The (spectral)-timing capabilities of the Athena X-ray Integral Field Unit (X-IFU)

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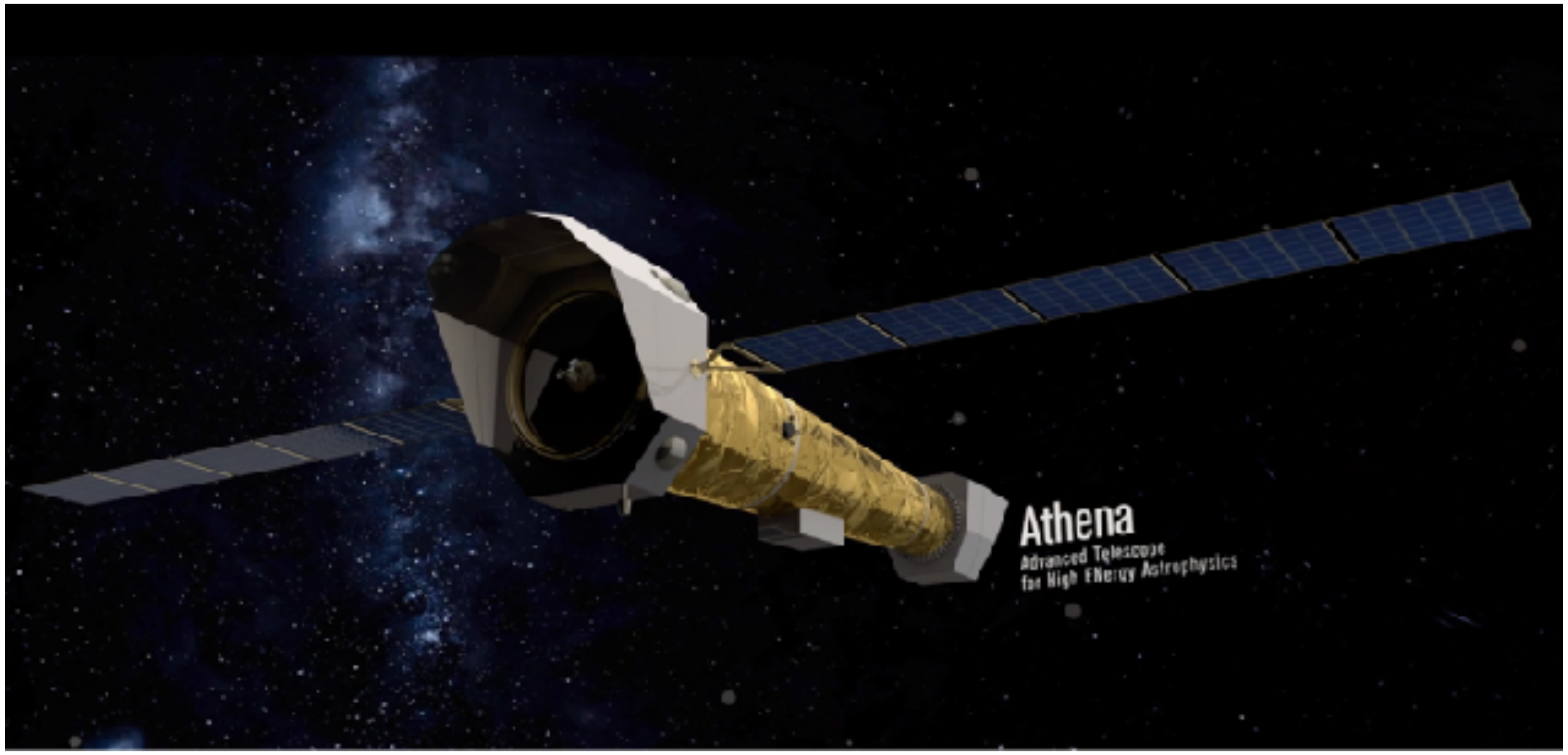
On behalf of the Athena Science Study Team, the Athena Community, the X-IFU Consortium, and particularly CNES for taking the responsibility of delivering X-IFU

with inputs from Elias Kammoun (IRAP) and Philippe Peille (CNES)

Timing X-ray Binaries, October 7-8th, 2021

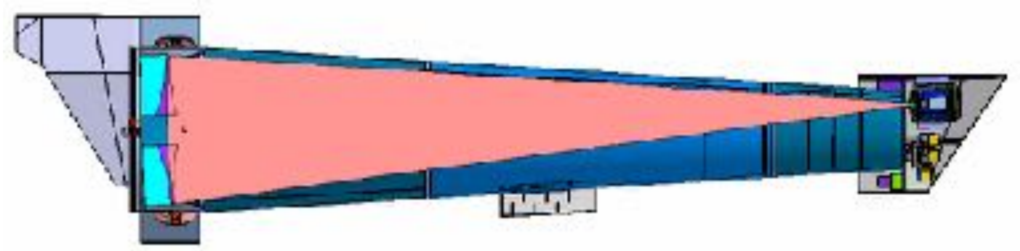
Athena in a nutshell

- Athena: Advanced Telescope for High ENergy Astrophysics
  - To succeed to XMM-Newton and Chandra, and to follow XRISM, as a pathfinder to Athena
- Second Large mission of the European Space Agency Cosmic Vision Science program (possibly operating simultaneously with the third large mission : LISA)
  - With NASA and JAXA 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

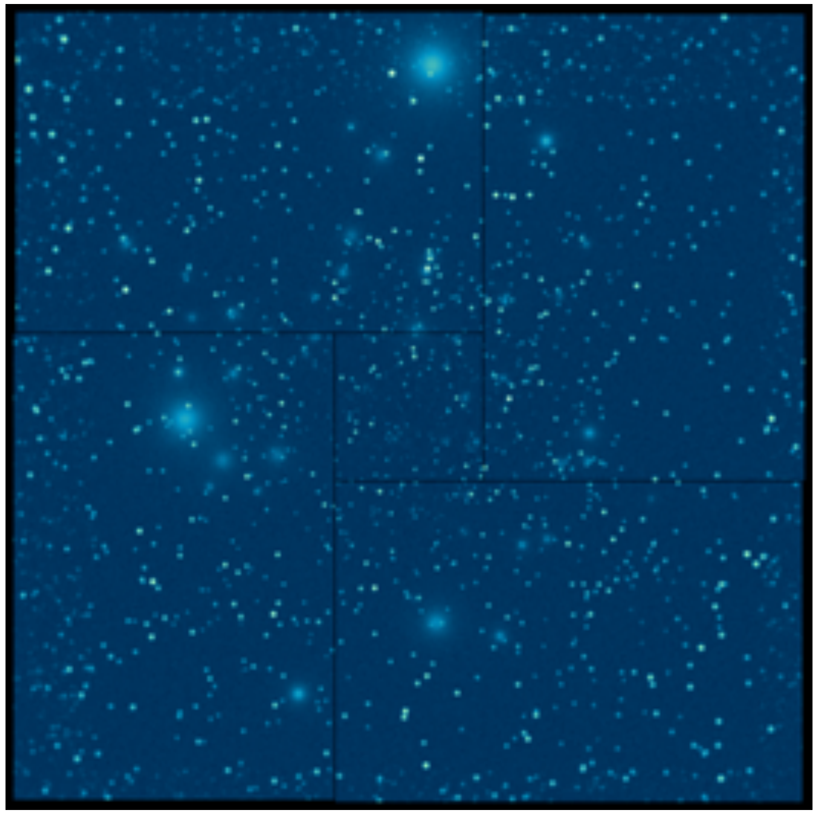


Athena in a nutshell

- 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

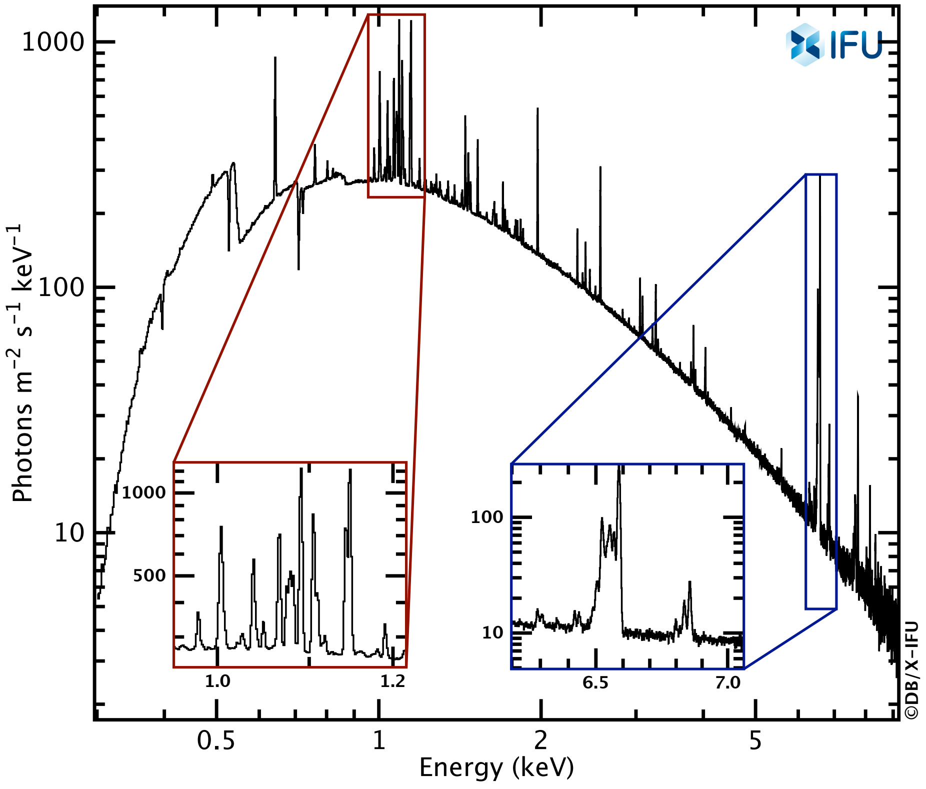


WFI simulated image
Hundreds of sources per image



Credits: WFI team

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

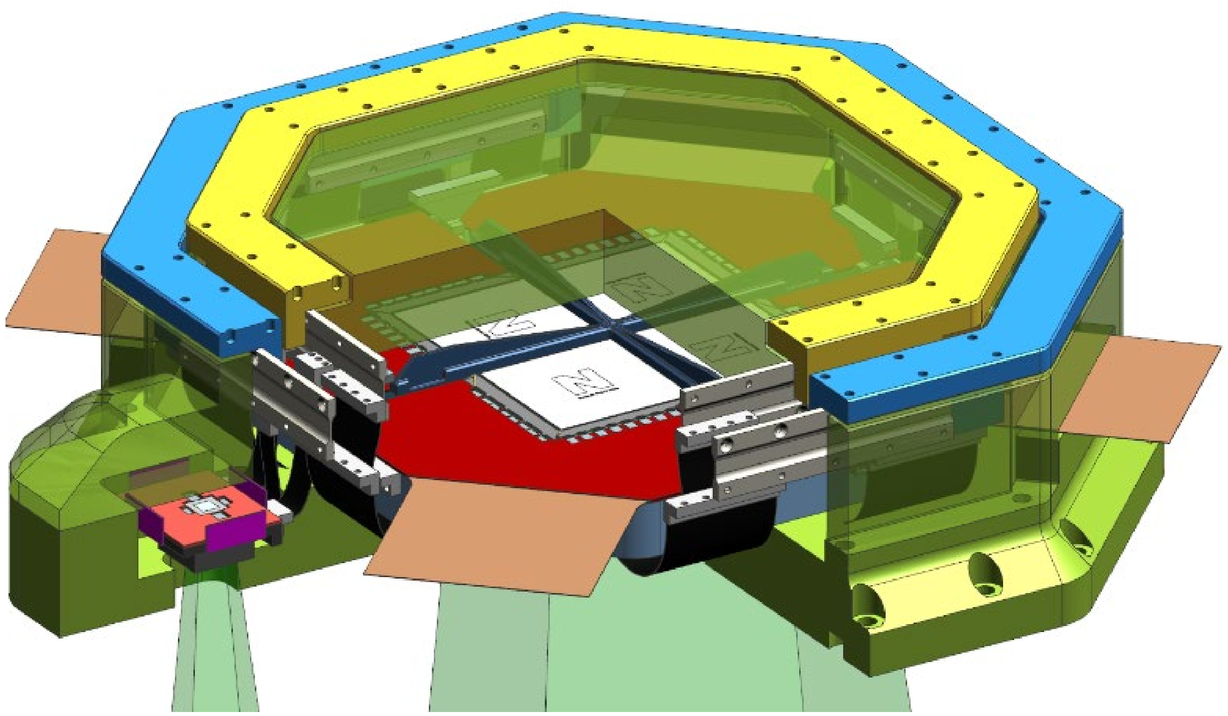


Credits: X-IFU team (data courtesy of C. Pinto and A.C. Fabian)

Science payload

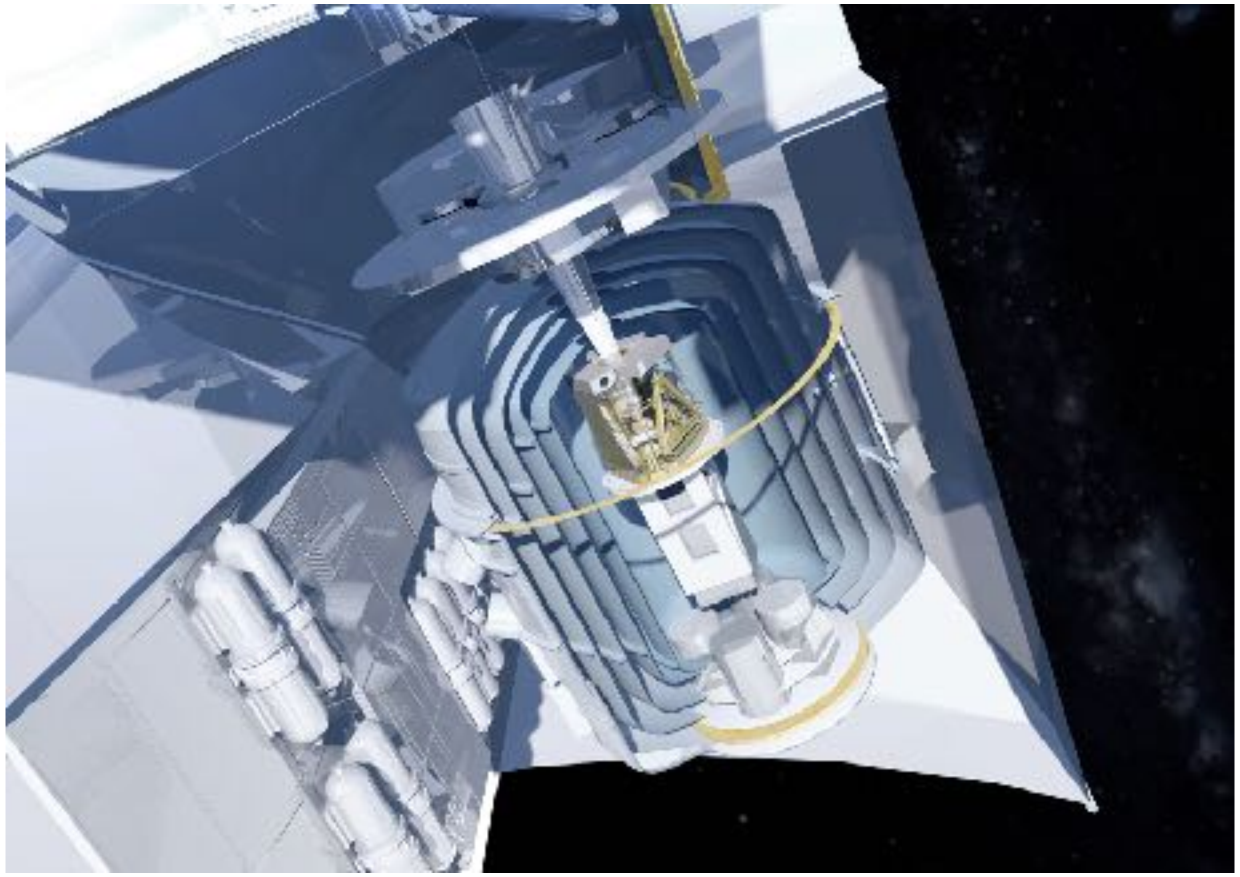
Wide Field Imager (WFI)	X-ray Integral Field Unit (X-IFU)
Silicon Active Pixel Detector based on DEPFET technology	Large format micro-calorimeter array (Transition Edge Sensors)
Field of view: 40´×40´ square	5′ hexagonal field of view (equivalent diameter)
Spectral resolution < 80 (<170) eV @ 1 (7) keV	2.5 eV spectral resolution up to 7 keV
Separate chip for fast readout of very bright sources (10 Crab,170 eV)	Out of focus observations of bright sources (1 Crab, 10 eV)

The mechanical layout of the WFI instrument



Credits: MPE and WFI team

The X-IFU cryostat and focal Plane Assembly

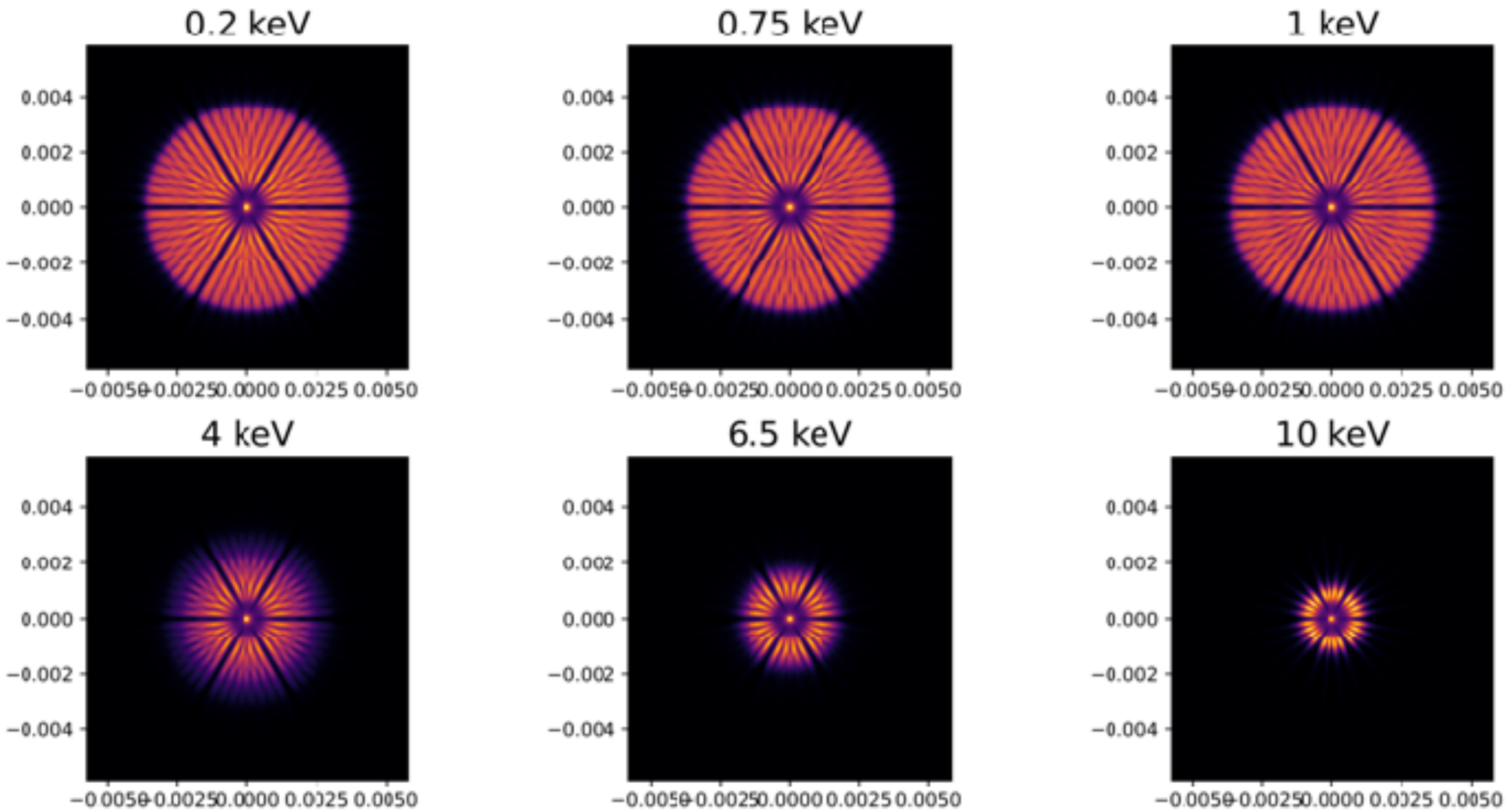


Credits: X-IFU team

X-IFU bright source observations

- Enabled by the mirror capability to change its focal length (35 mm out of 12 m)
  - distributing the point spread function over several hundreds of pixels so that each pixel receives a small fraction of the source flux
    - ➡ which can be further reduced by the addition of filters to suppress the numerous low energy photons

Energy dependent out-of-focus point spread function of the Athena optics



Credits: Dick Willingale/Elias Kammoun

Count rate dependent energy resolution

- X-IFU will time tag each photon with an accuracy of 10 μs
- The accuracy with which the energy of the photon is reconstructed depends on its energy, as well as on the time separation with the preceding and succeeding photons
  - Four grades are defined : high (2.5 eV), medium (3 eV), low (<7 eV), limited (~30 eV) resolution
  - We define the throughput as the fraction of events reconstructed at a given grade as a function of the source intensity over an energy band pass
  - To limit the source flux on the detector and to preserve high energy photons (above 2-3 keV), bright sources will be observed with a Beryllium filter (two thicknesses will be available)

Higher resolution events will have no close events before and after

Lower resolution events will have close events before and after

Timeline for a high resolution event

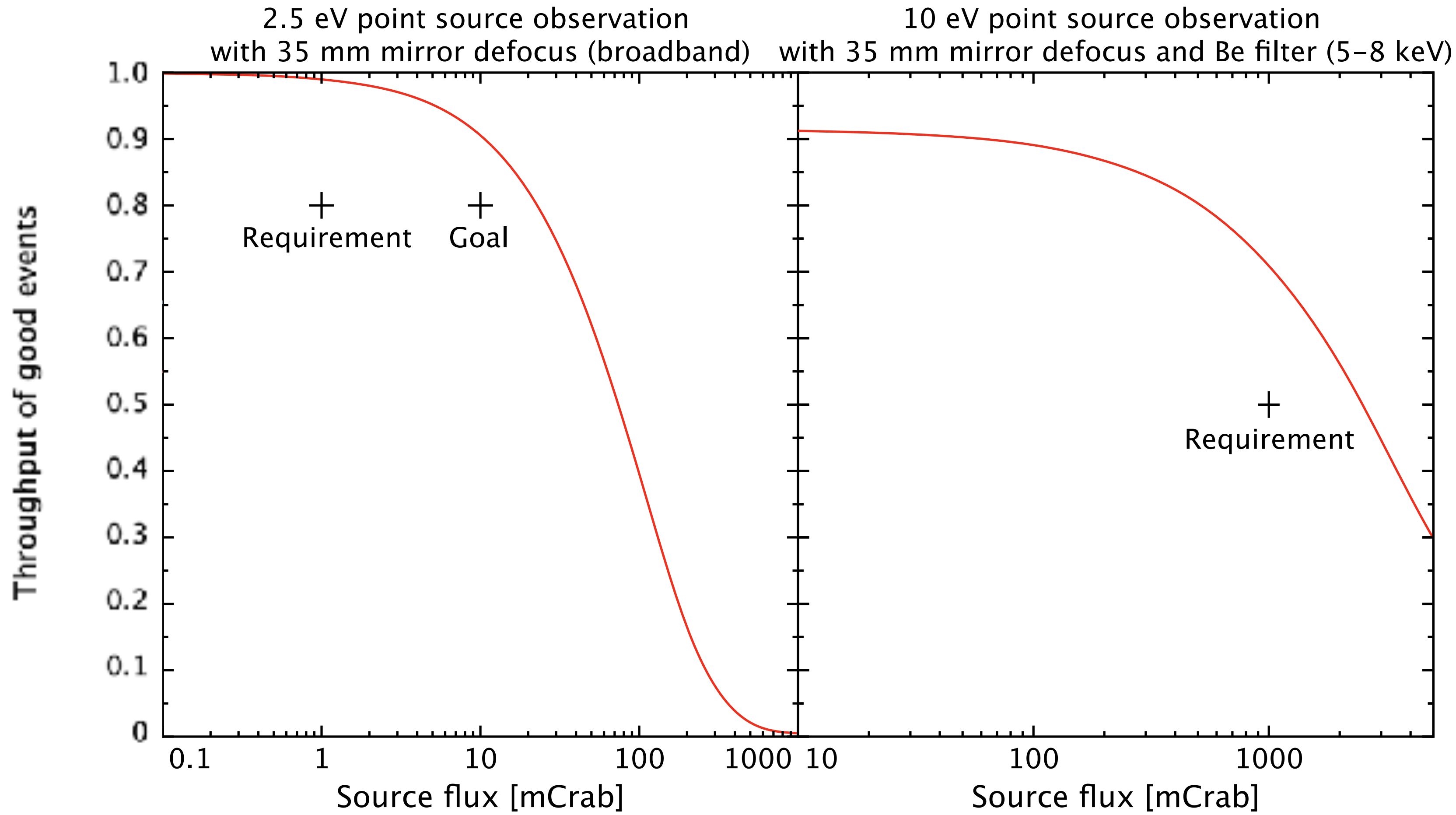
Timeline for a medium resolution event

Grade	**Time between pulse start and previous pulse start**	**Time between pulse start and next pulse start**	Resolution
High Resolution	>1227 samples (7.9 ms)	> 8192 samples (52.4 ms)	2.5 eV
Medium Resolution	>1227 samples (7.9 ms)	> 512 samples (3.3 ms)	3 eV

X-IFU requirements & performance

Key requirement	Science drivers
2.5 eV throughput for point sources : 80% at 1 mCrab (Requirement) 2.5 eV throughput for point sources : 80% at 10 mCrab (Goal)	X-raying missing baryons with bright line of sights GRB afterglows and bright quasars
10 eV throughput for bright point sources : 50% at 1 Crab (5-8 keV)	Probing stellar mass black hole and neutron star accretion disks & winds/ouflows

Estimated throughput for point sources: 10 mCrab corresponds to a count rate of 650 cps over the array with 600 pixels receiving more than 0.6 cps for a maximum of 1.2 cps. With a beryllium filter cutting most of the low energy events, 1 Crab corresponds to ~ 90000 cps over the full array with a maximum count rate of 30 cps.

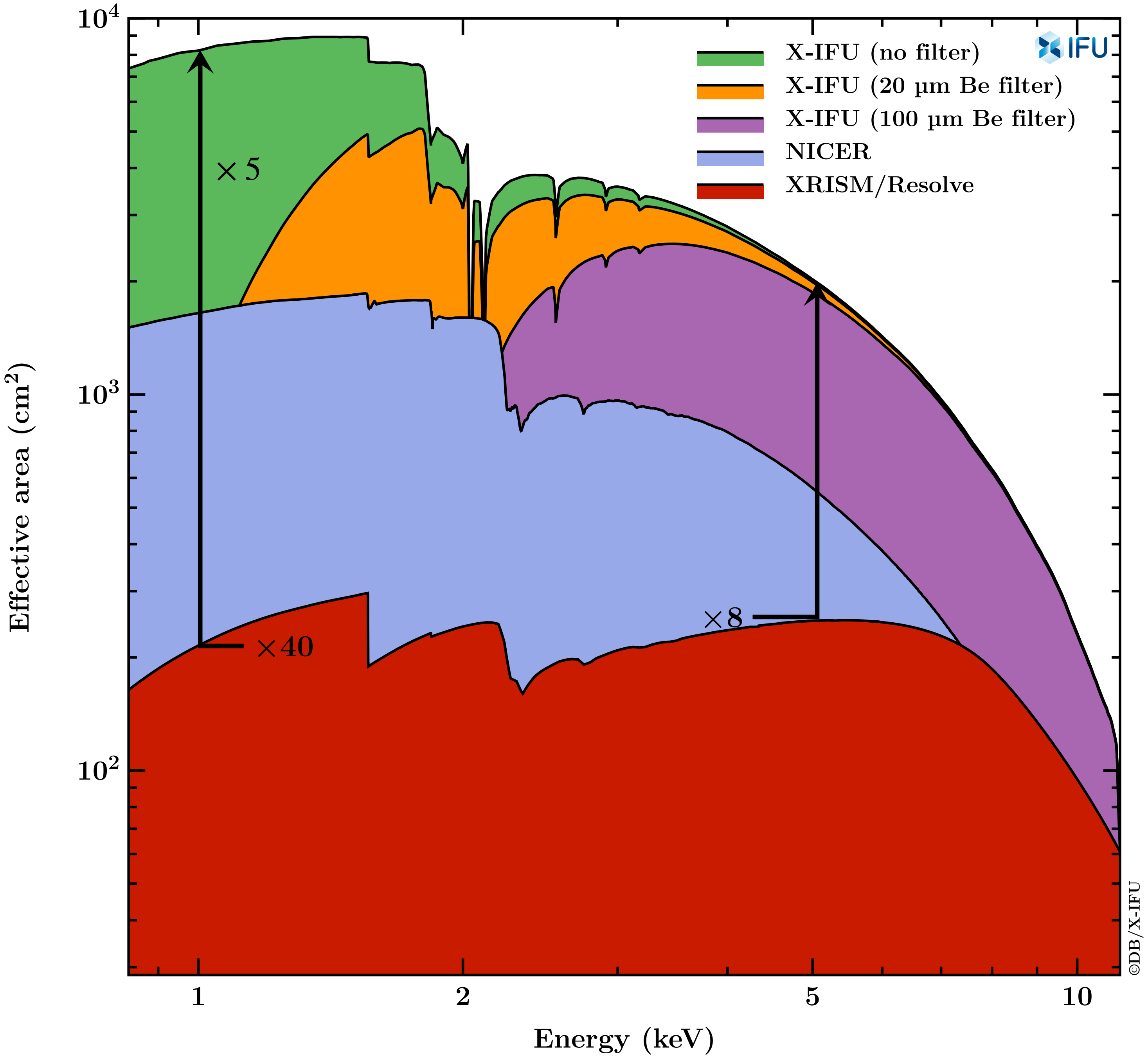


Credits : Philippe Peille and the X-IFU performance team

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

Effective area comparison

Effective area of X-IFU versus Nicer and XRISM/Resolve. Two Be filter thicknesses are shown for X-IFU (the thinner filter is still under optimisation).

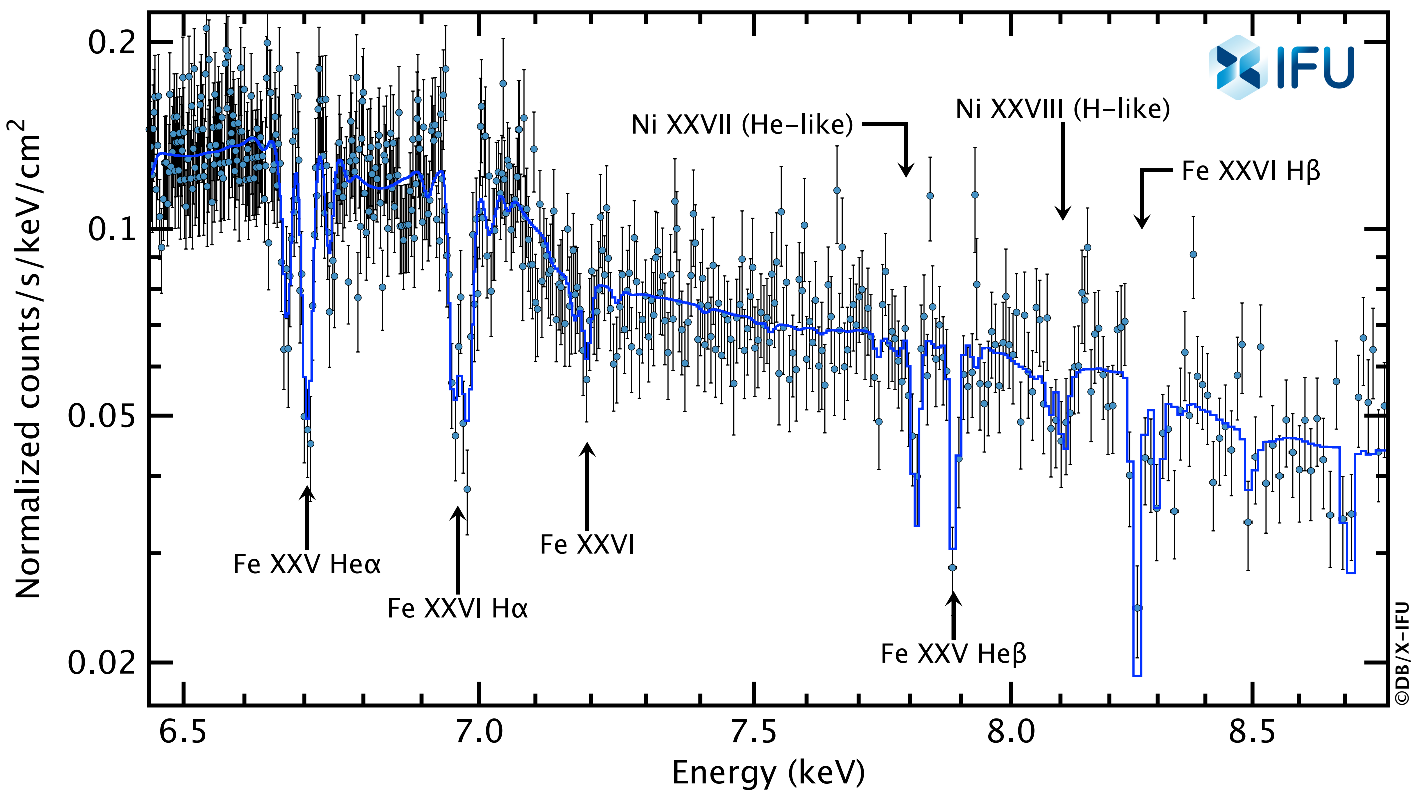


Credits : X-IFU team

Conclusions

- X-IFU will be the first high resolution X-ray spectrometer capable of observing bright X-ray sources, up to 1 Crab intensity, with micro-second time resolution and better than 10 eV spectral resolution
  - Even brighter sources (up to 10 Crab) will be observable with the fast detector of the Wide Field Imager with better than CCD type spectral resolution (<170 eV @ 7 keV)
- This makes Athena a suitable mission for observing bright X-ray binaries
- Athena is on its way to implementation for a launch in the mid-30s, following-up eXTP, bringing in the capability of performing high resolution X-ray spectroscopy of bright X-ray binaries

X-IFU simulated observation lasting only ~120 seconds of the Black Hole binary GRS1915+105. A disk wind, as reported in Miller et al. (2016) has been simulated. This rich set of features will enable unprecedented studies of the structure of the disk winds on dynamical timescales.



Data from J. Miller adapted from Miller et al. (2016, Astrophysical Journal Letters, 821, L9)