The Athena X-ray Integral Field Unit

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On behalf of the X-IFU Consortium with strong support from the X-IFU Science Advisory Team (Massimo Cappi, IASF-BO, IT & Etienne Pointecouteau, IRAP, F)

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The Athena X-ray Integral Field Unit

- X-IFU is the Athena cryogenic high-resolution X-ray spectrometer for Athena to be launched at the end of the next decades (☛ M. Guainazzi's talk)
- It is developed under the leadership of IRAP and CNES (France) by a worldwide consortium
  - ✓ with major contributions from Netherlands and Italy
  - ✓ and additional important contributions from **six** other ESA member states (Belgium, Finland, Germany, Poland, Spain, Switzerland)
  - ✓ and from two international partners (Japan and the United States)

What the X-IFU will do for you ?

- It will measure the physical properties of hot plasmas: velocity, turbulence, metal abundances, ionization, density, temperature, energy dependent time lags…
  - ✓ 3D mapping down to **5'' angular size** over a **5' field of view**, absorption/emission line spectroscopy with **2.5 eV** resolution, continuum measurement up to **12 keV**, spectral-timing analysis with time resolution down to **10µs**
- It will observe a broad range of astrophysical sources, in a wide variety of environments and conditions (redshift, mass, mass accretion rate, magnetic field, viewing geometry, obscured, unobscured,…)
  - ✓ In the filaments of the cosmic web where the missing baryons are thought to reside
  - ✓ From the early groups to the local massive galaxy clusters (z ~2)
  - ✓ From cluster cores to cluster outskirts
  - ✓ Around compact objects: white dwarfs, neutron stars, stellar mass black holes, intermediate mass black holes, supermassive black holes in AGN
  - ✓ Around stars at different evolution stages, exoplanets, planets
  - ✓ In supernovae remnants, the interstellar medium,…
- From the faintest extended diffuse distant sources to the brightest nearby X-ray point sources up to ~1 Crab intensity level (enabled by the defocussing of the optics)

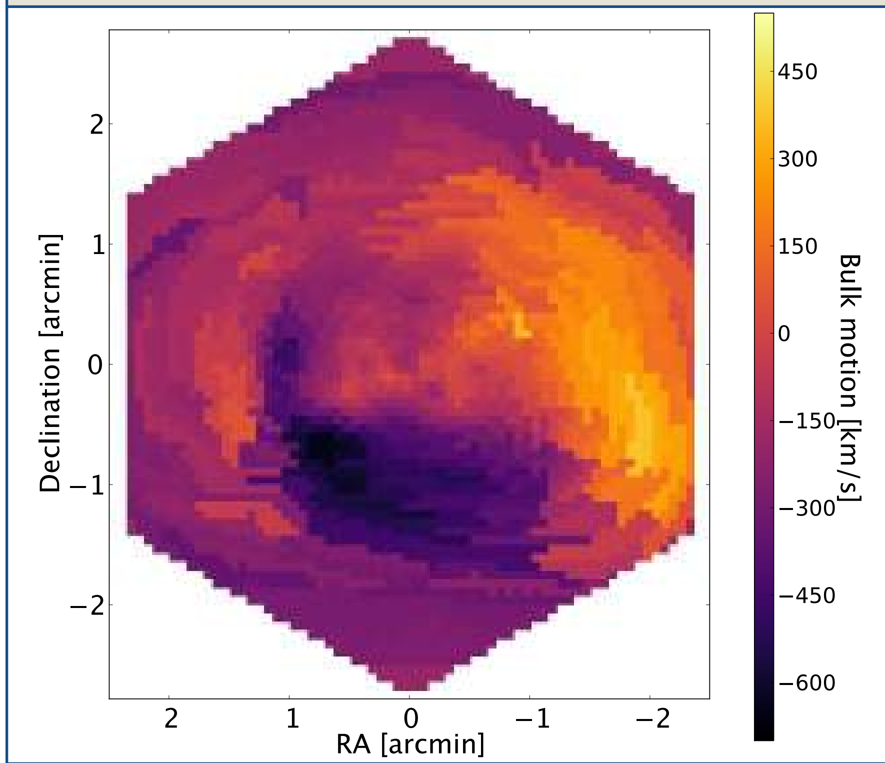
What the X-IFU is designed for ?

- How matter assembles in dark matter potential?
  - ✓ Mapping bulk motion and turbulence of hot cluster gas
- How was the Universe chemically enriched?
  - ✓ Mapping metals and measuring abundances from the epoch of cluster formation
- Were and what are the missing baryons?
  - ✓ Observing the Warm Hot Intergalactic Medium in absorption using background light sources (AGN and GRB afterglows) and in emission
- How do black holes work?
  - ✓ Measuring spins, observing disk-corona interaction, jets, winds and outflows, from very low to super Eddington accretion rates, across the compact object mass scale and down to the epoch of the formation of the first stellar mass black holes
- How black holes interact with and shape their surroundings?
  - ✓ Observing feedback in clusters, galaxy centers, galaxies
- How stars and (co-)planets co-evolve? How stars live and explode?
  - ✓ Observing solar system bodies, star-exoplanets systems, stellar winds, mapping metals in SNR
- Which unknown phenomena will be discovered by X-IFU in the era of multi-messenger, transient observations?

Breakthrough observations — I

ATHENA X-IFU X-ray Integral Field Unit

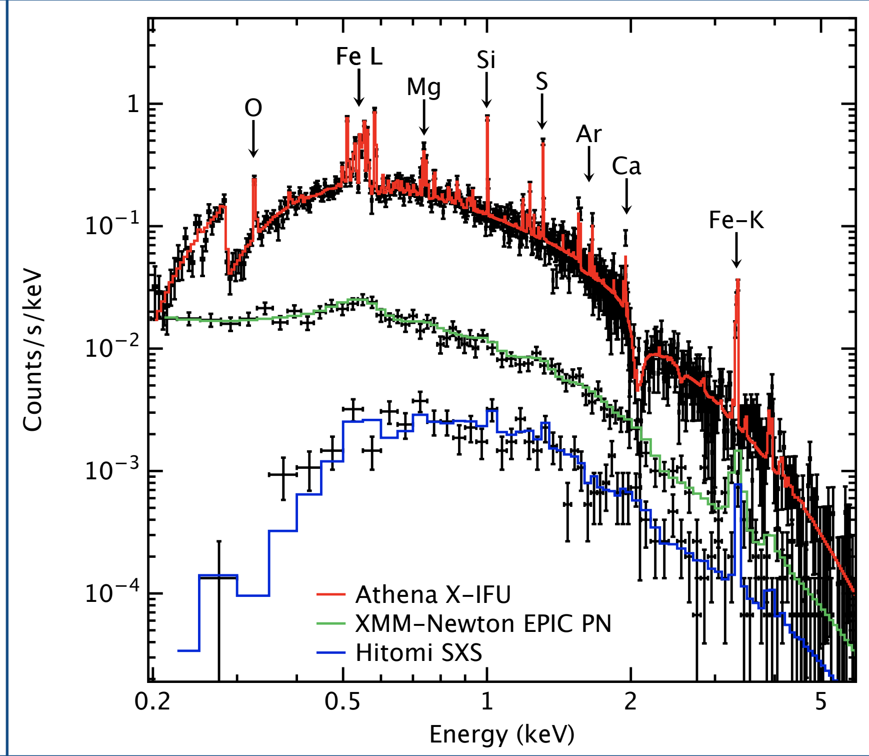
Accretion in dark matter halos



Simulated velocity map of hot cluster gas derived from multiple atomic line shifts

Courtesy Ph. Peille et al.
See Poster by E. Cucchetti

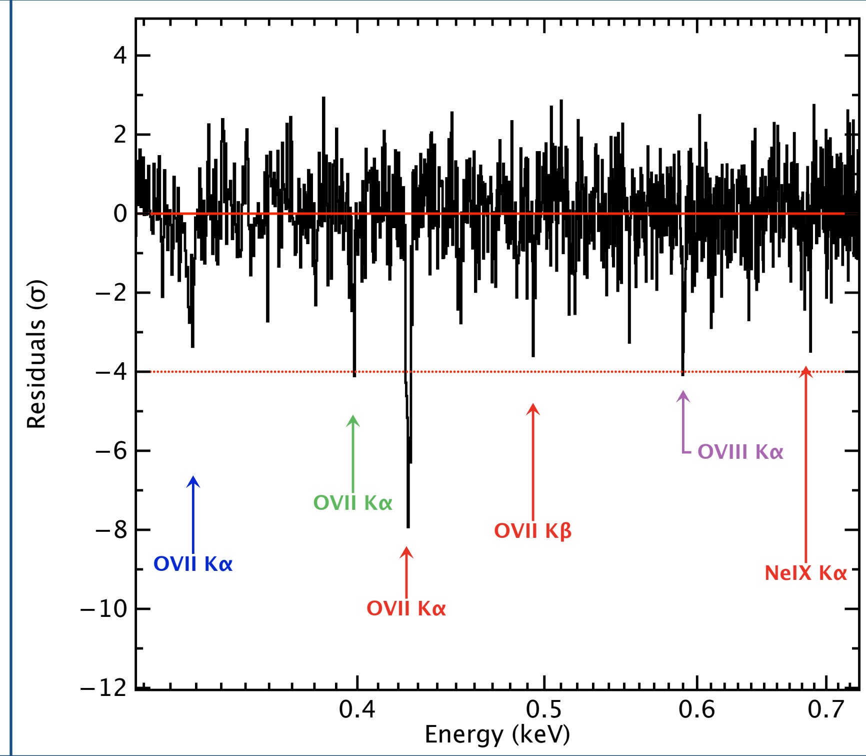
Chemical enrichment of the Universe



Metal rich X-IFU spectrum compared with XMM-Newton and Hitomi/XSX

Courtesy E. Pointecouteau et al.

Missing baryons revealed



Multi-filament WHIM absorption X-ray spectrum using a bright GRB afterglow.

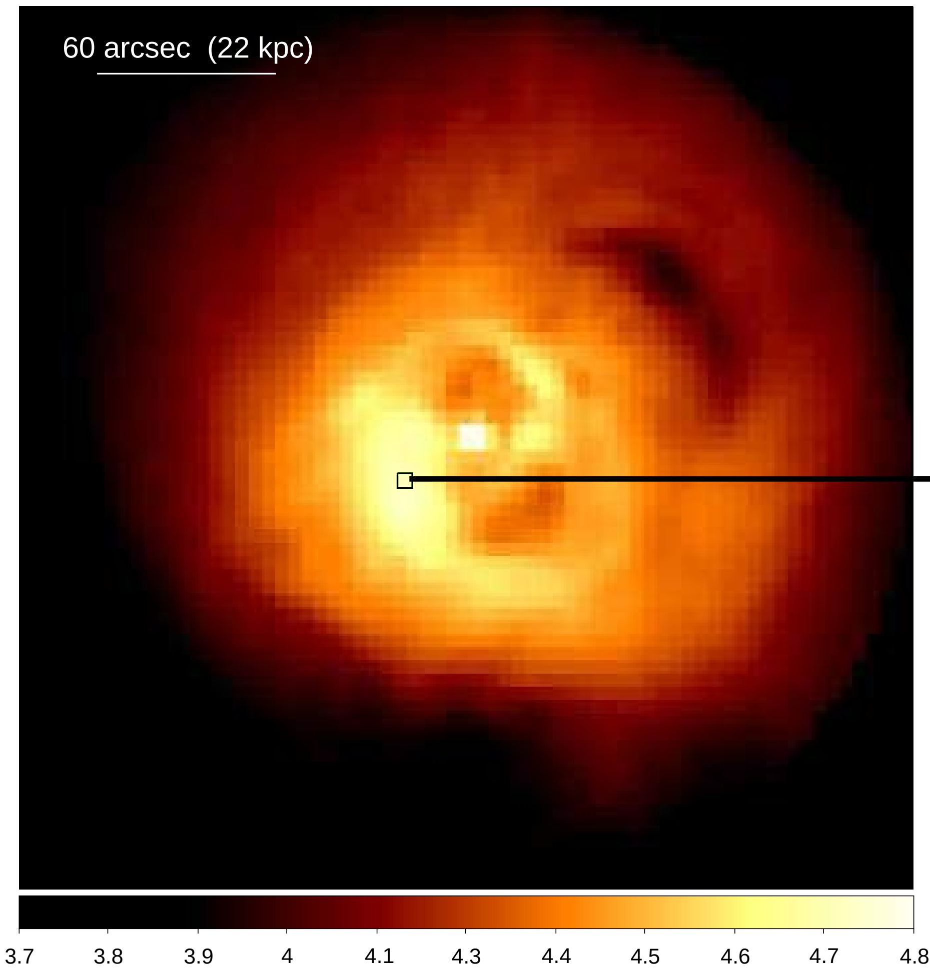
Courtesy F. Nicastro et al.

Relevant spatial scales, velocity resolution down to 20 km/s, high SNR enabled by the spectral resolution, low instrumental background

irap

Breakthrough observations — II

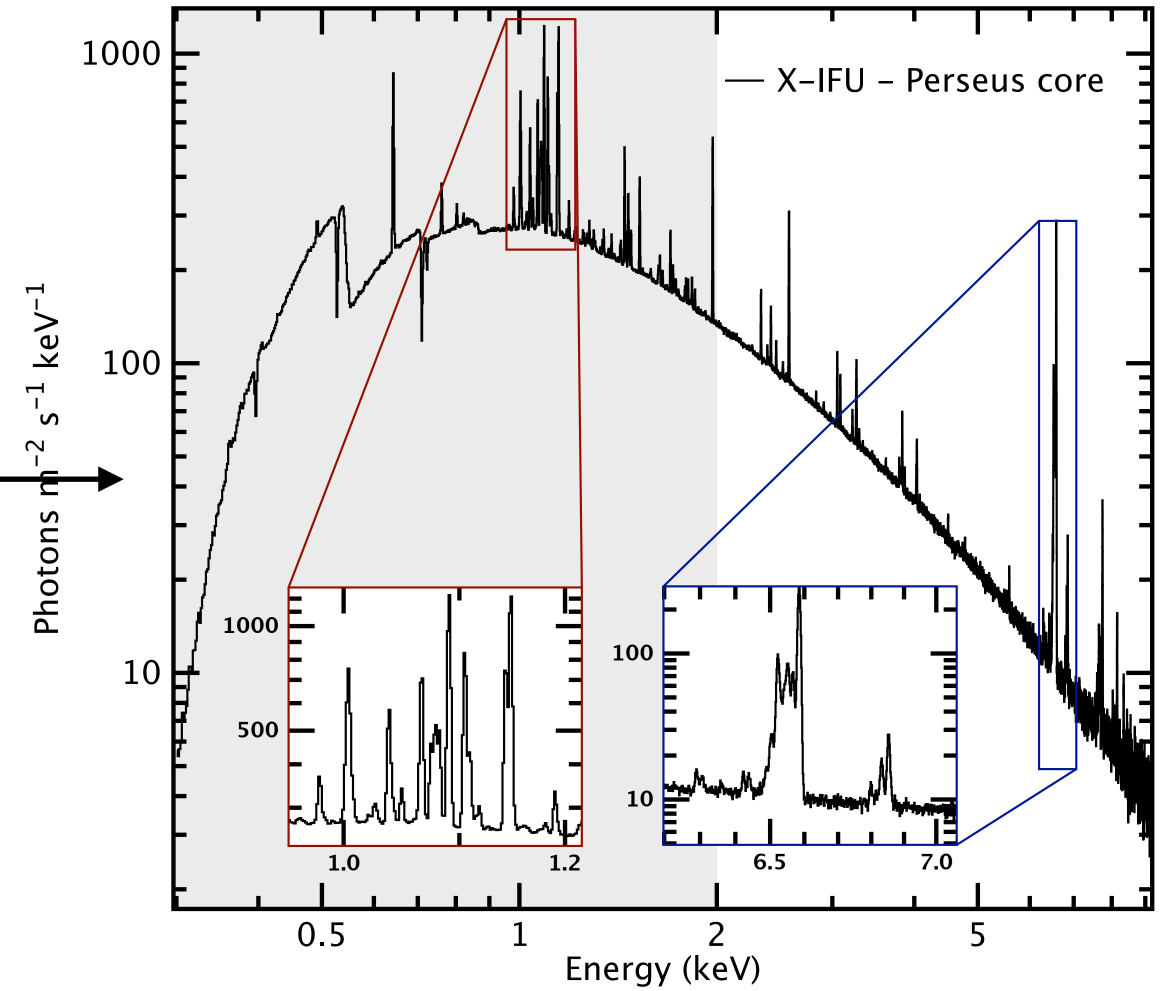
Cluster feedback



Simulated X-IFU image of Perseus.

Courtesy J. Sanders

Gas dynamic and jet energy dissipation in clusters

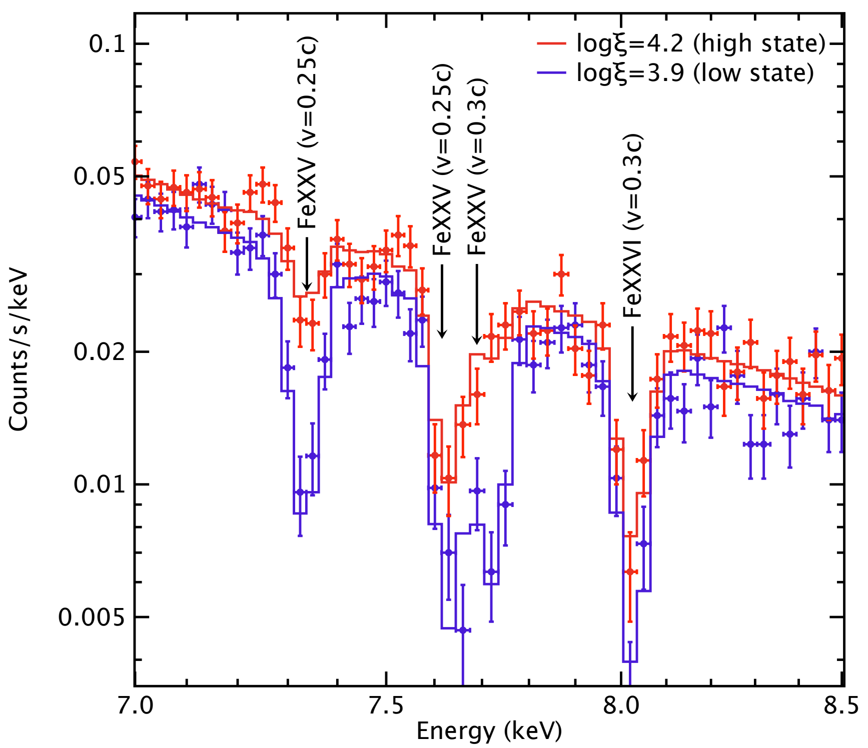
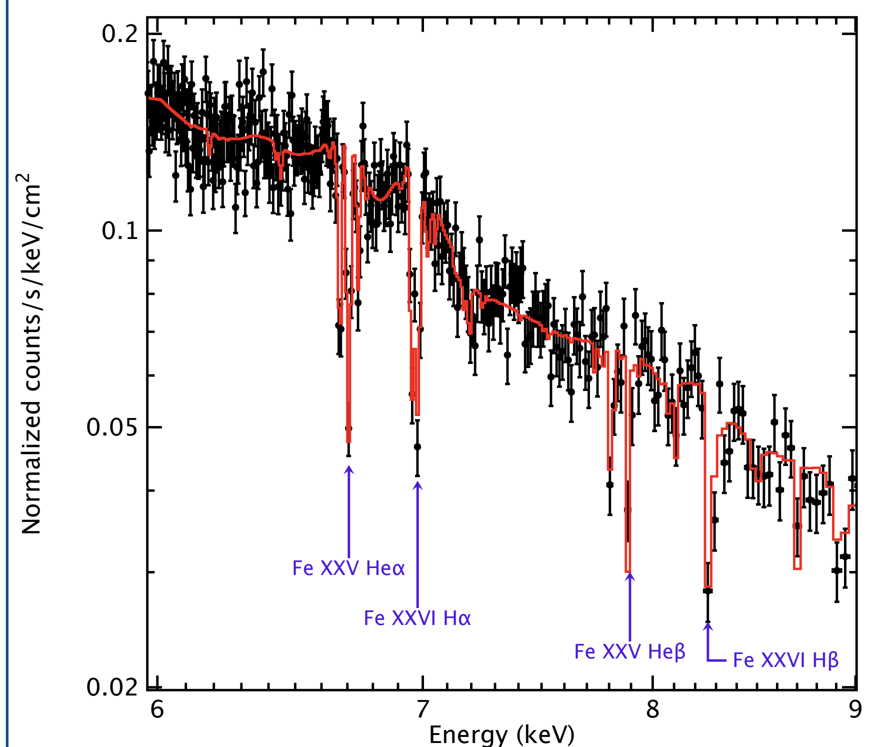
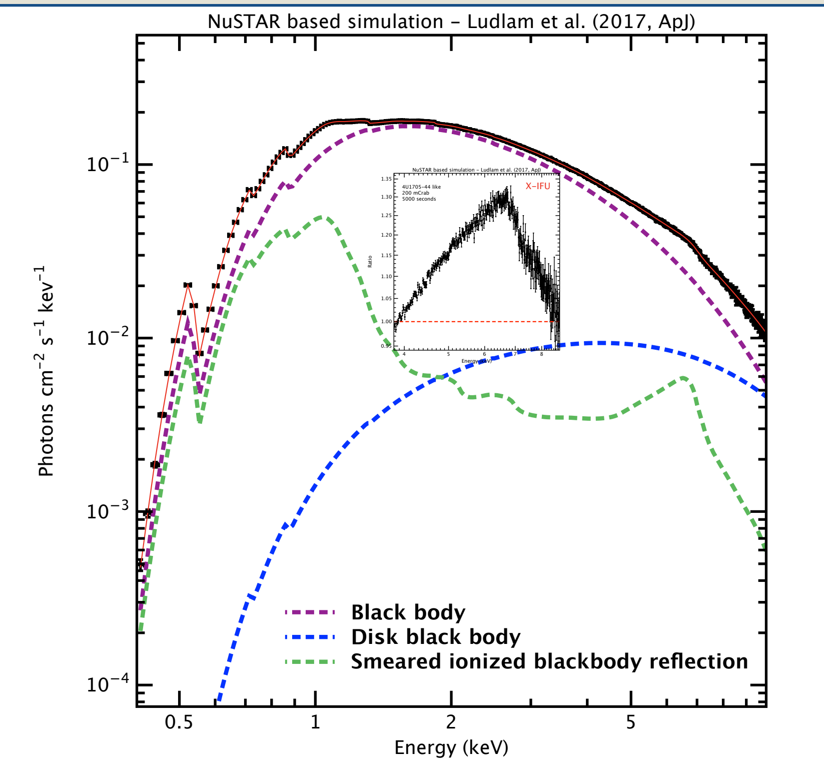


X-IFU pixel size spectrum of Perseus Region not observed by SXS indicated in grey.

Courtesy C. Pinto & A. Fabian for the Hitomi spectrum

Small spatial scales, high SNR, broad band coverage, low instrumental background

Breakthrough observations — III

AGN outflows	Black hole winds	Understanding accretion
		
Simulated ultra-fast outflow spectrum for two velocities and ionization states	Disk wind spectrum of the stellar mass black hole GRS1915+105	Broad band X-IFU spectrum of the neutron star low-mass X-ray binary 4U1705-44.
Cappi, Done et al 2013, arxiv:1306.2330	Courtesy J. Miller	Courtest R. Ludlam.

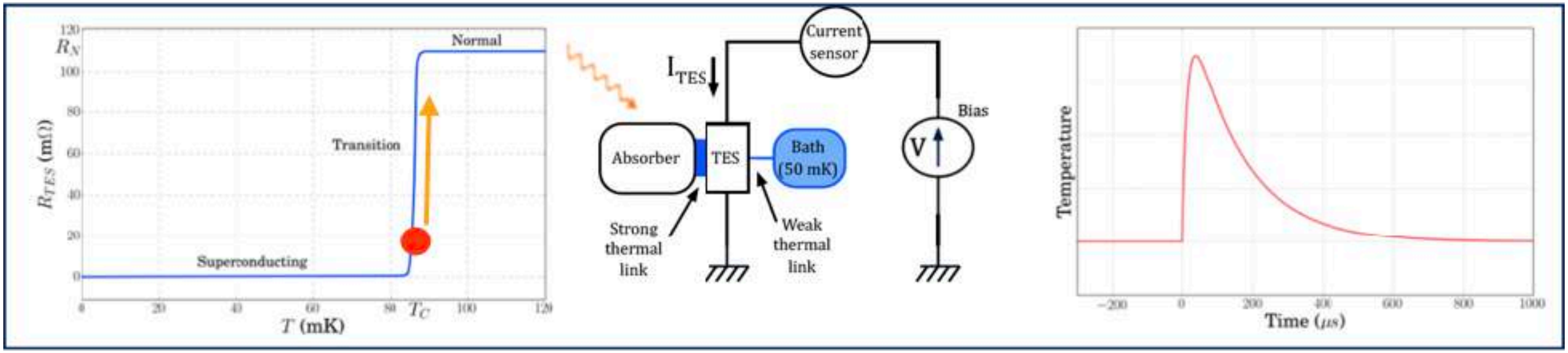
Relevant time scales, high signal-to-noise ratio up to 10 keV, broad band coverage, bright source count rate capability

Main X-IFU performance requirements

Parameter	Value	Main science drivers
Spectral resolution	2.5 eV (E < 7 keV)	Matter assembly in clusters - Jet energy dissipation on cluster scales - Census of warm-hot baryons - *Bulk motion of 20 km/s* - *Weak line sensitivity - Resolving OVII like triplet*
Field of view	5' (equivalent diameter)	Matter assembly in clusters - X-ray cooling cores - Metal production and dispersal - Jet energy dissipation in clusters - *To map nearby clusters out to R_{500}*
Pixel size	~ 5'' (~mirror PSF HEW)	Jet energy dissipation in clusters - AGN ripples in clusters - Cumulative energy deposited by radio galaxies - *Matches structure size and minimizes confusion*
Background level	$<5\ 10^{-3}$ count/s/cm^2/keV	Matter assembly in clusters - Metal production and dispersal - *Required for low surface brightness sources*
Low-energy threshold	0.2 keV	Census of warm-hot baryons - Physical properties of the WHIM - *OVII and C V lines at 0.31 keV*
Count rate capability	1 mCrab (2.5 eV, 80% eff.) 10 mCrab (2.5 eV, 80% eff.,goal) 1 Crab (<30 eV, 30% eff.)	Probing the WHIM with GRB afterglows, Probing black hole and neutron star accretion & winds - *Brightest point source requirement*

Micro-calorimeter principle

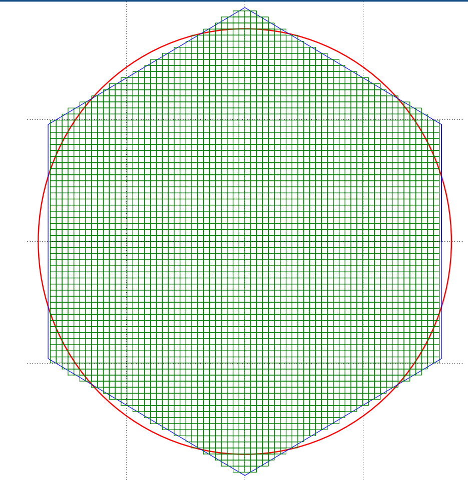
- The X-IFU will be based on a large format Transition Edge Sensor hexagonal array (with a ~250 μm pitch)
- A TES is a microcalorimeter (superconducting resistive material) which senses the heat deposited by an X-ray photon on its absorber

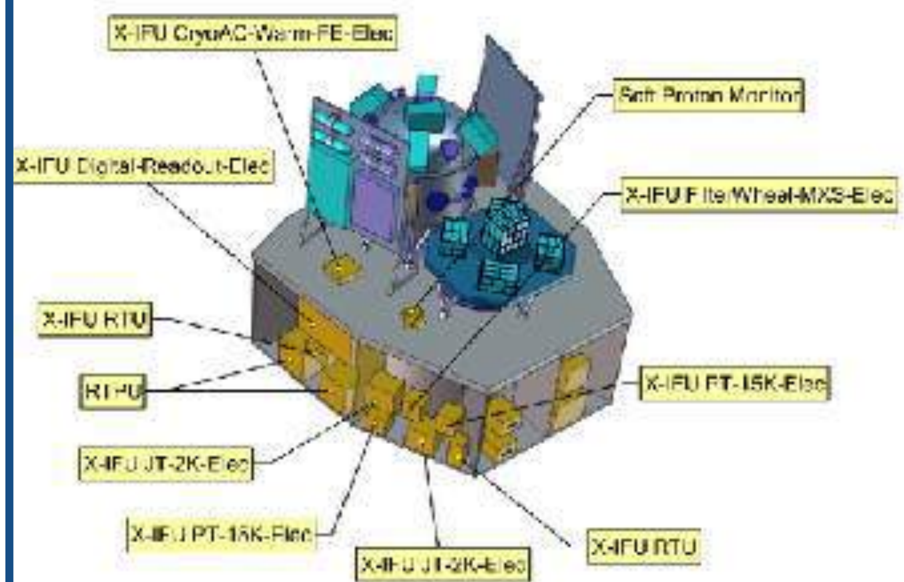


- Require operating temperatures below 100 mK, highly sensitive devices difficult to operate in space

X-IFU main features

- The prime TES array (hexagonal) is actively shielded by a second TES array to meet the low background requirement
- Cryogenic chain down to 50 mK as an assembly of mechanical coolers at different interface temperatures to guarantee mission lifetime and high observing efficiency
- Frequency domain multiplexing readout (40 pixels readout) to keep heat load at 50 mK as low as possible
- Event processing returning arrival time, energy, grade of each photon
- On-board calibration sources for accurate energy calibration
- A set of user selectable filters on a filter wheel (optical, Be, grey ,….)
- Agressive technology developments to meet the performance requirements

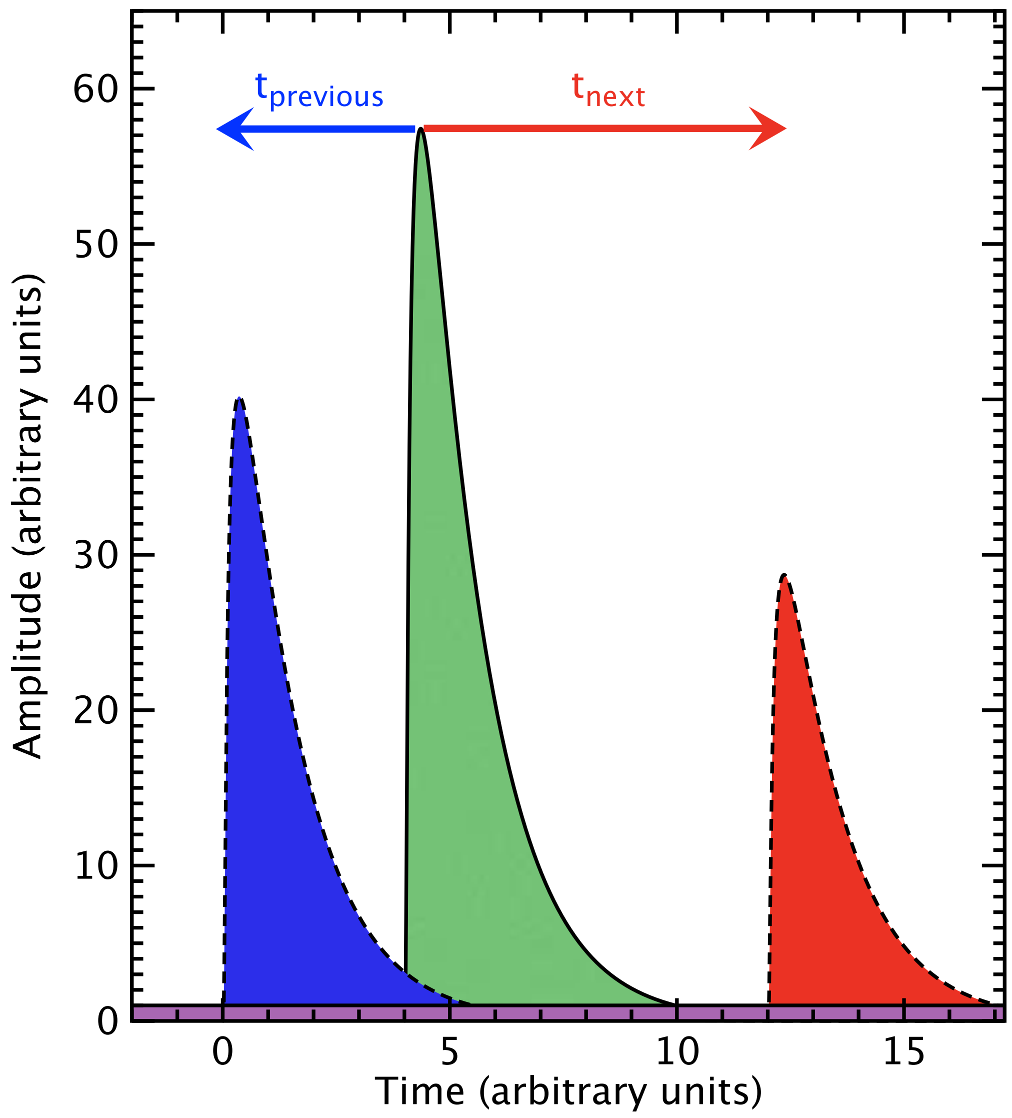




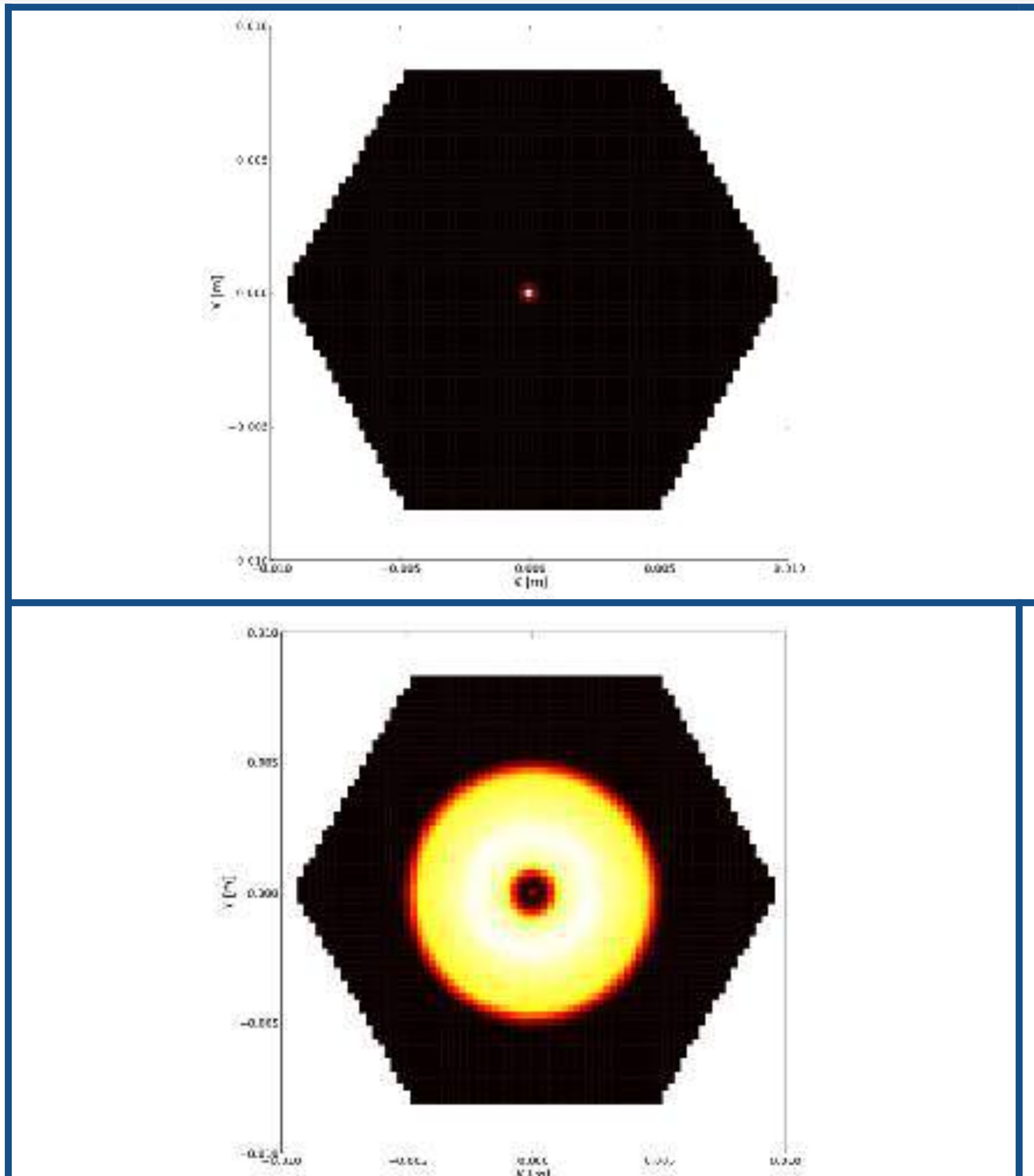
800 kg — 2500 W — Courtesy of ESA, CNES

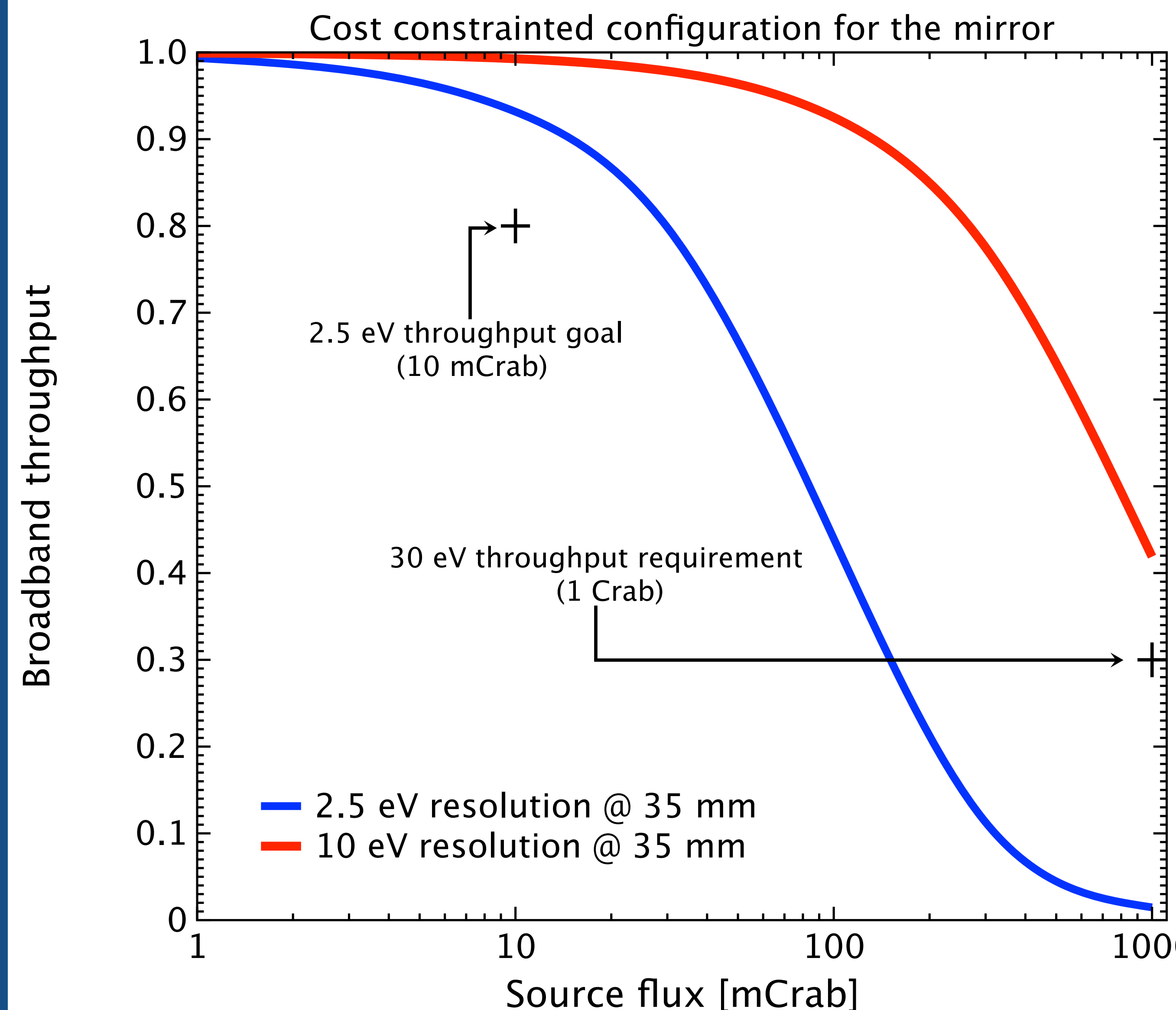
X-IFU count rate performance

- Time resolution is ~10 μs (pile-up free)
- The grade of an event depends on the separation between the preceding pulse and the subsequent one
  - ✓ The highest grade corresponds to 2.5 eV resolution
  - ✓ The lowest grade would be 10-30 eV resolution
- Grade ratios depend on source count rate (distribution of counts over the pixels)
- Defocussing of the optics enables to spread the mirror PSF over a larger number of pixels, hence enable the X-IFU to cope with brighter sources and still deliver high resolution events



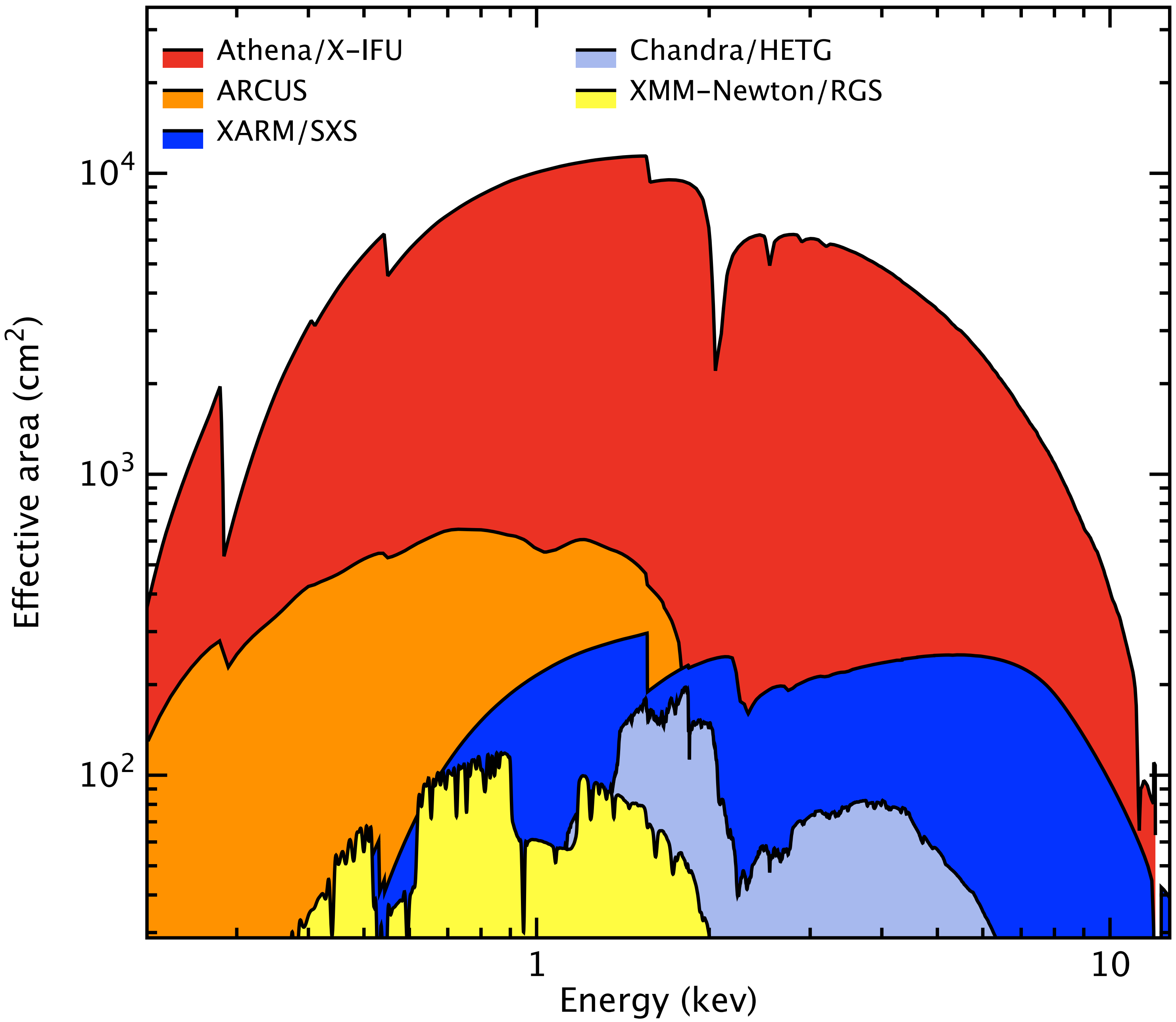
Count rate capability





Courtesy of the e2e simulator team led by J. Wilms (Ph. Peille & T. Dauser)

Effective area comparison - limited to high resolution spectrometers



A factor of ~100 improvement in effective area at 0.5 keV compared to XARM/SXS (~40 @ 1 keV)	*A factor of ~10 improvement in effective area at 6-7 keV compared to XARM/SXS*

Weak line sensitivity

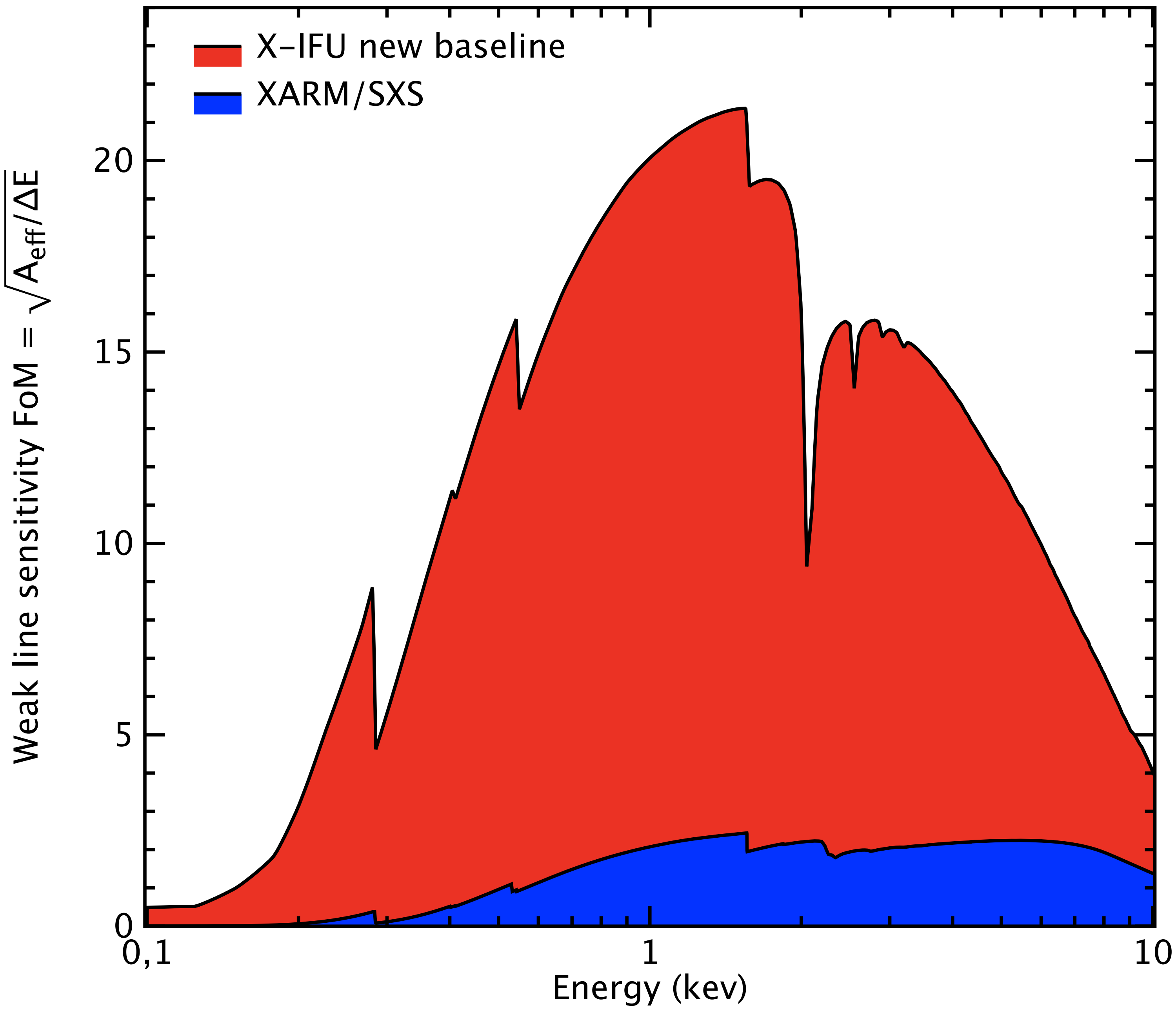
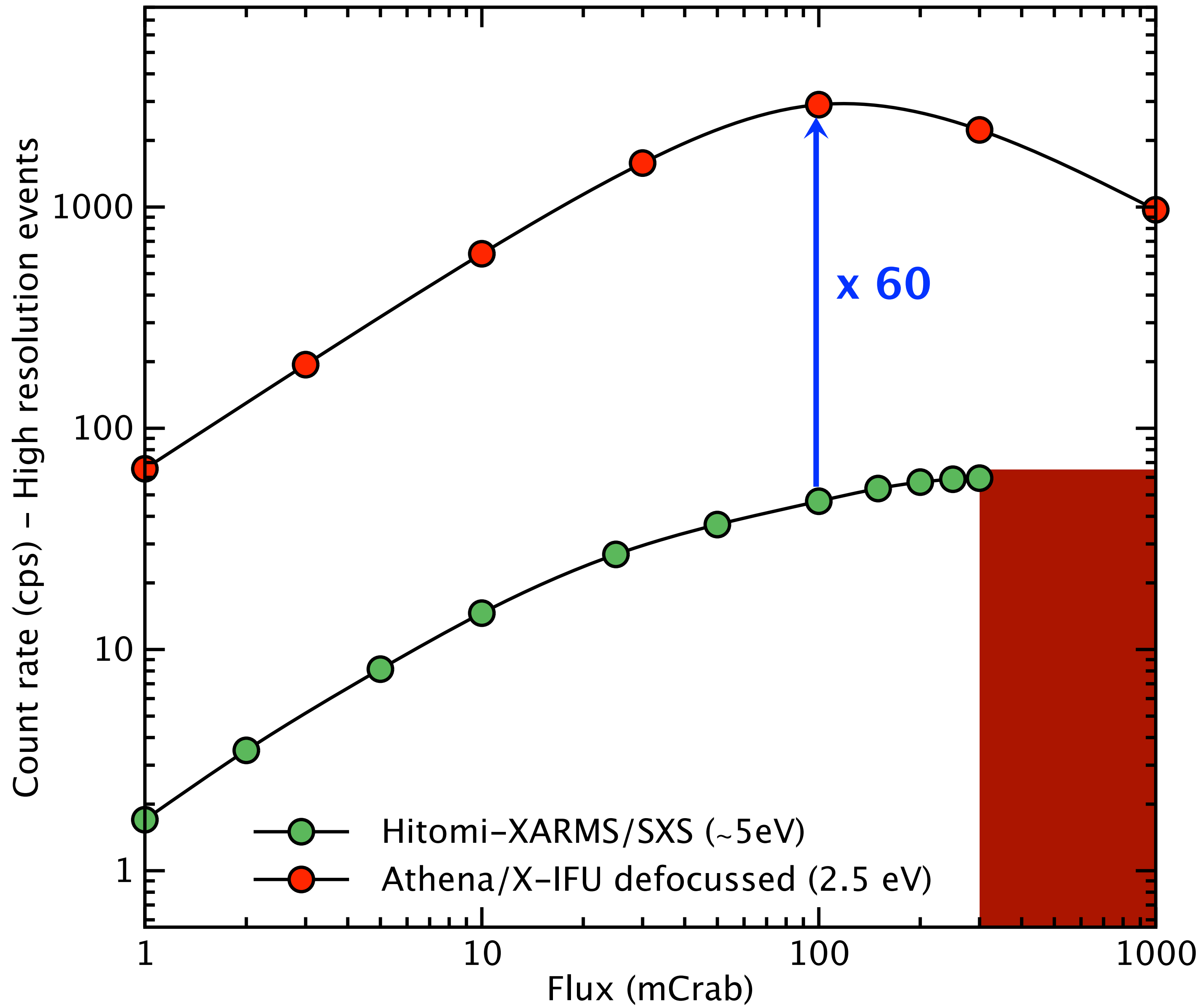


Figure of merit for weak line sensitivity 10 times better than foreseen with XARM/SXS, taking advantage of the higher effective area and better spectral resolution

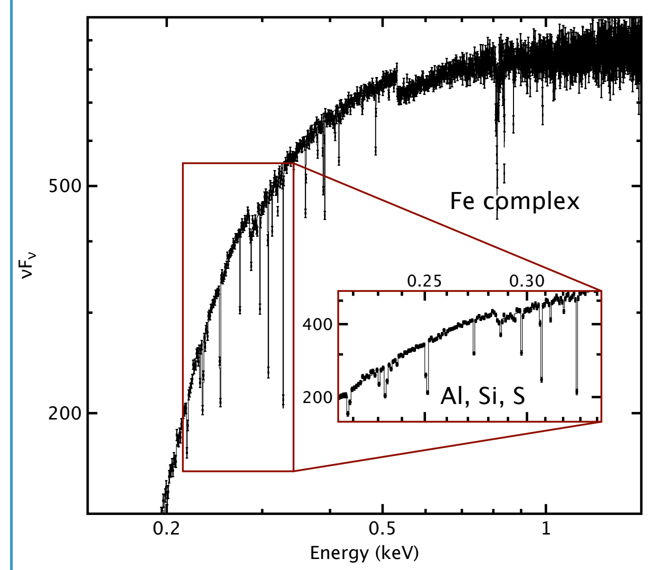
Count rate capability comparison

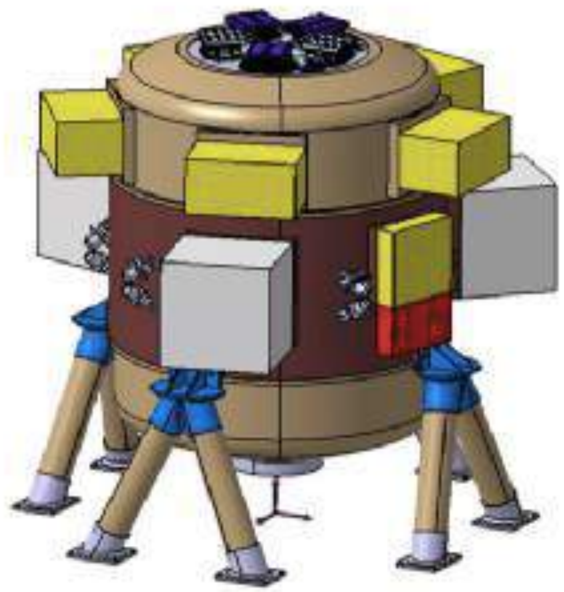


A factor of ~60 increase of count rates at high spectral resolution	*Extension of the source intensity observable above 300 mCrab*

Conclusions

- X-IFU science case builds up on the power of X-ray spectroscopy whose revolutionary potential has been highlighted during this meeting
  - ✓ XARM/SXS will revolutionize the field further and may define completely new science objectives for X-IFU
  - ✓ Importance of multiwavelength data, better modeling highlighted, better atomic data too
  - ✓ **X-IFU has huge discovery potential, e.g probing the ISM at z>7 with GRBs**
- The X-IFU performance requirements are very ambitious, at the very edge of what can be achieved with state of the art technology
- The X-IFU is currently in its feasibility study phase while its overall design is being consolidated (no instrument de-scopes considered so far)
  - ✓ Enabling technologies are being developed with significant progresses in key areas (e.g. cryogenic chain, readout chain, TES)
  - ✓ A major technological challenge, but the X-IFU consortium carries all the expertise to face it





Thanks to you and to them !