The Athena X-ray Integral Field Unit (X-IFU)
& the foreseen Czech Republic contribution

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&
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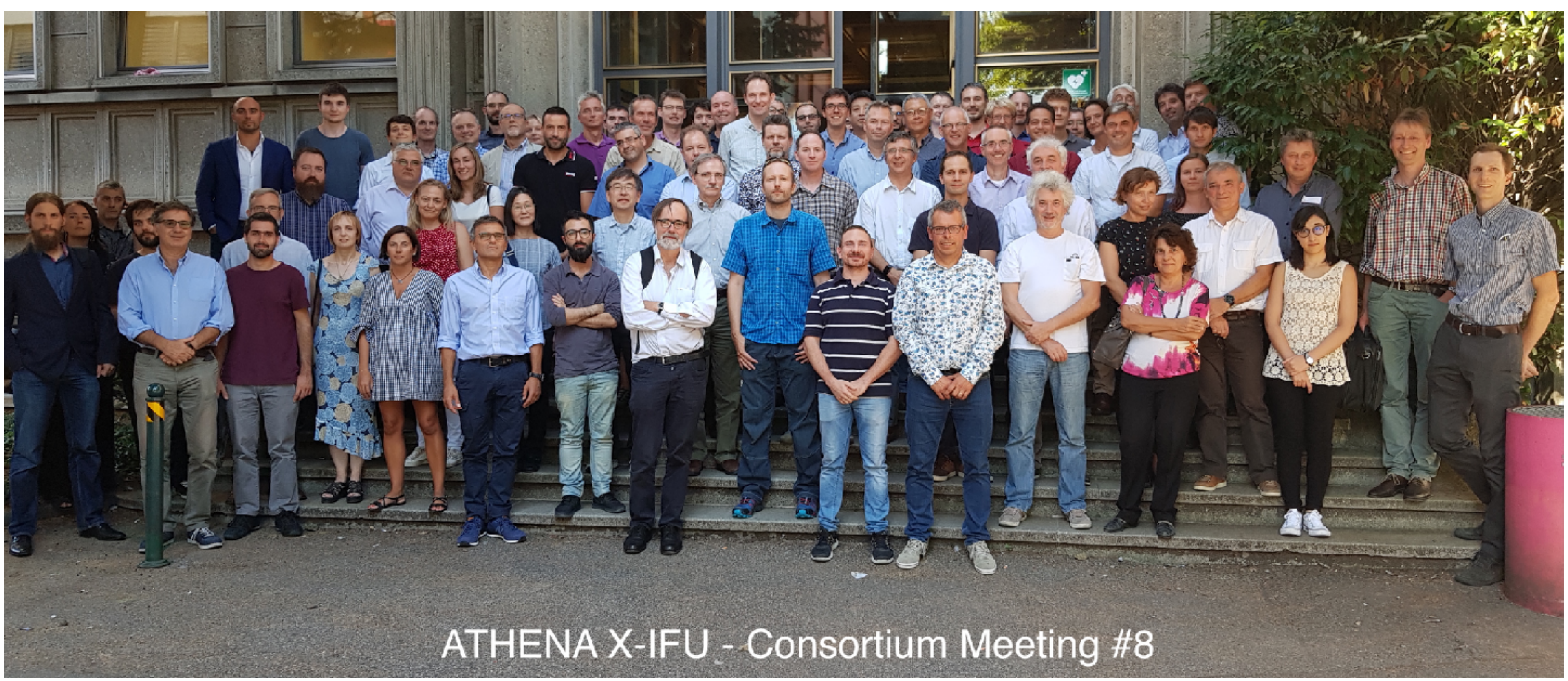
on behalf of the X-IFU Consortium

10 years of the Czech Republic in ESA
Nov. 12-15th, 2018, Prague

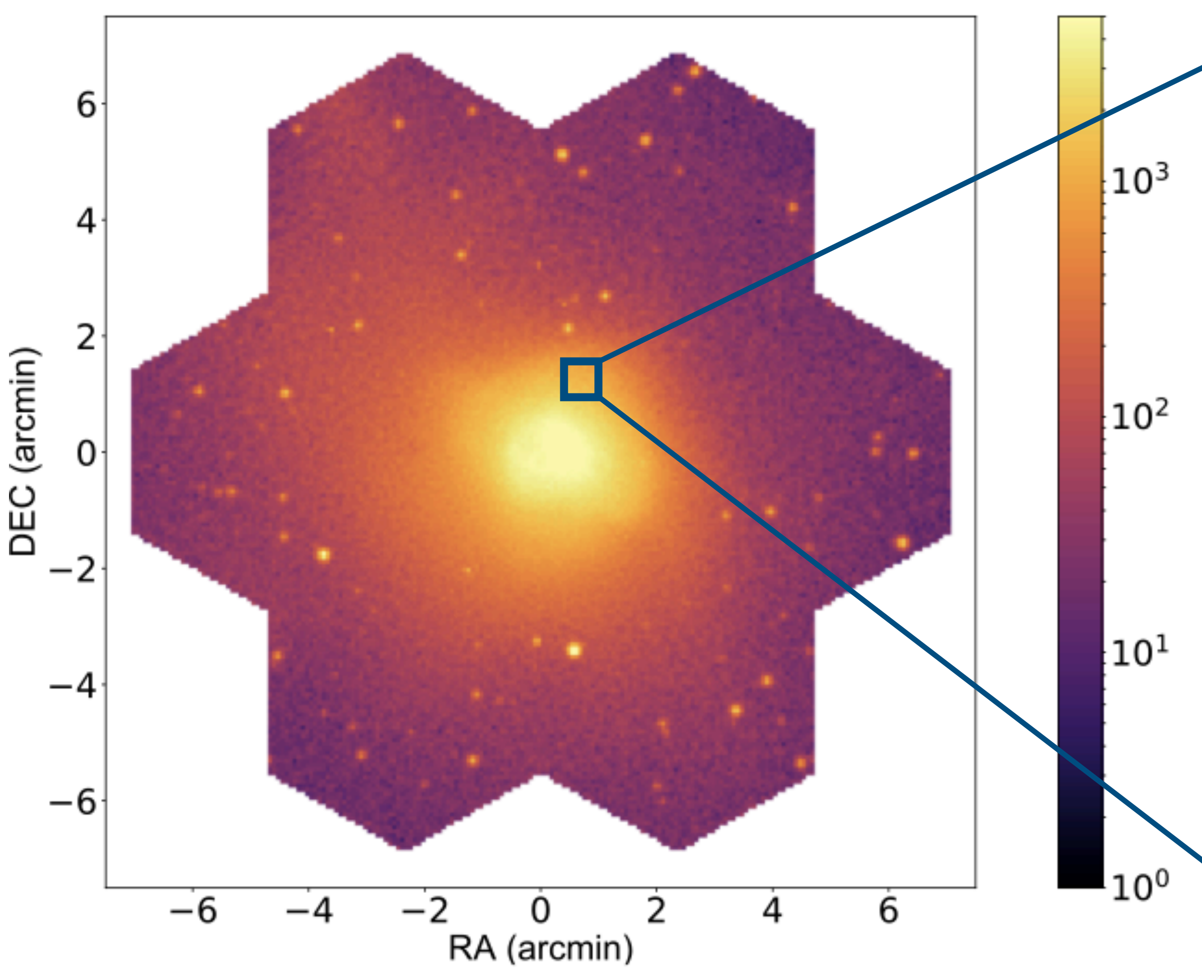
The Athena X-ray Integral Field Unit consortium

- X-IFU is the X-ray micro-calorimeter of the Athena space observatory
- Built by a Consortium led by France (IRAP & CNES)
  - with Netherlands and Italy as prime contributors
  - and science and hardware contributions from eight other ESA members states (Belgium, ***Czech Republic***, Finland, Germany, *Ireland*, Poland, Spain, Switzerland)
  - and key contributions from Japan and the United States

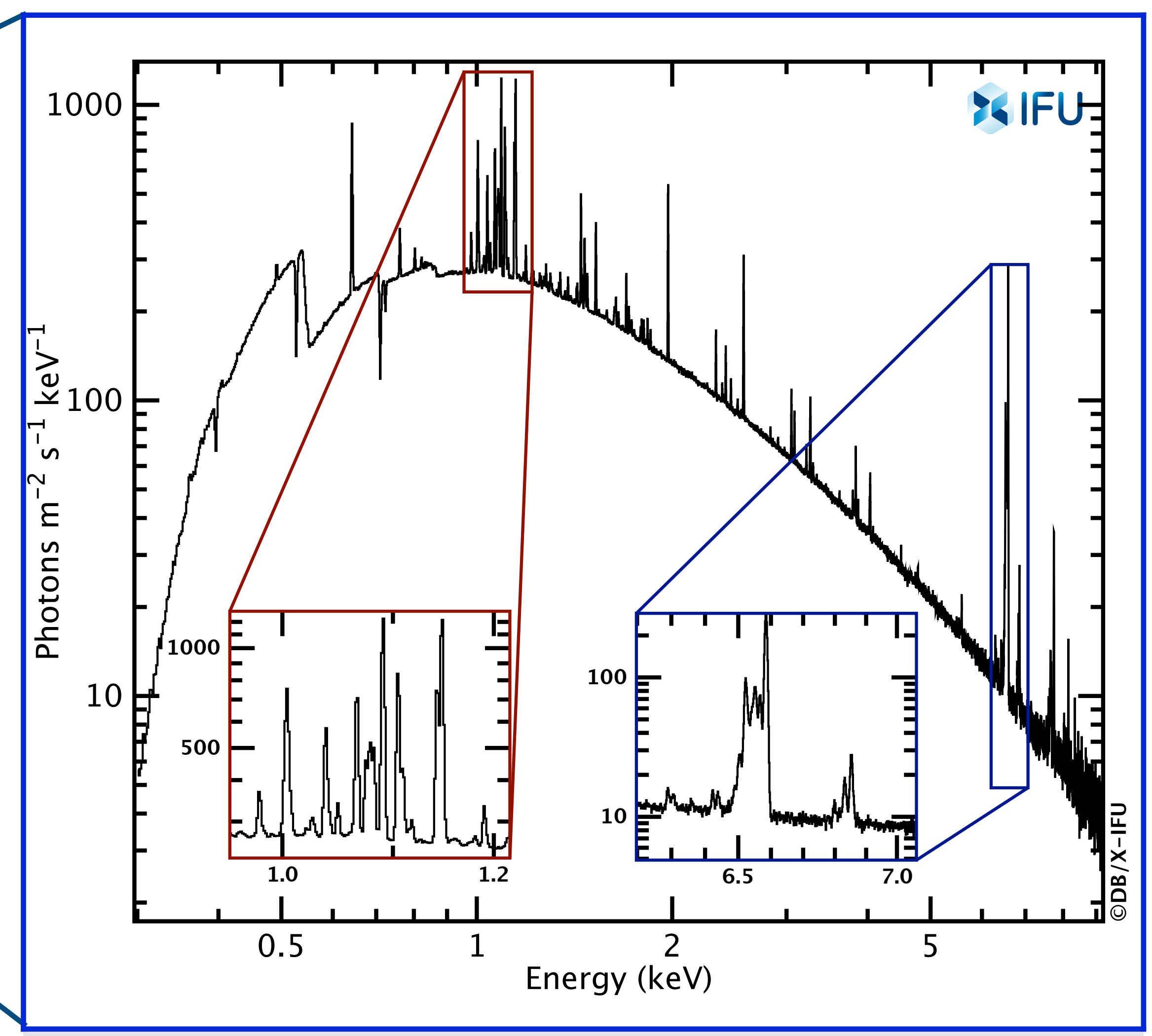


What is an X-ray Integral Field Unit?

- An X-IFU provides spatially resolved high spectral resolution X-ray data
  - An X-ray image and many X-ray spectra (flux versus energy)

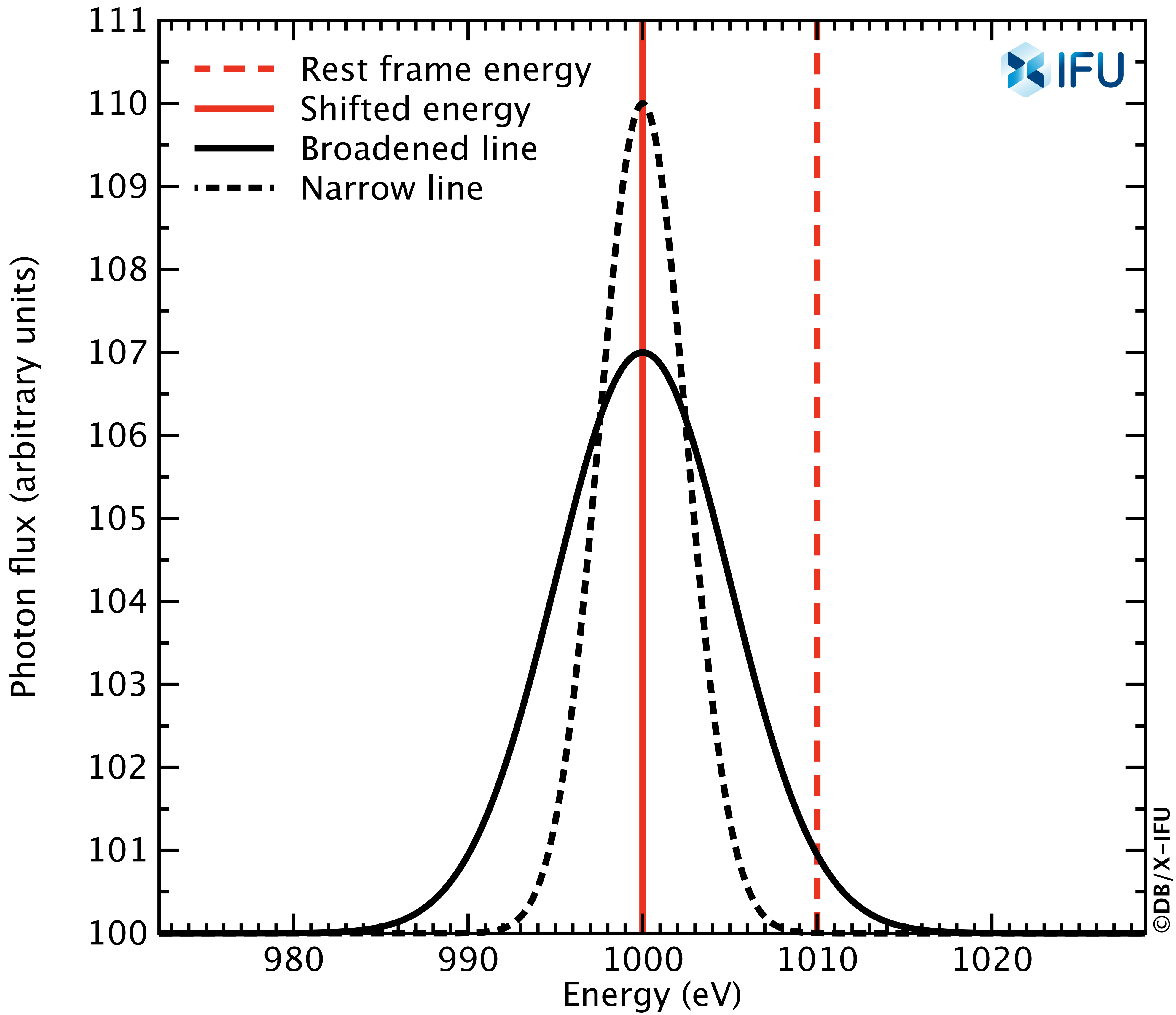


2D X-ray image: surface brightness of a galaxy cluster



High resolution spectrum of a small region of the image

The power of X-ray spectroscopy

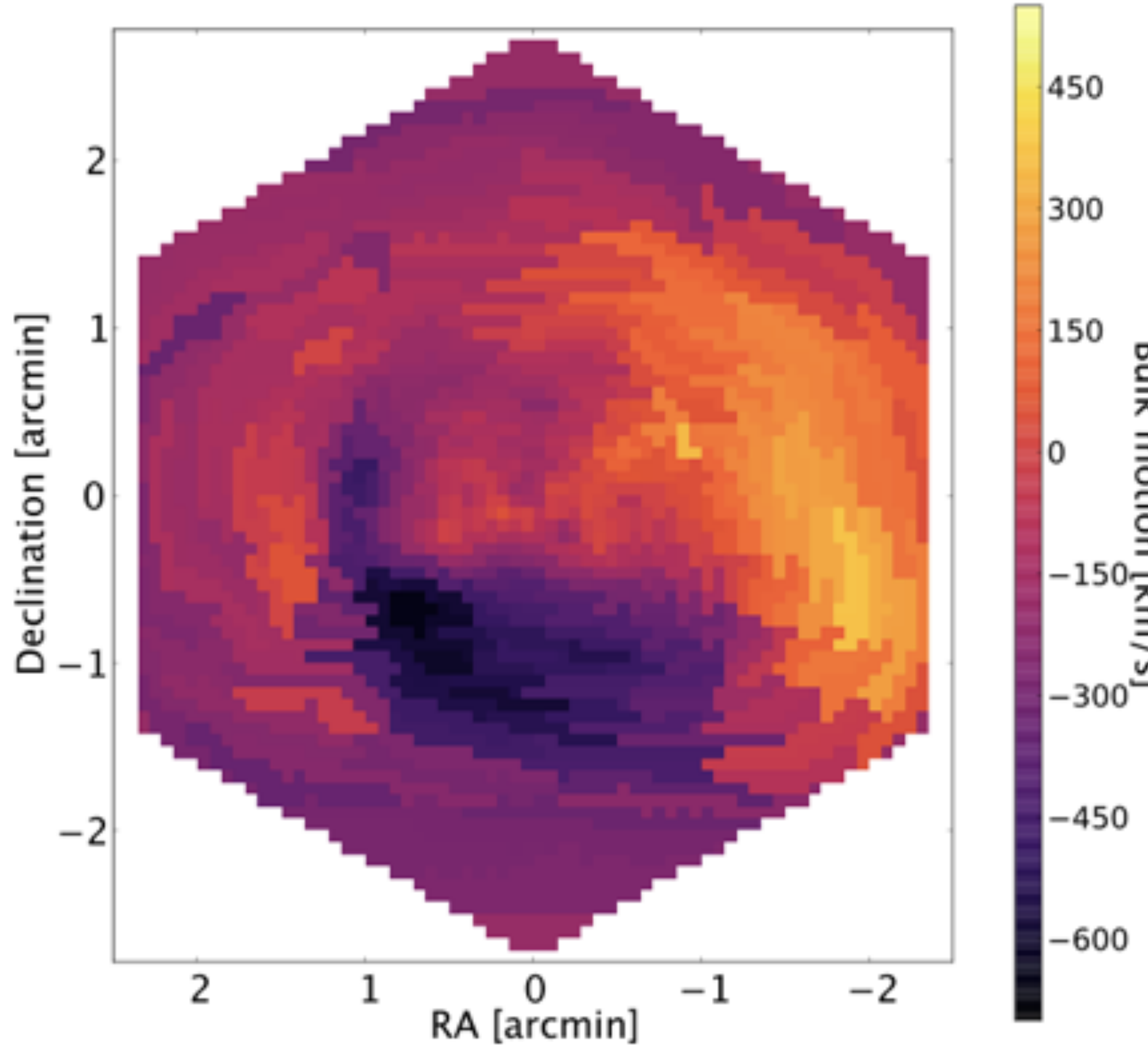


Big questions for big projects

- How has the Universe evolved from the dark ages to today?
  - Tracking the formation, the dynamical and chemical evolution of the largest scale structures
    - ➡ X-ray probe: Hot gas trapped in dark matter potential wells
- How do black holes work and shape the Universe at all scales?
  - Probing accretion/ejection processes
    - ➡ Xray probe: Accretion powered X-rays generated around black holes

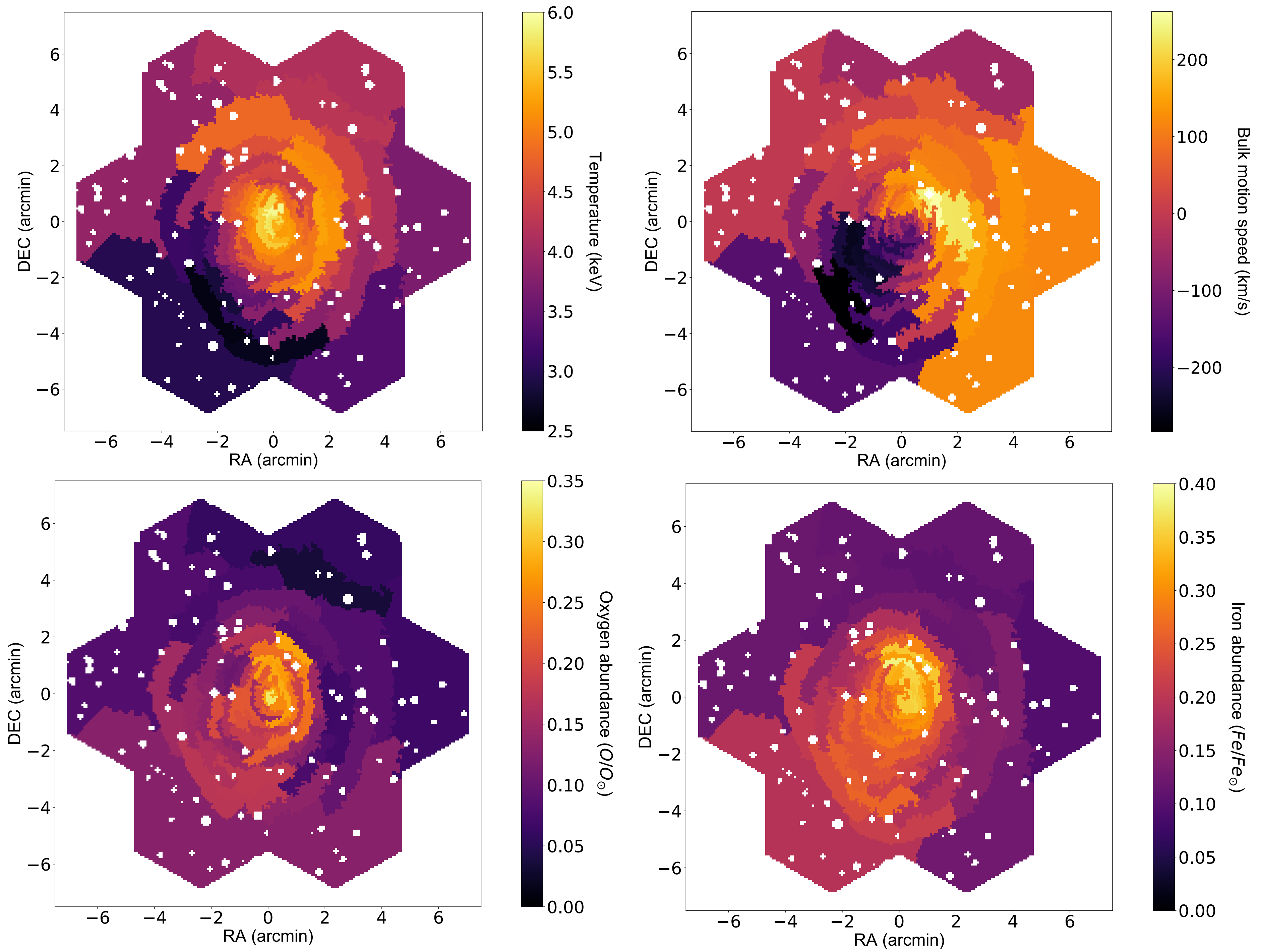
X-IFU core science

- Probing the dynamical and chemical state of baryonic matter across cosmic time
  - By mapping hot gas trapped in dark matter potential wells to measure bulk velocities, turbulence, abundances, temperatures, densities…
    - ➡ From the first galaxy groups to the local massive clusters
- Hitomi has unveiled in one single cluster observation the true power of high-resolution spectroscopy, leading to unexpected discoveries



Simulated velocity map of bulk motions of hot plasma in cluster: Courtesy of Ph. Peille and Ed. Cucchetti

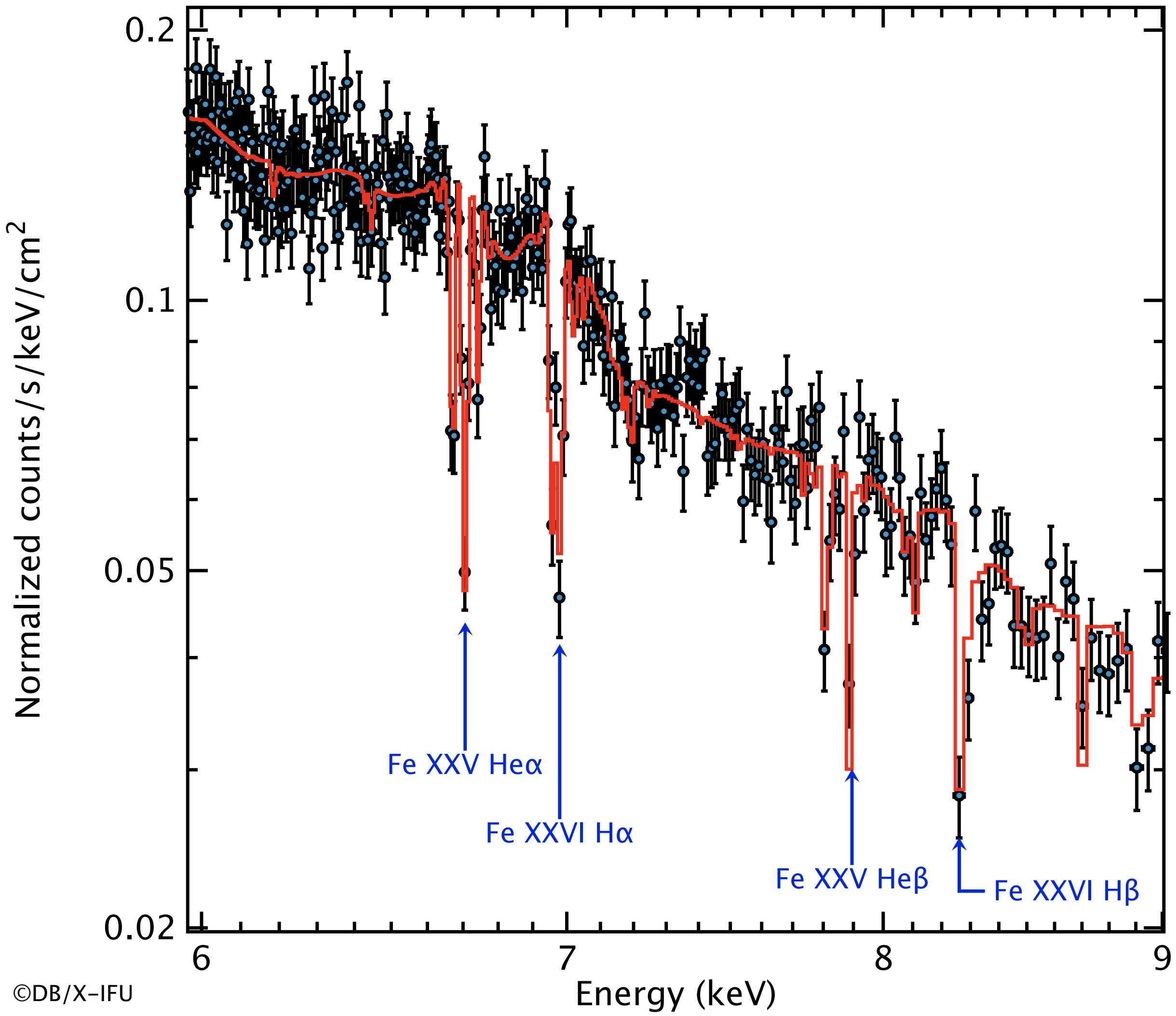
Plasma diagnostics in one observation !



X-IFU simulated image of a nearby galaxy cluster from Cucchetti et et al. (2018, A&A)

X-IFU core science

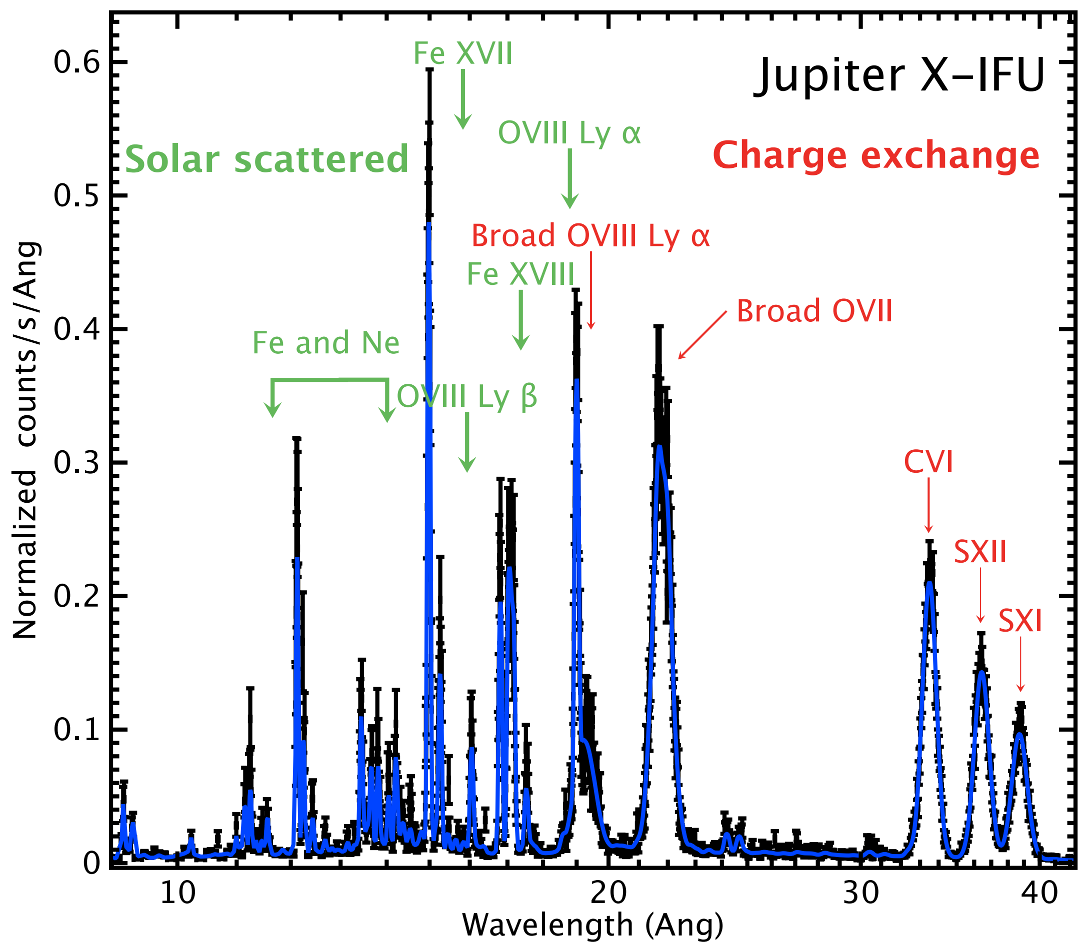
- Probing black holes at work in shaping the Universe and their surroundings
  - By performing time resolved spectroscopy of accretion disks, winds, outflows and jets
  - From the faintest AGN to the brightest X-ray binaries



X-ray binary spectrum with high velocity wind absorption features. Courtesy of J. Miller et al.

X-IFU observatory and discovery science

- By providing hot plasma diagnostics in a wide range of astrophysical settings
  - Planets: interaction of solar wind with planet environment
  - Exoplanets and their host stars
  - Stellar physics across the mass/age range
  - Supernovae: explosion mechanism, heavy element production
  - Stellar endpoints: dense matter
  - Interstellar dust and medium: composition
- Giant discovery space with ToO follow-up in the era of time domain astronomy



Jupiter X-IFU spectrum showing different line emission mechanisms. G. Branduardi-Raymont et al.

X-IFU key spectral requirements

- Spectral resolution: 2.5 eV up to 7 keV
  - Cluster physics (broadening down to 20 km/s) and missing baryons
- Energy band pass: 0.2 to 12 keV
  - Missing baryons
  - Black hole spins, winds and ultra-fast outflows
- Background requirement: $<5\ 10^{-3}$ counts/s/cm^2/keV (E> 2 keV)
  - Cluster physics and cluster chemical evolution

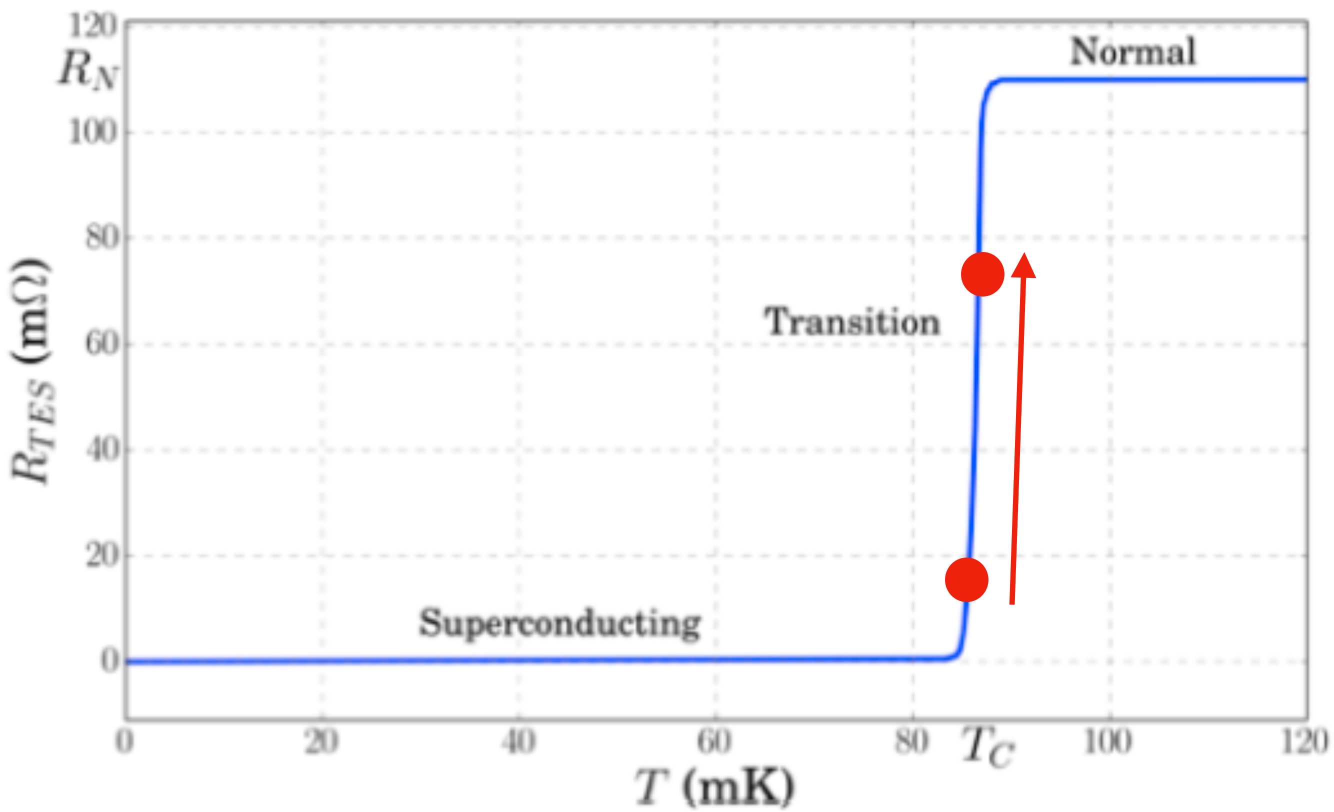
X-IFU key imaging requirements

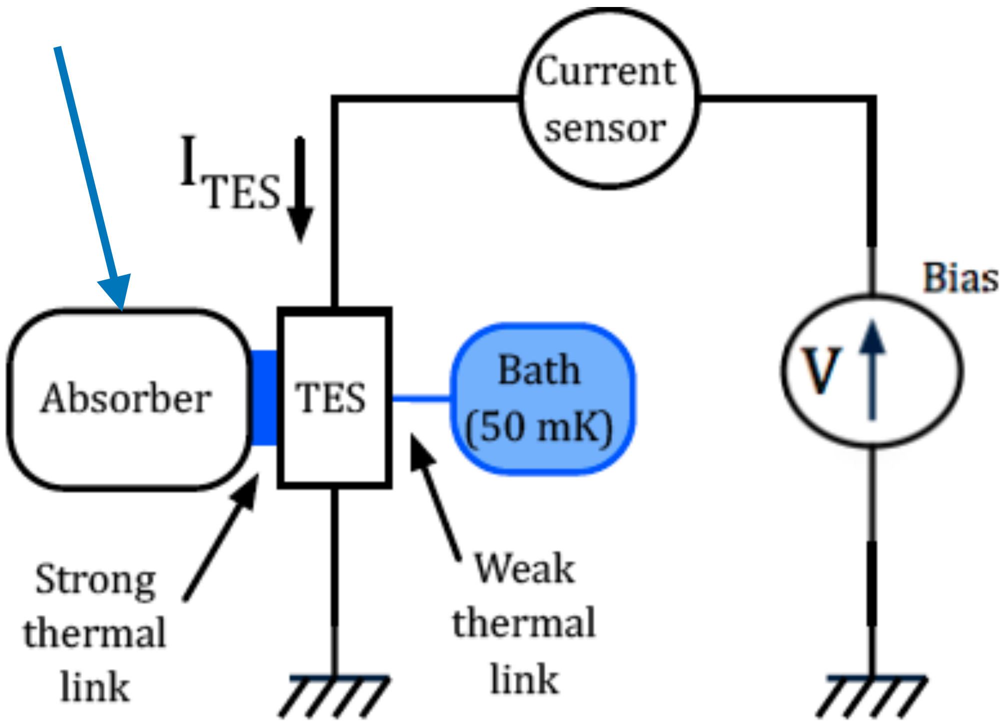
- Field of view: 5′ (equivalent diameter)
  - Cluster physics out to their outskirts
- Pixel size: <5 arcsec
  - Cluster feedback on relevant spatial scales and to minimize confusion
    - ➡ Pixel pitch is 275 μm (4.7″) leading to 3168 pixels to cover the field of view

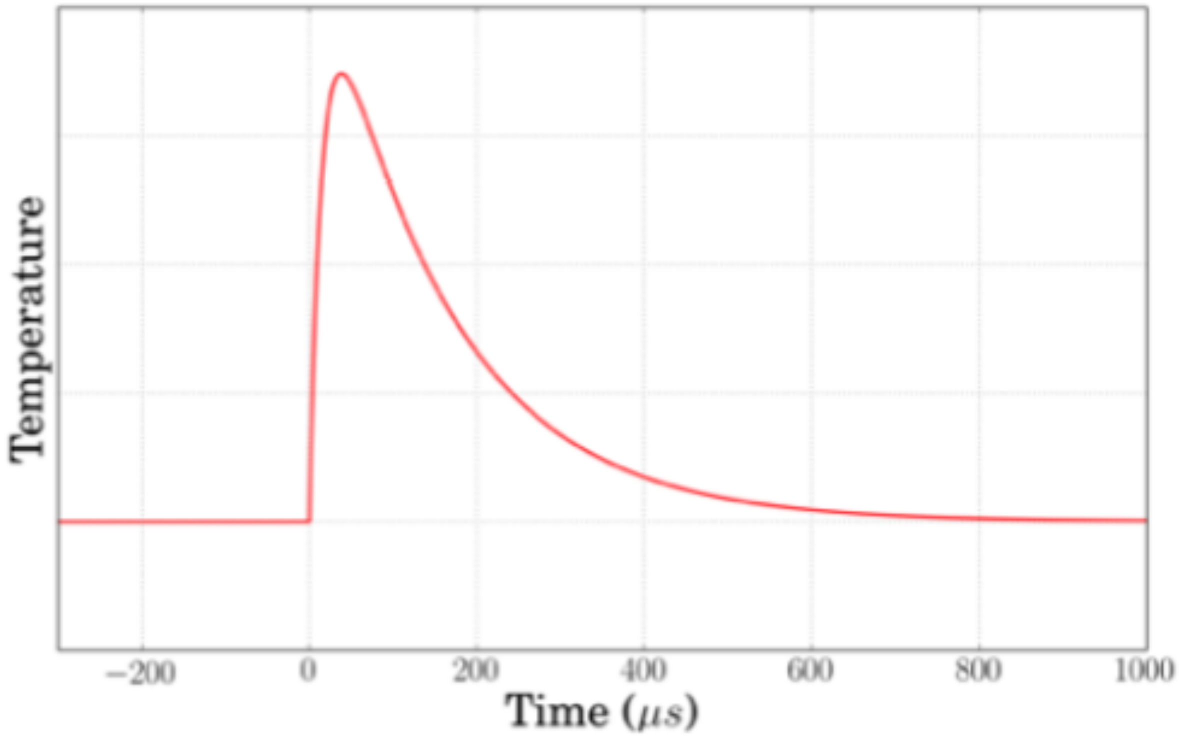
X-IFU key timing requirements

- 2.5 eV throughput for point sources: 80% at 1 mCrab and 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 between 5 and 8 keV
  - Probing stellar mass black hole and neutron star accretion disks & winds
- 2.5 eV throughput for extended sources: 80% at 2 10^{-11} ergs/s/cm^2/arcmin^2 (0.2-12 keV, brightest knots of Perseus)
  - Cluster physics and feedback

Transition Edge Sensor principles



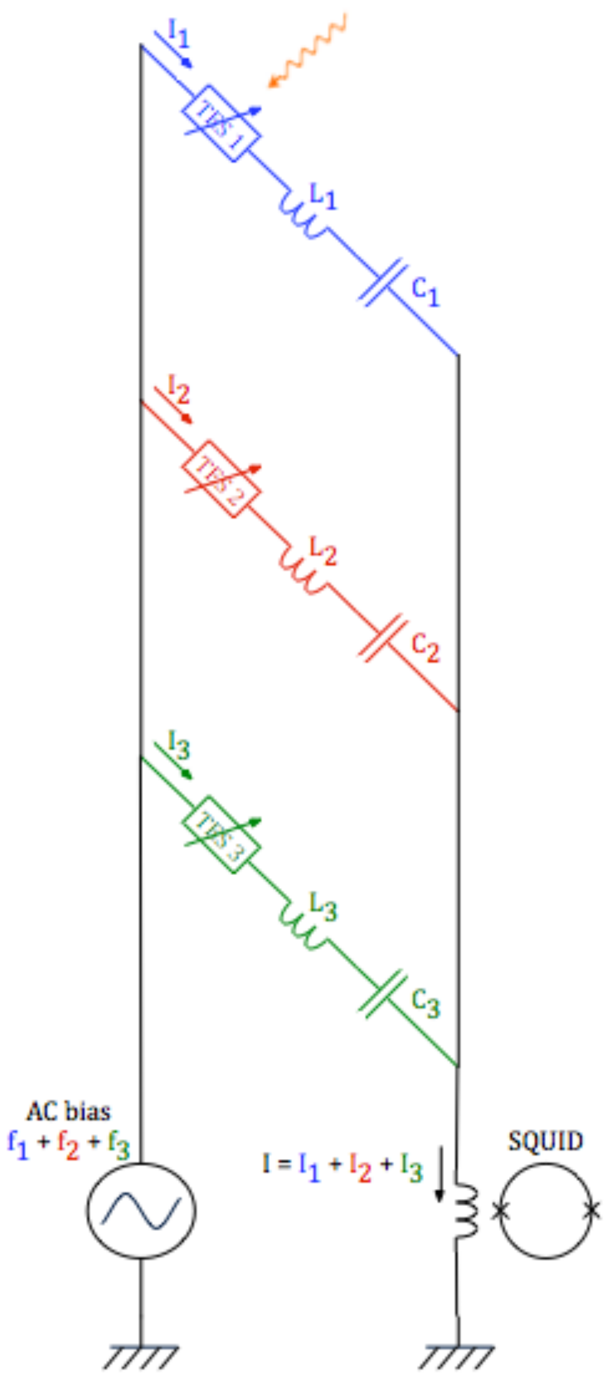


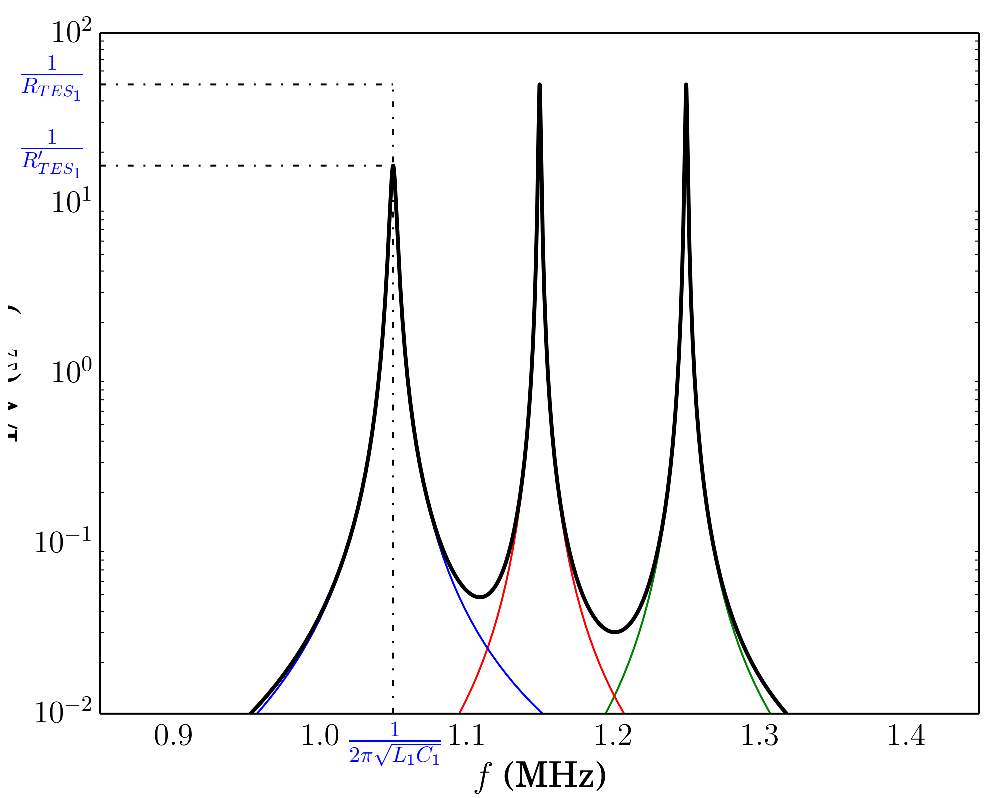


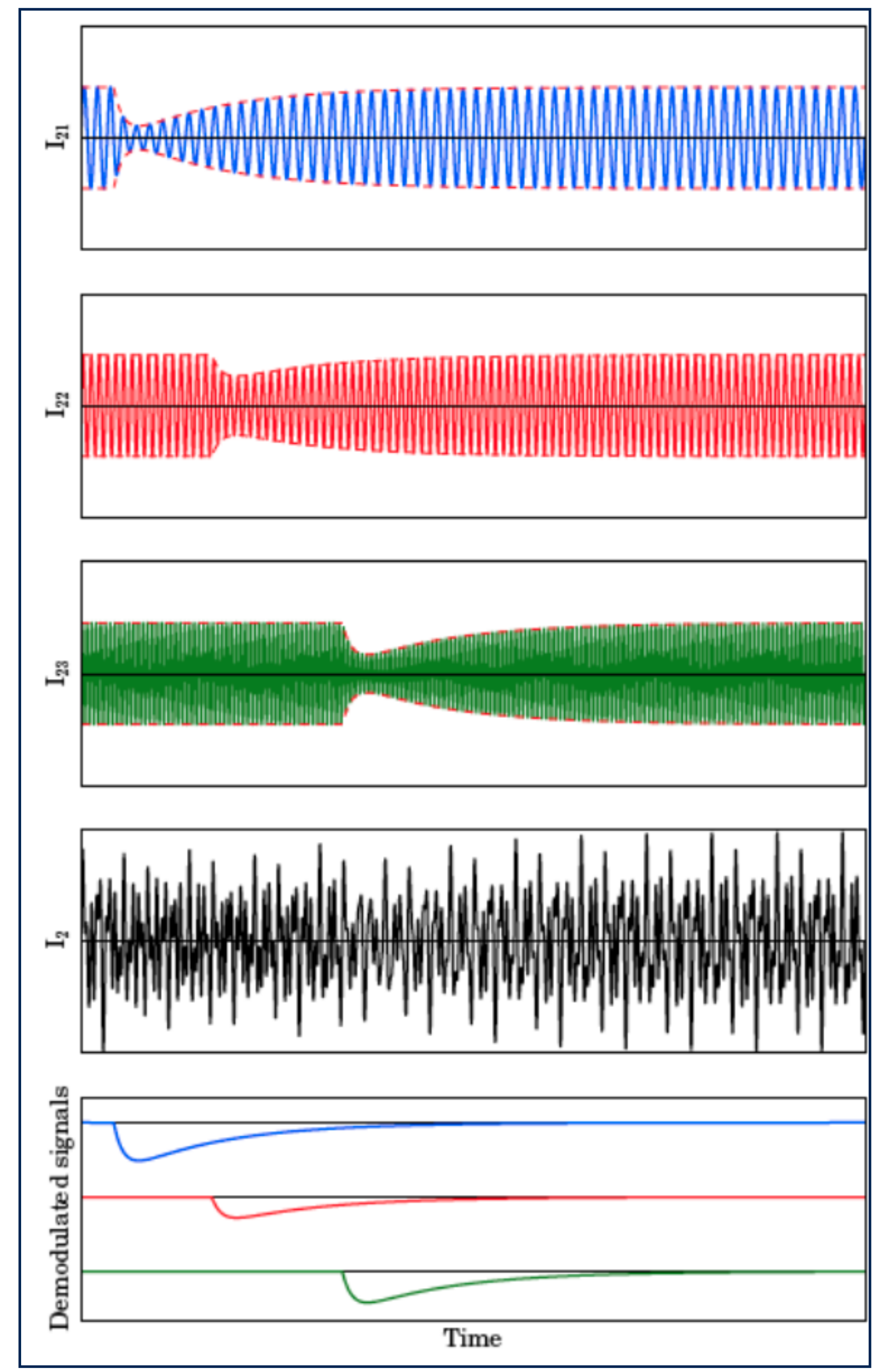
Courtesy L. Ravera

Multiplexed readout

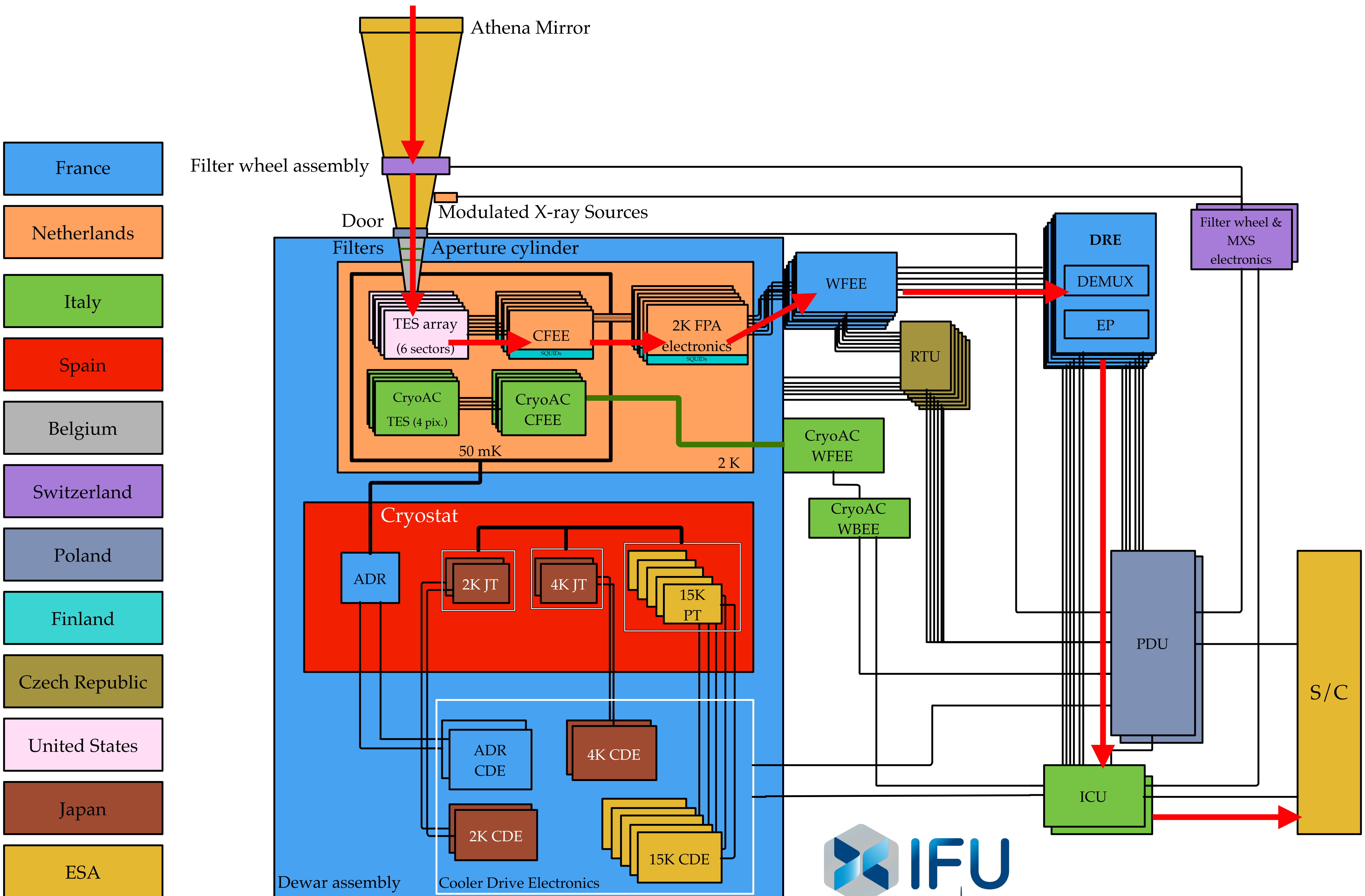
Courtesy L. Ravera





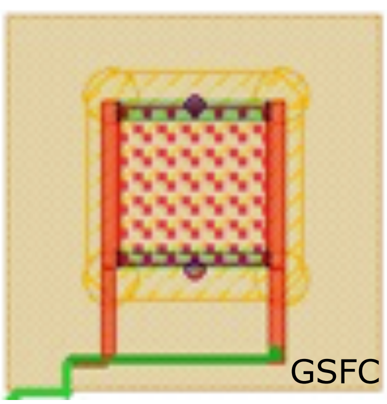
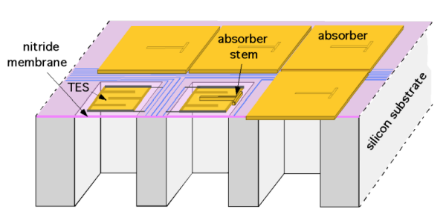
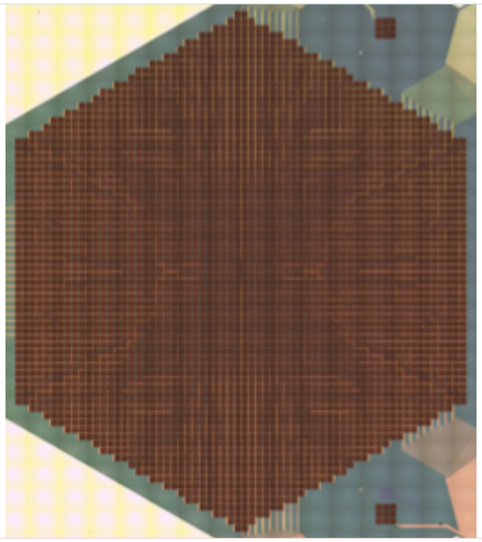
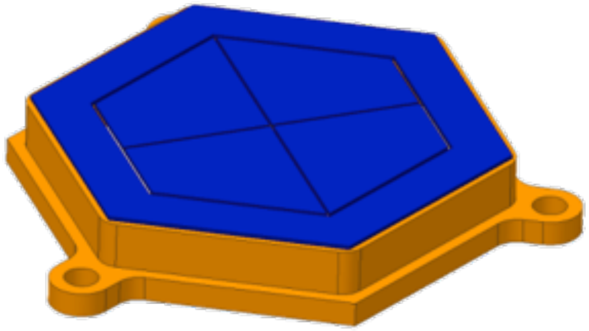
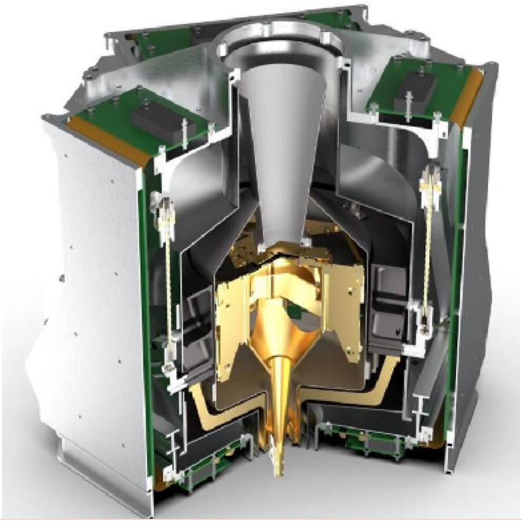


The X-IFU Functional Diagram



TES array and focal plane assembly

- 3168 Mo/Au Transition Edge Sensors of 275 μm pitch with absorbers of 1.7 μm of Au and 4.2 μm of Bi operated at ~100 mK, with an anti-coïncidence detector, all supported by a focal plane assembly

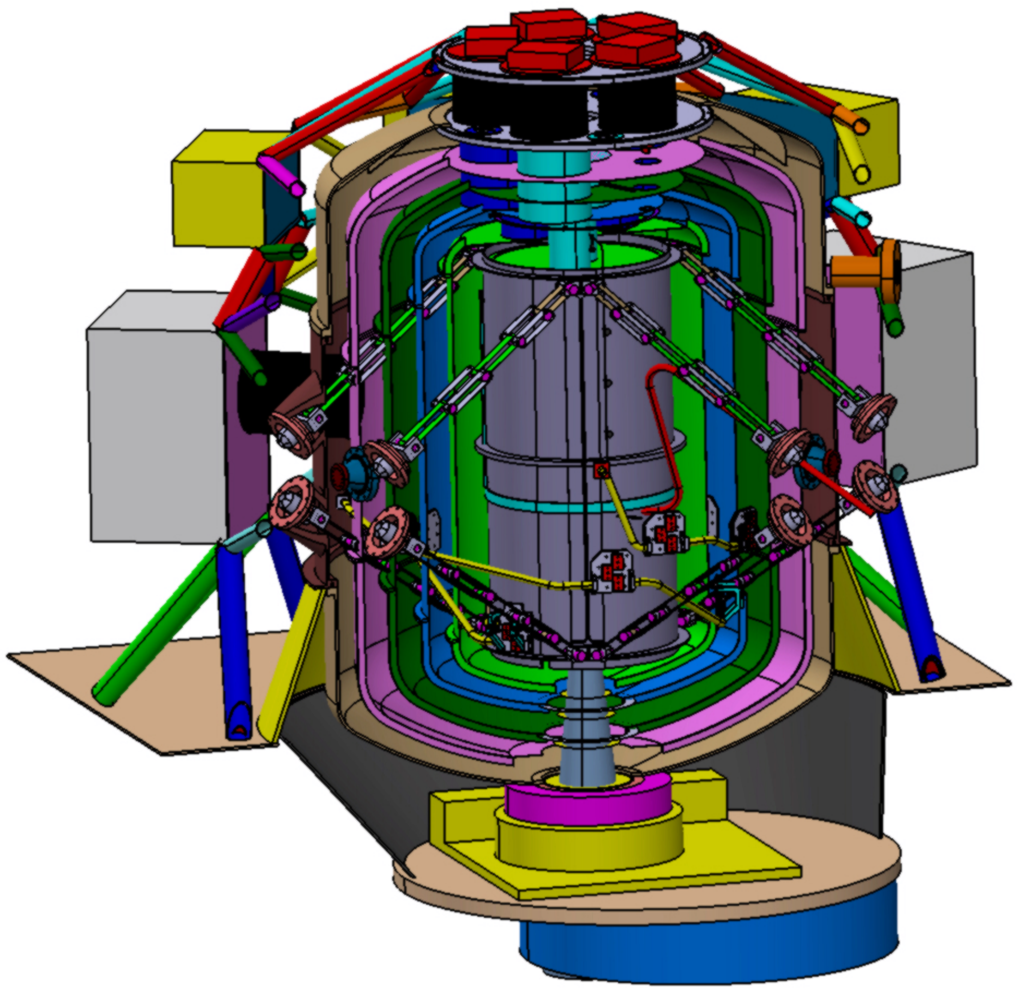
				
Stripe less 100-120 μm MoAu TES thermistor on SiN membrane (NASA)	Filled-array of TES pixels with Au/Bi absorbers (NASA)	Large format array of TES (NASA)	TES cryogenic active anti-coincidence detector (<1 mm) (INAF)	Focal Plane Assembly Demonstration Model (SRON)

SPIE. ASTRONOMICAL TELESCOPES + INSTRUMENTATION

Barret+ (2018) and references therein

X-IFU cryogenic chain

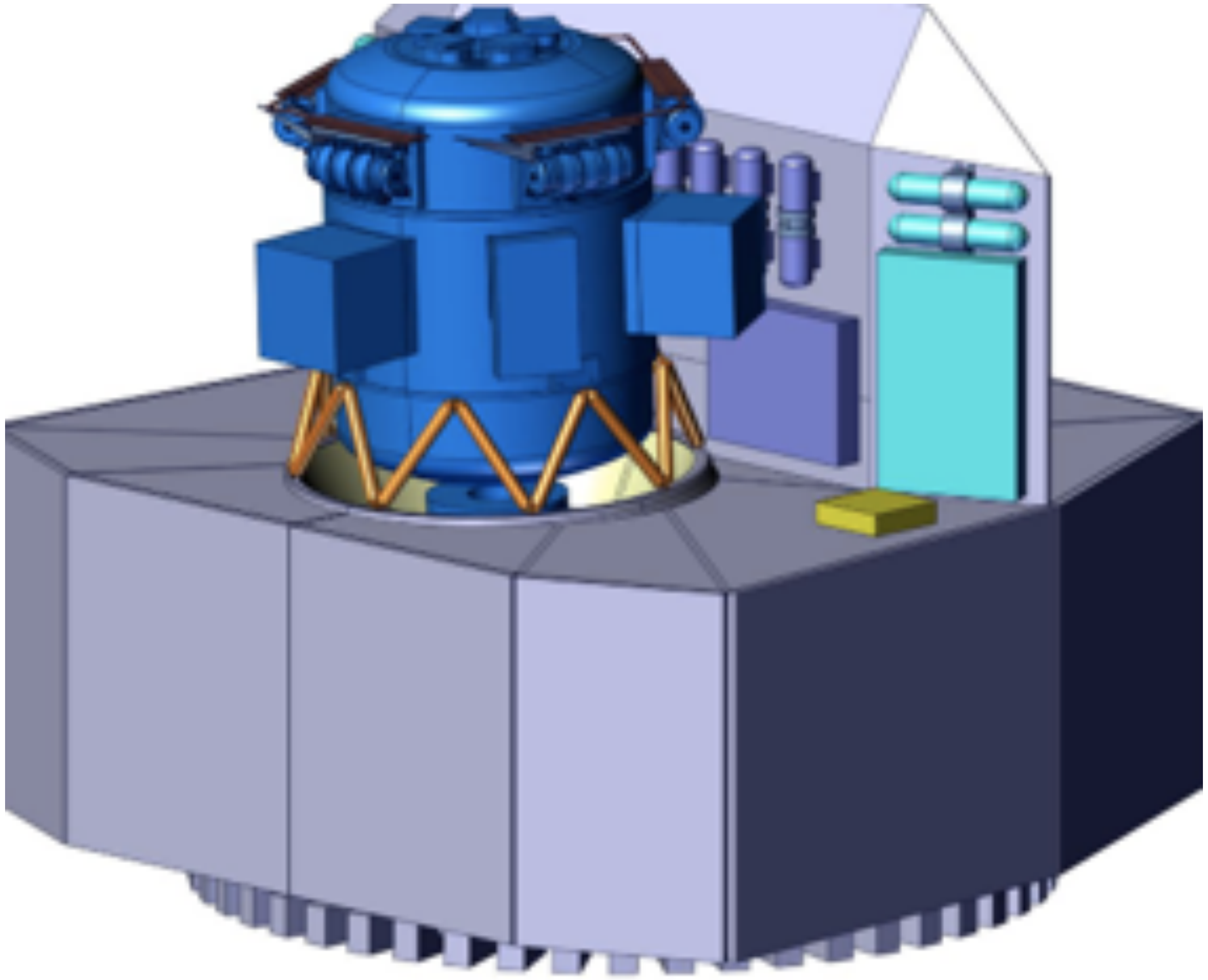
- Multi-stage mechanical coolers:
  - Five 15K Pulse Tubes (ESA from ALAT)
  - Two 4K Joule-Thomson (JAXA)
  - Two 2K Joule-Thomson (JAXA)
  - One last stage 50 mK sorption-ADR (CEA-SBT)
- Thermal budgets within required margins requires a passively cooled shield at 200 K
  - Full redundancy at all stages but the last one
- Cool time of 32 hours and regeneration time of 8 hours



The X-IFU Dewar assembly undergoing final design optimization. Courtesy of the CNES project team.

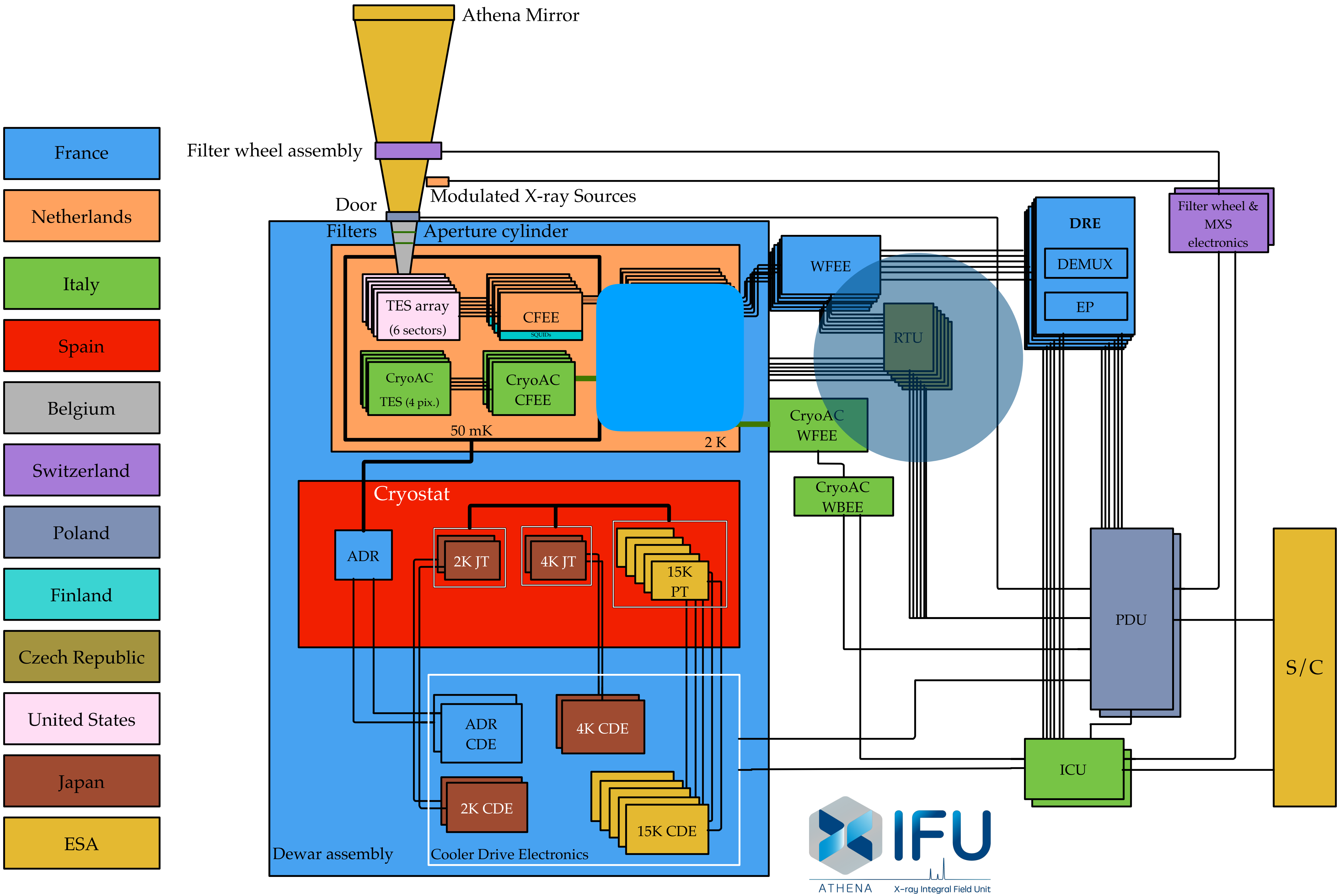
X-IFU instrument budgets

- Mass budget: ~800 kg
- Power budget: ~3.0 kW



X-IFU mounted on the Science Instrument Module. Courtesy of M. Ayre (ESA study team). X-IFU dewar design is currently undergoing a final design iteration (not shown here)

The foreseen Czech contribution: RTUs



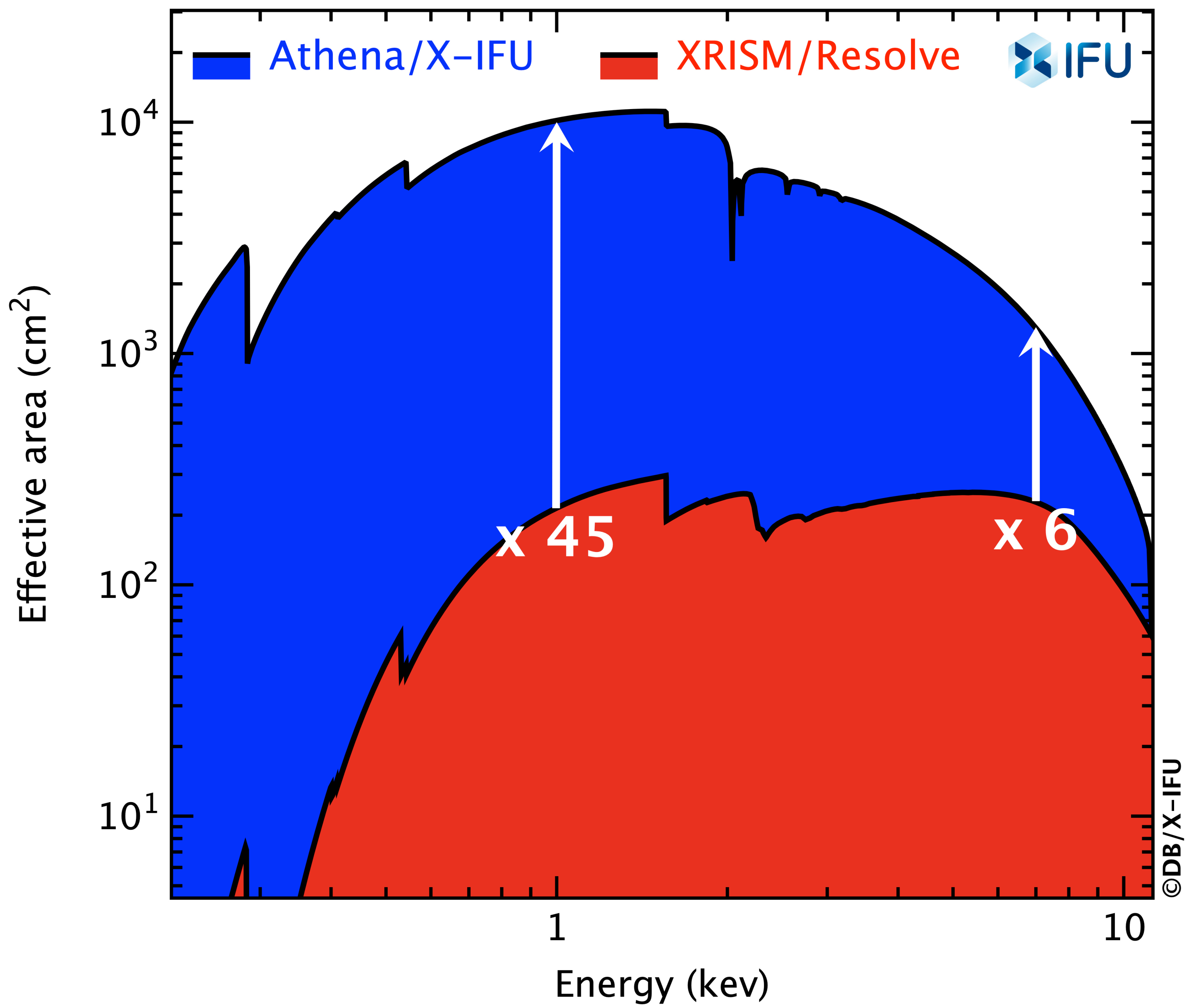
Remote Terminal Units

- Data handling units providing numerical data interfaces of several subsystems with the Instrument Control Unit
  - Key sub-system required to send configuration and powering commands, to read data (e.g. temperatures, housekeeping)…
- Procurement by the Czech Republic is a joint proposal by:
  - Jiří Svoboda (Astronomical Institute of the Czech Academy of Sciences)
  - Jan Souček (Institute of Atmospheric physics of the Czech Academy of Sciences)

  ➡ Supported by scientific interests in Athena (X-IFU) science
- Formalization of the entry of Czech Republic in the X-IFU Consortium pending on funding approval
  - All lights green for this to happen by Q4/18

Effective area

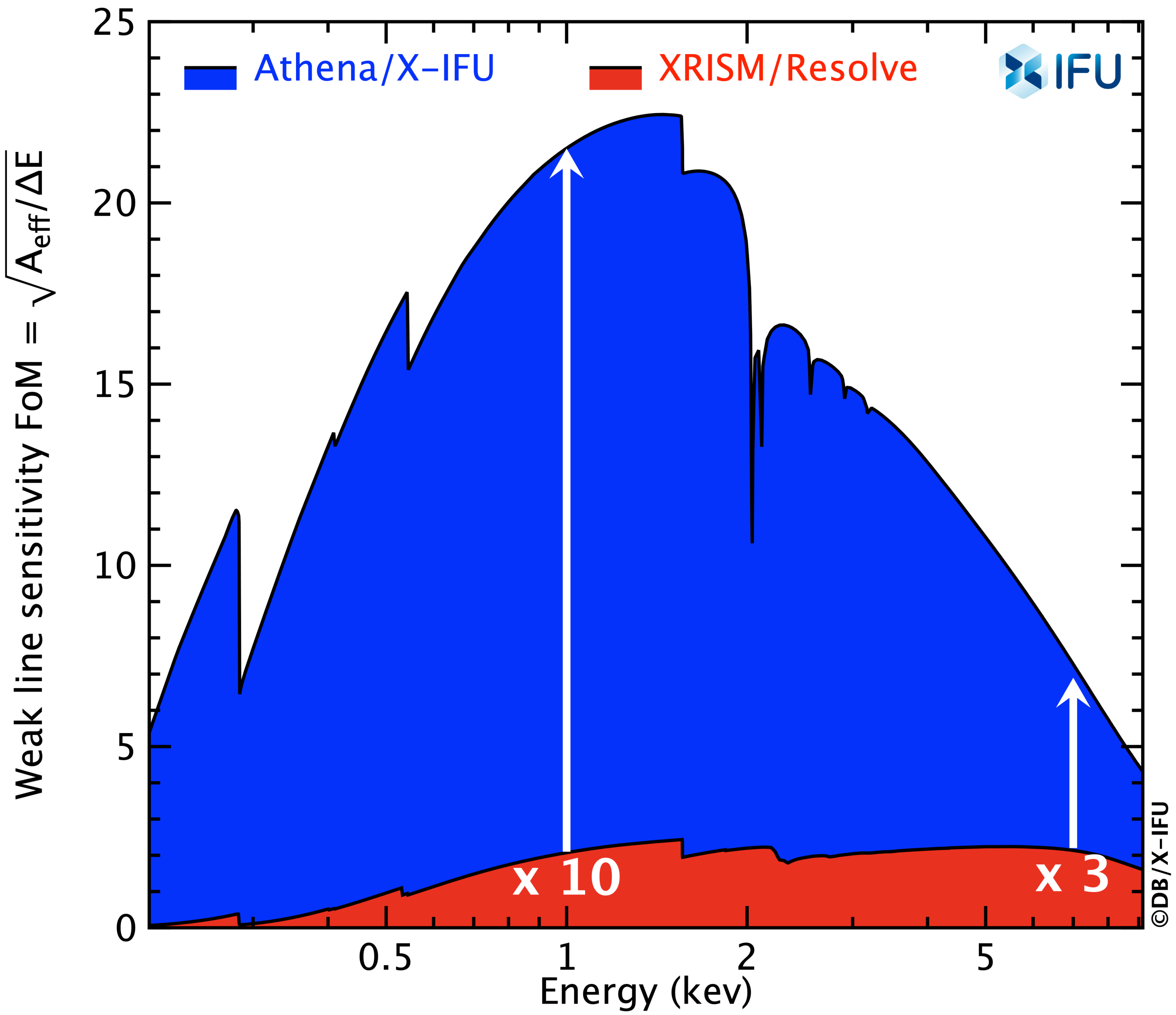
- Effective area is the product of the mirror effective area and the X-IFU filter attenuation and the absorber stopping power
  - ➡ 45 times larger than XRISM/Resolve @ 1 keV



Effective area comparison between the Athena/X-IFU and XRISM/Resolve instruments.

Weak line sensitivity

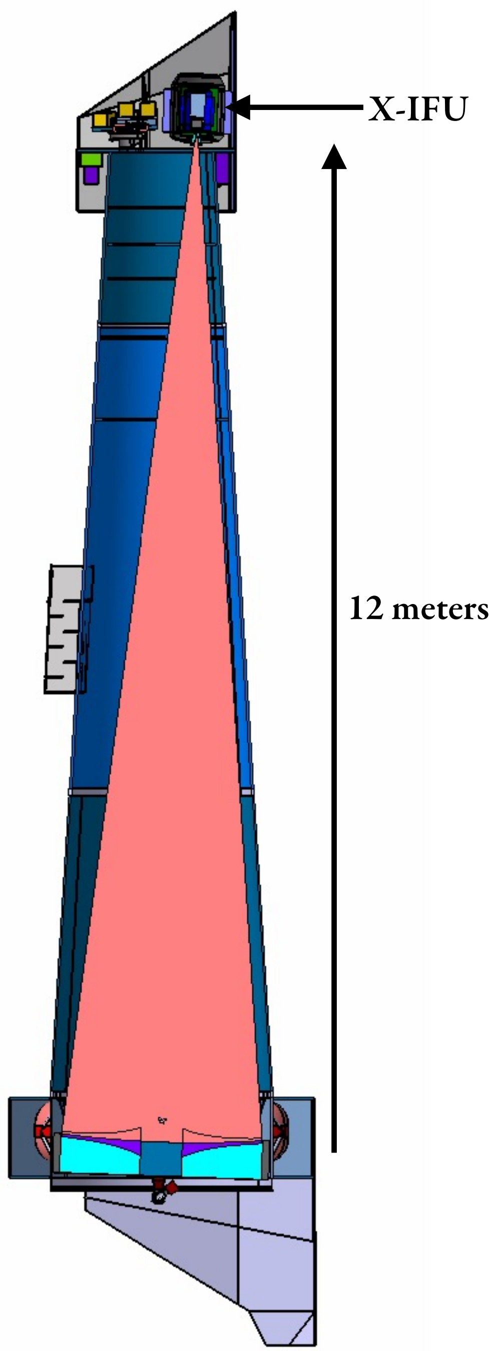
- Weak line sensitivity $\propto \sqrt{A_{eff}/\Delta E}$
  - Factor 10 better than XRISM/Resolve at 1 keV: ~2 eV/5 eV & larger effective area
  - Better imaging 1′ versus 5″ pixels

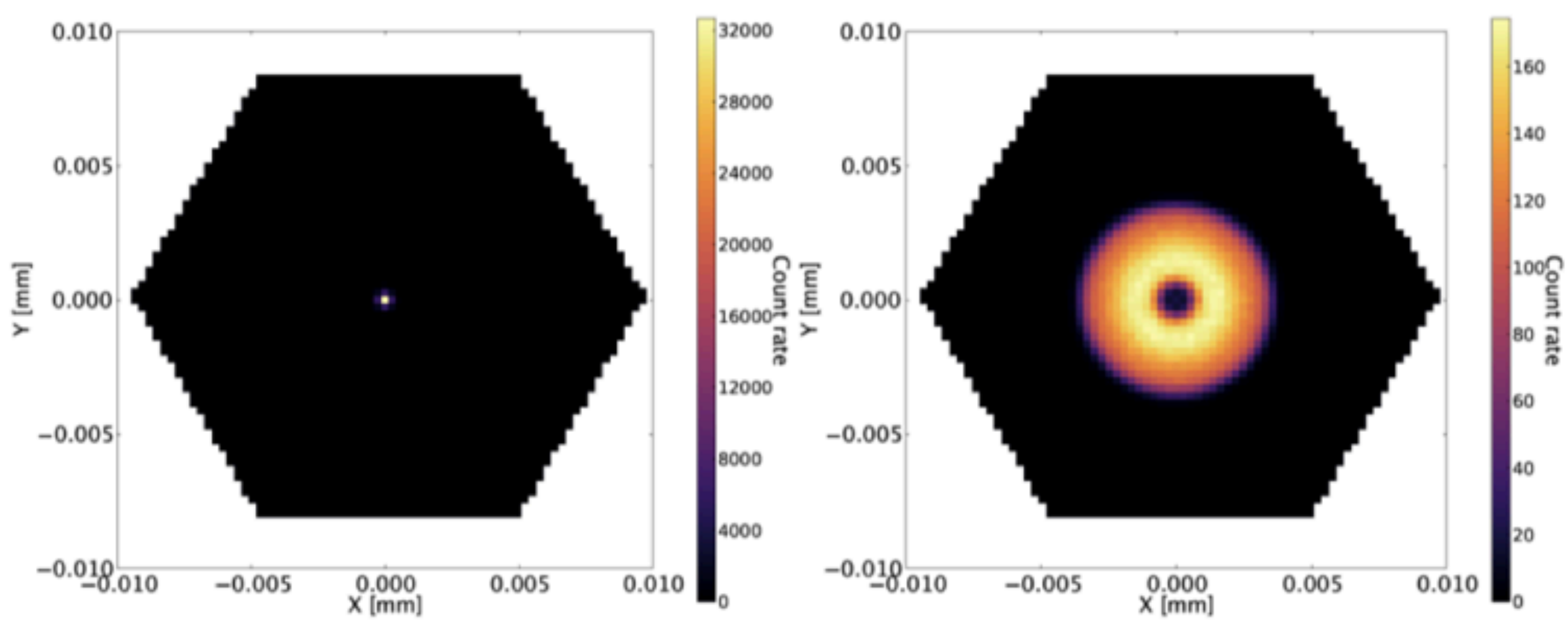


Comparison of the weak line sensitivity of Athena X-IFU and XRISM Resolve spectrometers

Count rate performance

- Athena offers a defocussing capability for the optics

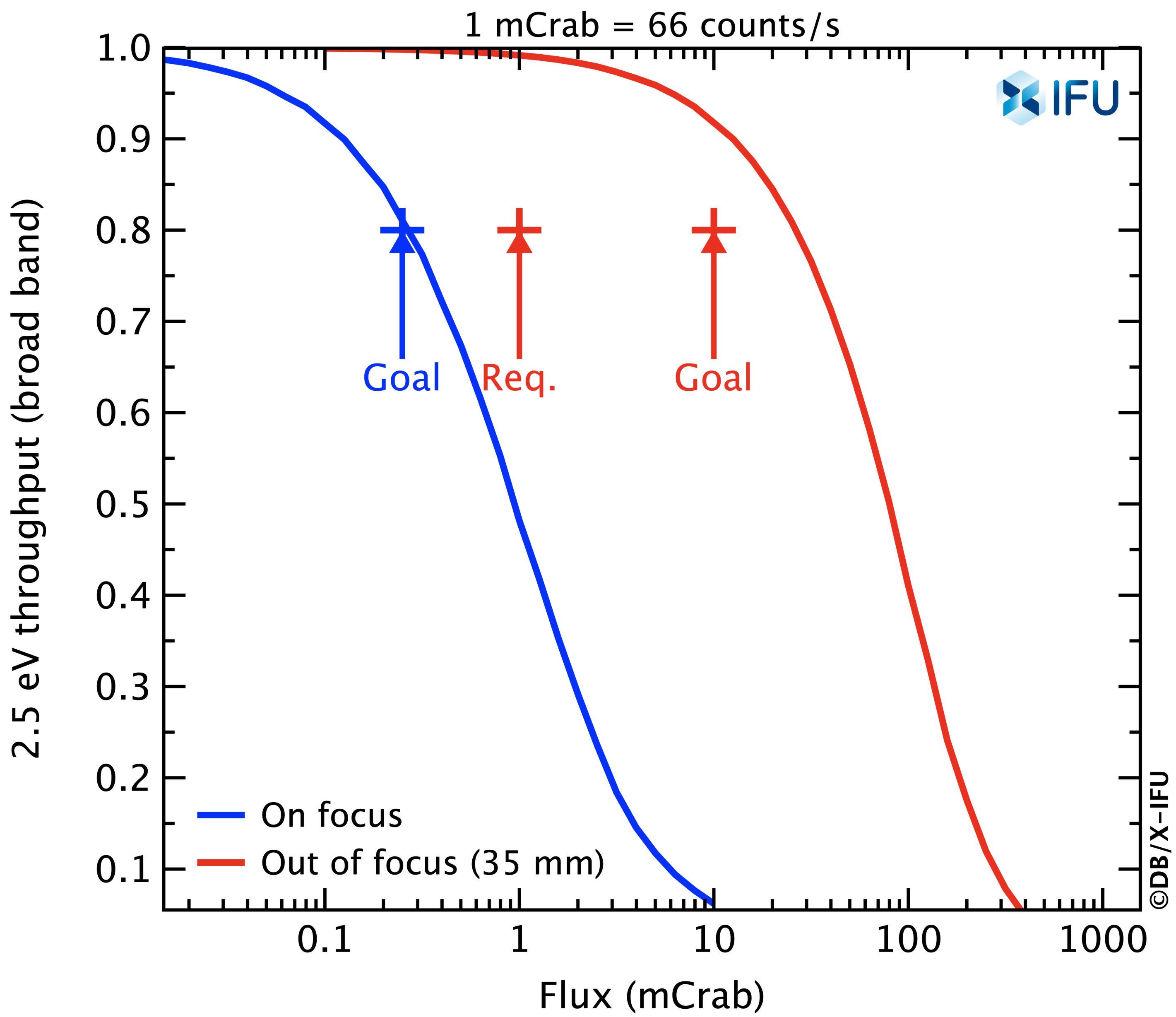




A point source in focus and out-of-focus by 35 mm

Count rate performance

- Count rate performance is defined by the pixel speed, cross talk and record length required for achieving the spectral resolution
  - Defocussing of the optics spreads the PSF, hence very bright point sources can be observed



Count rate performance in different mirror and instrument configurations (Courtesy of Th. Dauser and E. Cucchetti)

Conclusions

- X-IFU has revolutionary capabilities by combining high spectral resolution, fine imaging and high throughput up to the brightest X-ray sources
  - We have to anticipate that after XRISM, X-ray astronomy will be a completely new field
- X-IFU has reached a stable and robust baseline configuration meeting its top-level performance requirements
  - All the components entering into the performance budgets are understood, closing now the last round of optimization
- Technology demonstration on key instrument components has made significant progresses : cooling chain demonstrator, TES and readout electronics, filters…
  - Technology plan in place to bring those key elements to TRL5 at mission adoption
- Next milestone: Instrument preliminary requirement review in Q1/19
- Looking forward to the Czech Republic contribution !

Thanks to you and to all of them

IFU
ATHENA X-ray Integral Field Unit

irap astrophysique & planétologie

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SRON Netherlands Institute for Space Research

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