The Athena X-ray Observatory

focusing on diffuse X-ray sources

Didier Barret

X-IFU Principal Investigator

Directeur de Recherches

Institut de Recherche en Astrophysique et Planétologie

CNRS, UPS, OMP, CNES

dbarret@irap.omp.eu

@DidierBarret

Astrophysics of hot plasma in diffuse X-ray sources, ESAC, Madrid, June 12-14th, 2019

Conclusions

- Athena is your next large X-ray observatory
- Athena has revolutionary capabilities
  - Spatially resolved high resolution spectroscopy
  - Wide field imaging
- Athena is on the safe path for a launch in the early 2030s

Outline

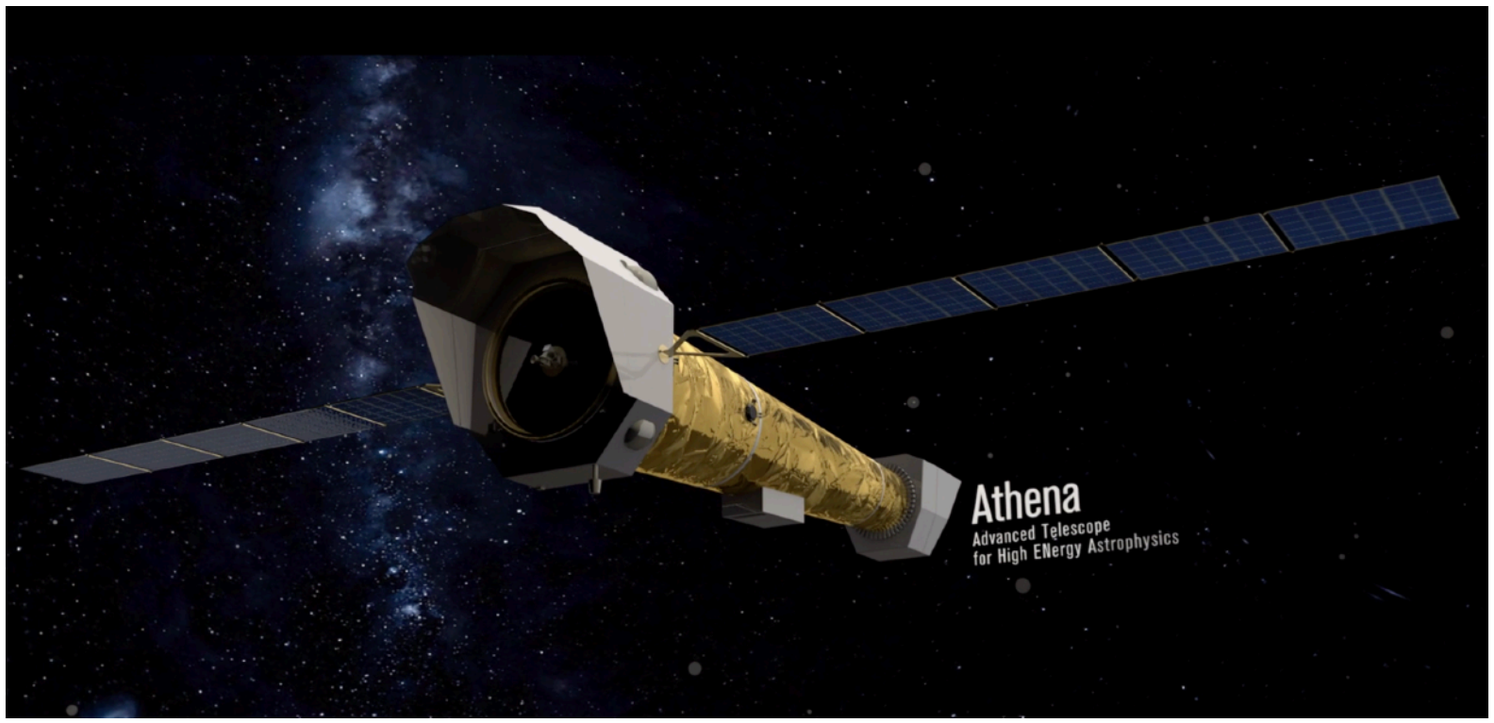
- Conclusions
- Athena in a nutshell
- Athena science on diffuse X-ray sources
- Science payload and missions
- Performance
- Current state of development
- Conclusions

Special thanks:

- to the Athena Science Study Team: D. Barret, A. Decourchelle, A.C. Fabian, M. Guainazzi, J.W. den Herder, H. Matsumoto, K. Nandra, L. Piro, R. Smith, R. Willingale
- to the Athena Working Groups and Topical Panels
- to the ESA study team
- to the WFI, X-IFU instrument consortia
- to the Athena Community Office (ACO)

Athena in a nutshell

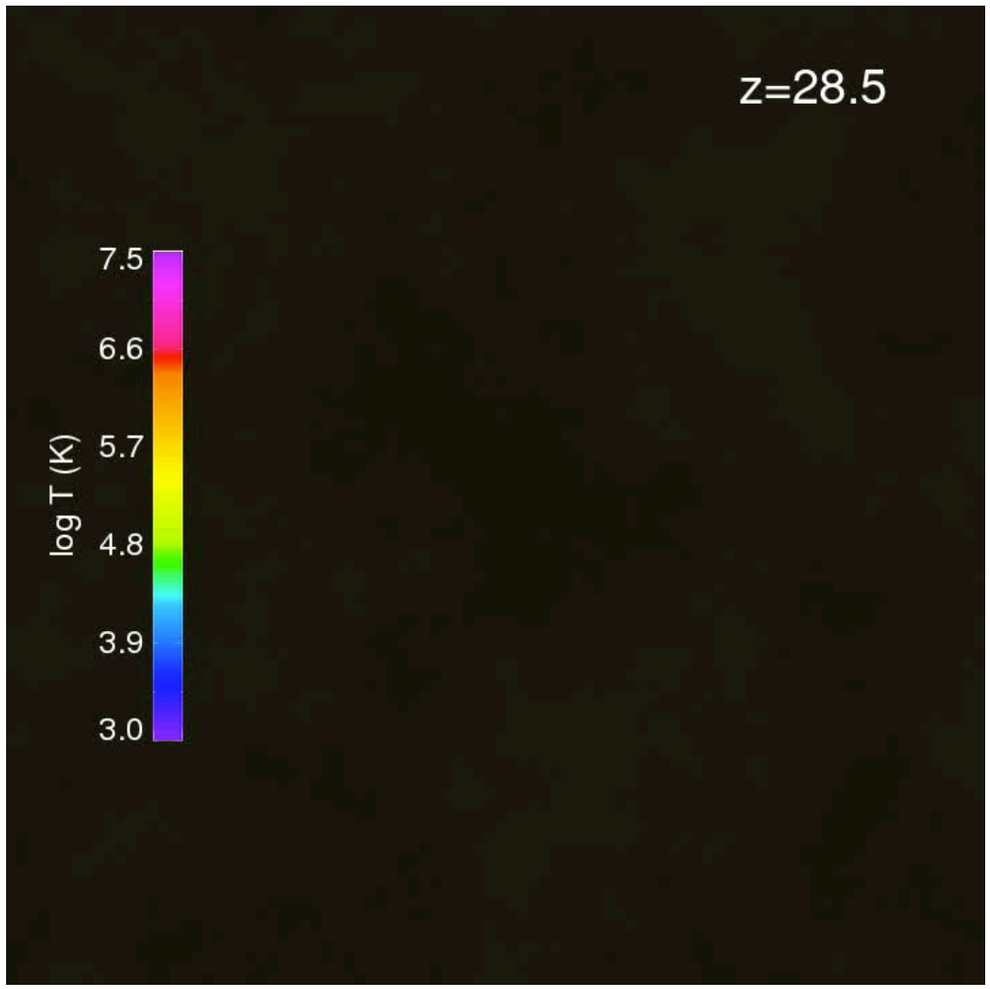
- Athena: Advanced Telescope for High ENergy Astrophysics
  - The big X-ray observatory after the great XMM-Newton and Chandra
- Second Large mission of the European Space Agency Cosmic Vision Science program (before the LISA gravitational wave mission)
- Dedicated to The Hot and Energetic Universe
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



The Hot Universe

The Universe heating up

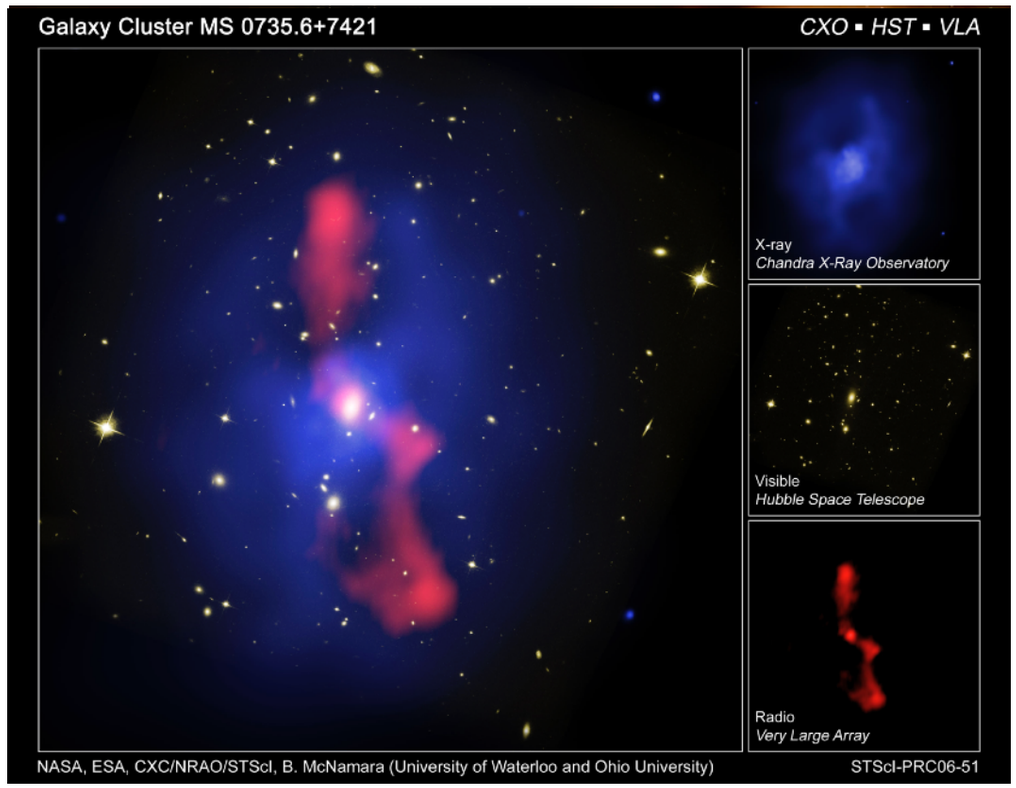
- How has the Universe evolved from the dark ages to today?
  - Tracking the formation, the dynamical and chemical evolution of the largest scale structures from the first groups to the massive clusters we see today
    - X-ray probe: Hot X-ray emitting gas trapped in dark matter potential wells
   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



Oppenheimer+09

The Energetic Universe

- How do black holes work and shape the Universe at all scales?
  - Probing accretion/ejection processes & interactions with the surroundings
    - Xray probes: Accretion powered X-rays generated around black holes & disturbed hot gas in clusters
    - Key parameters: energetics, density, velocity, temperature

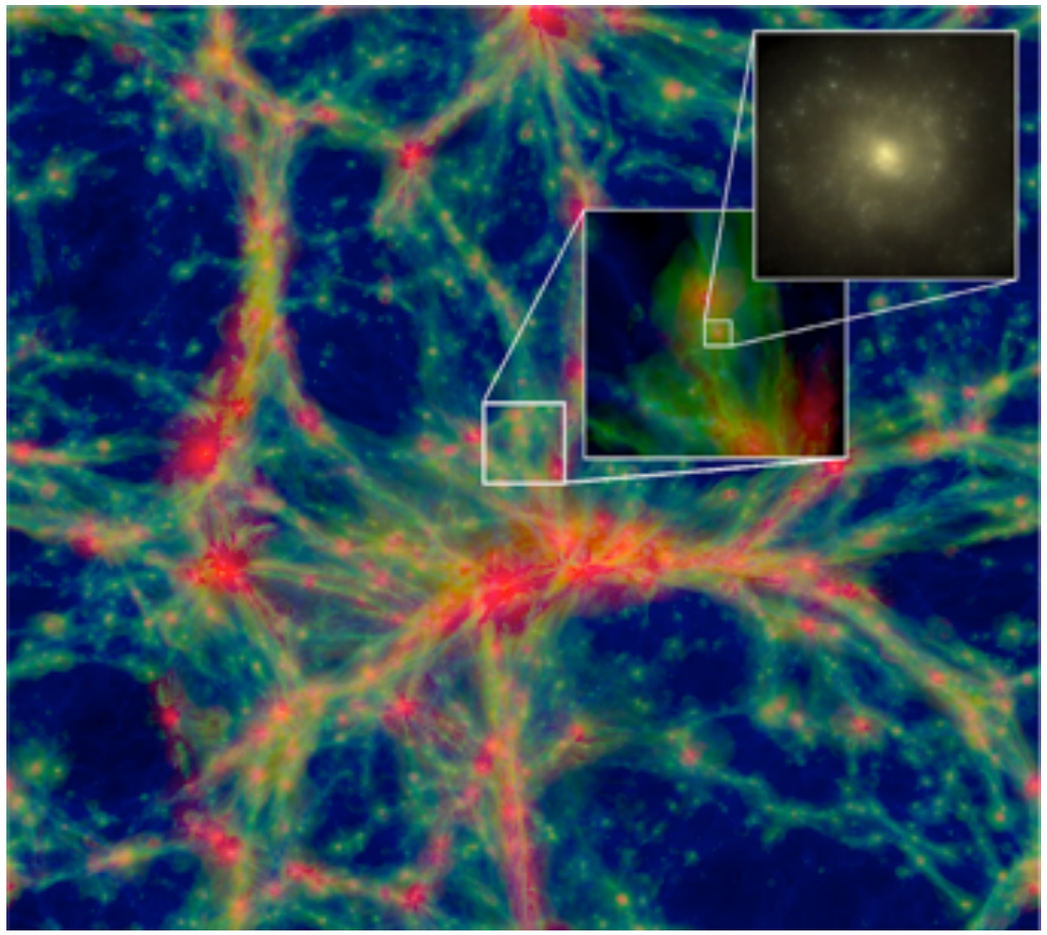


Diffuse X-ray sources with Athena

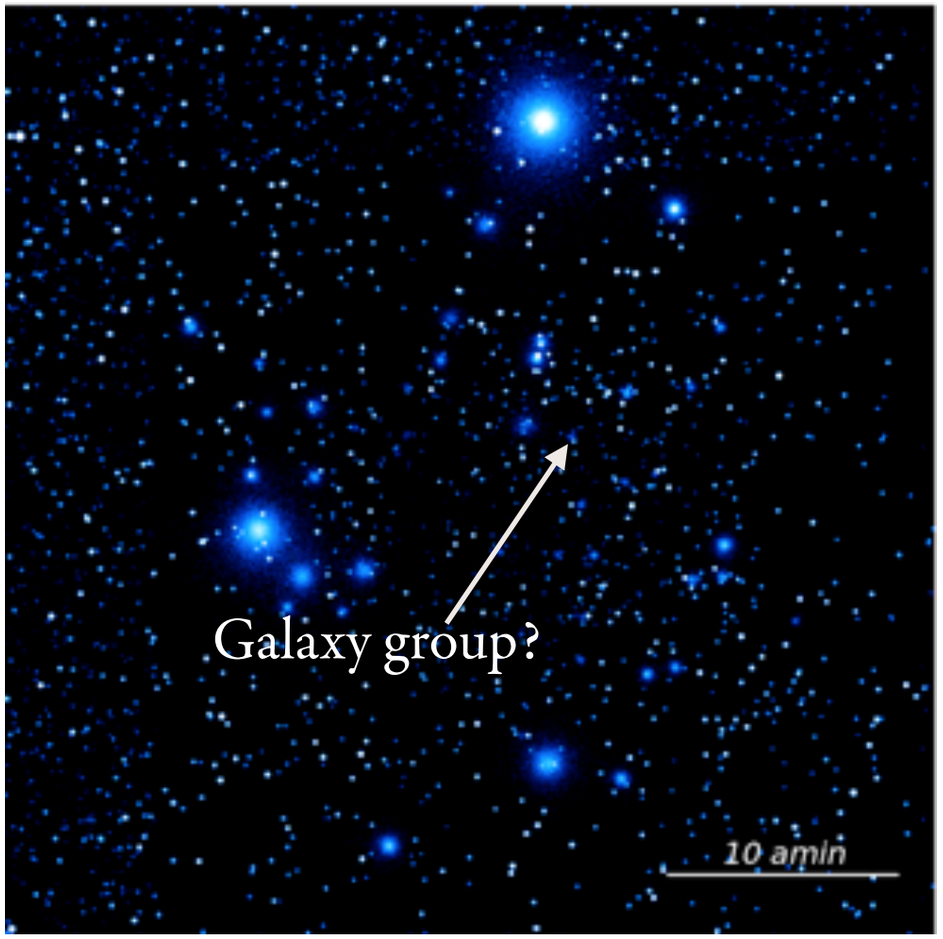
- Hot Universe is primarily related to diffuse X-ray sources
- Core Athena science goals include:
  - Galaxy groups and galaxy clusters
  - Warm-Hot Intergalactic Medium
  - Galactic center
- Observatory science goals include:
  - Revealing the chemistry of the cold interstellar medium
  - Constraining dust models from dust scattering halos
  - Probing the properties of the warm and hot gas of the interstellar medium in nearby galaxies.
  - Mapping young SNR to constraining SNIa and core-collapse explosion models and the shock dynamics

Galaxy groups

- Finding the first galaxy groups out to z~2
  - Measuring their Lx/T
    - ➡ Requires wide field shallow imaging



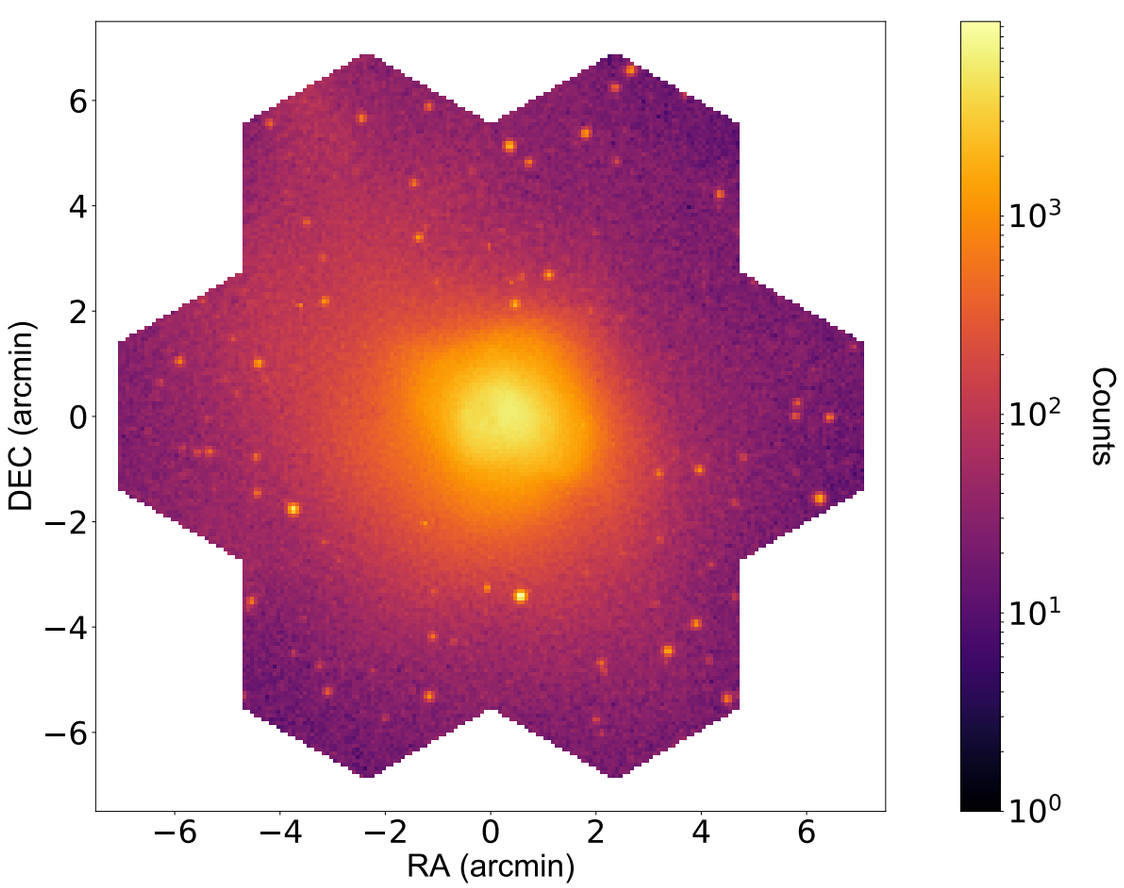
Temperature map for EAGLE sim. Schaye+15

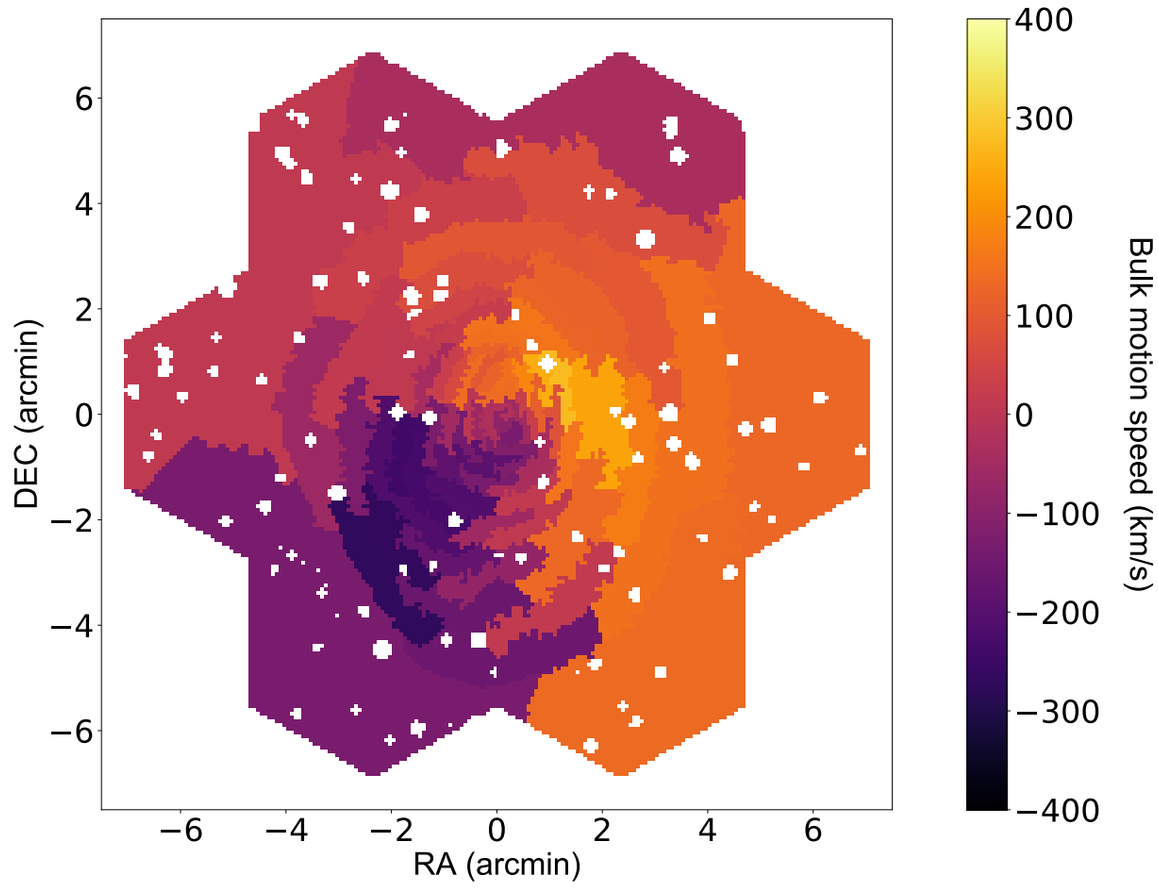


WFI simulations: MPE and WFI team

Cluster physics

- How matter accretes and evolves in dark matter potential?
- How energy from accreting supermassive black holes dissipate?
- ...

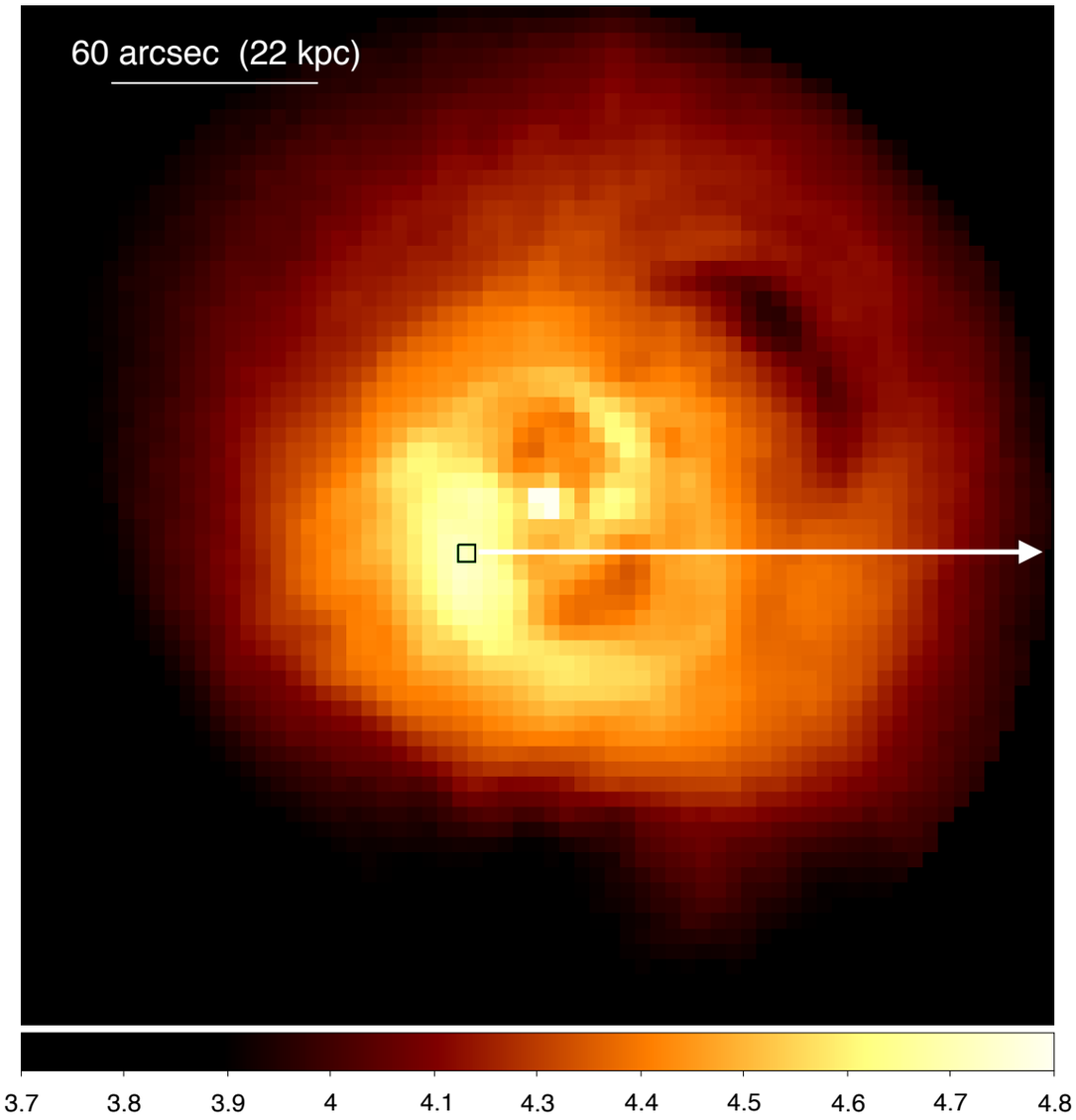


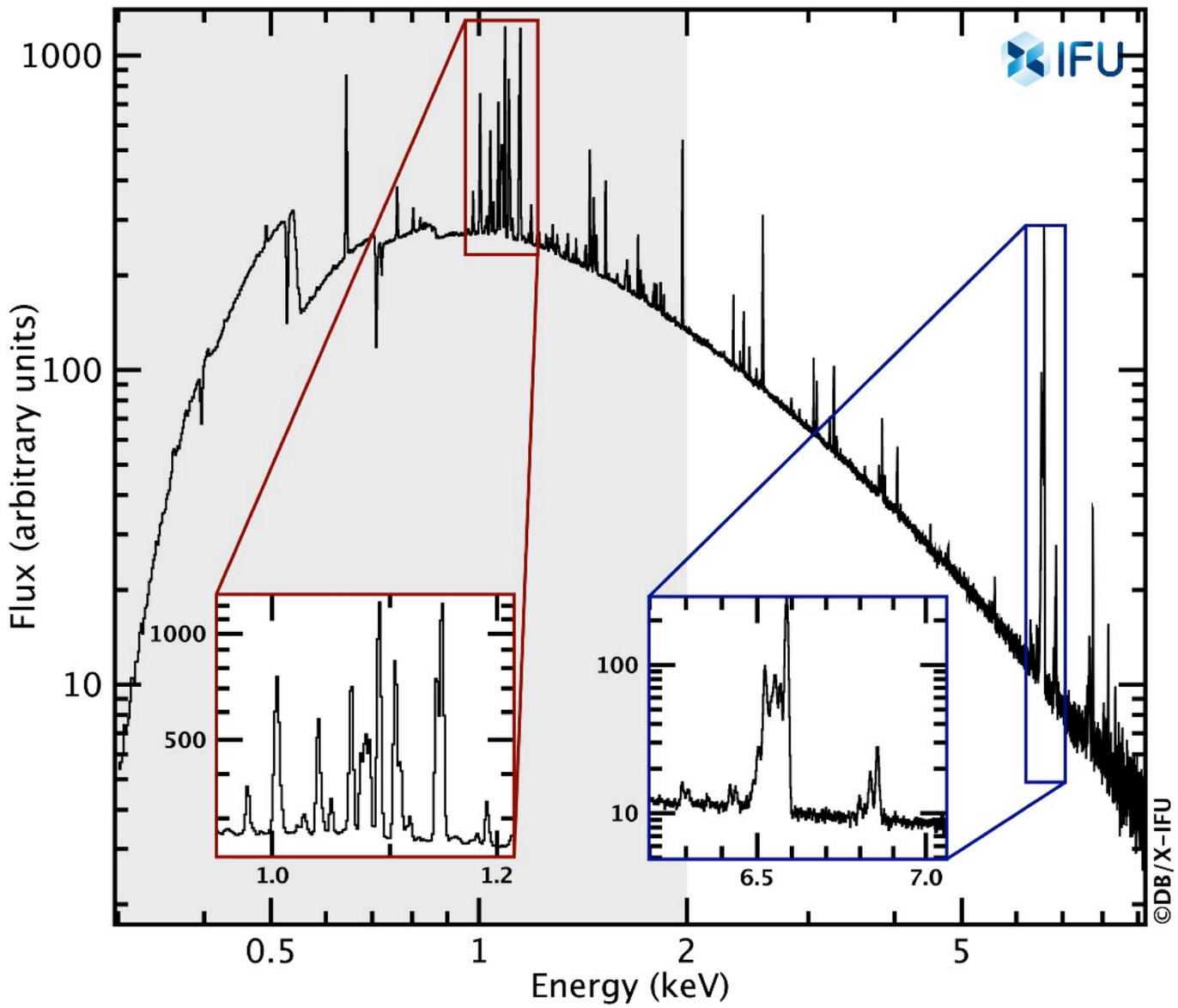


Surface brightness mass & bulk velocity map: Cucchetti+18

The power of 3D spectroscopy

- Each pixel provides a high resolution spectrum, down to 5” scales for the brightest objects

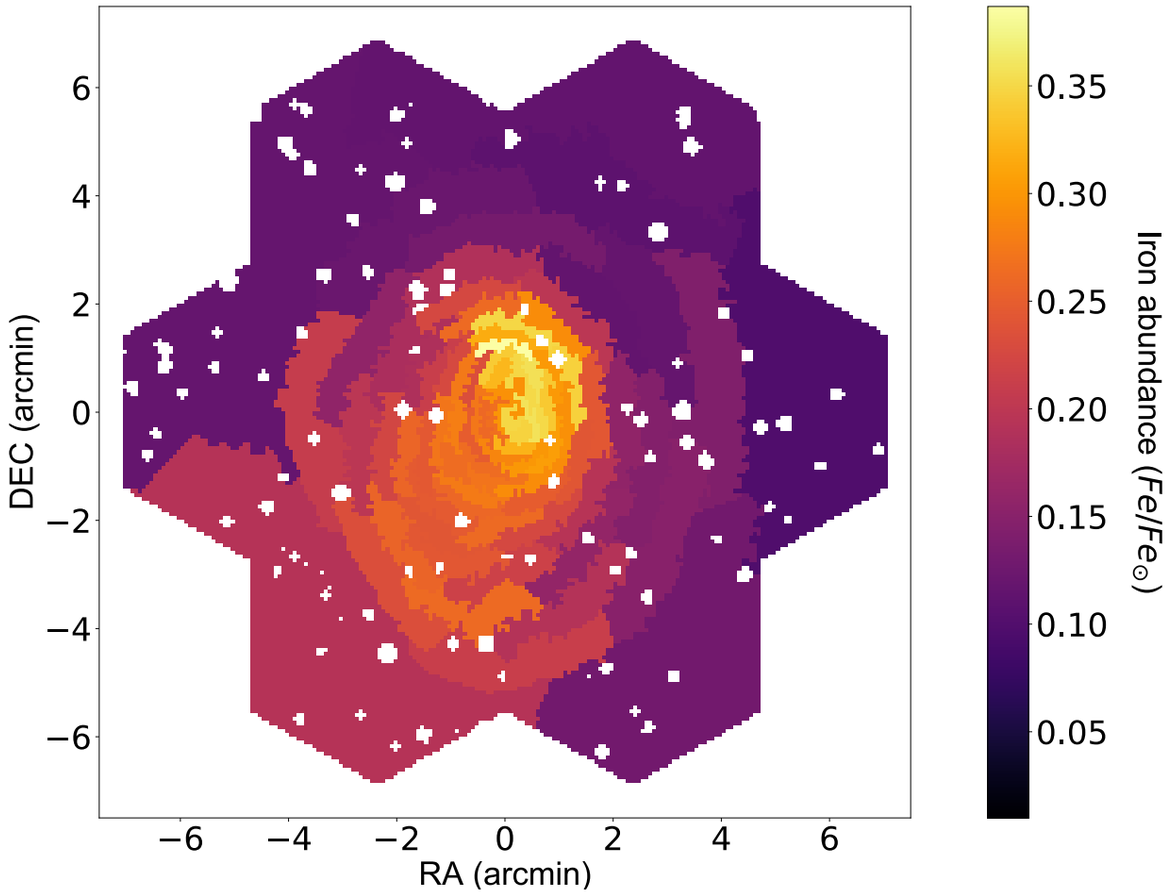


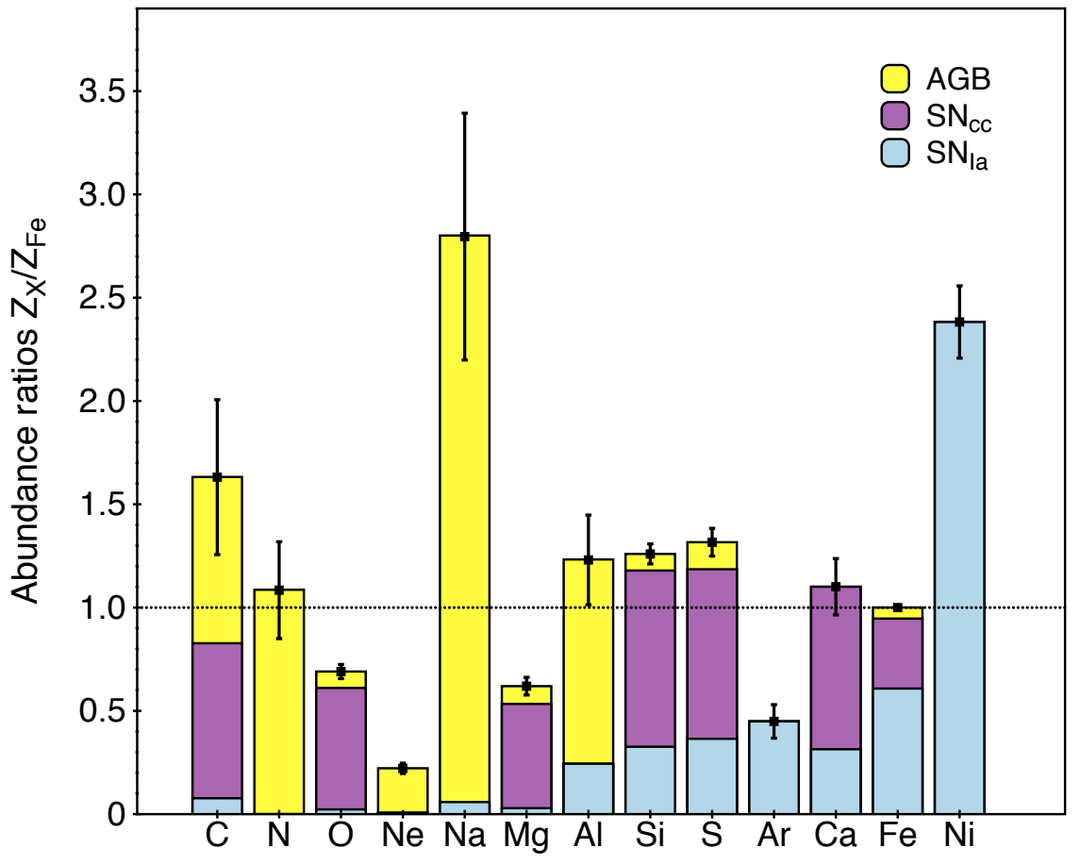


Perseus cluster image simulation by J. Sanders — Perseus spectrum simulated from data provided by C. Pinto & A. Fabian

Chemical evolution of the Universe

- Clusters of galaxies are the largest gravitationally bounded structures
- Cosmic chemical evolution traced by cluster gas
- How and when the elements were formed ?



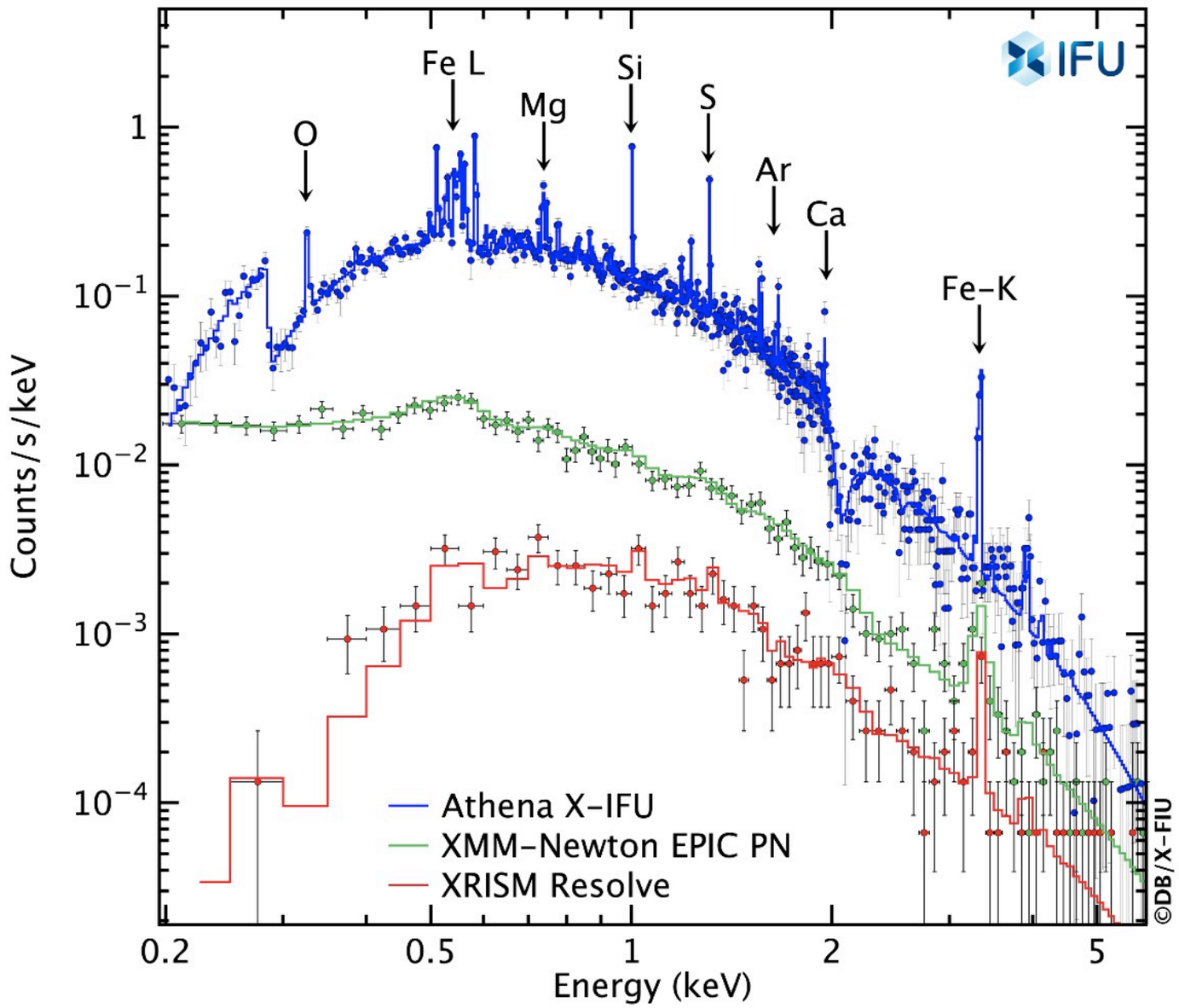


X-IFU Iron abundance map & comparison with metal factories: Cucchetti+18

Chemical evolution of the Universe

- Clusters of galaxies are the largest gravitationally bounded structures
- Cosmic chemical evolution traced by cluster gas

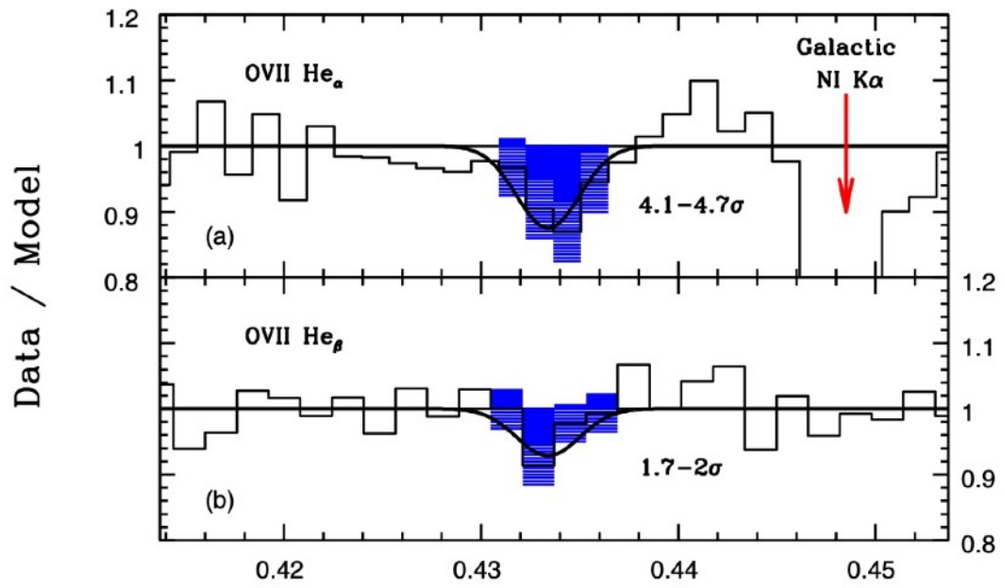
  ➡ Need to look up to the highest redshifts



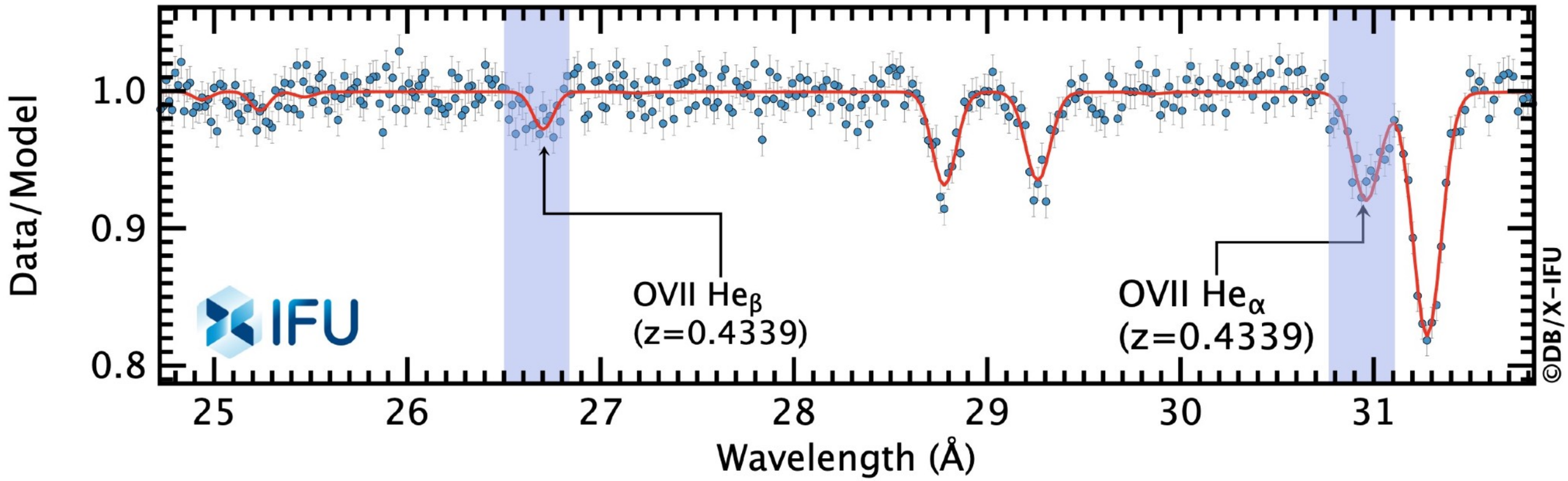
z=1 cluster spectrum seen by X-IFU: E. Pointecouteau+

Missing baryons

- Where are they? What they are?

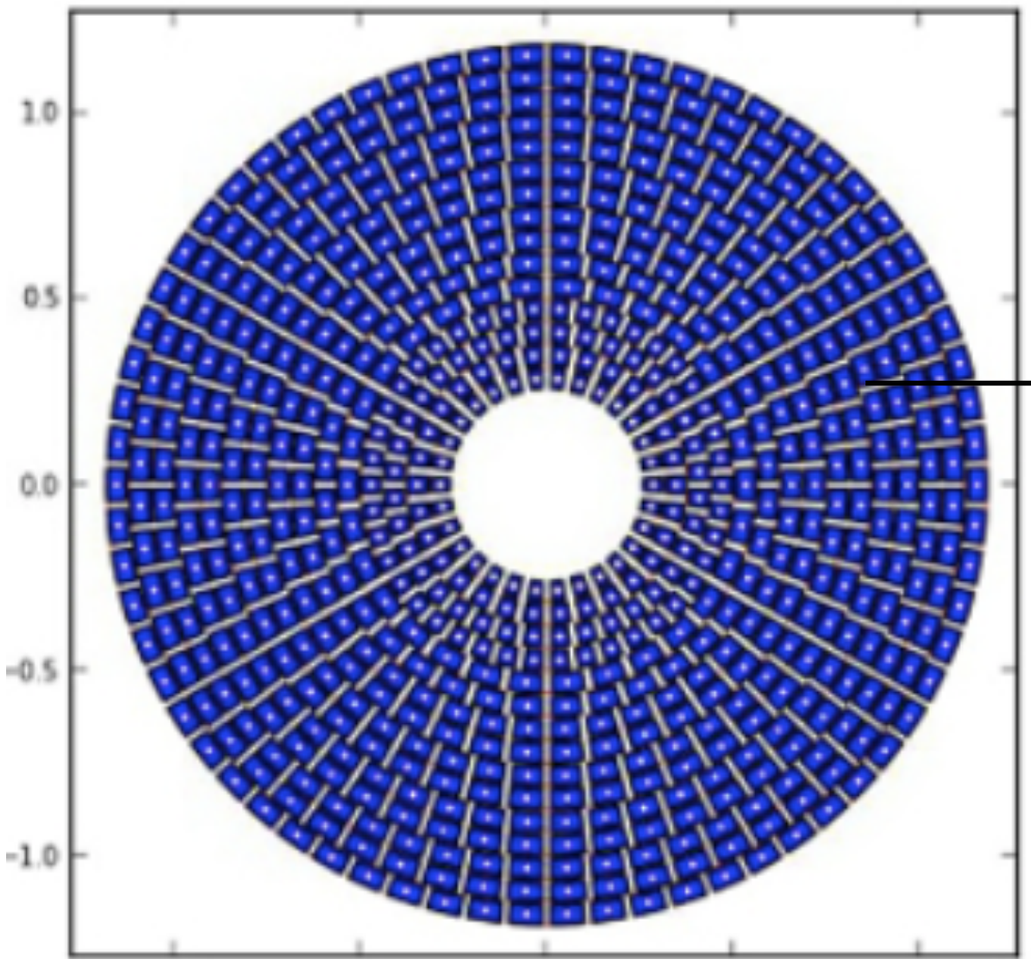


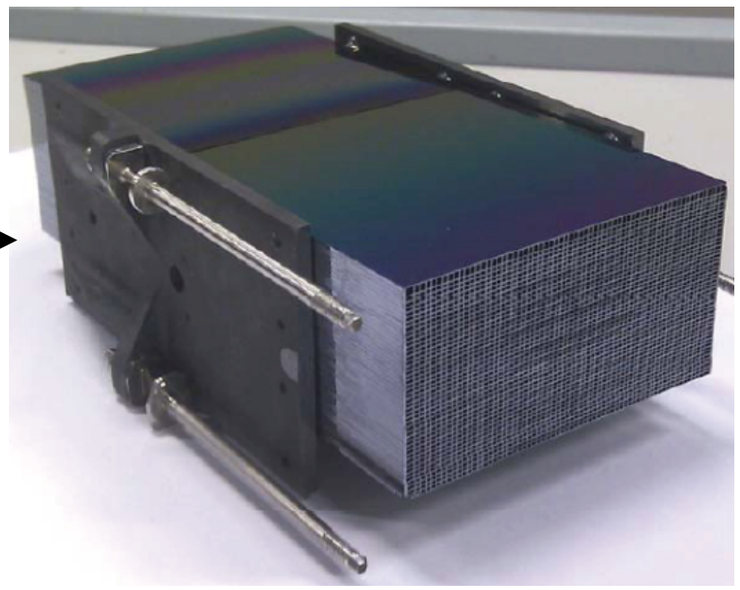
Nicastro+18.
RGS=1.75Ms
X-IFU simulations=160 Ks



The Athena science payload : Mirror

- Single monolithic large aperture grazing incidence movable X-ray telescope
  - Silicon Pore Optics developed by ESA
  - 1.4 m2 @ 1 keV, 0.25 m2 @ 6 keV
  - 5” (HEW)

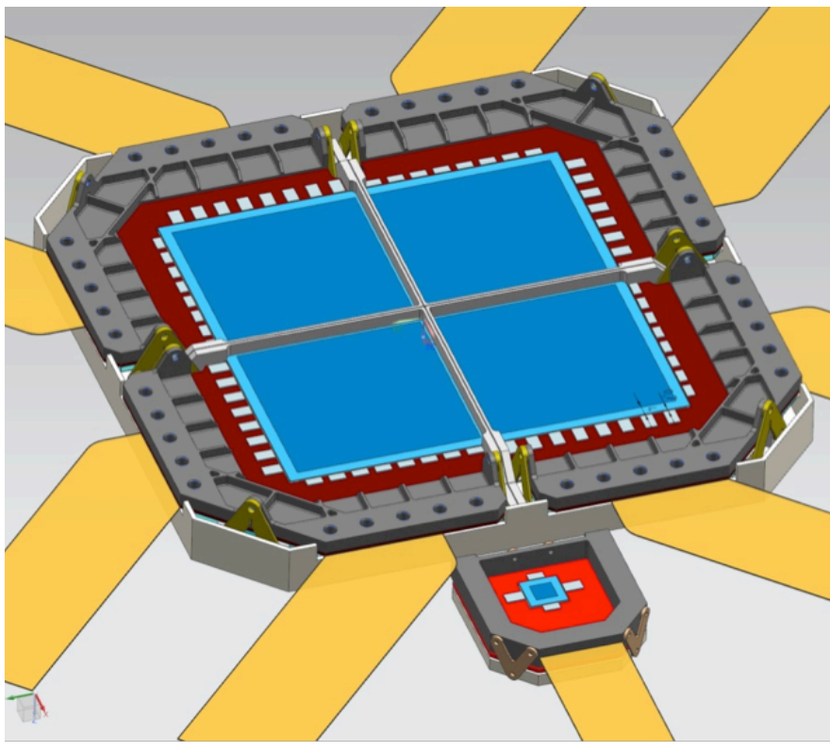


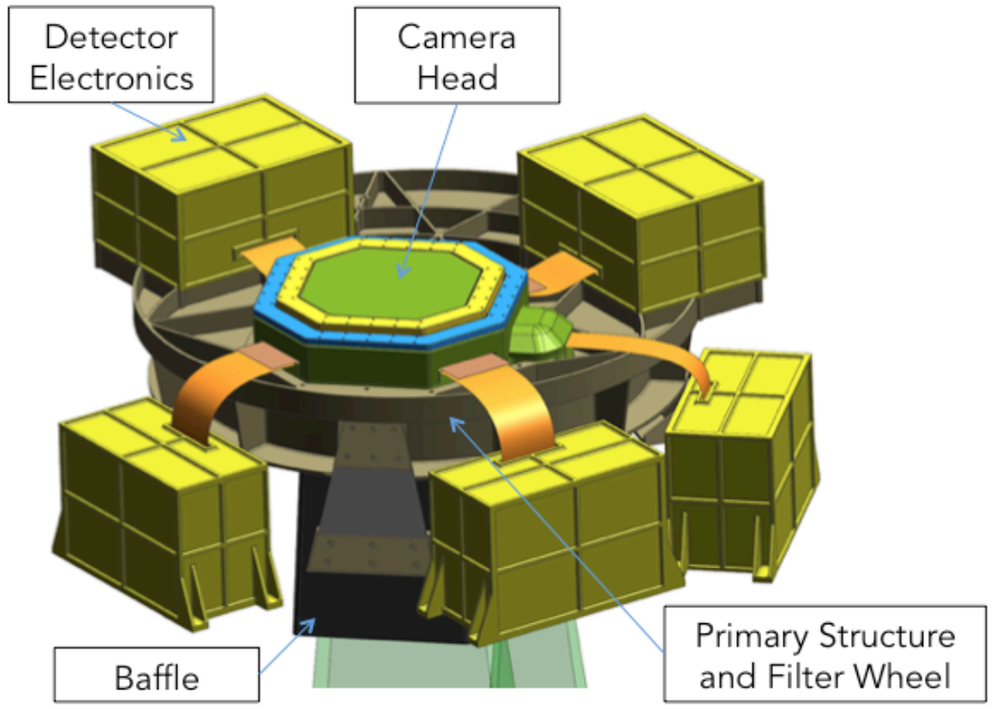


Credits: R. Willingale — ESA/Cosine

The Athena science payload: WFI

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

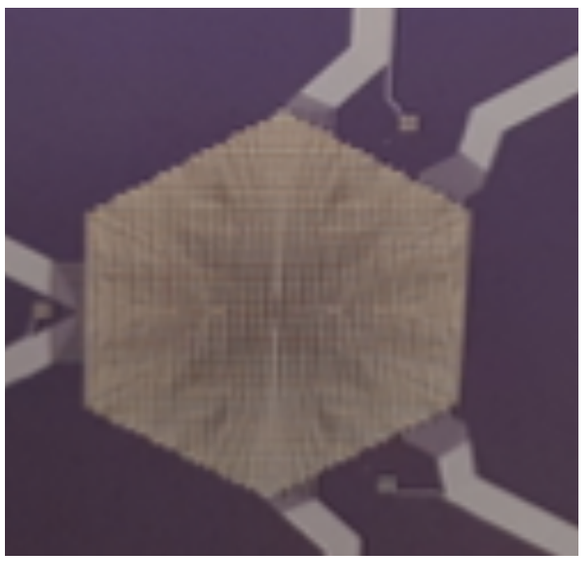


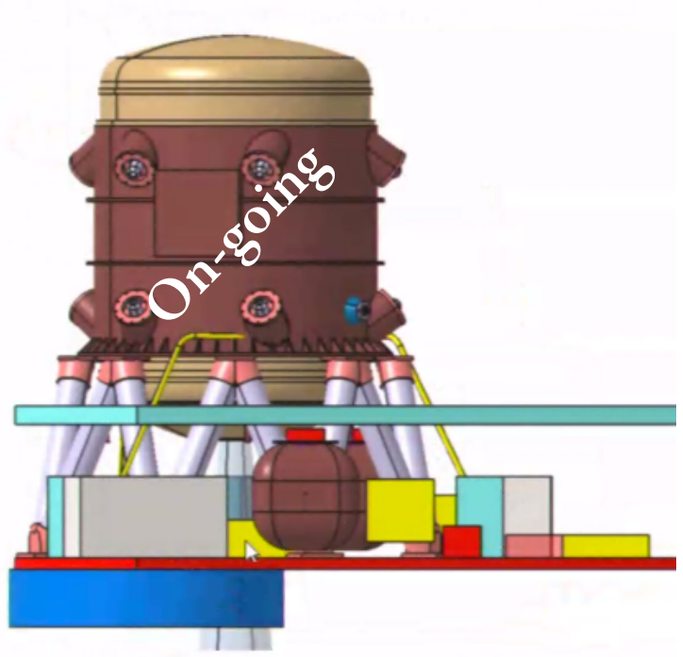


Credits: MPE and WFI team

The Athena science payload : X-IFU

- X-ray Integral Field Unit (X-IFU): Co-PIs: J.W den Herder (SRON) & L. Piro (INAF)
  - 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
  - Capability to observe bright sources thanks to the mirror defocussing
  - Cryogenic instrument cooled down to 100 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 Japan and the United States

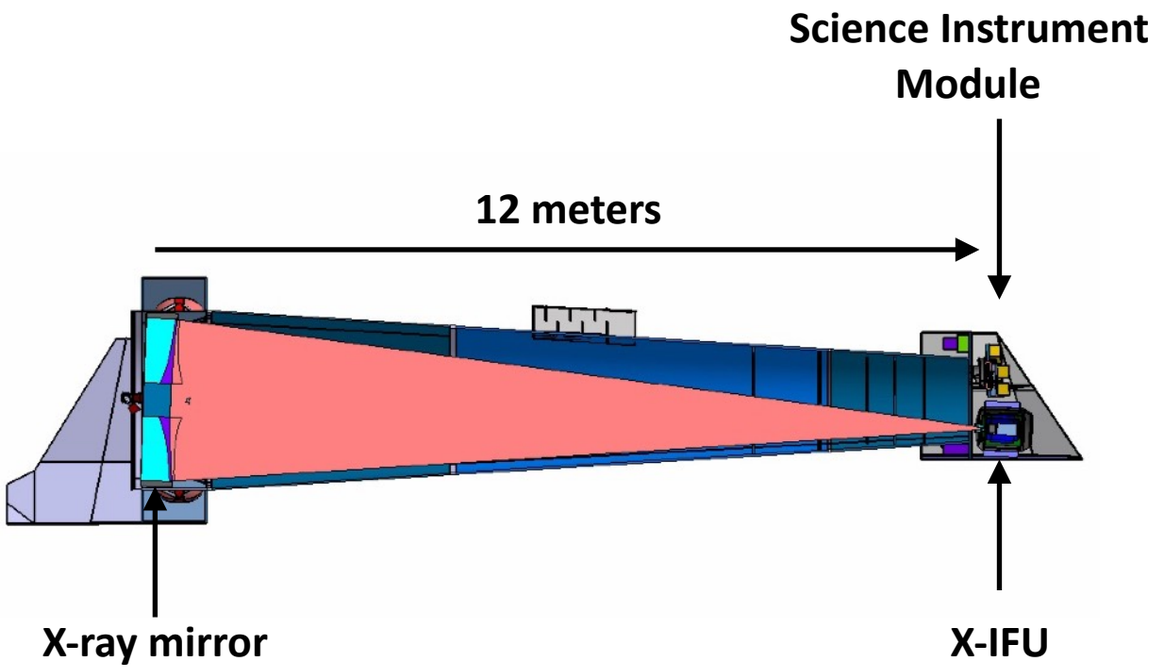


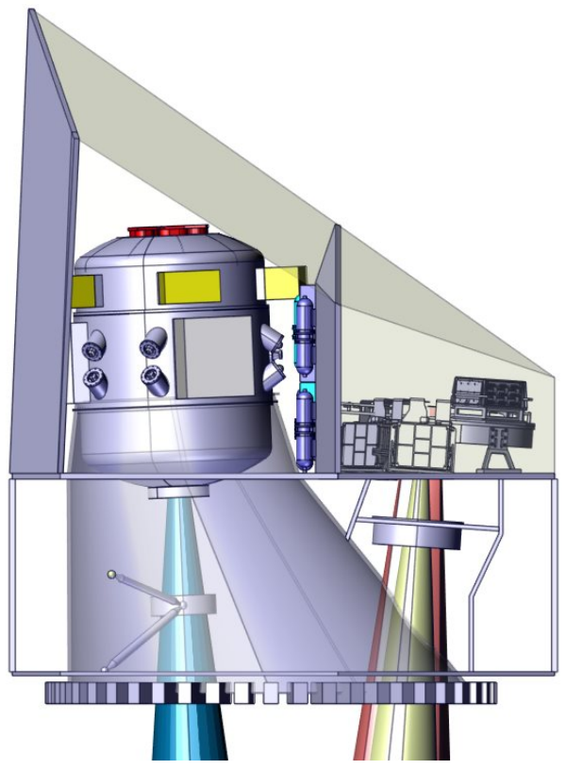


Credits: NASA/GSFC & CNES/IRAP/ESA and X-IFU team

The Athena spacecraft

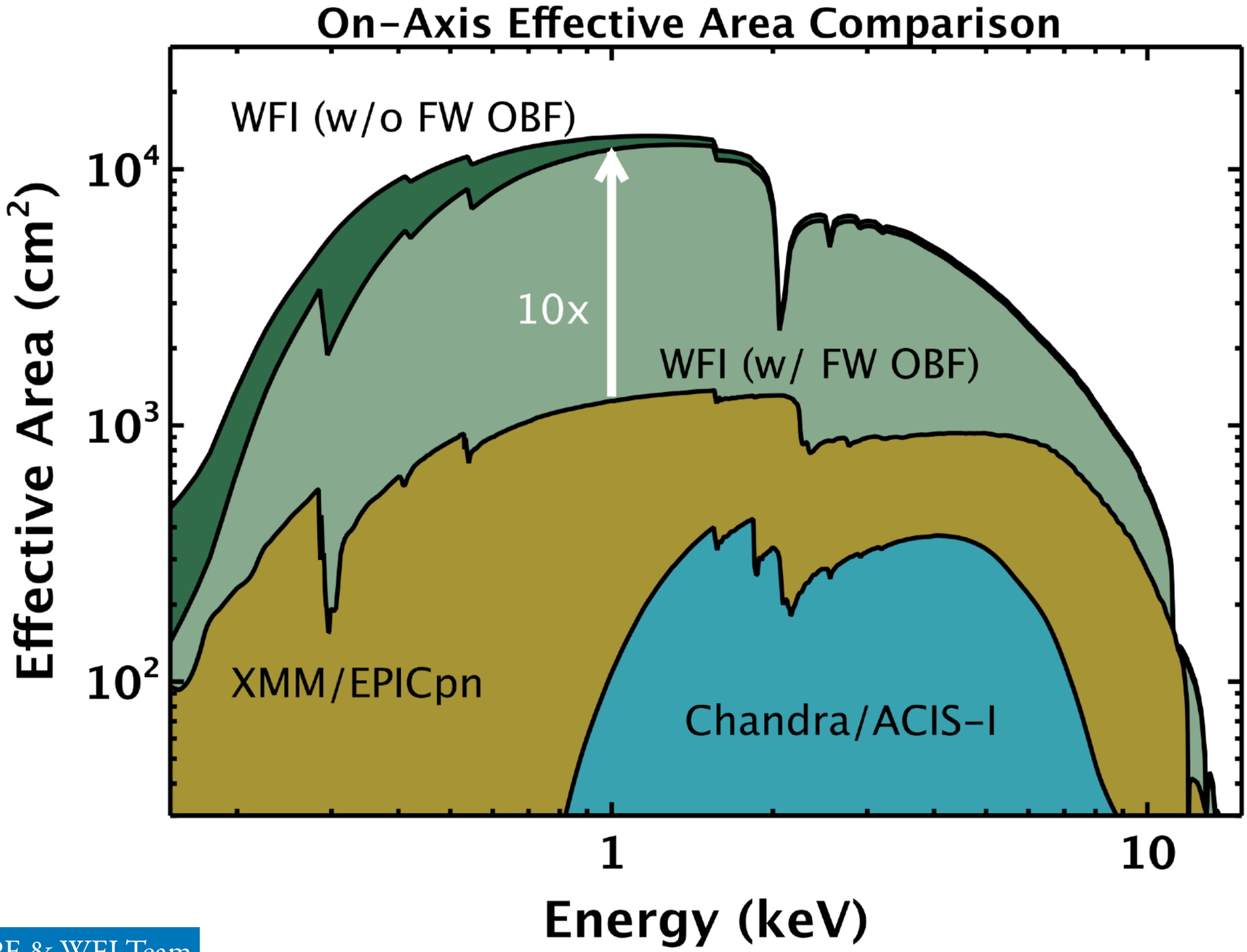
- Focal length: 12 meters (total height about 15 meters)
- Overall mass: 7 tons (X-IFU ~ 1 ton)
- 7 kWatts
- 4 year nominal mission lifetime with consumables/mechanical parts designed for 10 years
- Agile satellite to respond to ToO alerts in a few hours
- Launch to halo orbit L2 (or L1) by Ariane 6





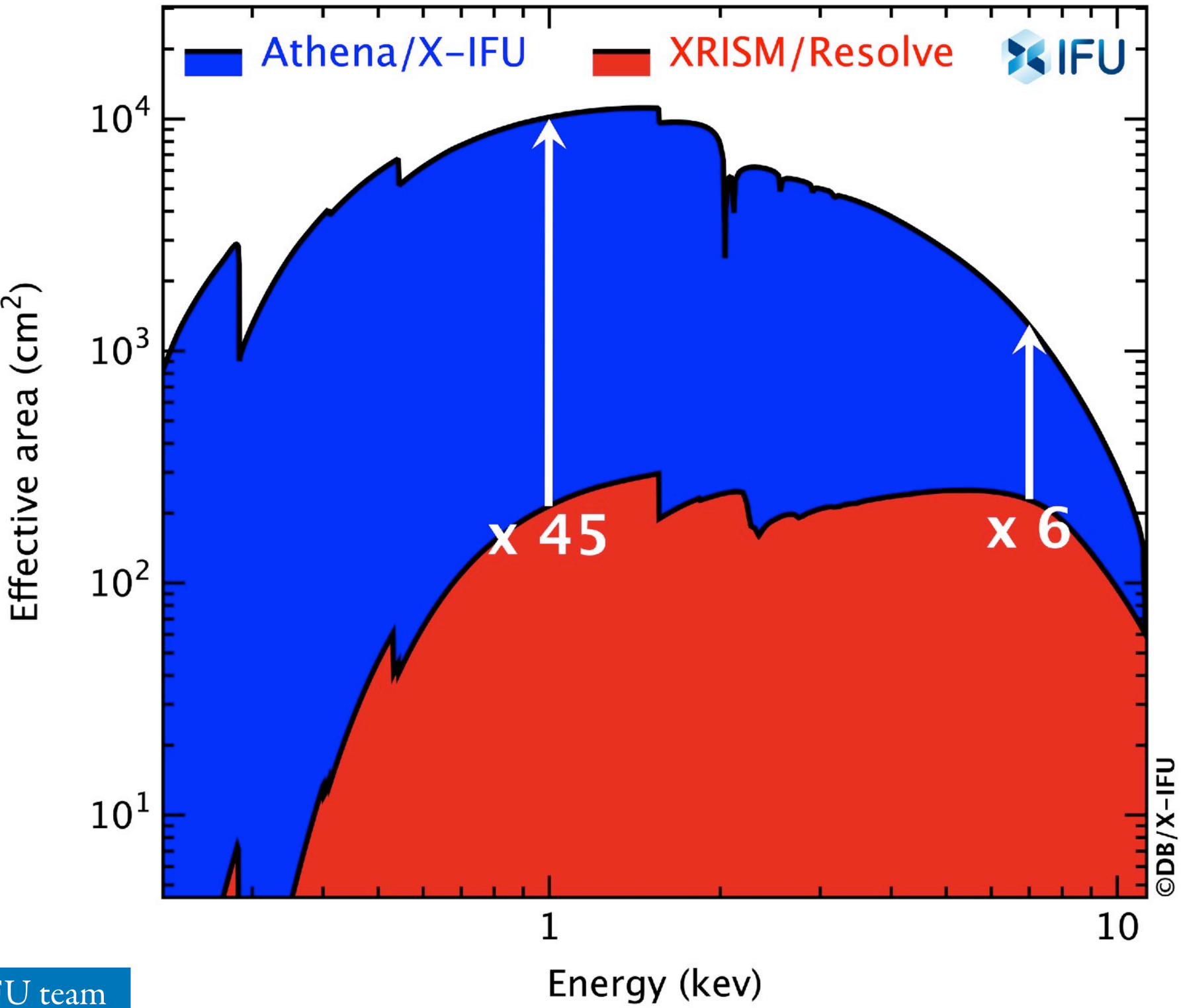
The Athena satellite and the Science Instrument Module (Credits to ESA)(credits to ESA)

Effective area — WFI



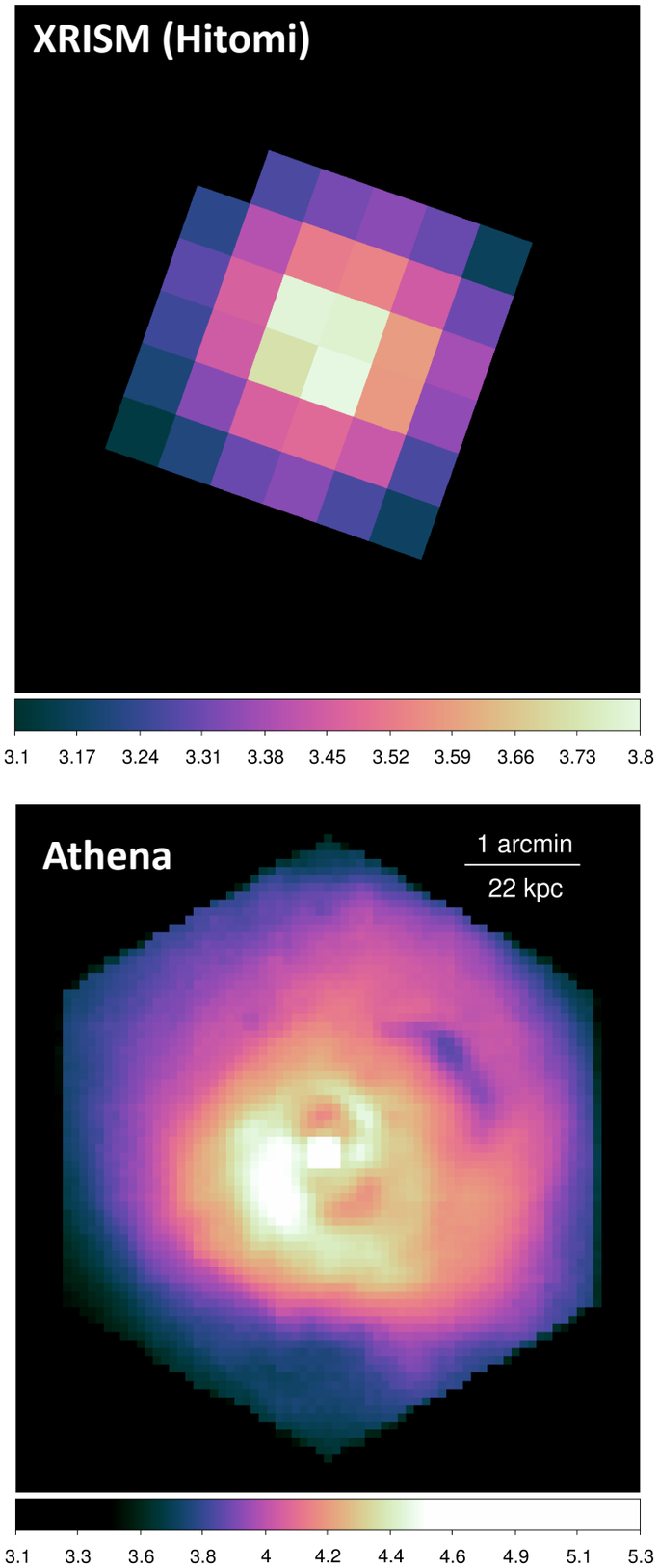
Credits: MPE & WFI Team

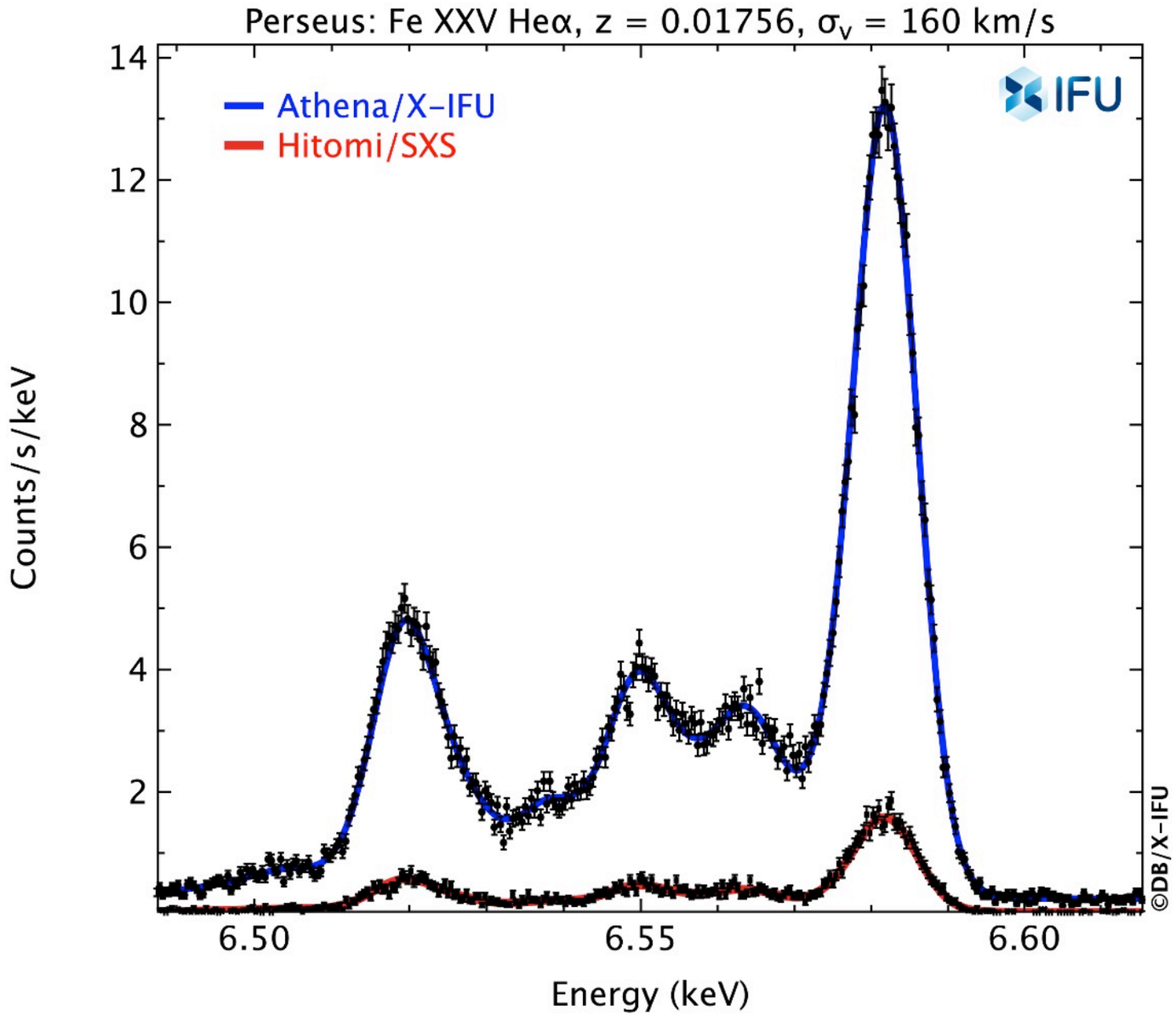
Effective area — X-IFU



Credits: X-IFU team

From XRISM to Athena: Perseus

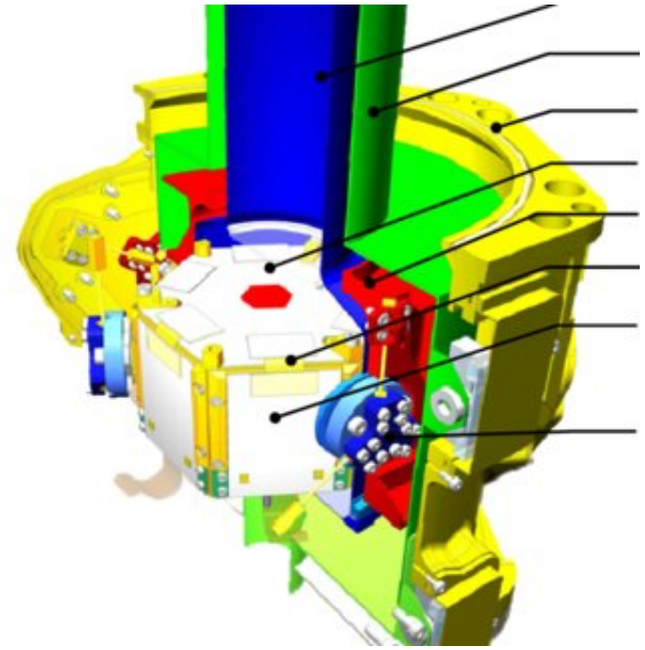




Credits: J. Sanders

Current status

- Both instruments have successfully completed their feasibility study phase (Phase A)
  - baseline designs meet the performance requirements
  - Phase A review at mission level (including mirror and S/C)
- Vigorous technology development plans on-going
  - Steady improvement in the optics towards 5" HEW
  - *A sensitivity analysis concluded that a resolution of 6.5" has a clear negative impact on a number of Athena science objectives, with the impact considered very severe if the HEW were to degrade to >8".*
  - Demonstrator of the X-IFU cooling chain to include a demonstrator of the focal plane assembly and readout electronics
- Mission adoption late 2021 (10 year implementation)
- Case is made to have overlap between Athena and LISA



Conclusions

- Athena is your next large X-ray observatory
- Athena has revolutionary X-ray capabilities
  - Spatially resolved high resolution spectroscopy
  - Wide field imaging
- XRISM will open a new window on the exploration of diffuse X-ray sources
  - Challenges for XRISM/Athena: calibration, background (+CX), atomic physics, data cube analysis
- Athena is on the safe path for a launch in the early 2030s
- Keep using XMM-Newton/Chandra, supporting and promoting Athena
- And start now preparing for the post-Athena mission in the voyage2050 for the long term science planning of ESA

A bright X-ray future

@AthenaXIFU