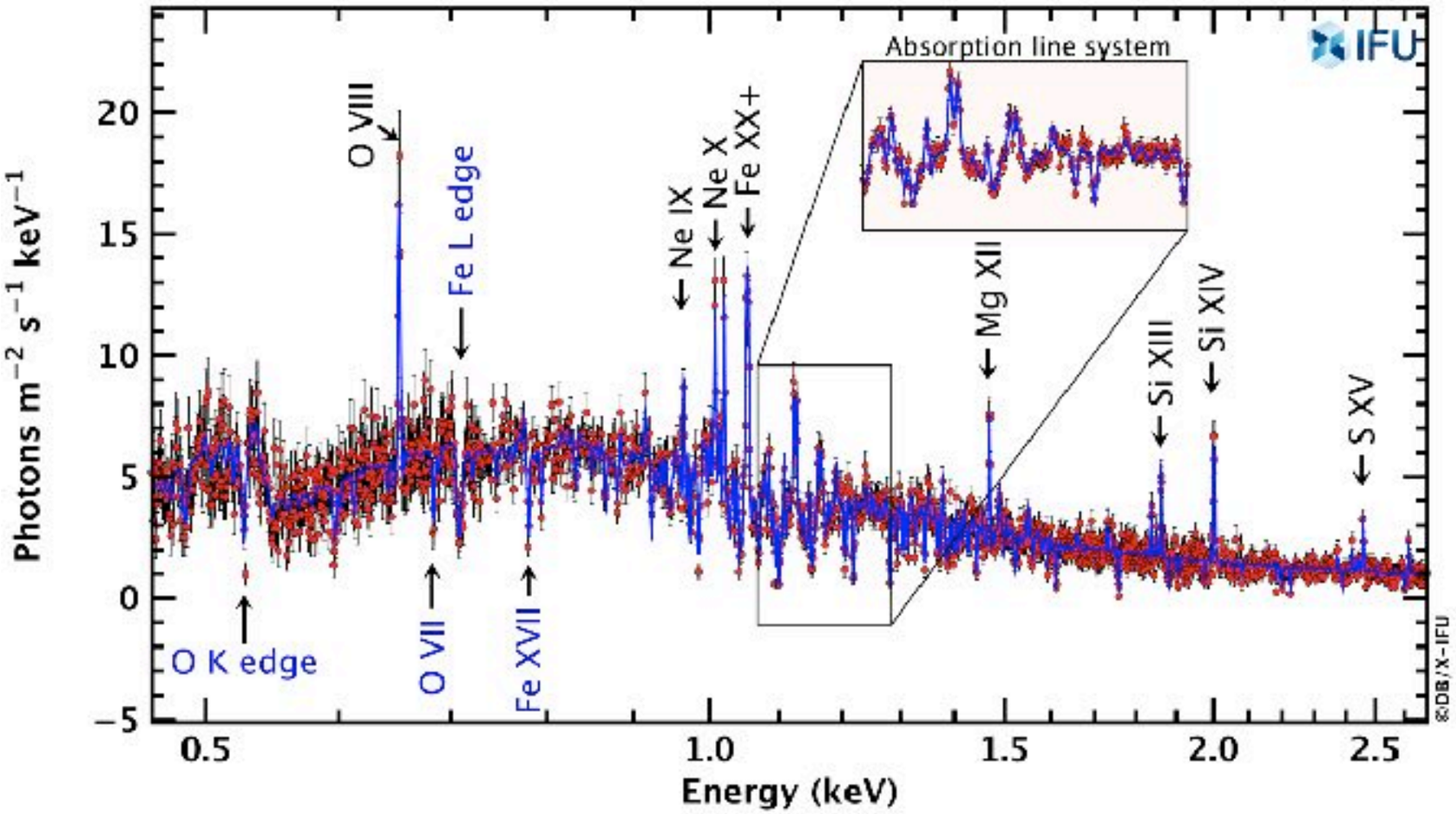
25 kilo-second simulated observation of the Ultra-Luminous X-ray source NGC1313 X-1. Power law model absorbed by an ultra-fast outflowing gas in photo-ionization equilibrium with velocity of 20% the speed of light. Emission lines are produced by a 1.3 keV collisionally-ionized equilibrium plasma

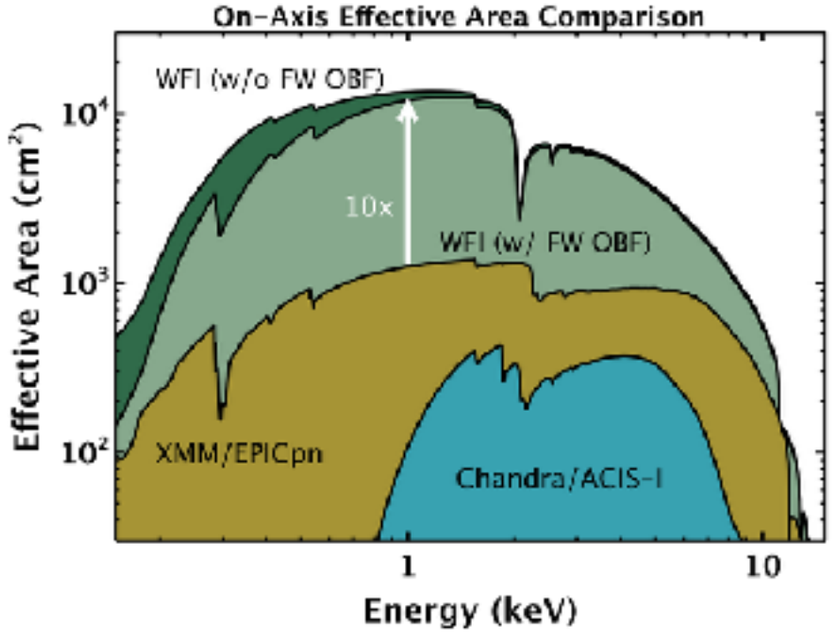


Pinto, Ciro, Middleton, Matthew J. and Fabian, Andrew C. 2016, "Resolved atomic lines reveal outflows in two ultraluminous X-ray sources", Nature, 533, 64P. The data for the plot are courtesy of Ciro Pinto (12/2018).

The Athena science payload : Mirror

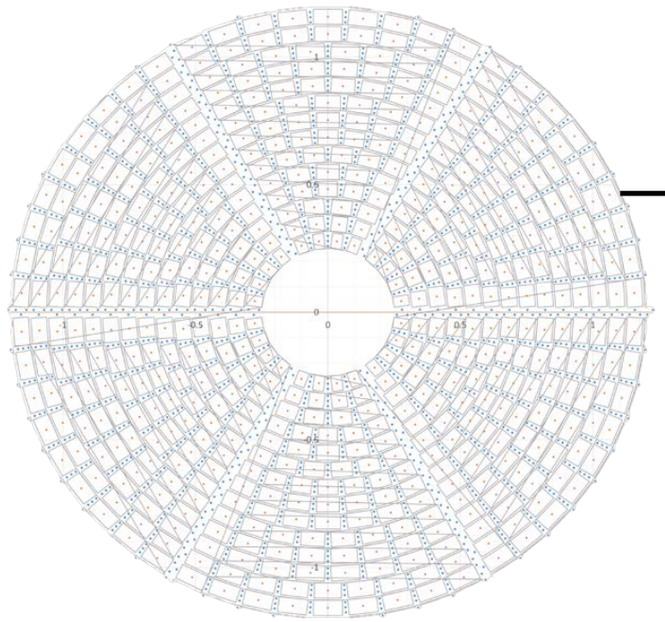
The mirror assembly — ESA

- Silicon Pore Optics developed by Cosine through ESA funding
- 1.4 m² @ 1 keV
- 0.25 m² @ 6 keV
- 5'' (HEW)
- Mirror can tilt and change in focal length
- ~ 600 mirror modules assembled in 6 petals



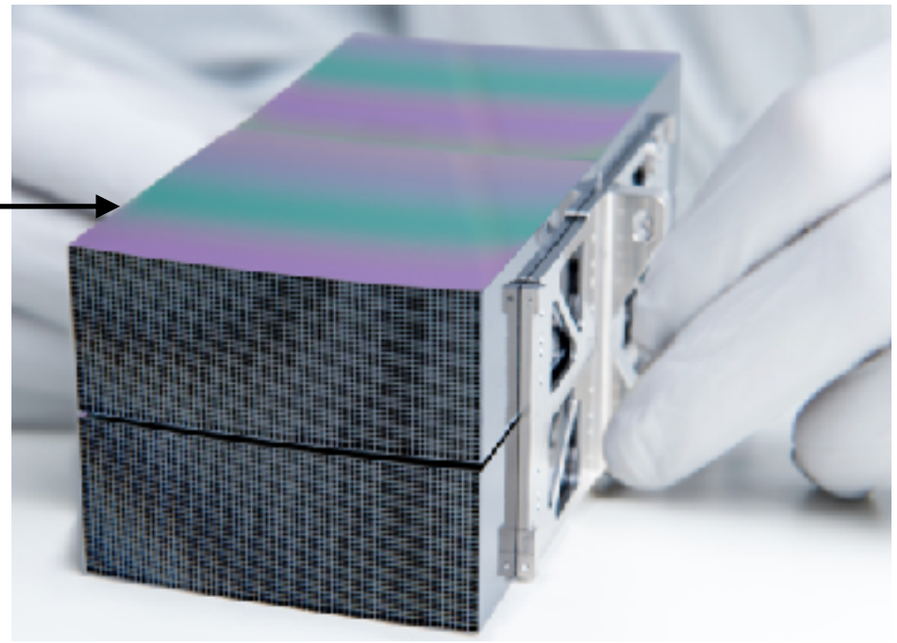
Credits (WFI team)

The Athena X-ray mirror assembly holding ~600 mirror modules



Credits ESA and D. Willingale

A SPO mirror module

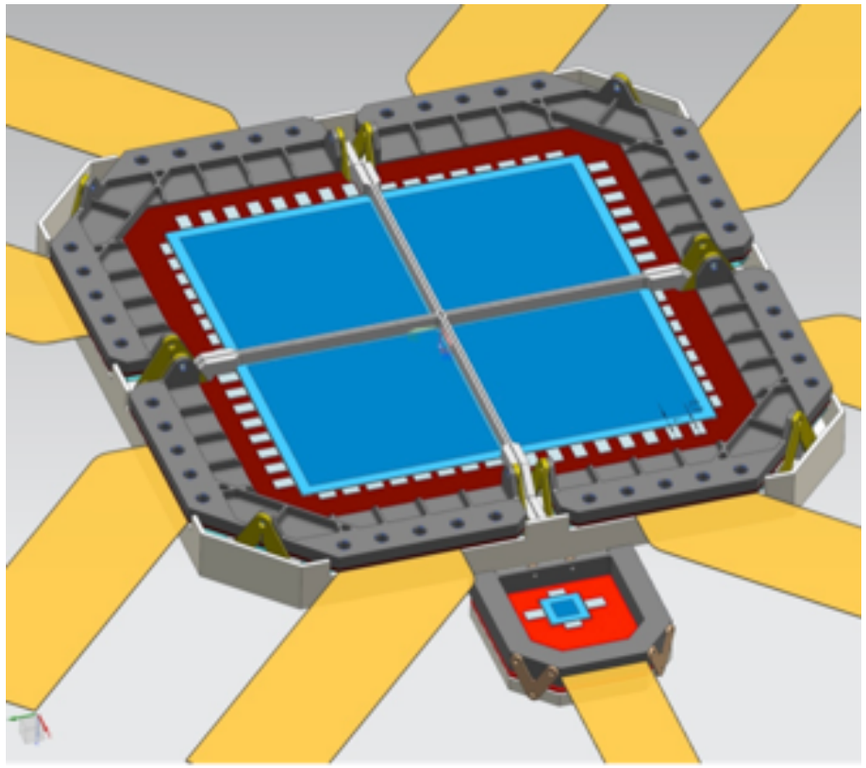


Credits ESA and Cosine

The Athena science payload: WFI

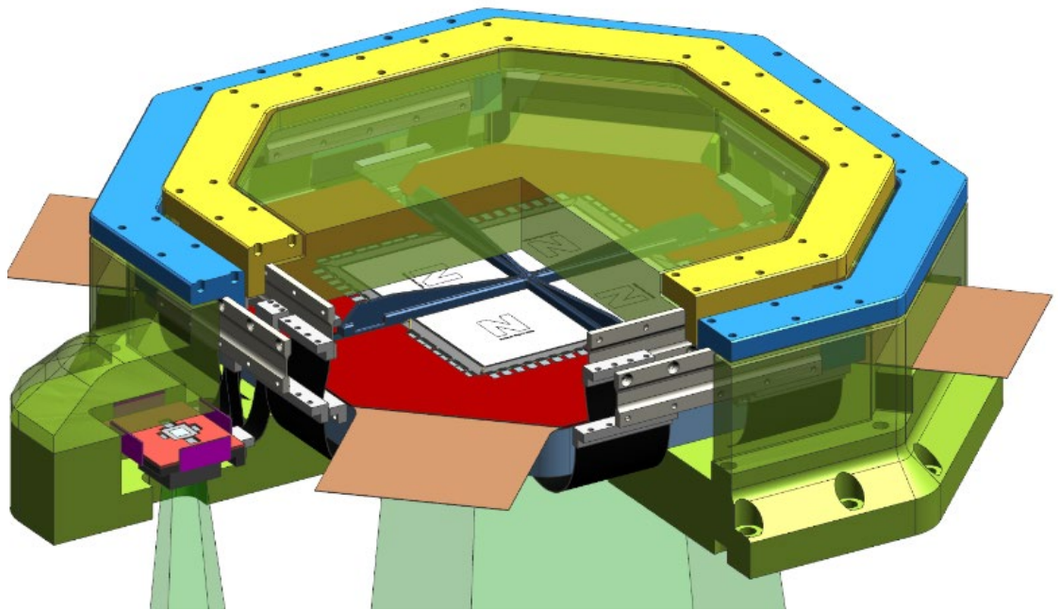
Wide Field Imager (WFI)
Silicon Active Pixel Detector based on DEPFET technology
Field of view: 40´×40´ square
2.2´´ pixel size (PSF oversample)
Spectral resolution <80 (<170) eV @ 1 (7) keV
Separate chip for fast readout of brightest sources up to 10 Crab intensity
Consortium led by MPE, with other European partners (DE, AT, DK, FR, IT, PL, UK, CH, P & GR) and NASA

The 4 WFI chips together with the fast detector chip



Credits: Credits: MPE and WFI team

The mechanical layout of the WFI instrument



Credits: MPE and WFI team

The Athena science payload : X-IFU

X-ray Integral Field Unit (X-IFU)

Large format micro-calorimeter array (Transition Edge Sensors)

2.5 eV spectral resolution up to 7 keV

5′ hexagonal field of view (equivalent diameter)

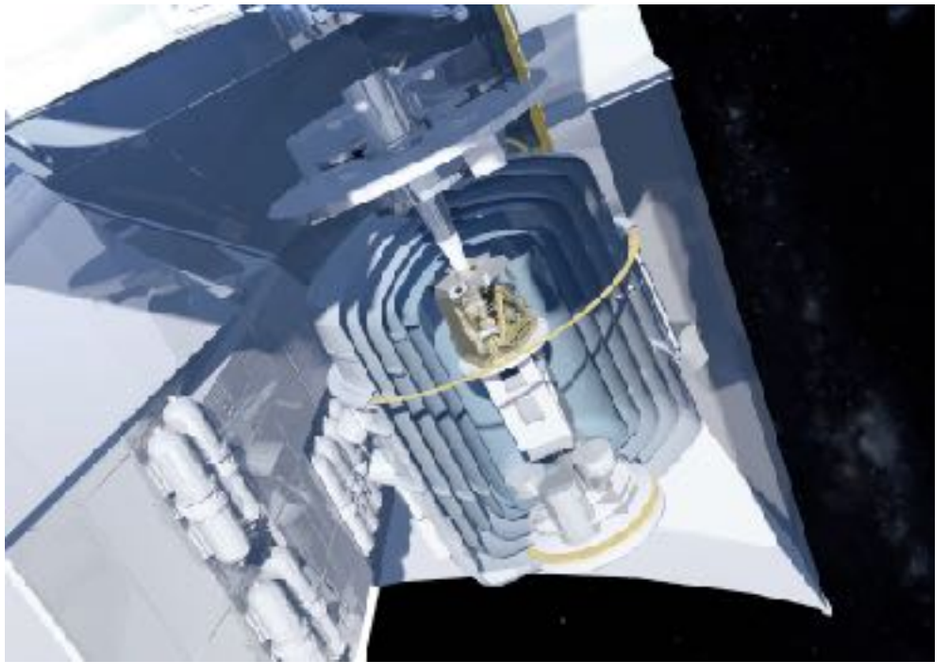
Low background thanks to active cryogenic shielding

Capability to observe bright sources thanks to the mirror defocussing (1 Crab, 10 eV, 5-8 keV)

Cryogenic instrument cooled down to 50 mK by a multi-stage cryogenic chain

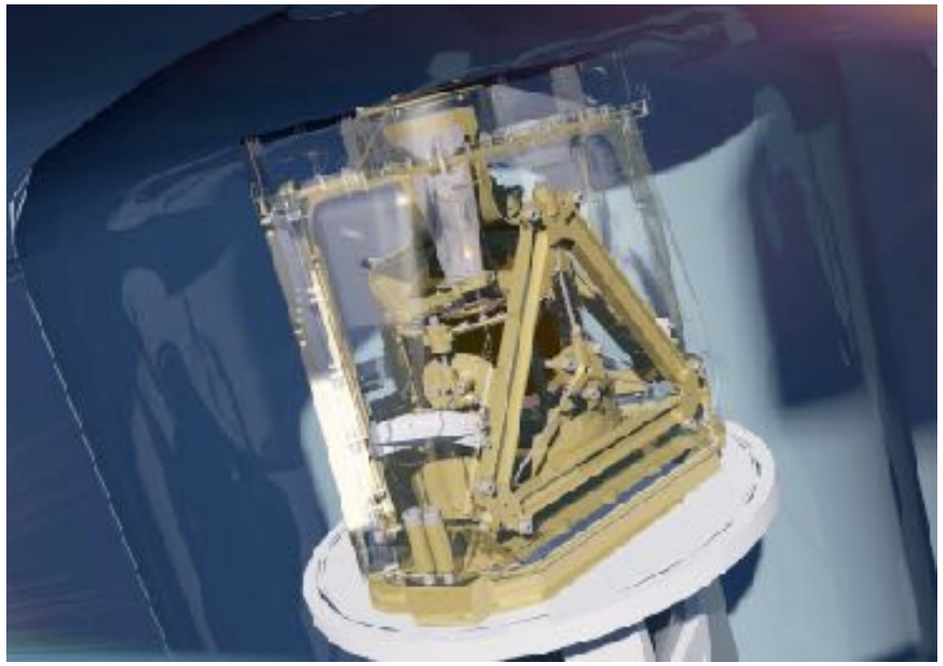
Consortium led by IRAP/CNES-F, with NL and IT and further ESA member state contributions from BE, CZ, FI, DE, IR, PL, ES, CH and contributions from the United States and Japan

The X-IFU cryostat



Credits: X-IFU team

The X-IFU Focal Plane Assembly

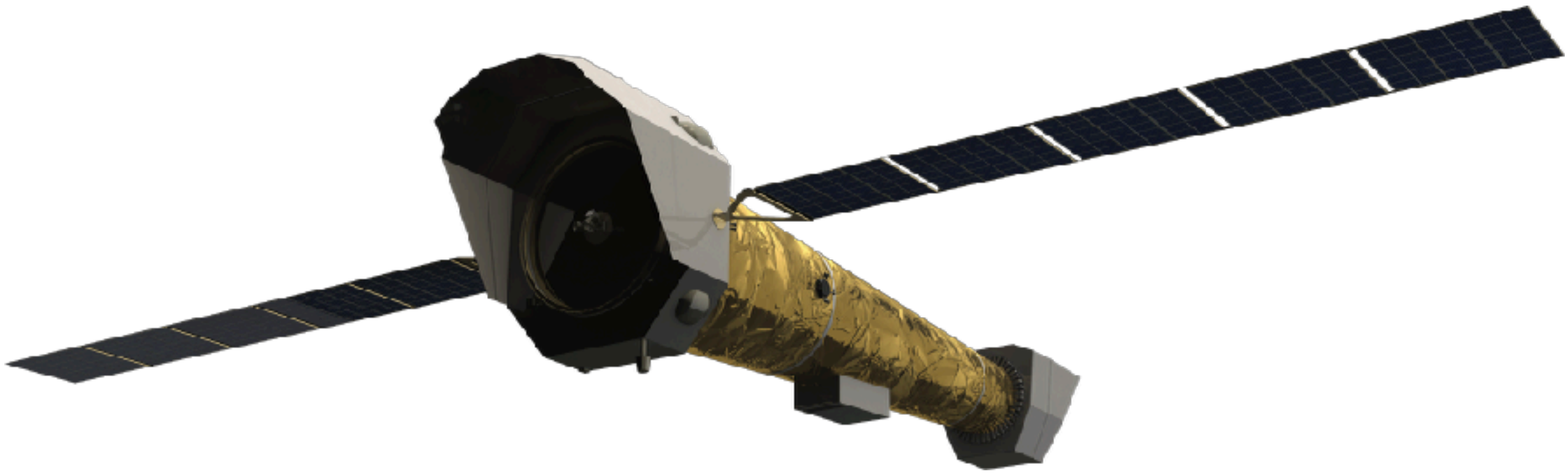


Credits: X-IFU team

The Athena spacecraft

- Large satellite
  - with a mass of about 7.2 tons (X-IFU ~ 1 ton)
  - a focal length of 12 meters (and total height about 15 meters)
- Agile satellite to respond to ToO alerts in a few hours, e.g. GRBS, multi-messengers
- Mission lifetime: 4 years with consumables/mechanical parts designed for 10 years
- Launched in 2034 by Ariane 6 to a halo orbit @ L1 for stable and known environment

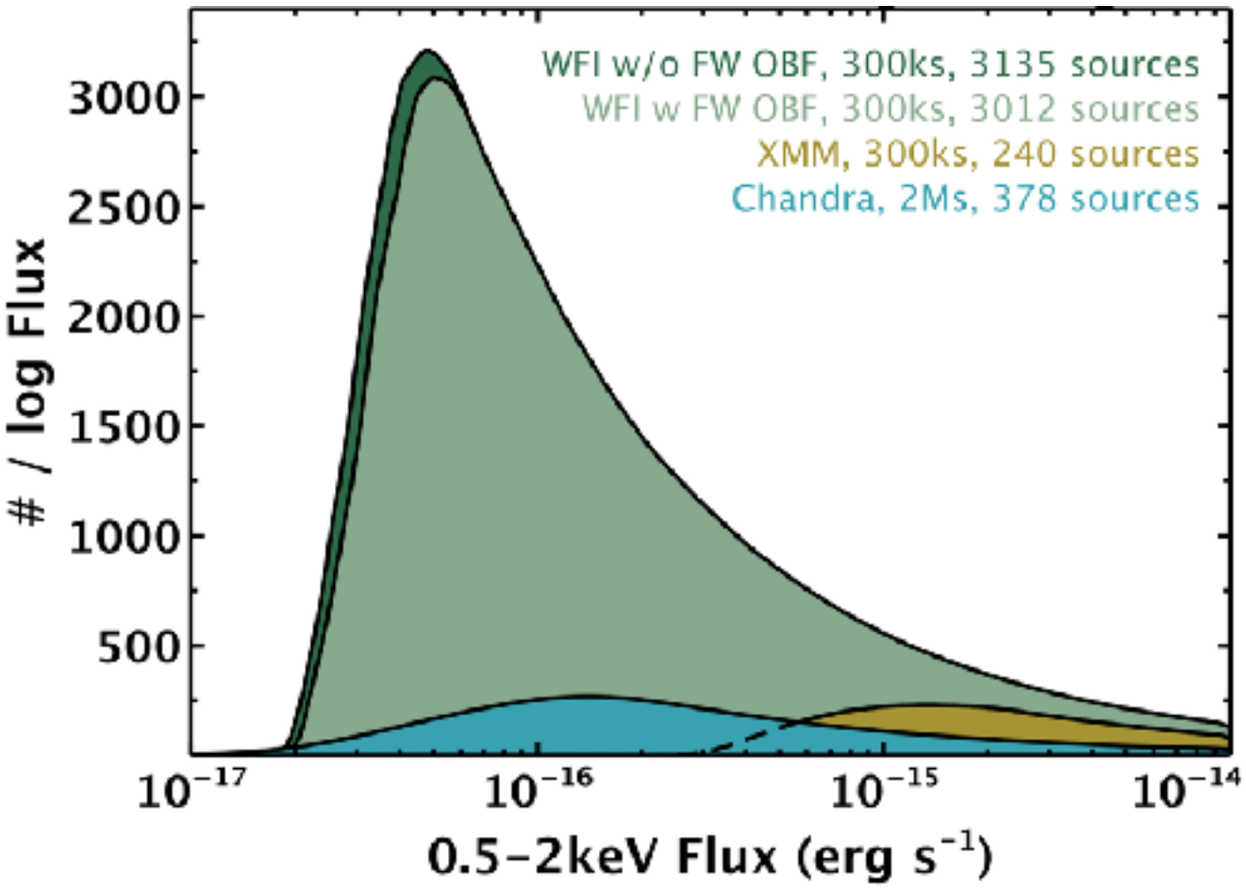
The Athena satellite



Credits : ESA & X-IFU team

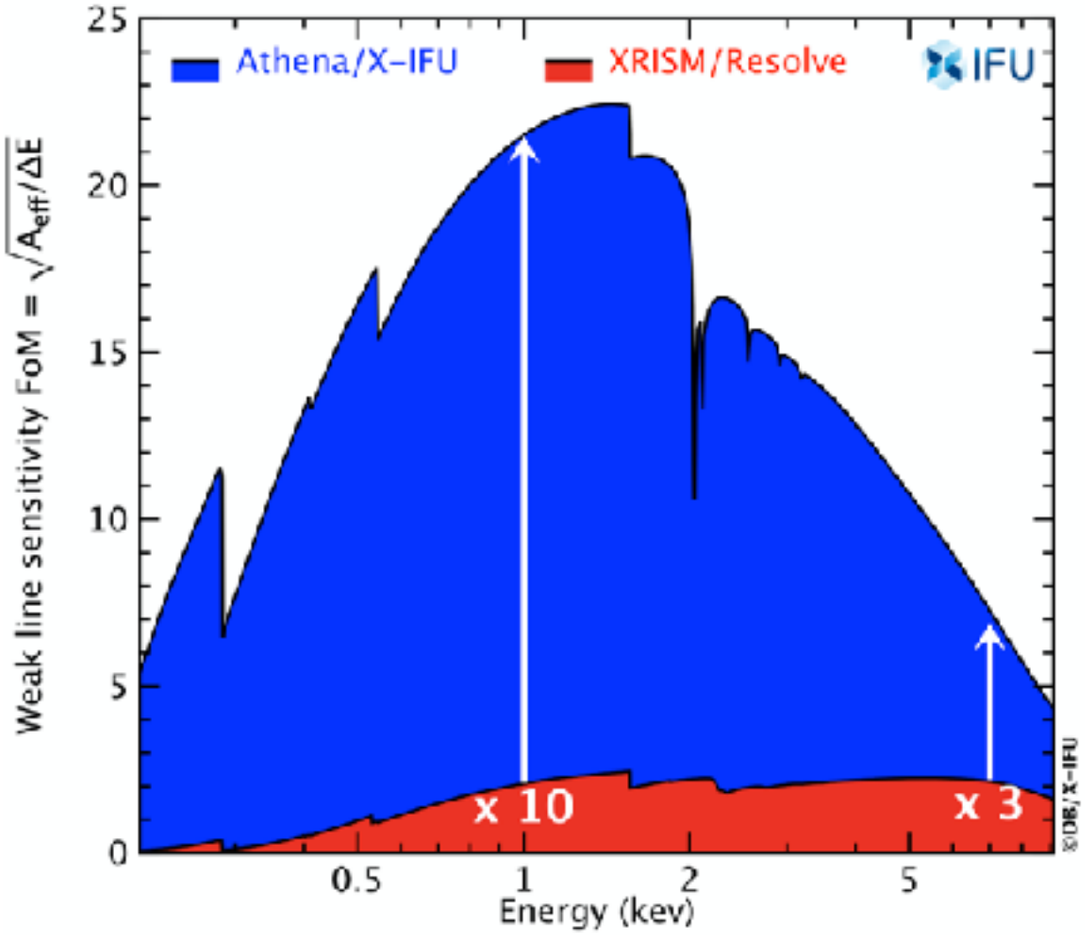
Key performances

WFI survey speed given as the number of sources in the images for different exposure times



Credits: Credits: MPE and WFI team

Weak line sensitivity folding in the effective area of the mirror and the spectral resolution of the instrument



Credits: IRAP and X-IFU team

- A leap by at least an order of magnitude in sensitivity over current or planned facilities
  - About 8 times more sources pointing in ~7 times shorter exposures with WFI (compared to Chandra)
  - 10 times weaker lines detected with X-IFU (compared to XRISM) and the capability to observe bright sources (up to 1 Crab intensity, with spectral resolution less than 10 eV)

Current status

- Both WFI and X-IFU are still designed against their original performance requirements
  - But pressure high to reduce the mass of the two instruments in view of the upcoming adoption of the mission
- Latest report on the optics indicate 10″ has been reached (twice the requirement)
  - Latest round of optimisation to be performed prior to adoption
  - ESA believed that 8″ could be considered for the red book
    - ➡ A sensitivity analysis concluded that a resolution of 6.5″ has a clear negative impact on a number of Athena science objectives using WFI (high-z AGN), with the impact considered very severe if the HEW were to degrade to >8″
    - ➡ Angular resolution degradation of lower impact for X-IFU, which on the other hand would suffer more for a non compliance of the effective area at both 1 and 7 keV. Technology demonstration activities on-going to recover the short fall
- Demonstration activities on critical technologies for X-IFU/WFI are ramping up, but key performances demonstrated already, e.g. X-IFU spectral resolution
- Preparation of the so-called "red book" in support of mission adoption (Q1/22)
  - To be supported by community driven Astronomy and Astrophysics papers (>Q4/22)
- Mission adoption planned for November 2022

Conclusions

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