ATHENA

The Athena X-ray Observatory

(and its X-ray Integral Field Unit)

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Outline

- Athena science - The Hot and Energetic Universe
- Athena science payload
- X-ray Integral Field Unit (X-IFU) performance optimization
  - relevant probing super-Eddington accretion
- Athena current status
- Conclusions

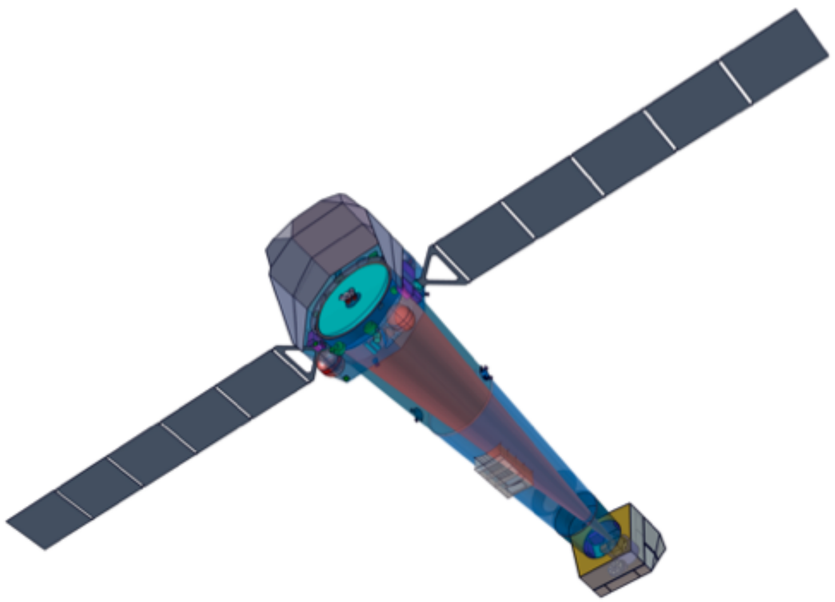
Athena science

- Scientific theme: The Hot and Energetic Universe
  - How does ordinary matter assemble in the large-scale structures?
    - Tool: X-ray emitting hot gas in clusters
  - How do black holes grow and shape galaxies?
    - Tool: Accretion powered X-rays onto compact objects
- Together with:
  - Observatory science from planets, stars, supernova remnants, interstellar medium…
  - Discovery science enabled in particular through a fast ToO capability to study the transient sky

Need to combine a large aperture X-ray telescope, wide field imaging, high-resolution spectroscopy and an agile spacecraft

Athena in a nutshell

- Second Large (L) mission of the ESA Cosmic Vision 2015-2035
- Launch year: end of 2028
  - with the newly developed Ariane 6 (64)
- A 7 ton spacecraft to be placed in a L2(L1) orbit
- Unprecedented collecting area in X-rays:
  - 2 m^2 at 1 keV and 0.17 m^2 at 7 keV
  - 5'' angular resolution
- Two focal plane instruments with a movable mirror assembly
  - The Wide Field Imager (WFI) optimized for fine imaging and bright sources
  - The X-ray Integral Field Unit (X-IFU) optimized for high-resolution spectroscopy



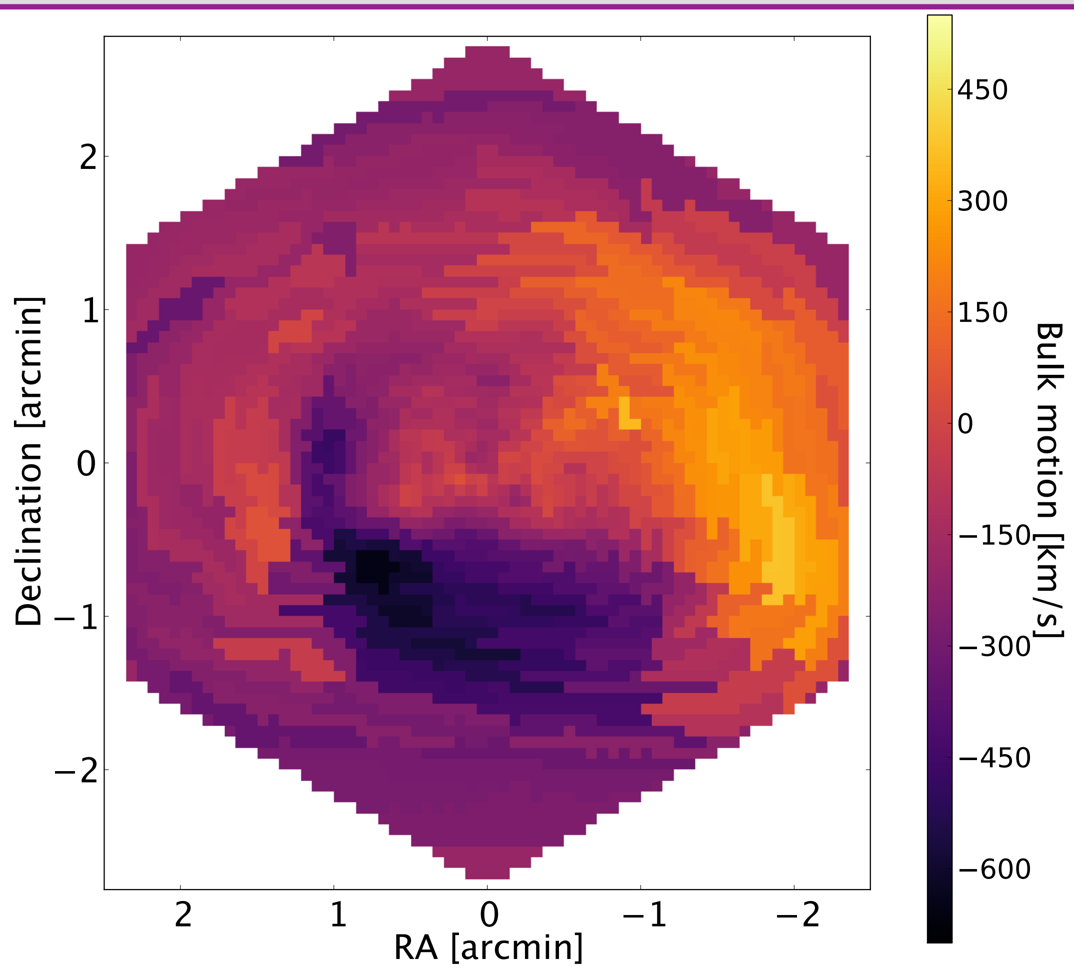
The Hot Universe - key questions

- How do baryons in groups and clusters accrete and dynamically evolve in the dark matter haloes?
- What drives the chemical and thermodynamic evolution of the Universe largest structures?
- What is the interplay of galaxy, supermassive black hole, and intergalactic gas evolution in groups and clusters?
- Where are the missing baryons at low redshift and what is their physical state?

Hot Universe

Accretion in dark matter haloes

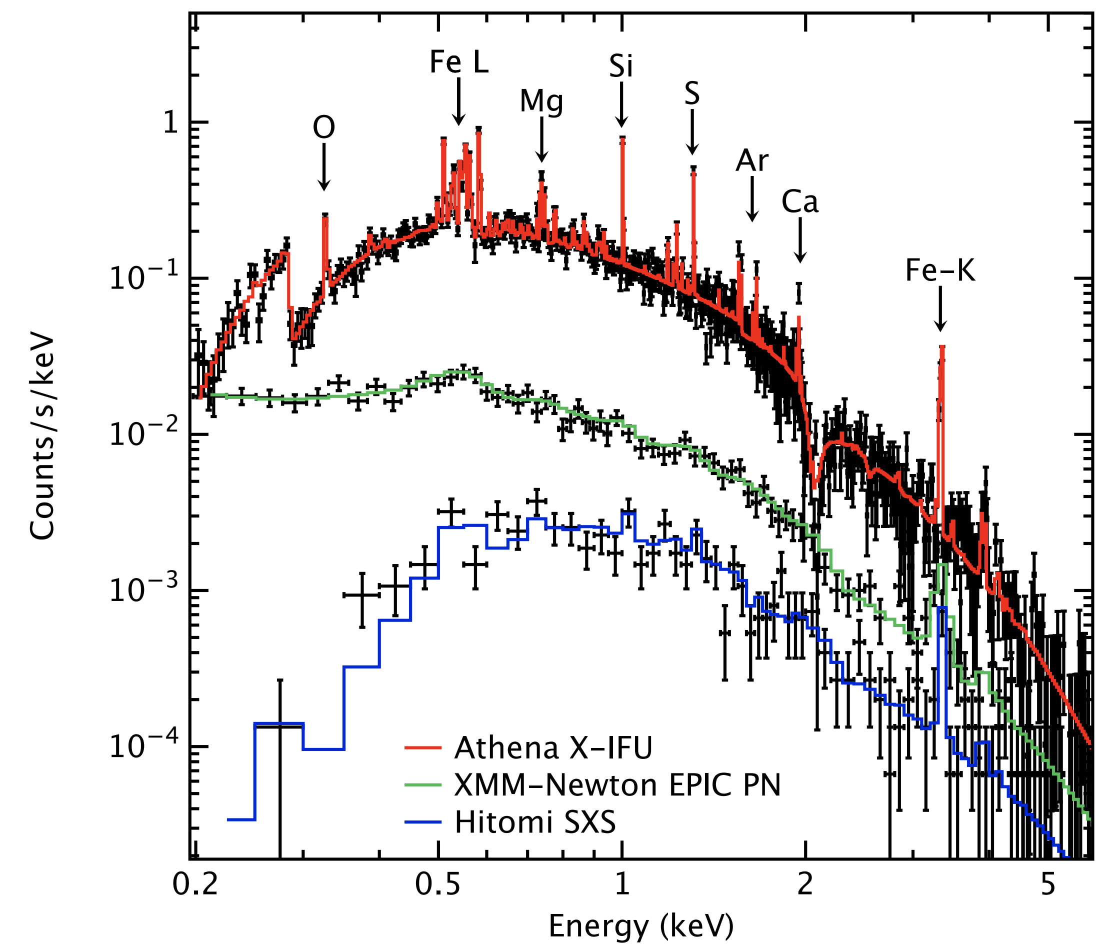
Map gas motions and turbulence to understand how baryons accrete and evolve in the largest dark matter potential wells of groups and clusters.



Simulated velocity maps (courtesy of Ph. Peille et al.). Ettori, Pratt et al. (2013) arXiv1306.2322

Chemical enrichment

Synthesize the abundances using yields of various SN types and AGB stars to determine when the largest baryon reservoirs in galaxy clusters were chemically enriched



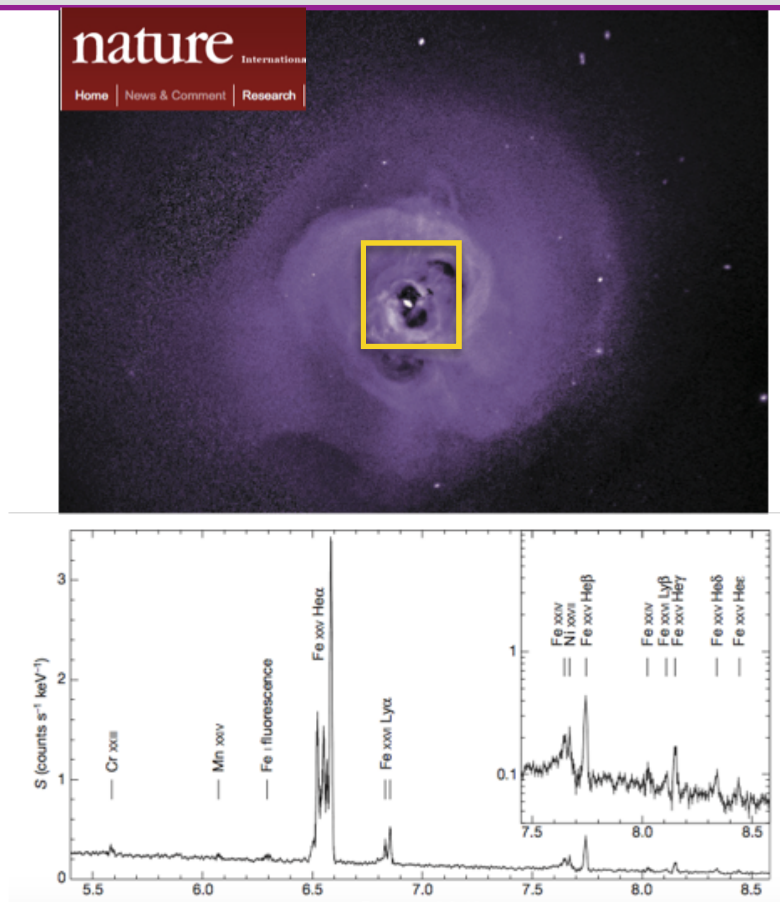
High resolution X-ray spectrum of a z=1 cluster. Pointecouteau, Reiprich et al (2013), arXiv: 1306.2319

Hot Universe

ATHENA X-ray Integral Field Unit

Cluster feedback

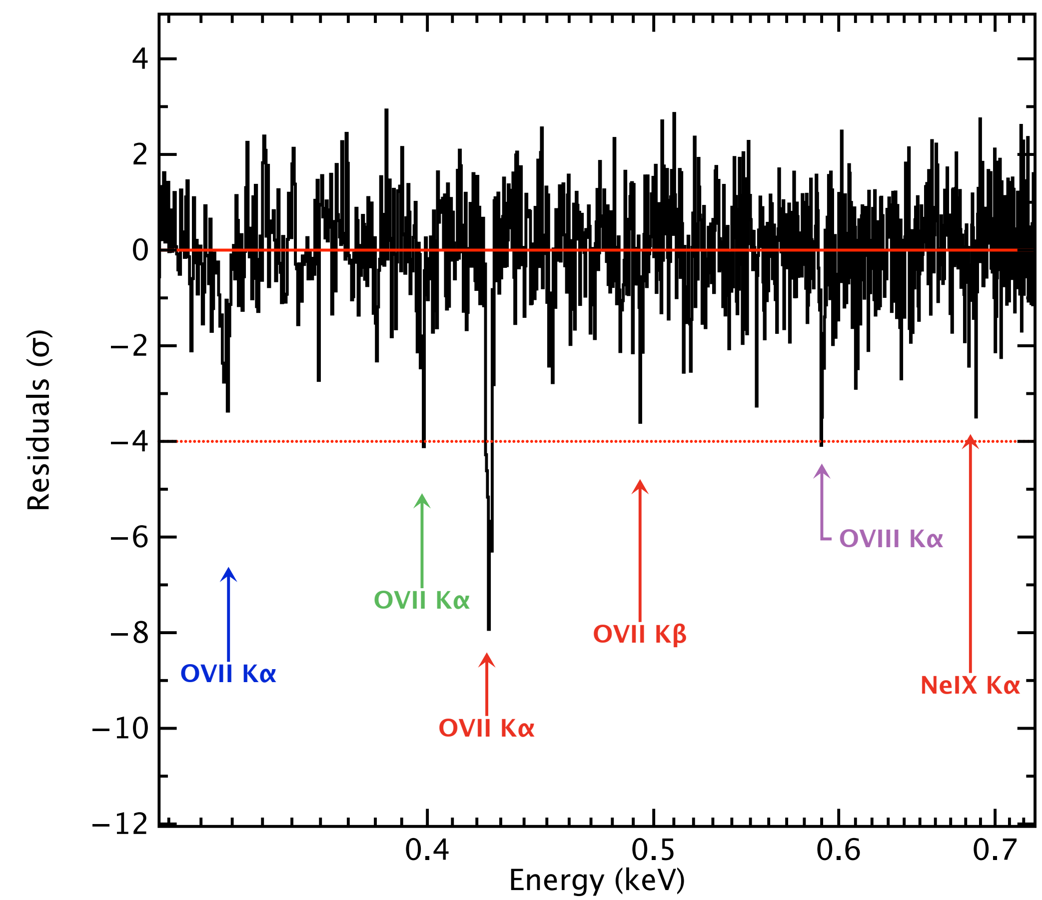
Measure hot gas bulk motions and energy stored in turbulence directly associated with the expanding radio lobes to understand how jets from AGN dissipate their mechanical energy in the intracluster medium, and how this affects the hot gas distribution



Spatially revolved high resolution spectroscopy of the Perseus cluster- Hitomi collaboration (2016)

Missing baryons

Measure the chemical composition, density, size, temperature, ionization and turbulence of the missing 50% of baryons at $z<2$ and reveal the underlying mechanisms driving their distribution on various scales, from galaxies to galaxy clusters, as well as metal circulation and feedback processes.



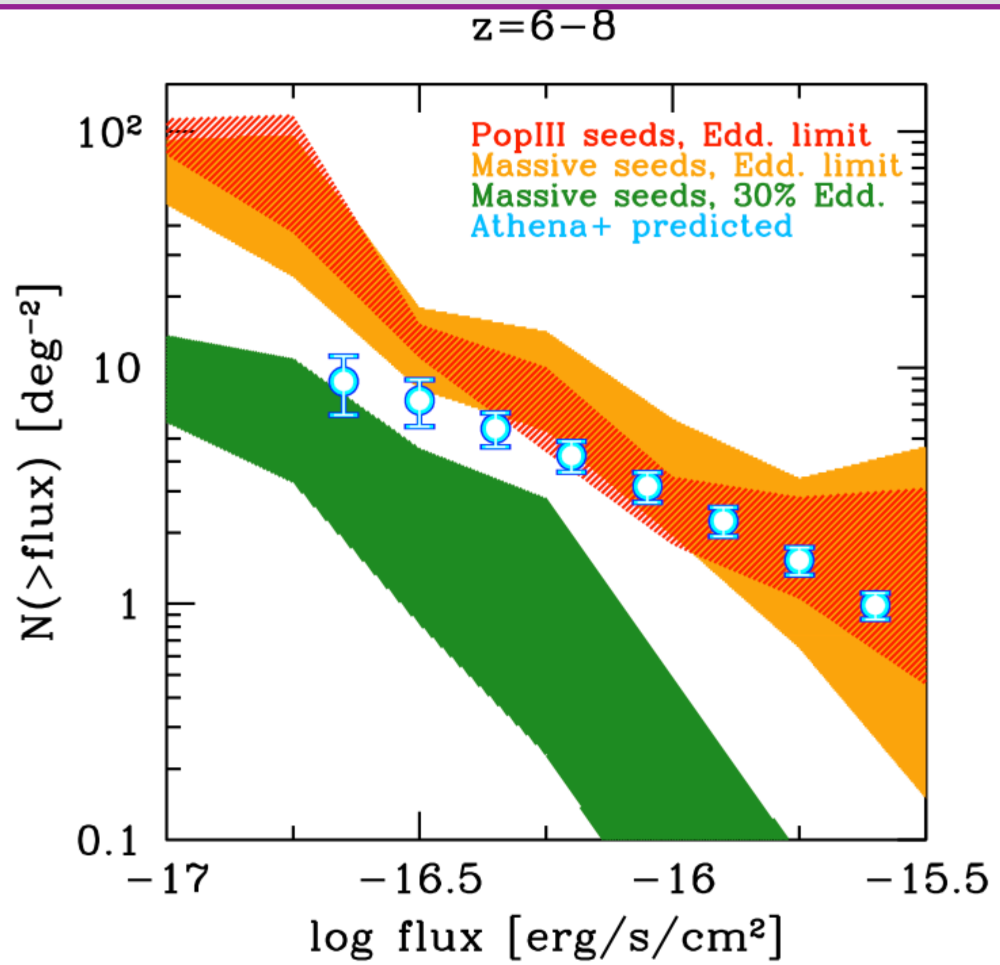
Multi-filament WHIM absorption X-ray spectrum using GRB afterglow. Barret et al. (2016), Courtesy of F. Nicastro

The Energetic Universe - key questions

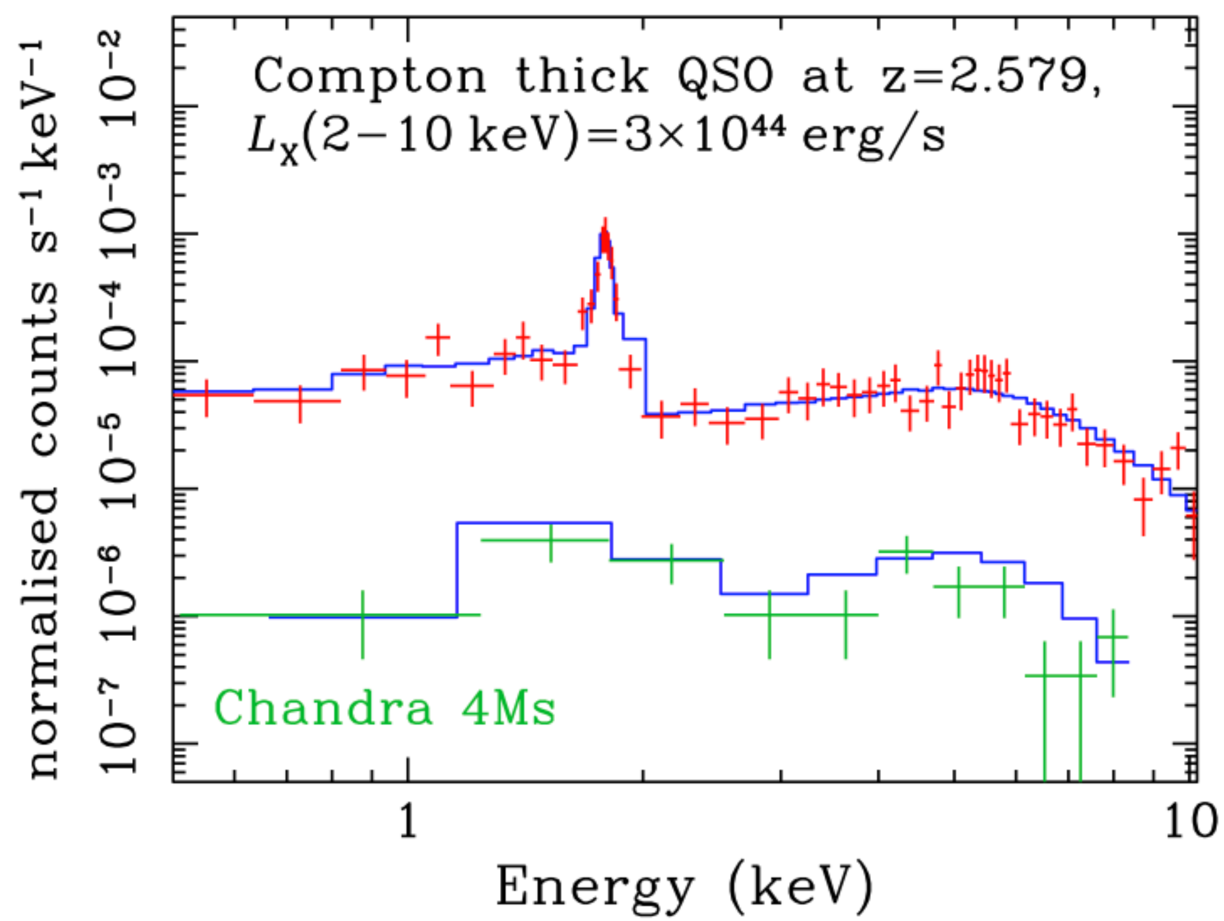
- How do early supermassive black holes form, evolve and shape the Universe?
- What is the role of (obscured) black hole growth in the evolution of galaxies?
- How do accretion-powered outflows affect larger scales via feedback?
- How do accretion and ejection processes operate in the near environment of black holes?

Energetic Universe

Black hole growth	Obscured accretion
Determine the nature of the seeds of high redshift (z>6) SMBH, which processes dominated their early growth, and the influence of accreting SMBH on the formation of galaxies in the early Universe.	Find the physical conditions under which SMBH grew at the epoch when most of the accretion and star formation in the Universe occurred (z~1-4)



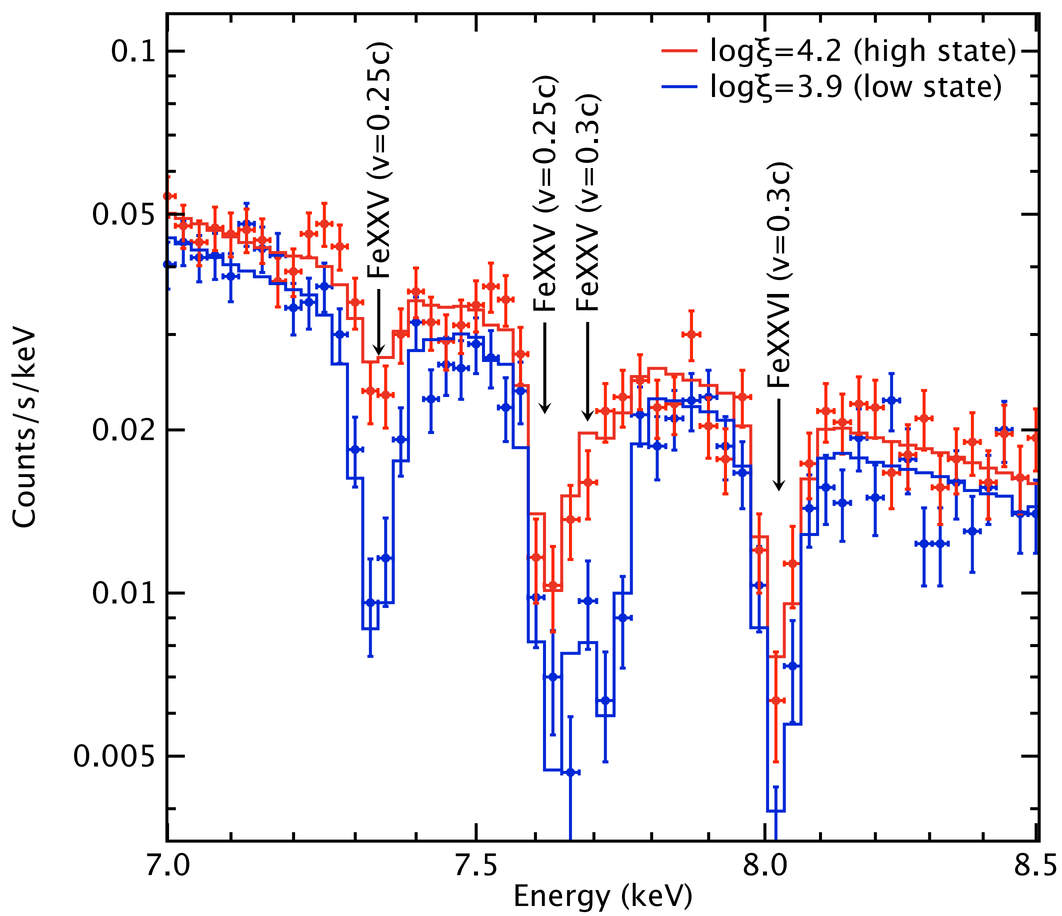
Flux distribution of AGNs in comparison with model predictions. Aird, Comastri et al. (2013) arXiv1306.2325



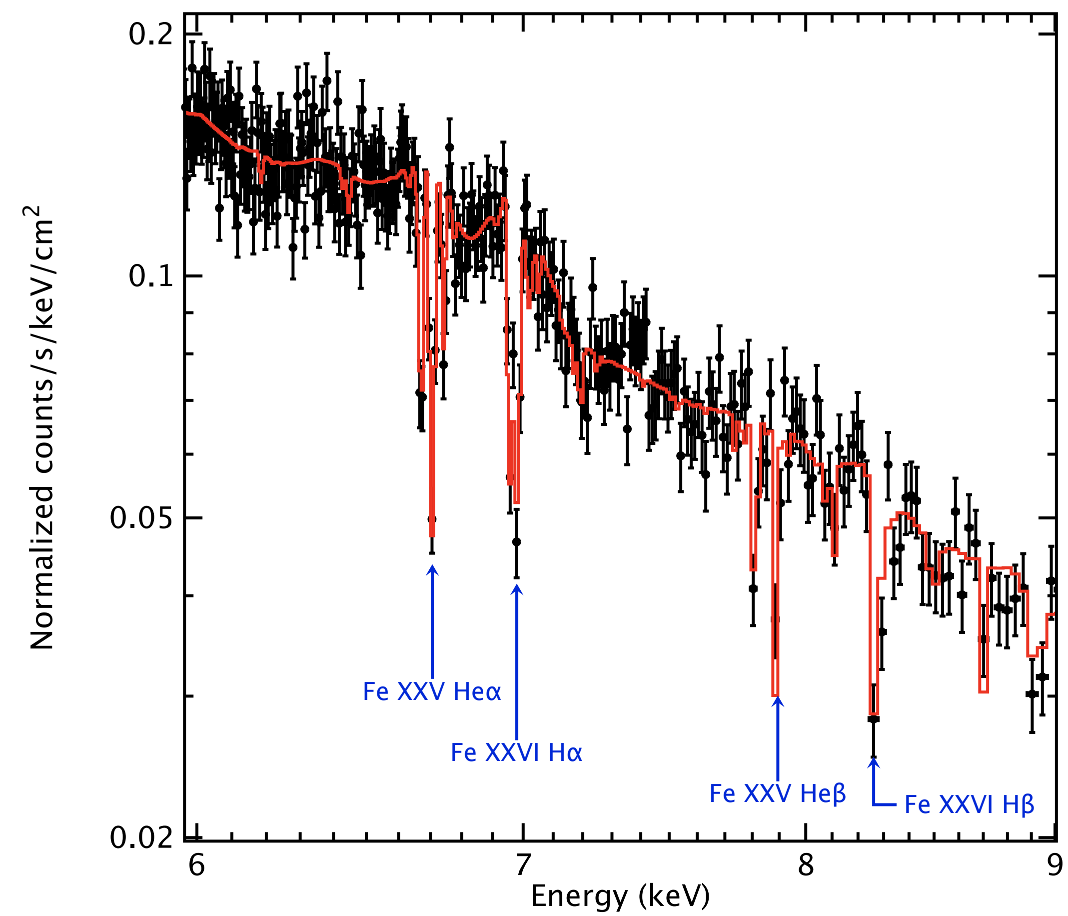
Compton thick AGN spectrum. Georgakakis, Carrera et al., (2013) arXiv1306.2328

Energetic Universe

AGN outflows	Black hole winds
Characterize ejecta, by measuring ionization state, density, temperature, abundances, velocities and geometry of absorption and emission features of the winds and outflows and determine how much energy these carry.	Probe outflow properties and disk magnetic fields in galactic binaries and in the same systems determine the relationship between the accretion disk and its hot electron plasma. Understand the interplay of the disk/corona system with matter ejected in the form of winds and outflows.



Simulated ultra-fast outflow spectrum - Cappi, Done et al 2013, arxiv: 1306.2330



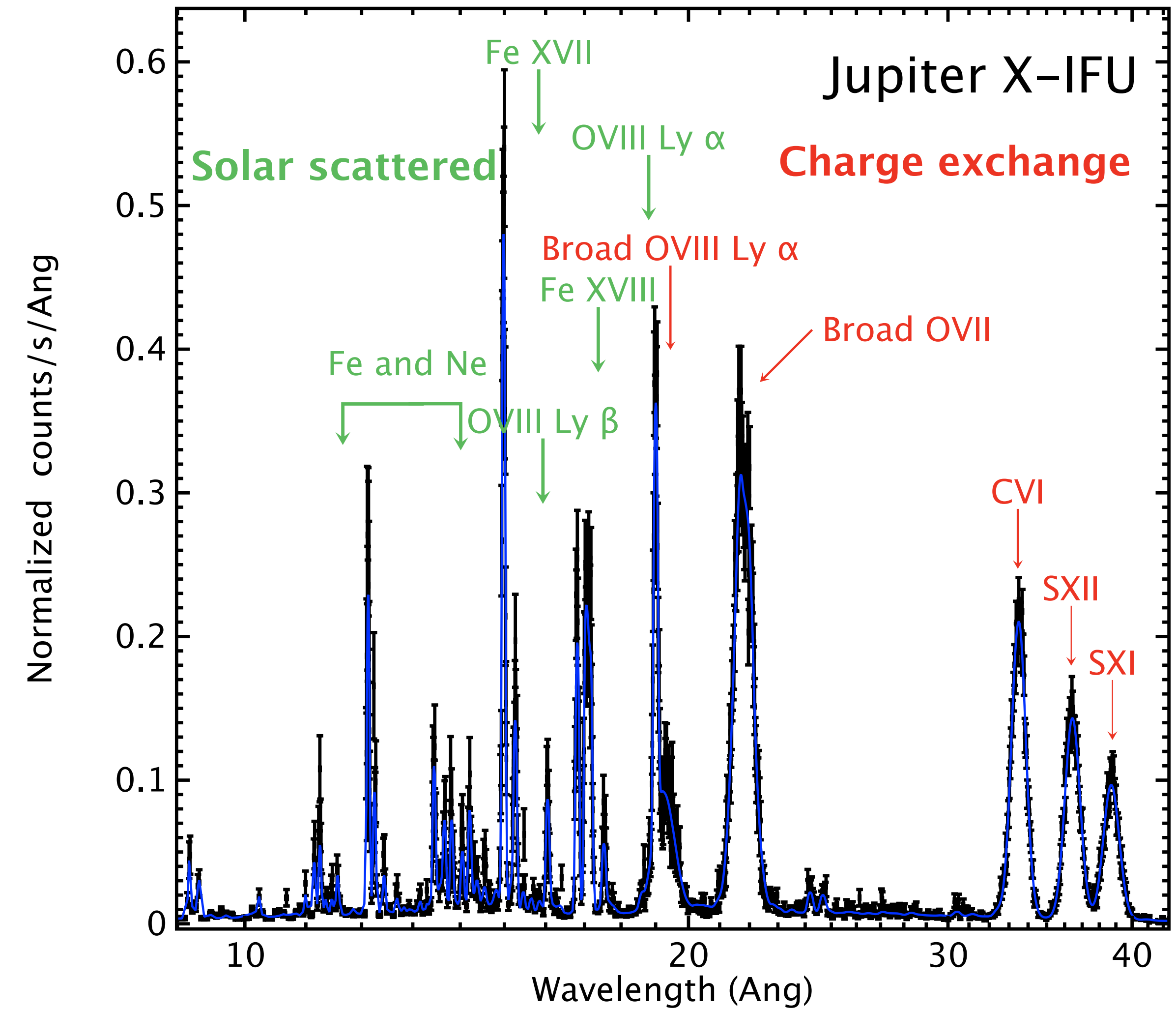
Disk wind spectrum of the stellar mass black hole GRS1915+105 - Barret et al. 2016 (courtesy J. Miller)

Athena performance requirements

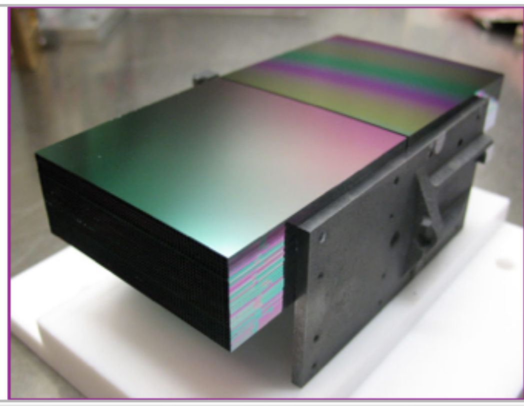
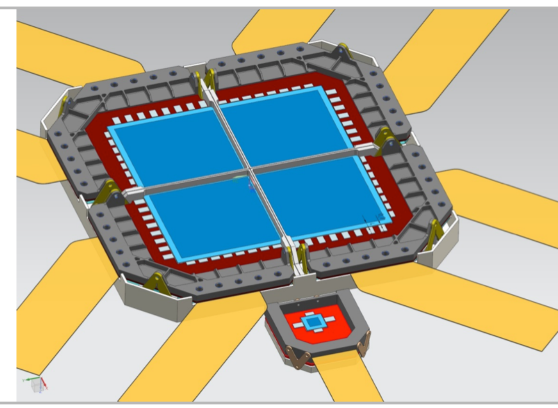
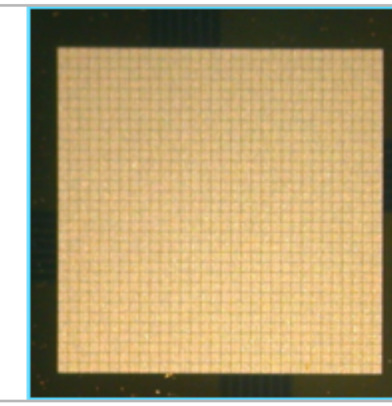
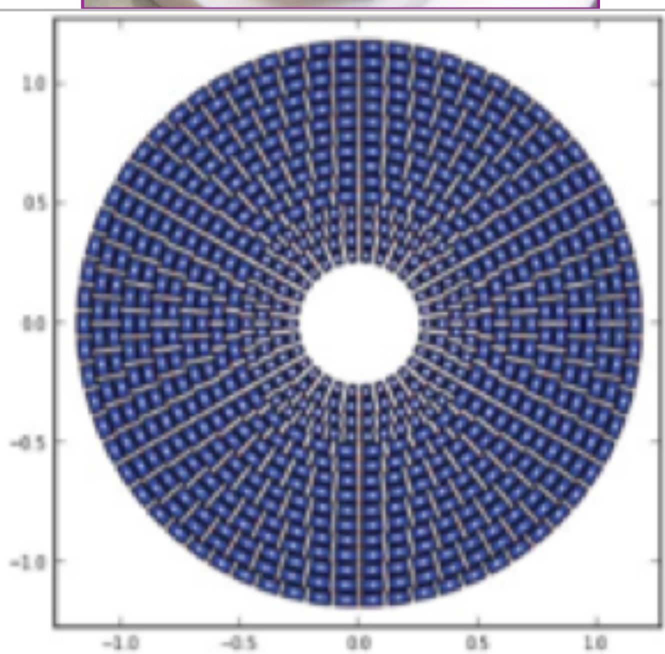
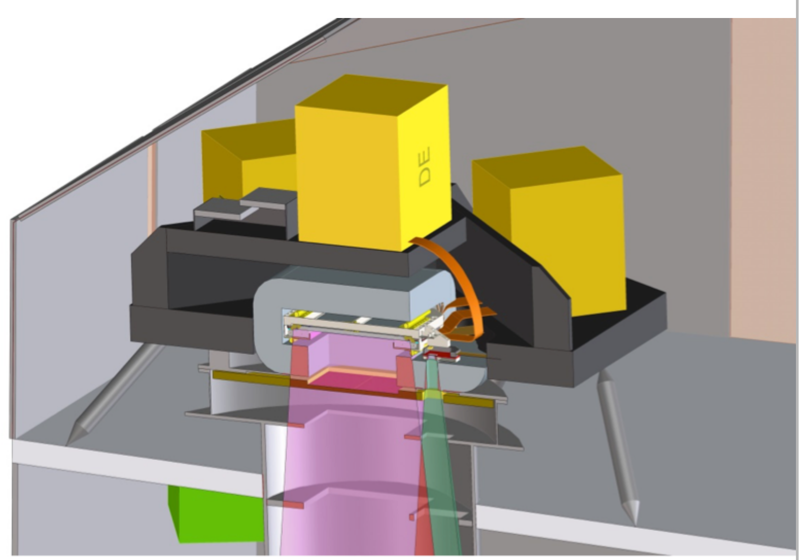
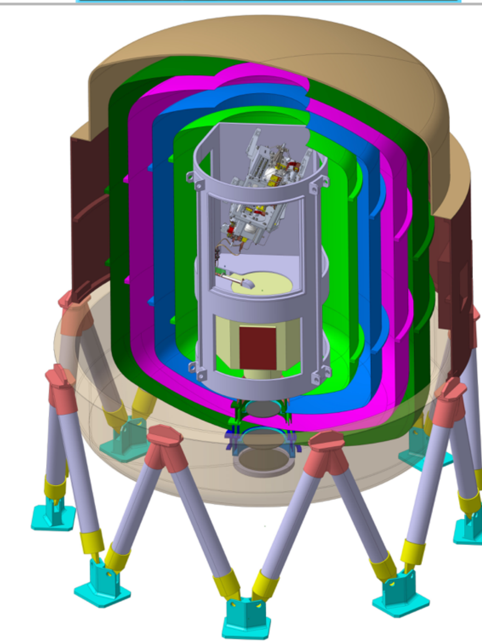
Parameter	Value	Driving science goals
Optics		
Effective area at 1 keV	2 m^2	Early groups, cluster entropy and metal evolution, WHIM, high redshift AGN, census of AGN, first generation of stars
Effective area at 7 keV	0.17 m^2	Cluster energetics (gas bulk motions & turbulence), AGN winds & outflows, SMBH & GBH spins
PSF HEW (< 8 keV)	5'' on axis, 10'' off axis	High z AGN, census of AGN, early groups, AGN feedback on cluster scales
X-IFU		
X-IFU spectral resolution	2.5 eV	WHIM, cluster hot gas energetics and AGN feedback on cluster scales, energetics of AGN outflows at z~1-4
X-IFU field of view	5' diameter	Metal production & dispersal, cluster energetics, WHIM
X-IFU background	< 5 10^{-3} counts/s/cm^2/keV	Cluster energetics & AGN feedback on cluster scales, metal production & dispersal
X-IFU count rate capability	1 mCrab 80% high-res events	WHIM using GRB afterglows
WFI		
WFI spectral resolution	150 eV	GBH spin, reverberation mapping
WFI field of view	40' x 40'	High-z AGN, census AGN, early groups, cluster entropy evolution, jet-induced ripples
WFI count rate capability	80% throughput at 1 Crab	GBH spin, reverberation mapping, accretion physics
WFI background	< 5 10^{-3} counts/s/cm^2/keV	Cluster entropy, cluster feedback, census AGN at z~1-4
Recons. astrometric error	1'' (3 sigmas)	High z AGNs
Satellite		
ToO trigger efficiency	40% in less than 4 hours	WHIM, first generation of stars

Observatory and discovery science

- Solar system bodies: sun interaction
- Exoplanets: magnetic interplay
- Star formation: brown dwarfs
- Massive stars: stellar winds
- Supernovae: explosion mechanisms
- Supernovae remnants: shock physics
- Interstellar medium: composition
- Stellar endpoints: dense matter at supra nuclear densities
- **Discovery science: unknowns**

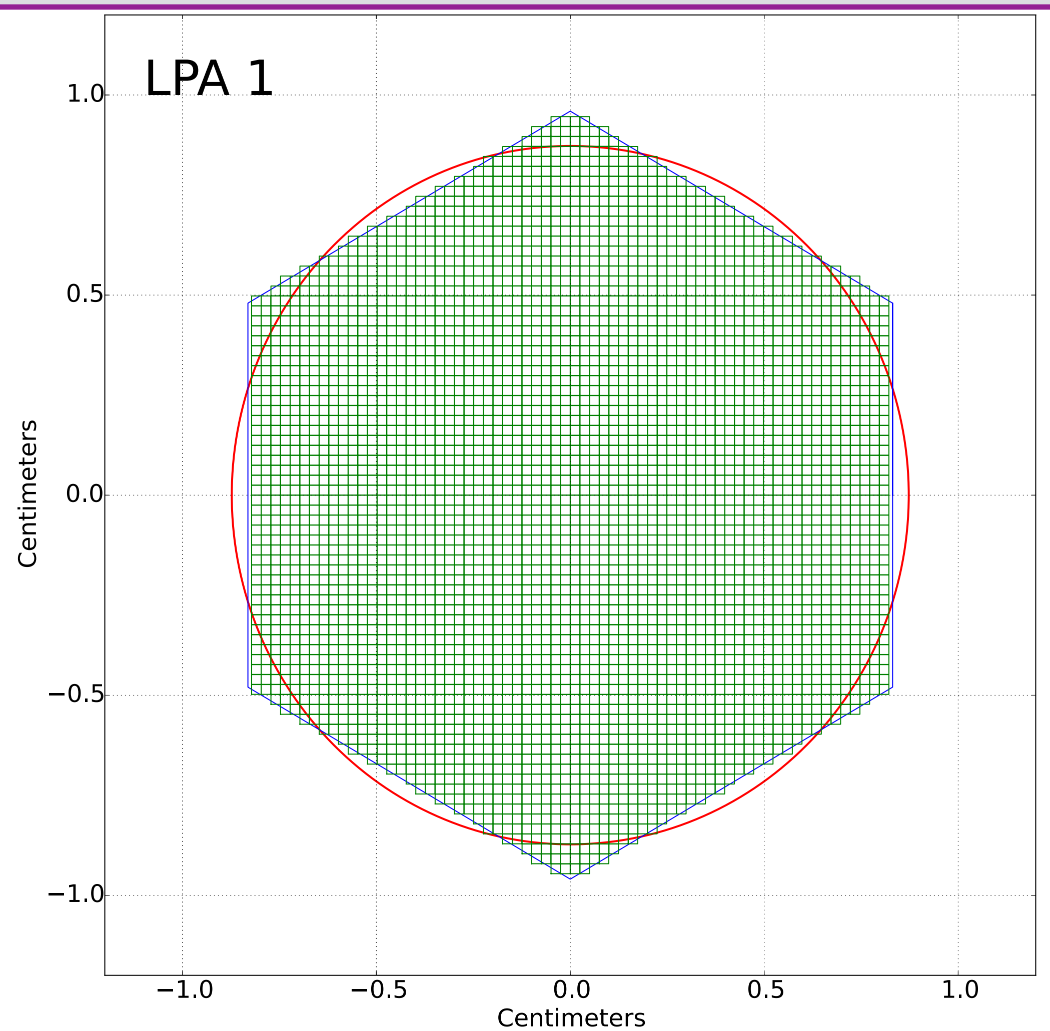
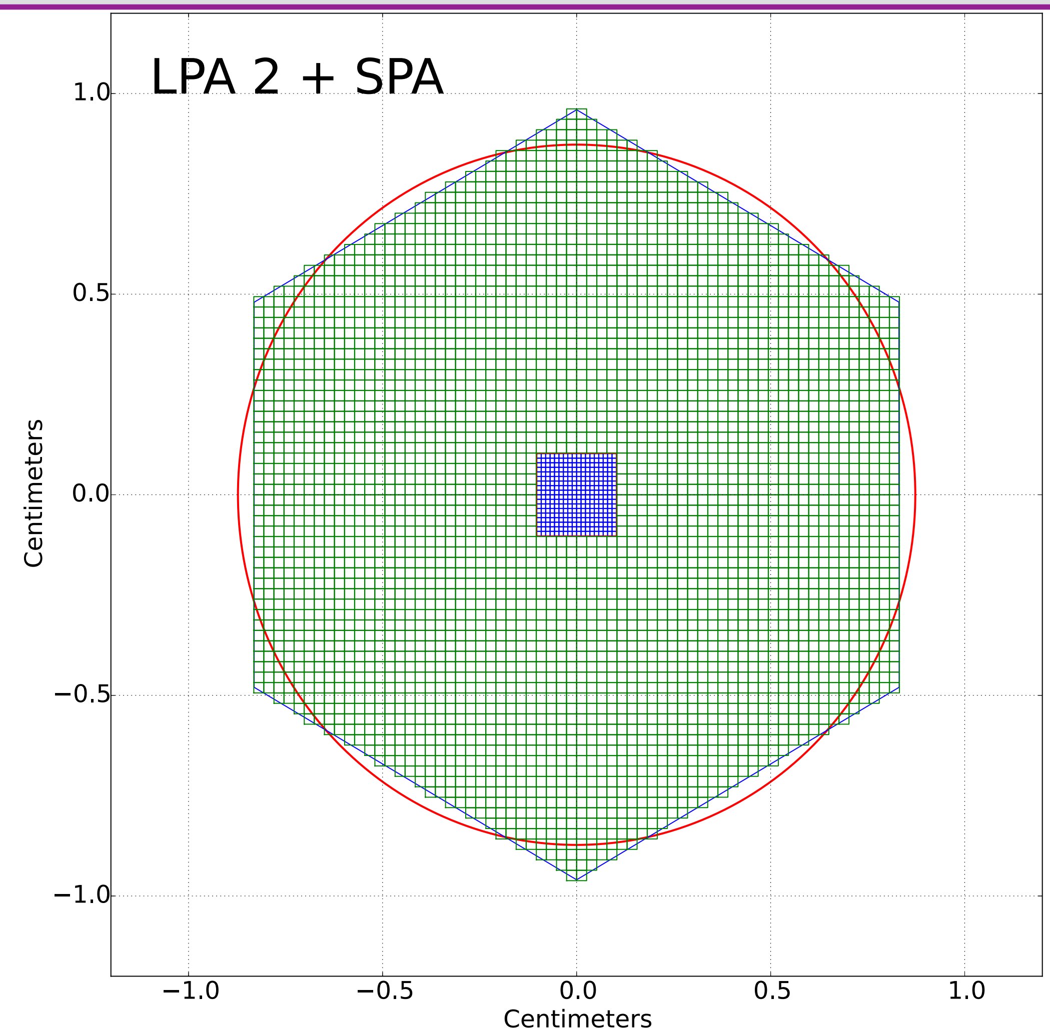


Payload

Optics	Wide Field Imager	X-ray Integral Field Unit
Light-weight Si-pore optics	**Active Pixel Sensors based on DEPFETs**	**Cryogenic imaging spectrometer, based on a large format of Transition Edge Sensors cooled at 50 mK with an active background shielding**
		
		
ESA & industry	**Consortium led by MPE (K. Nandra), with other European partners and NASA**	**Consortium led by IRAP/CNES-F (D. Barret), with SRON-NL (J.W. den Herder), INAF/IAPS-IT (L. Piro) and other European partners, NASA and JAXA.**

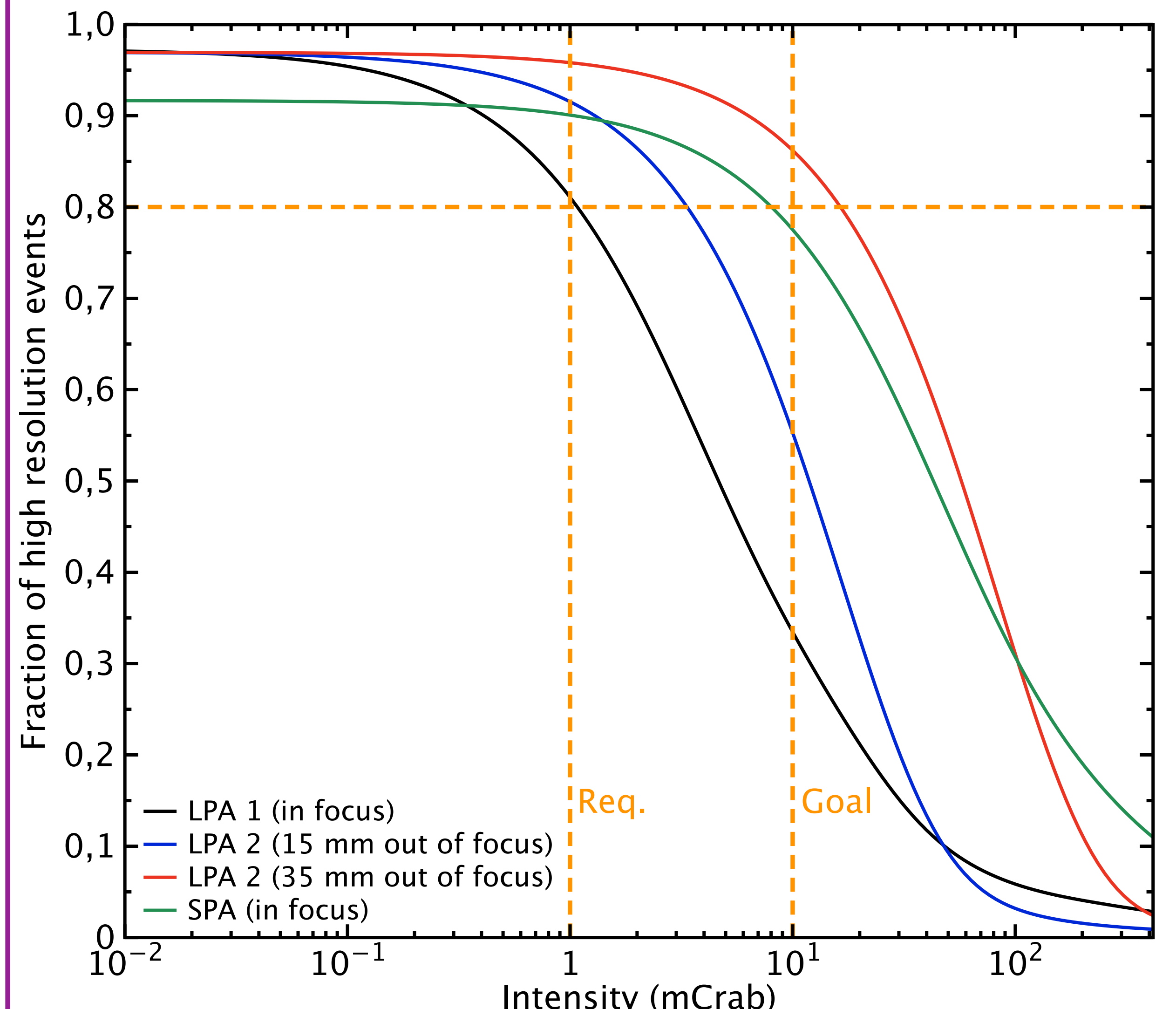
X-IFU performance optimization

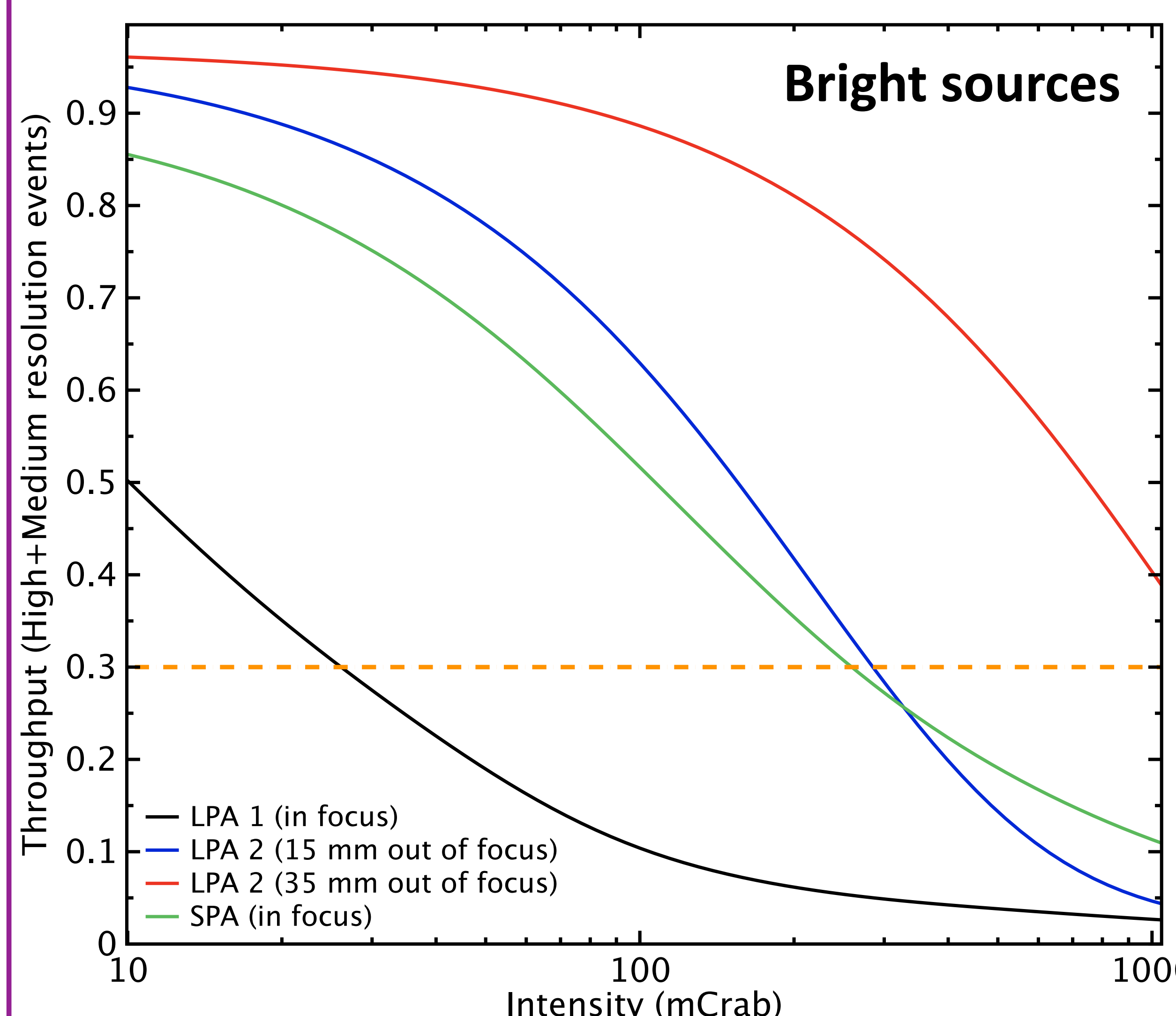
- Potential for improvements: count rate & spectral resolution (1.5 eV) & PSF oversampling

TES array baseline configuration - single size pixels	Addition of a Small Pixel Array
	
5' equivalent diameter field of view	**Barret et al. (SPIE 2016)**

X-IFU count rate capability

Fraction of high resolution events (2.5 eV)	Throughput for high and mid resolution events (<3-4 eV)



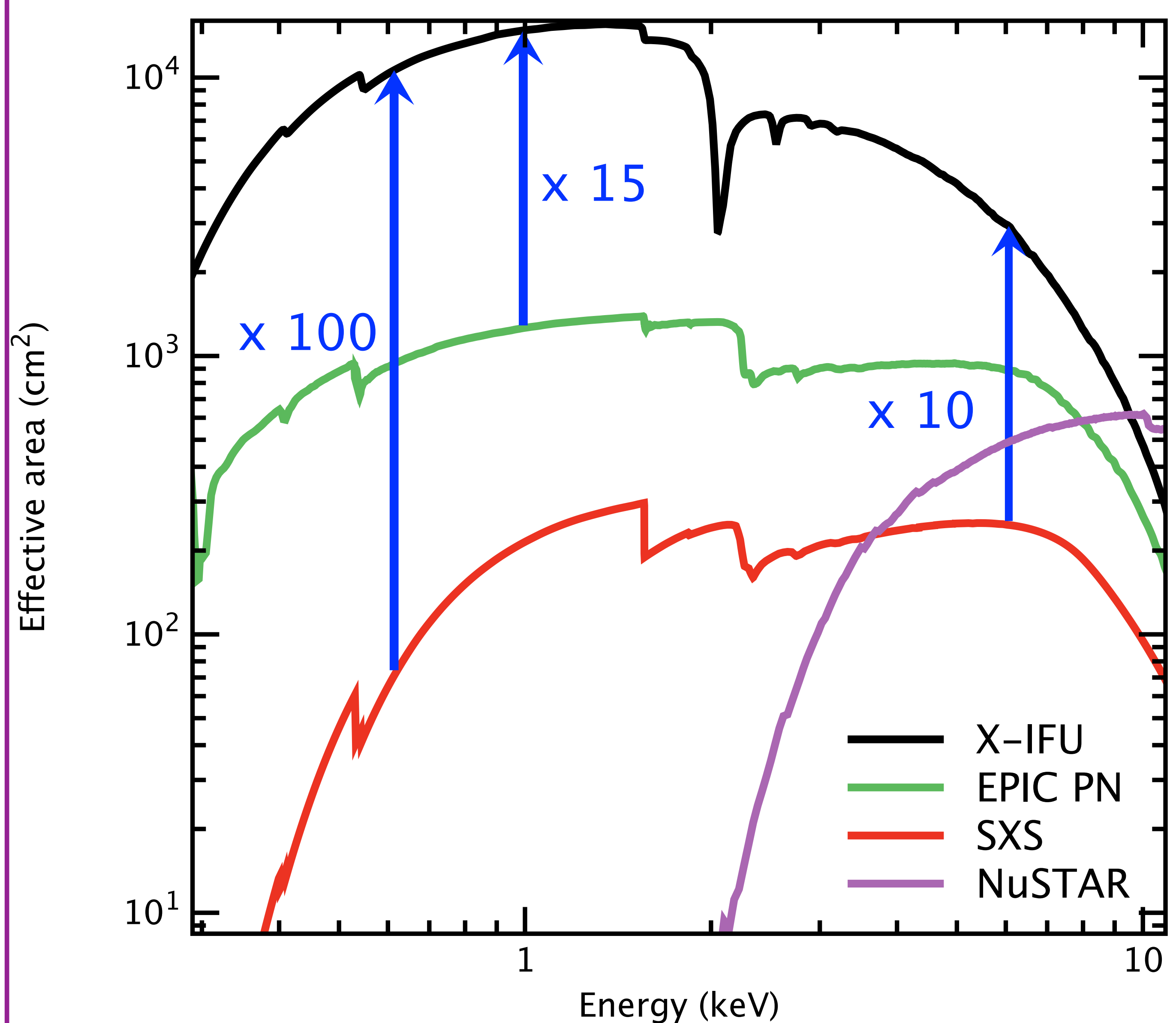


1 mCrab = 95 cps/s (over the whole detector array)

Barret et al. (SPIE 2016)

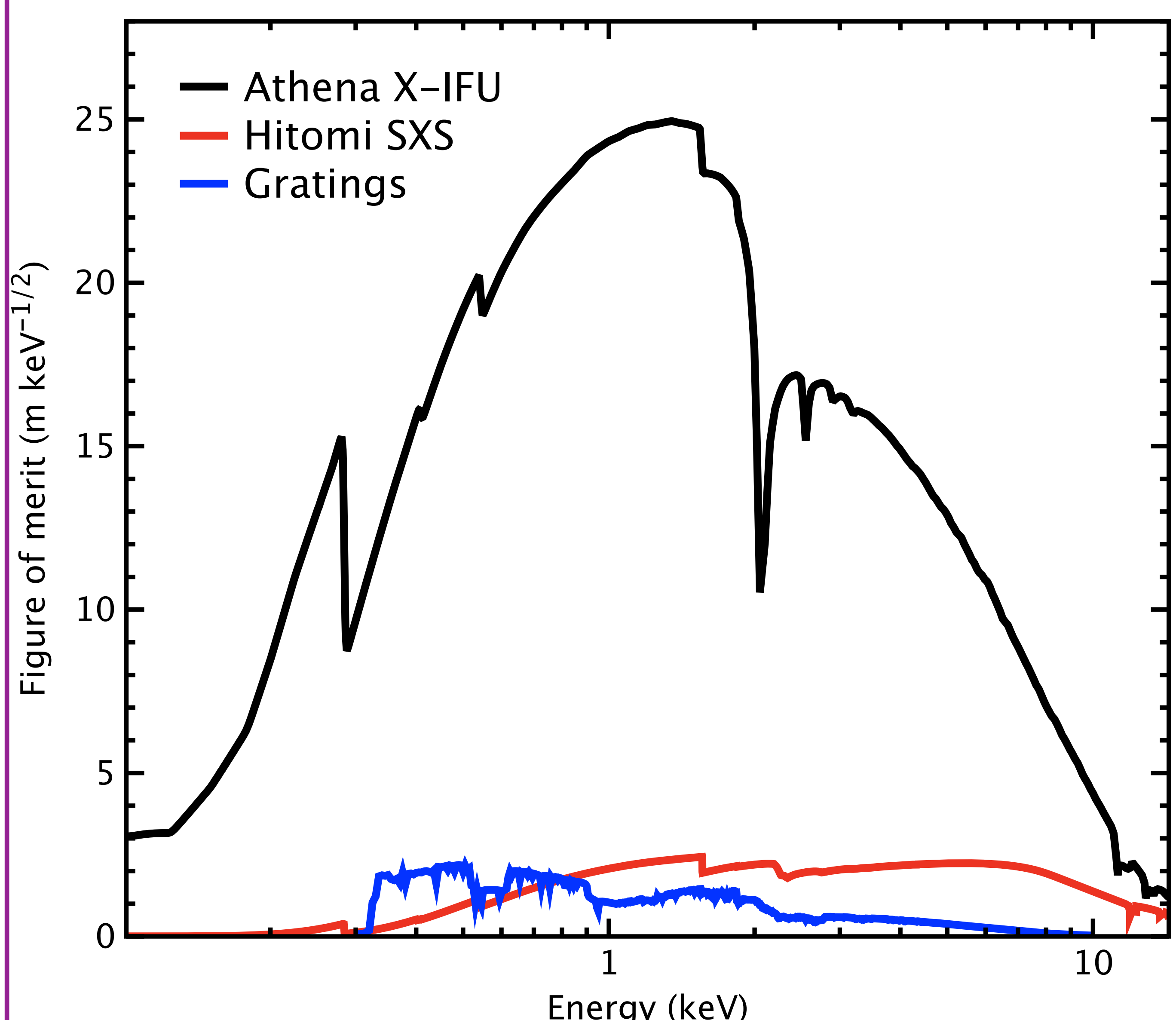
Effective area = spectroscopic capabilities

Effective area comparison between X-IFU and other facilities



Effective area = spectroscopic capabilities

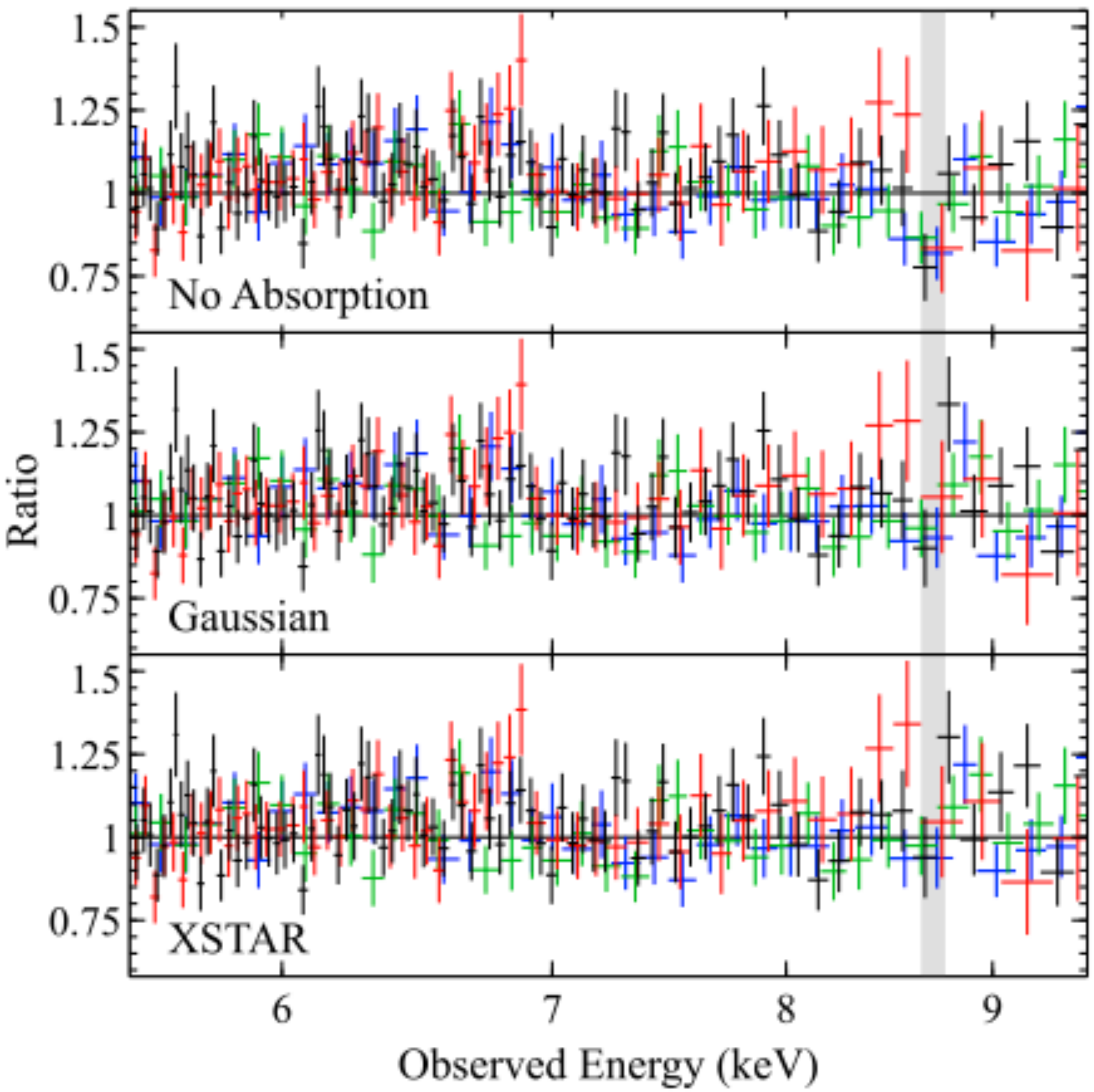
Figure of merit for spectroscopy measurements

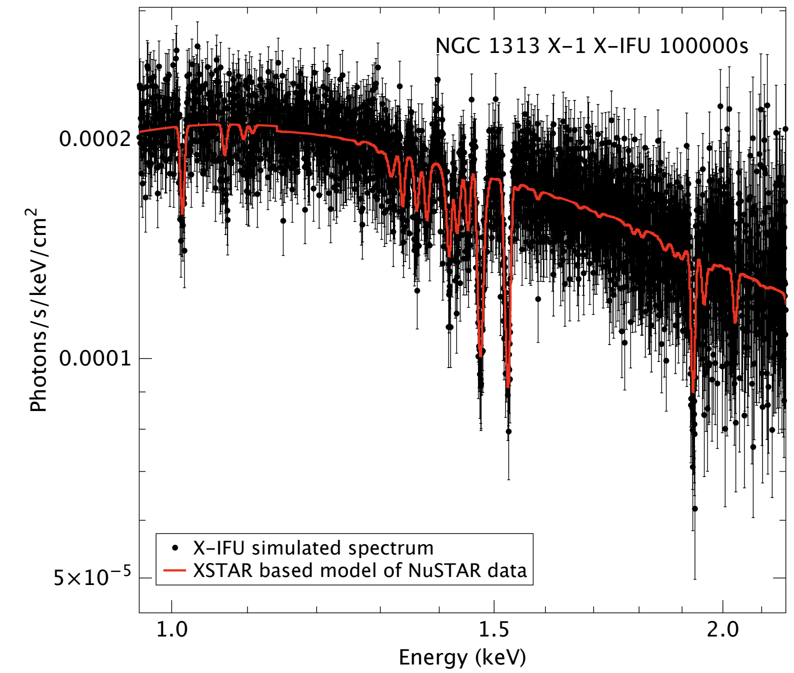


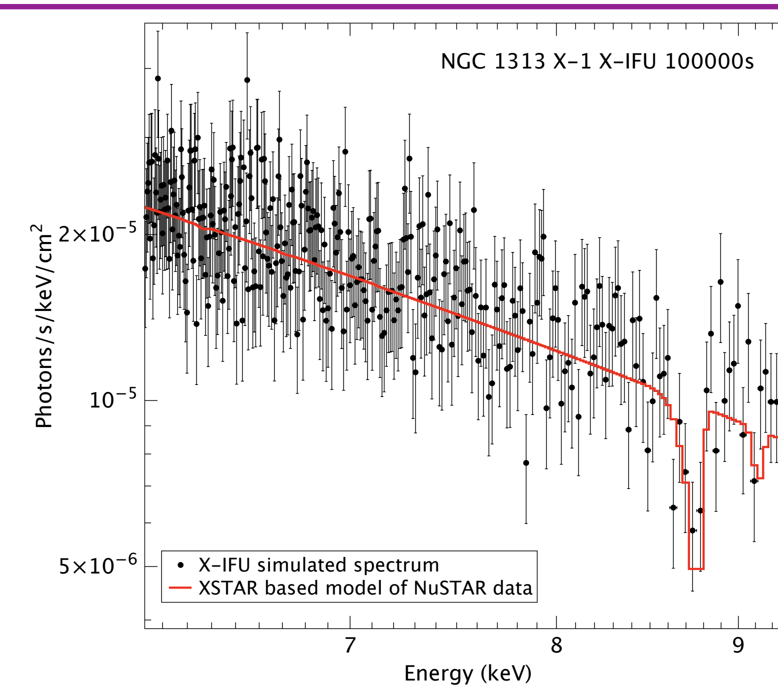
Spectroscopic capabilities

8.8 keV absorption line in NGC1313 X-1 seen by XMM-Newton and NuSTAR - Relativistic outflow Fe XXV (6.67 keV, 0.25 c) or Fe XXVI Kα (6.97 keV, 0.2 c)	Broad band spectroscopic capability of X-IFU

Walton et al.(2016)







Current status of Athena

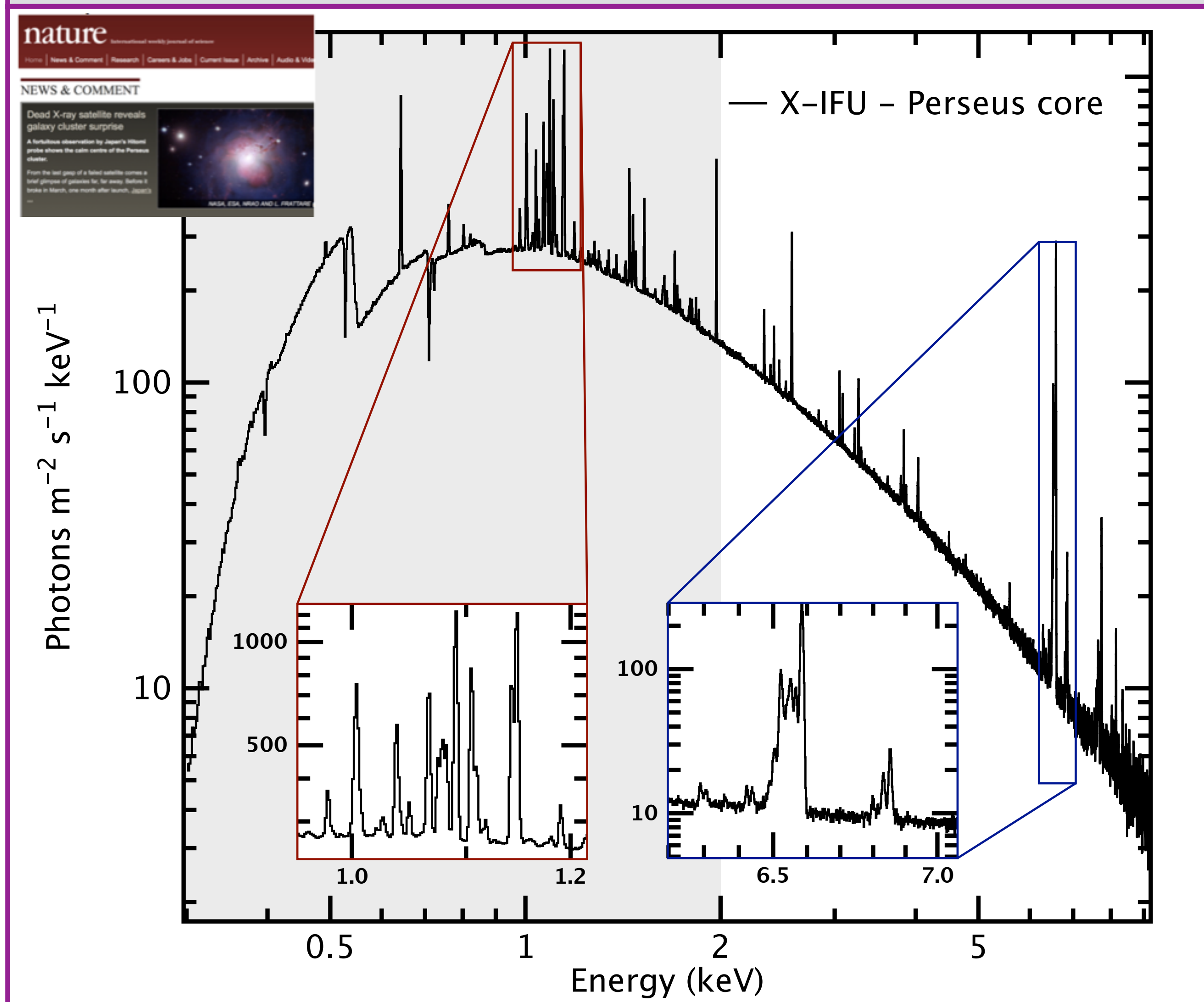
- Mission Consolidation Review (May 2016) concluded that:
  - The two missions concepts studied (small and large mirrors) are sound
  - The instrument switching mechanism is through a movable mirror assembly
    - Offers also defocussing to increase the X-IFU count rate capability
  - The instrument resources are challenging: all being addressed or fixed
  - The mass lift capacity of Ariane 64 up to 7 tons
  - Consolidation of the cost at completion is required (transfer of focal plane module to the instrument consortia, firming up international contribution to the mission and some payload elements, industrial costs, …)
  - **Mission concept to be carried over considers the large mirror**

Conclusions

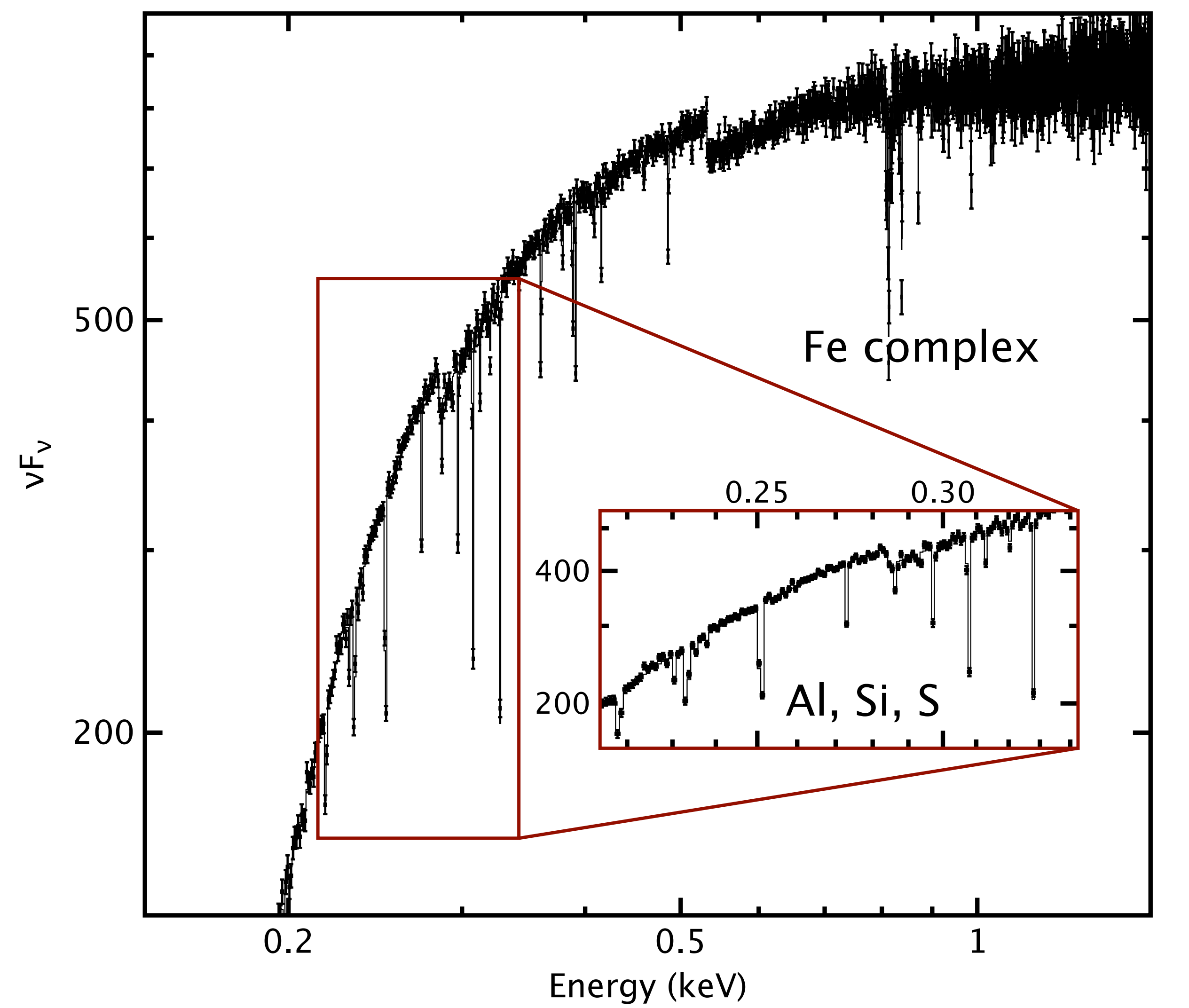
- Athena will provide breakthrough capabilities in wide field imaging and high resolution X-ray spectroscopy
- Athena feasibility studies are progressing well
  - The large mirror configuration is the baseline for the upcoming study phase
  - Instrument baseline designs are being consolidated with no degradation of performance up to now
    - Join the Athena community and support the mission
- X-IFU will be a powerful tool to study super-Eddington accretion:
  - disk coronae, winds, relativistic outflows, surrounding materials thus enabling to connect accretion physics to feedback process across the broad mass scale of compact objects
    - See more from C. Pinto, M. Middelton

Hold on and thank you for your support

The wealth of information provided by such a spectrum, that will be measured on sub-arc minute scales enables in depth studies of the physical properties of the hot cluster gas (e.g. temperature, density, turbulence, bulk motion, abundance, . . .)	High-z GRB afterglows probing the ISM composition at z>7-10 and tracing the first generation of stars to understand cosmic re-ionization, the formation of the first seed black holes, and the dissemination of the first metals.



Perseus core X-IFU simulated spectrum based on Hitomi - Model courtesy of C. Pinto and A. Fabian



Barret et al. (2016) - Courtesy of L. Piro