The Athena X-ray Integral Field Unit

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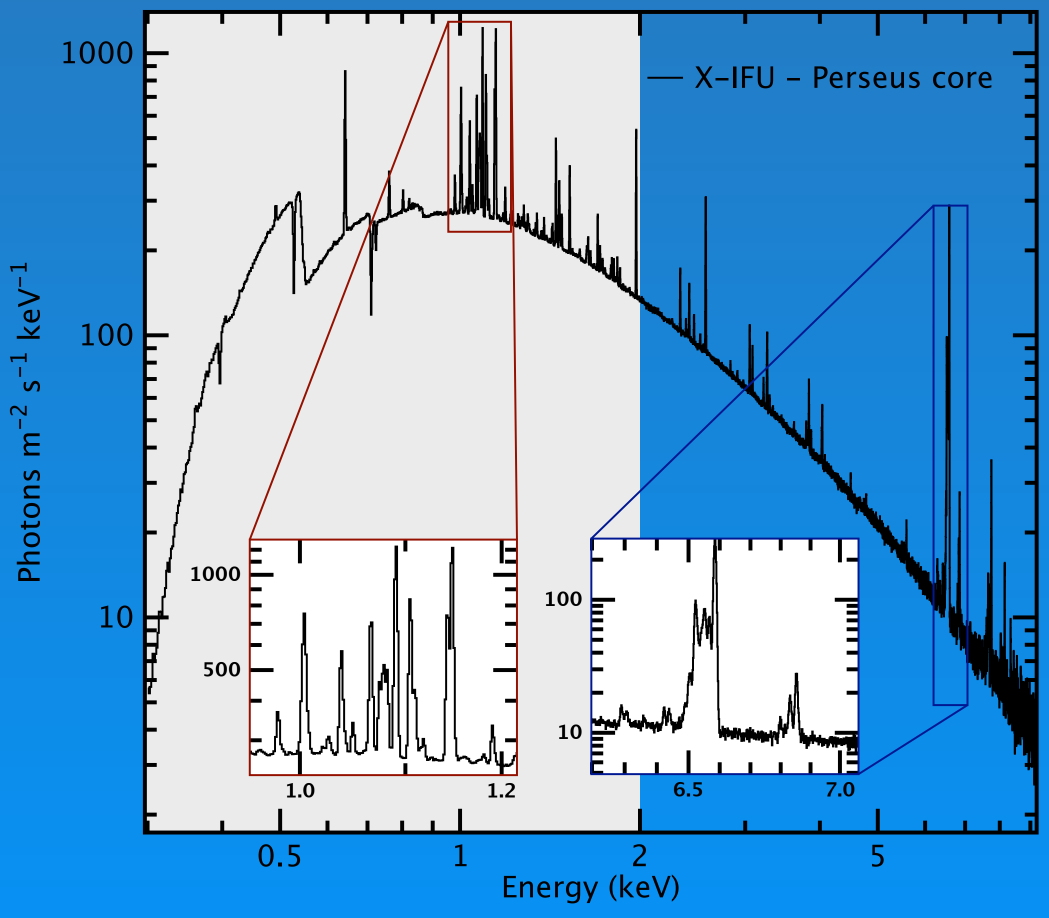
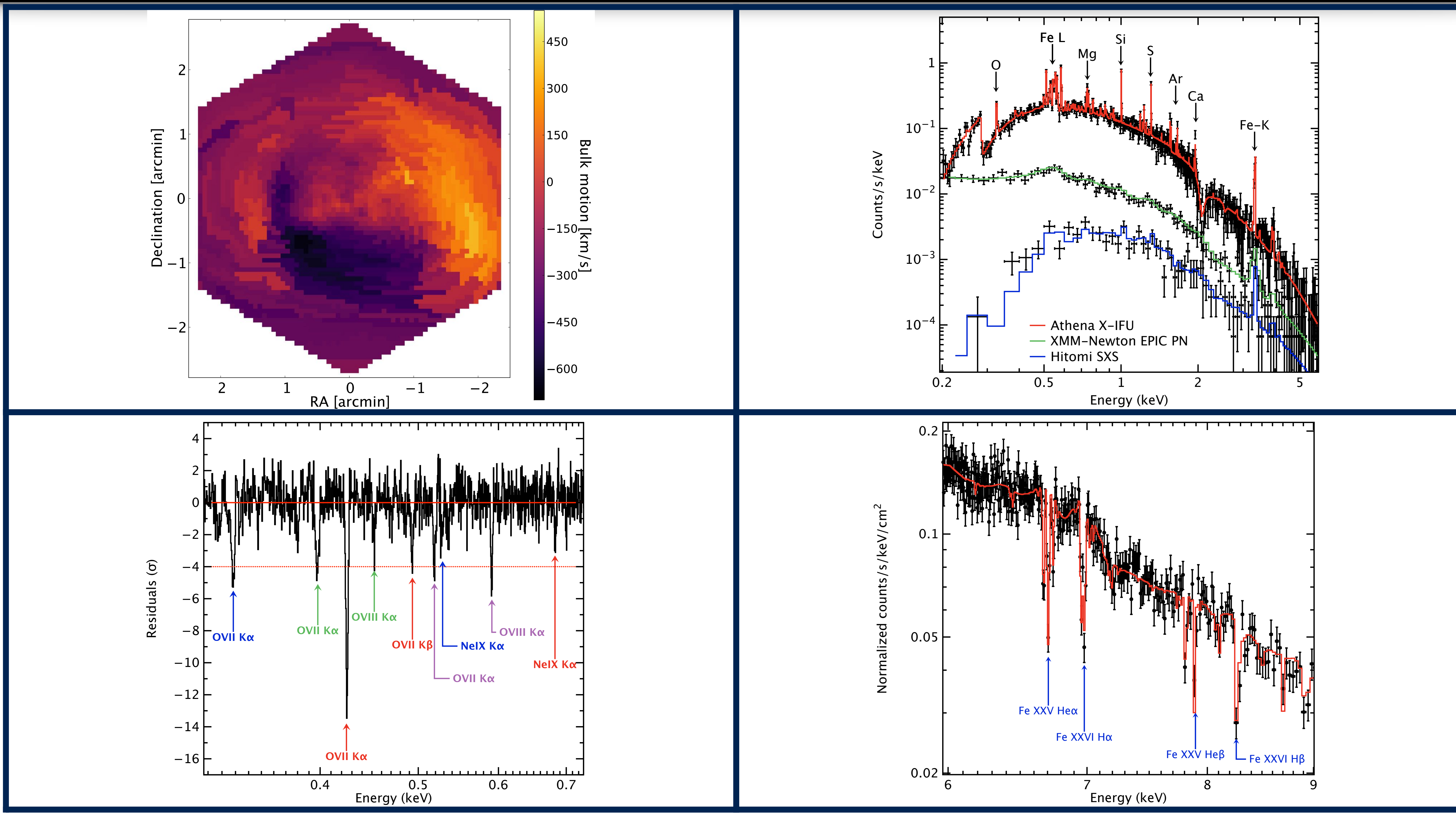


On behalf of the X-IFU Consortium with strong support from the X-IFU Science Advisory Team (Massimo Cappi, IASF-BO, IT & Etienne Pointecouteau, IRAP, F)

The Athena X-ray Integral Field Unit

- X-IFU is the Athena cryogenic high-resolution X-ray spectrometer providing 2.5 eV spectral resolution (0.2-12 keV), on 5'' pixels on a field of view of 5'
- It is developed under the leadership of IRAP and CNES (France)
  - ✓ with major contributions from Netherlands and Italy
  - ✓ and additional contributions from 6 other ESA member states (Belgium, Finland, Germany, Poland, Spain, Switzerland)
  - ✓ and from two international partners (Japan and the United States)

Driving Athena science



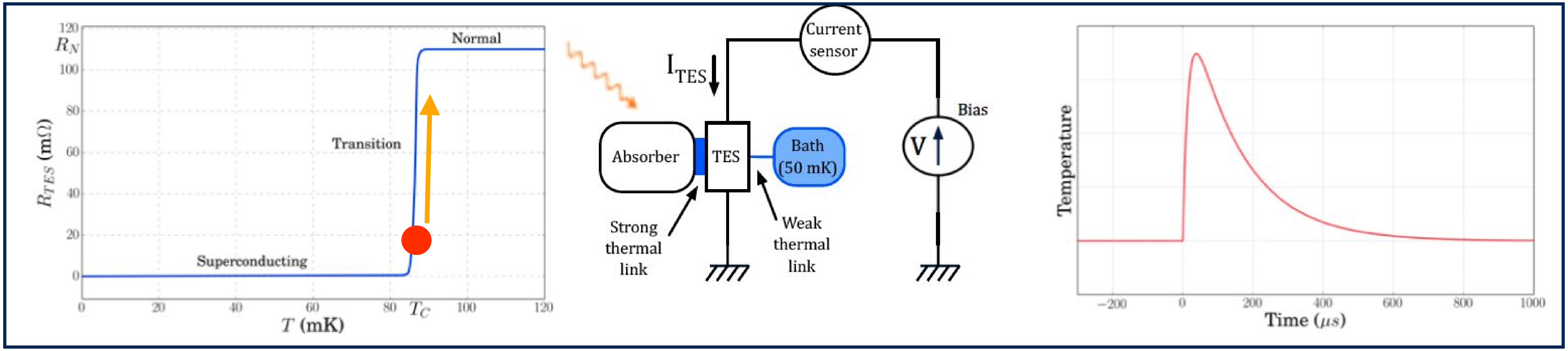
Courtesy of the X-SAT (F. Nicastro, J. Miller, E. Pointecouteau) and E. Cucchetti, Ph. Peille. From Barret et al. (2016)

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*
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 winds - *Brightest point source requirement*

Micro-calorimeter

- X-IFU is based on a large array of Transition Edge Sensors (TES)



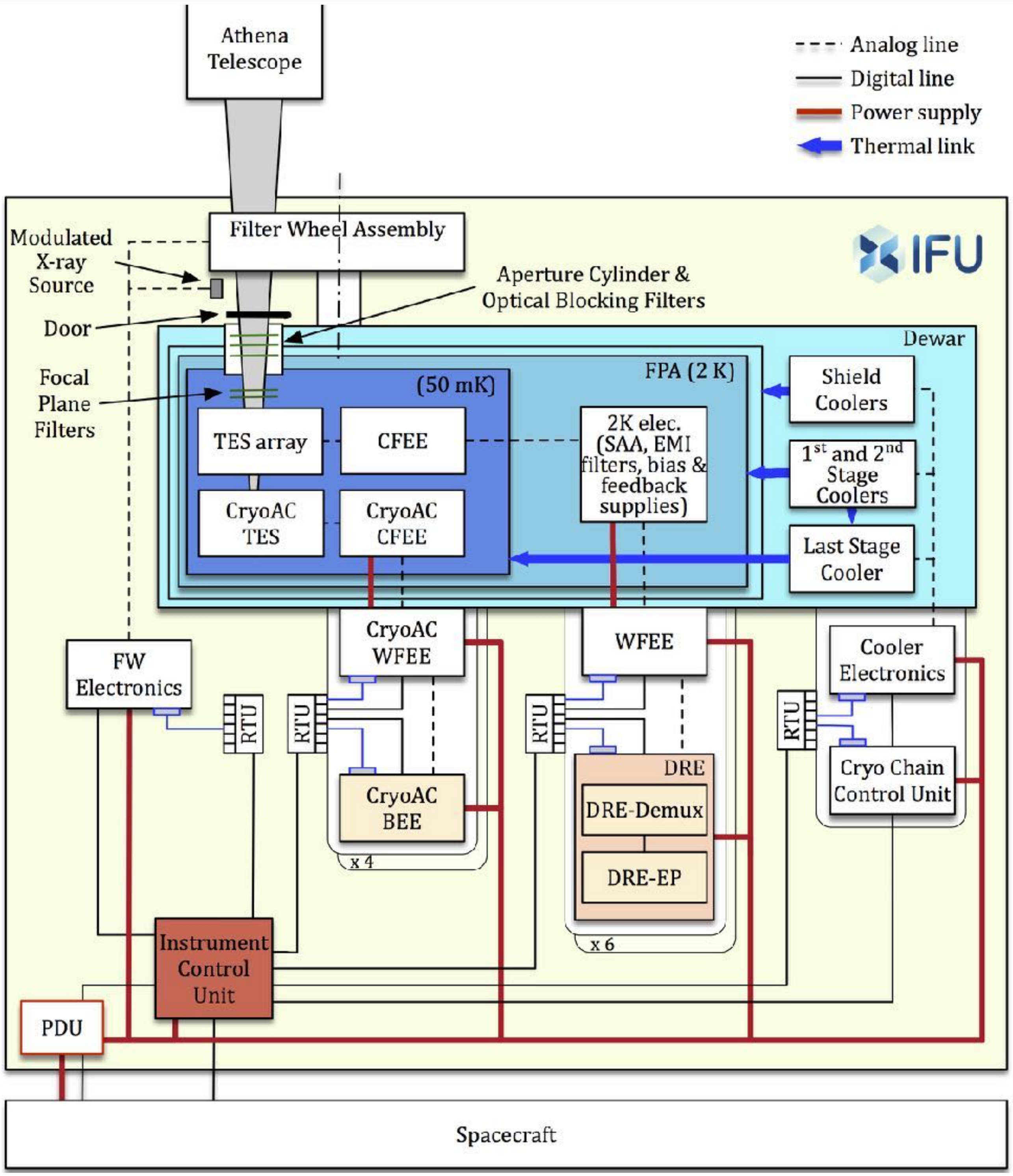
1. The TES is cooled to lie in its transition between its superconducting and normal states

2. When a photon hits the absorber, it heats up both the absorber and the TES whose resistance increases

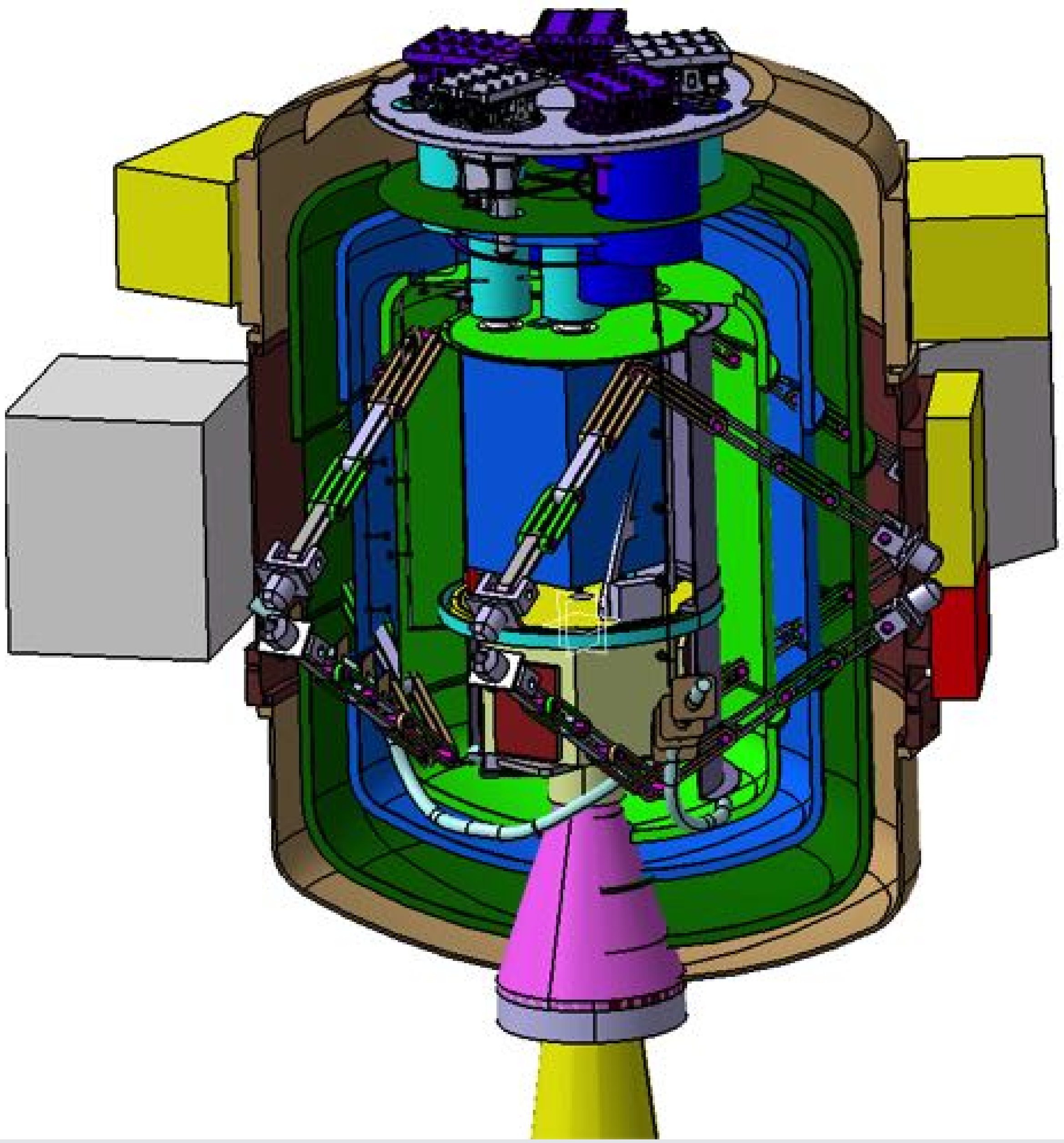
3. Under a constant voltage bias, the change of the TES resistance leads to a change of the current passing through the TES

4. The change in temperature (or resistance) with time shows a fast rise and a slower decay

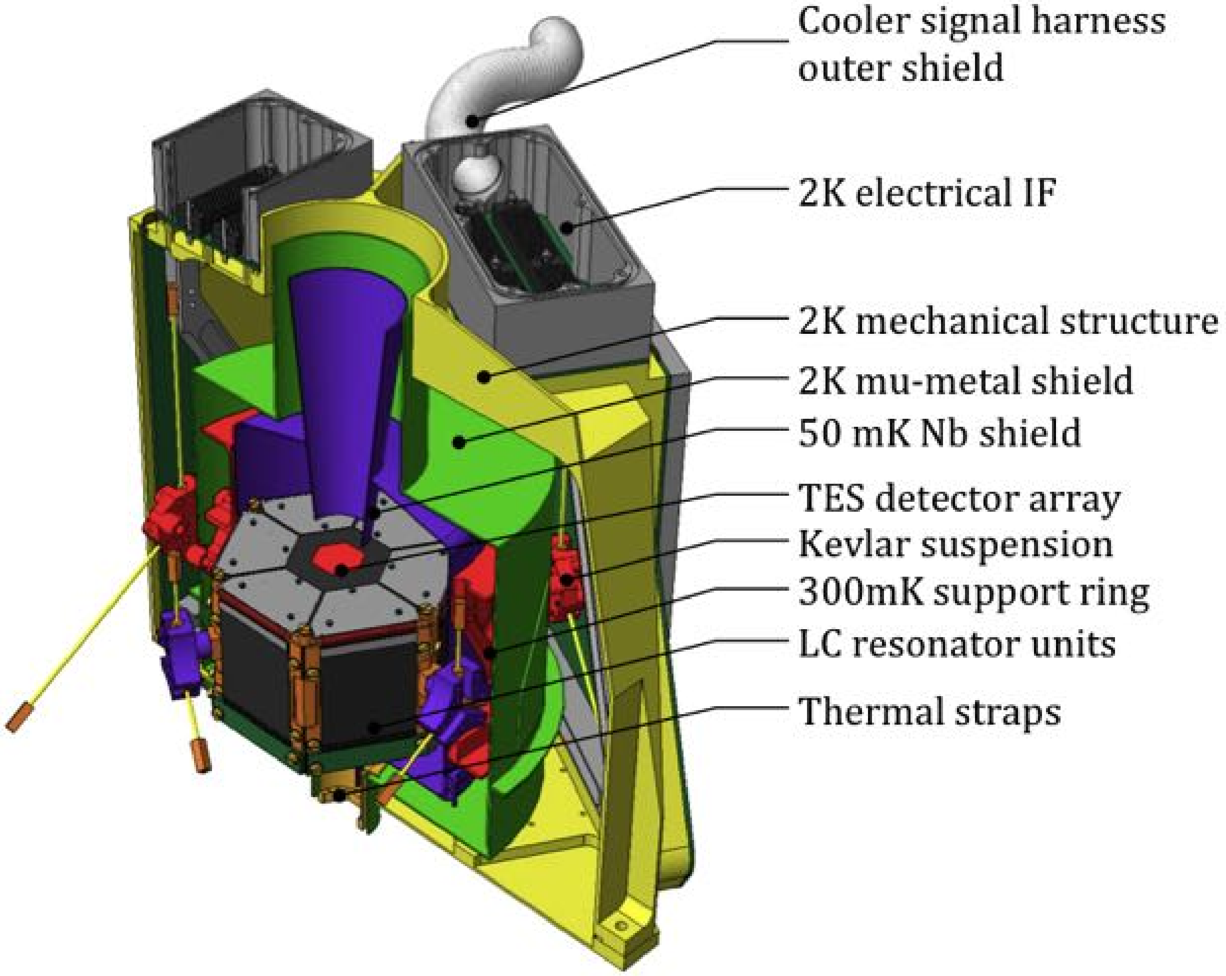
The X-IFU functional block diagram



The X-IFU mechanical/thermal design



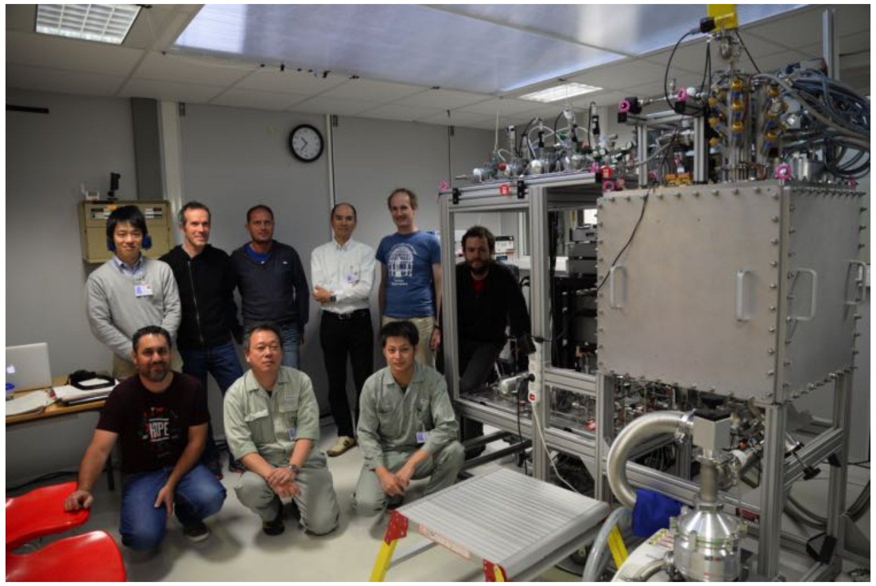
The X-IFU Dewar assembly. **Courtesy of A. Pradines (CNES).**

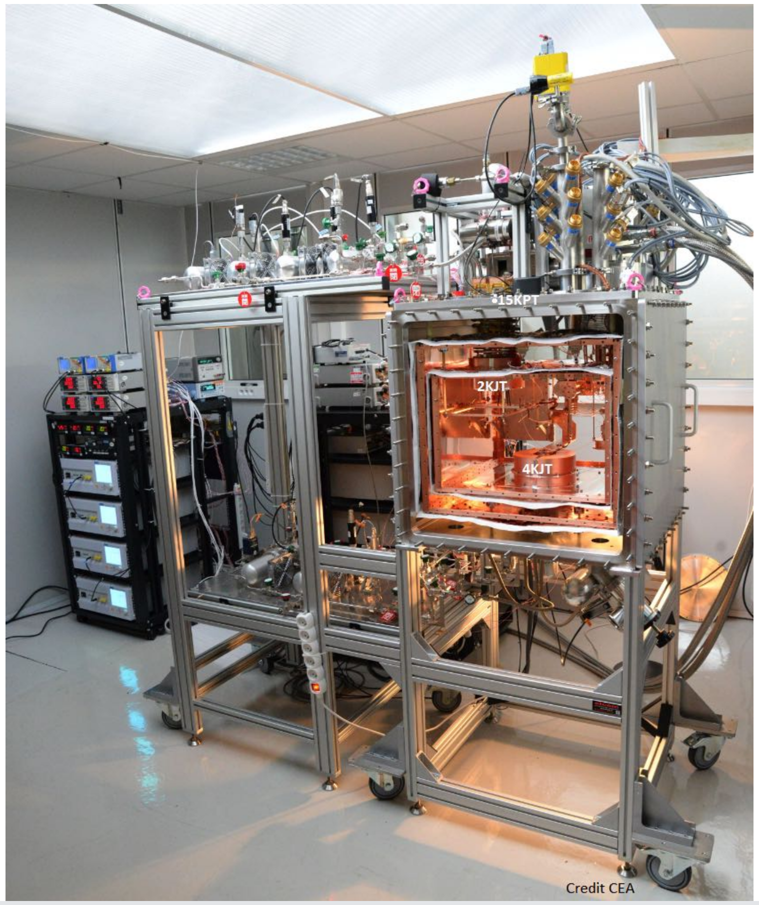


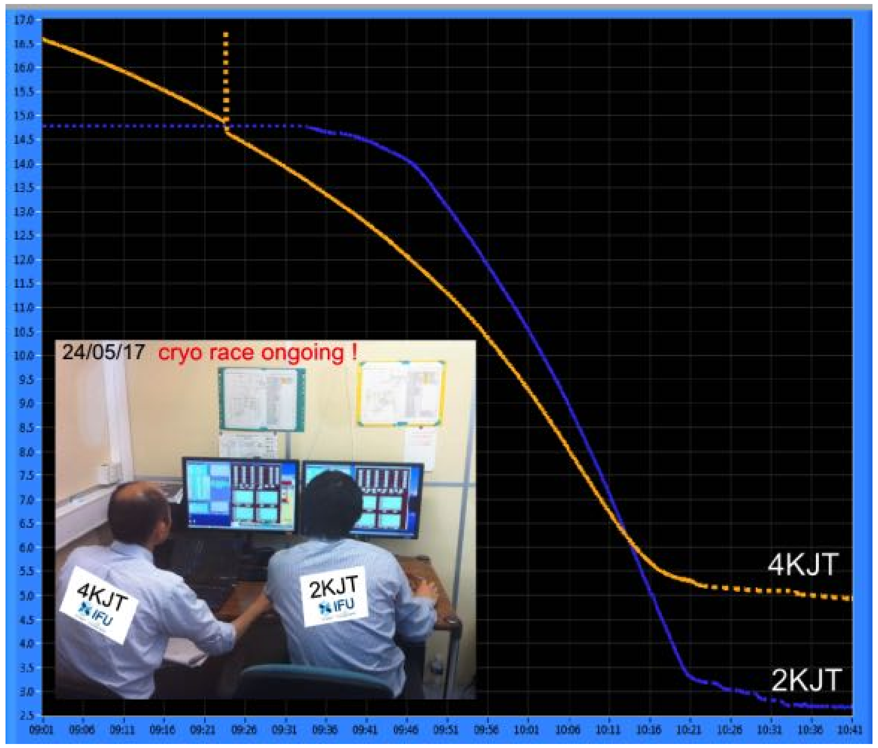
The X-IFU Focal Plane Assembly. **Courtesy of H. van Weers (SRON).**

X-IFU technology status

- 50 mK cooling chain technology demonstrator being developed under ESA CTP contract with CNES lead and X-IFU consortium partners (JAXA, CAB-INTA, CEA, SRON, IRAP)



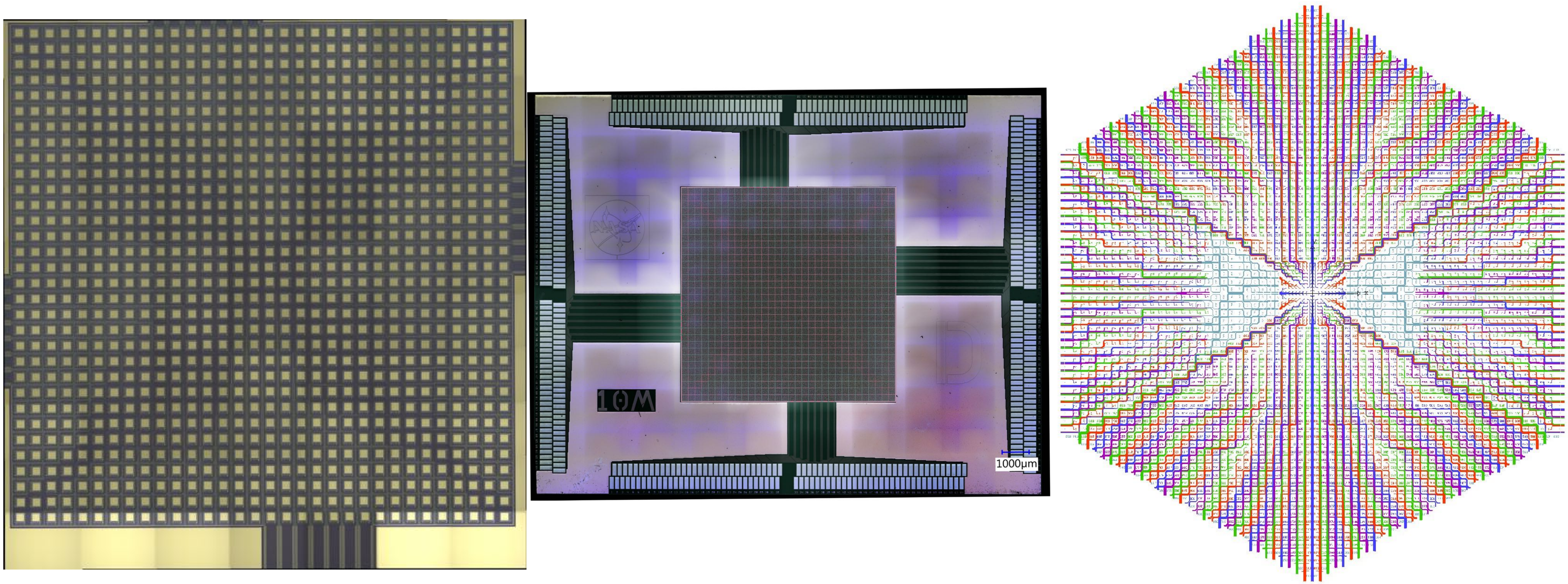




French Japanese cooler coupling - very promising results
Air Liquide 15K Pulse Tube cooler coupled with JAXA 2K Joule Thomson cooler in a dedicated cryostat at CEA (Grenoble).
Courtesy of M. Ledu (CNES) for the international DCS team.

X-IFU technology status

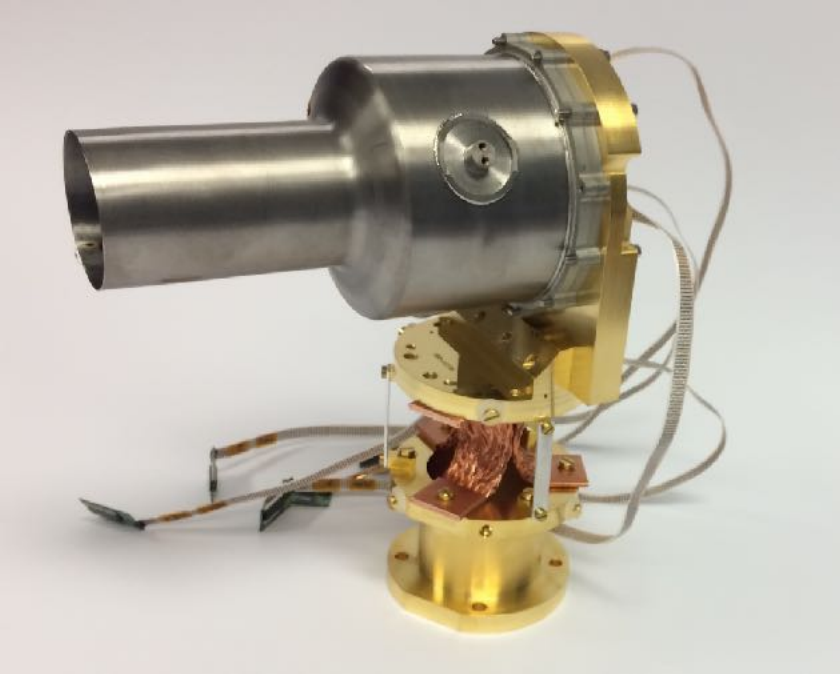
- Large format TES array being fabricated and tested at GSFC

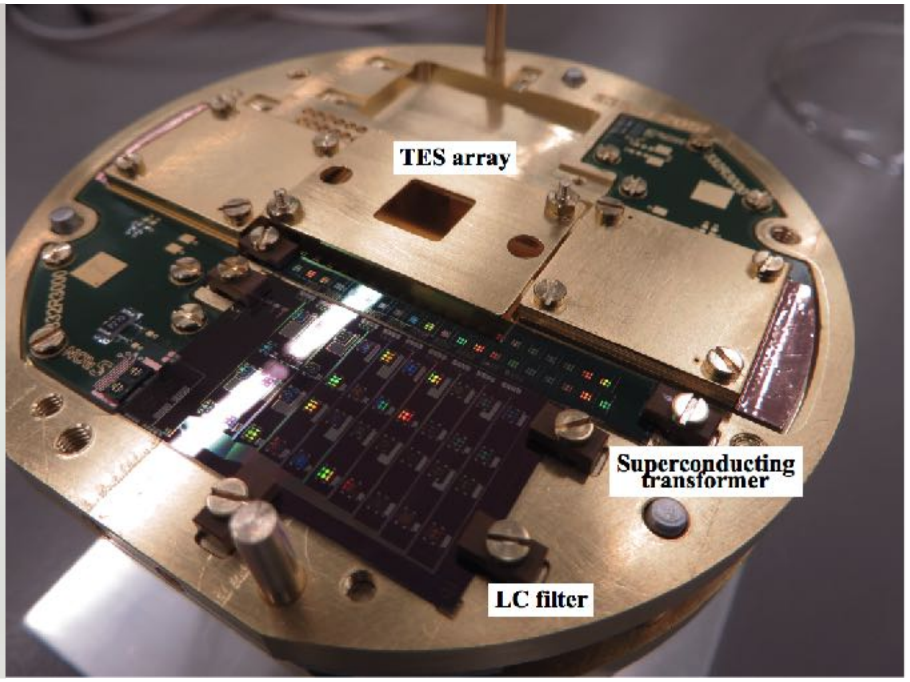


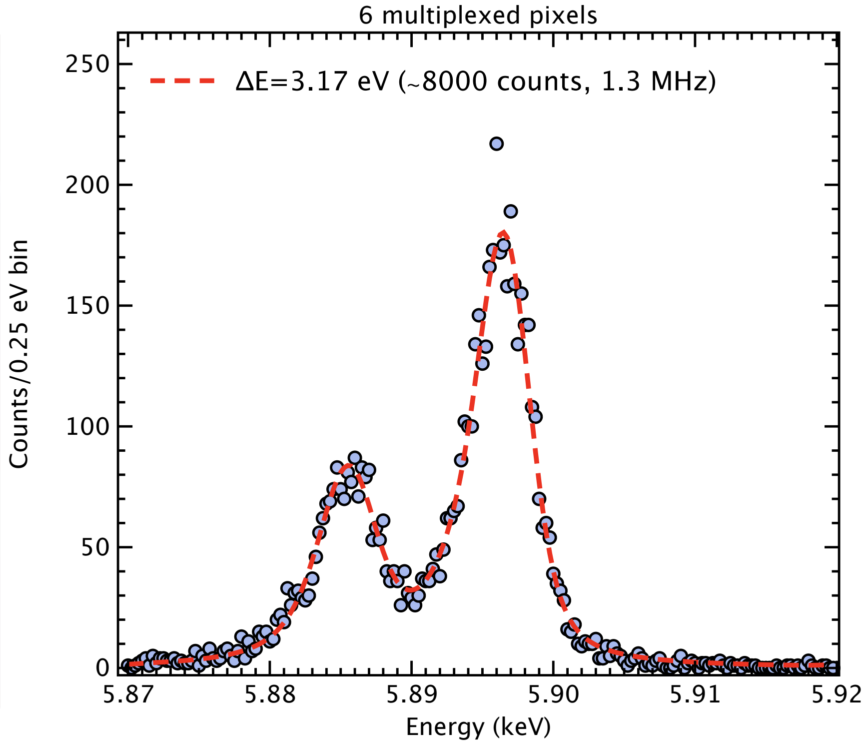
Photograph of a candidate X-ray microcalorimeter array to be used in the Athena X-IFU demonstration model. This is a 32x32 array of pixels on a 250 µm pitch. Each pixel is suspended on a 0.5 µm thick silicon nitride membrane. The absorbers consist of a bilayer of bi-layer of Au (1.5 µm) and Bi (3 µm). **Courtesy of S. Bandler for the GSFC TES team.**

X-IFU technology status

- Frequency Domain Multiplexing readout approaching the required spectral resolution







FDM set up and spectral resolution achieved. **Courtesy of H. Akamatsu for the SRON FPA team.**

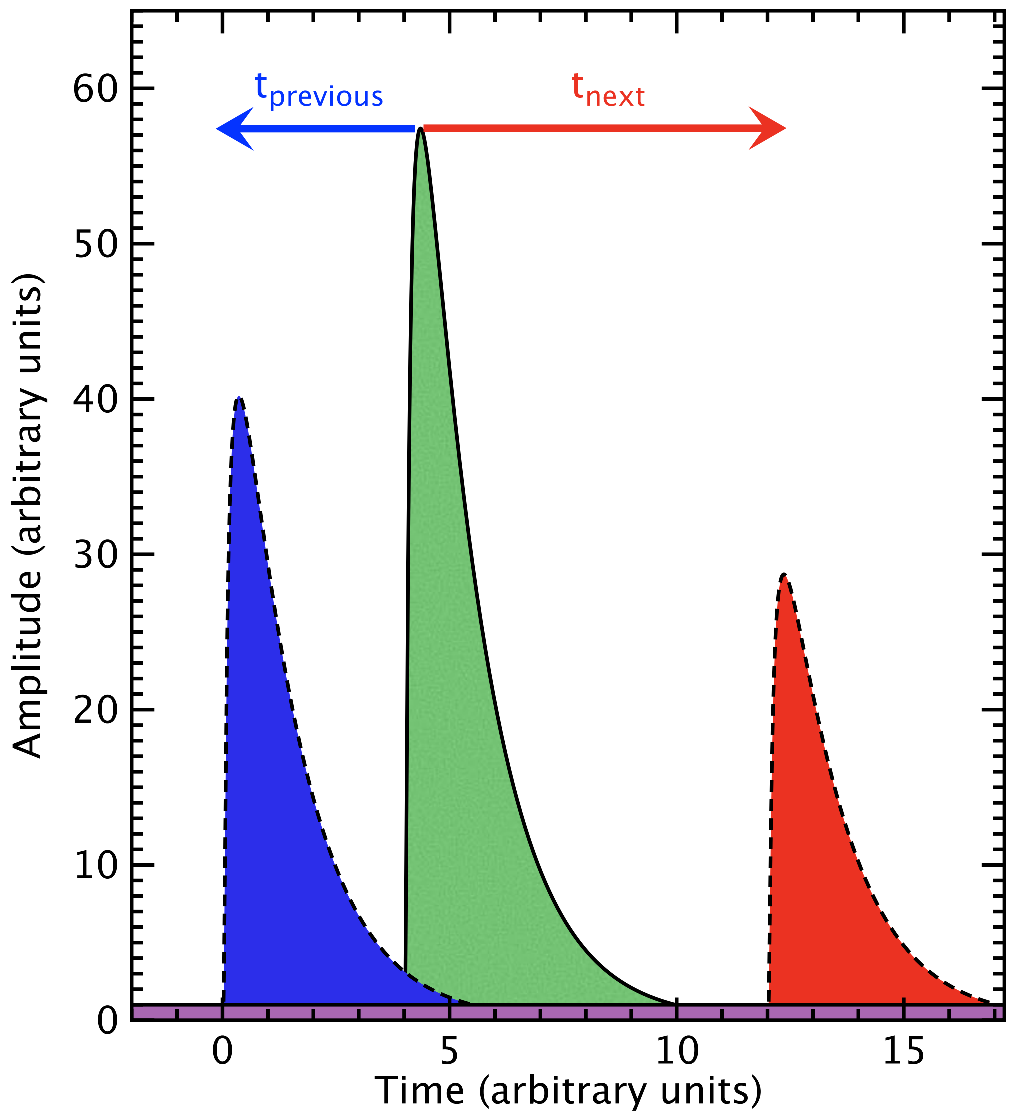
- Additional technologies developed (CryoAC, cold and warm electronics components, thermal filters,…)

X-IFU count rate performance

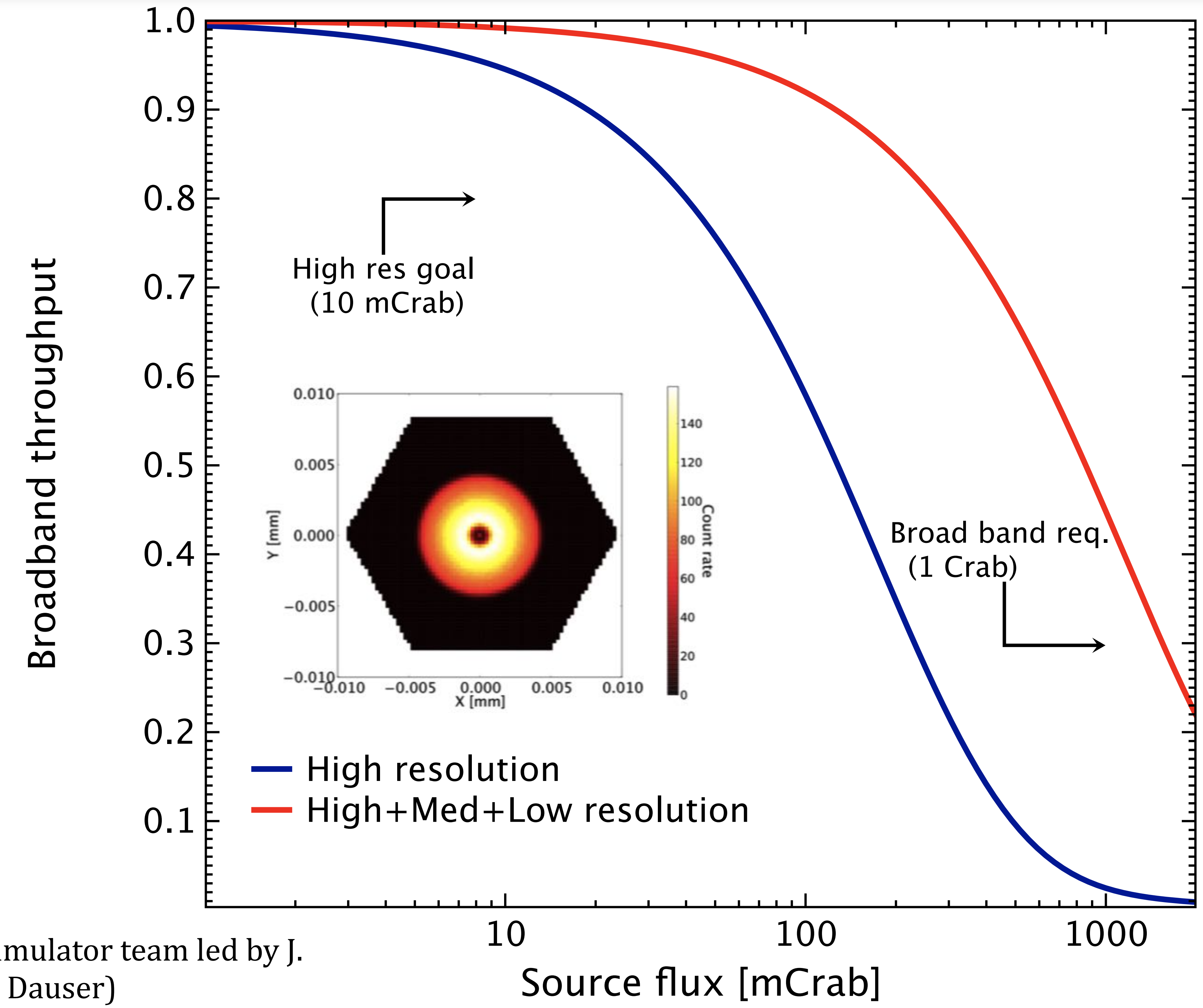
- The X-IFU as an integral field spectrometer is primarily designed to look at diffuse sources (clusters) but will also observe point sources, some of which may be bright (GRB afterglows, X-ray binaries)
  - ✓ X-IFU holds great potential for breakthrough discoveries provided that it has a high count rate capability
- Defocussing of the optics is a requirement for Athena and therefore the X-IFU can be optimized accounting for that capability
  - ✓ Defocussing spreads the PSF over a larger number of pixels, thus improving the overall count rate capability, while keeping a reduced rate of events to be processed per pixels (average a few cps/pixel)

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
- Three different grades are considered for the events:
  - ✓ High resolution (2.5 eV)
  - ✓ Med resolution (~3 eV)
  - ✓ Lower resolution (from 3 eV to less than 30 eV)
- Throughput depends on count rate and can be computed as a function of the energy resolution that is required

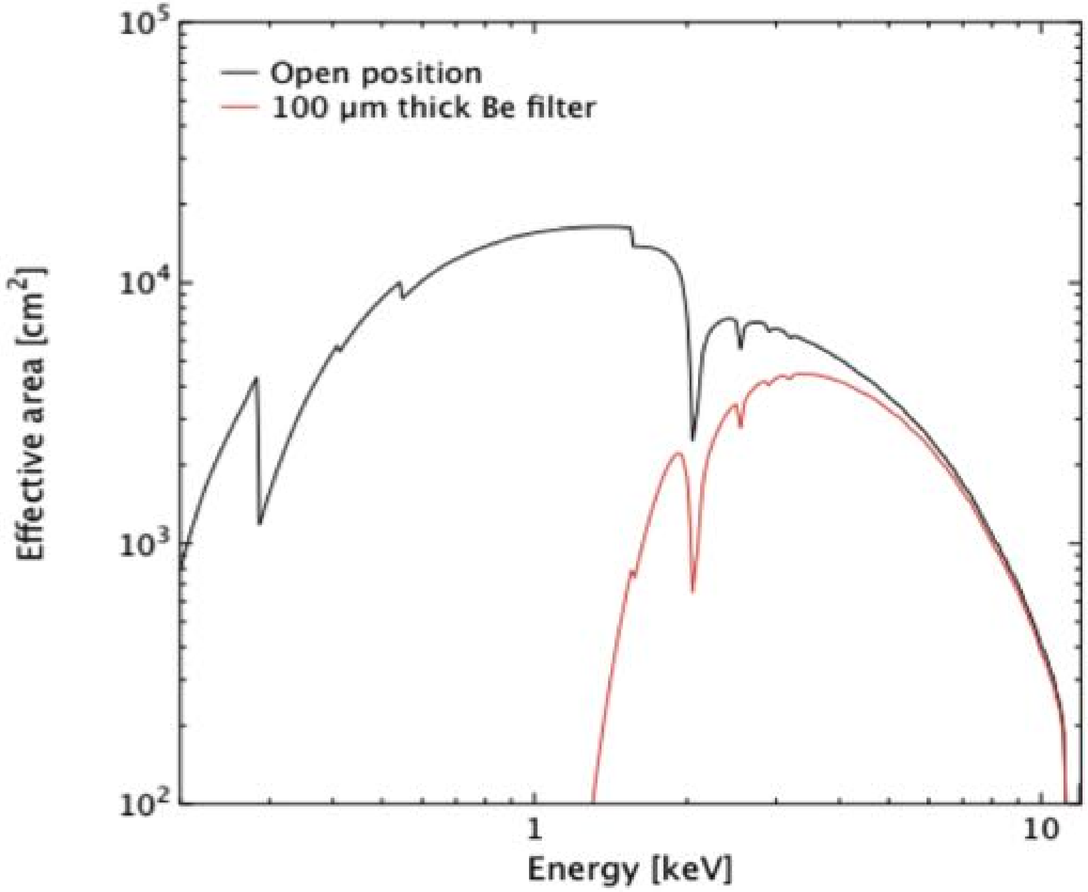


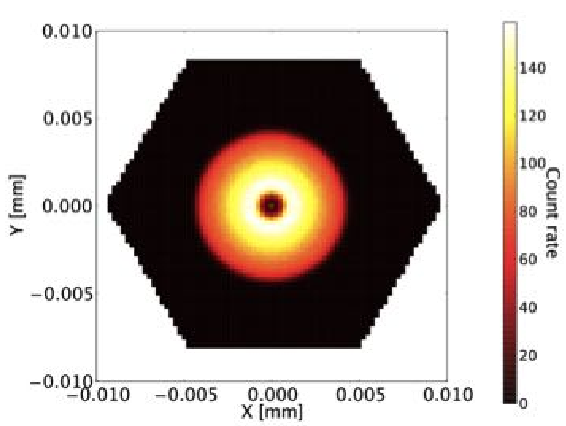
X-IFU count rate performance

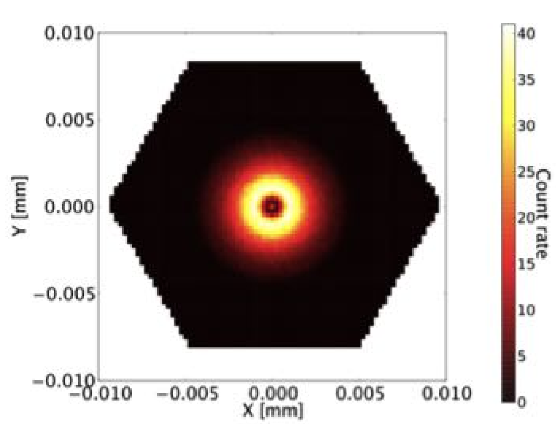


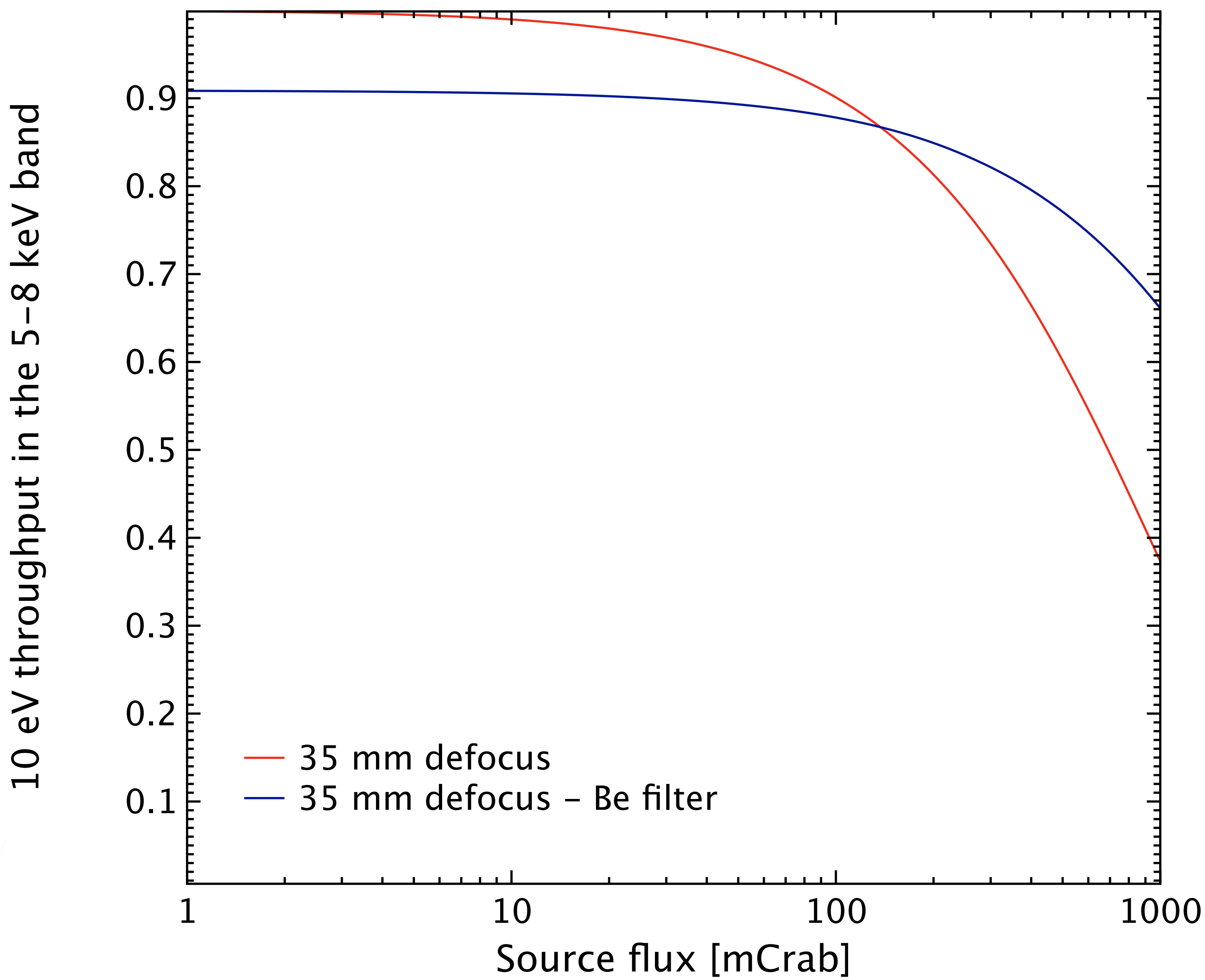
Courtesy of the e2e simulator team led by J. Wilms (Ph. Peille & T. Dauser)

Further optimization - Adding a Be filter



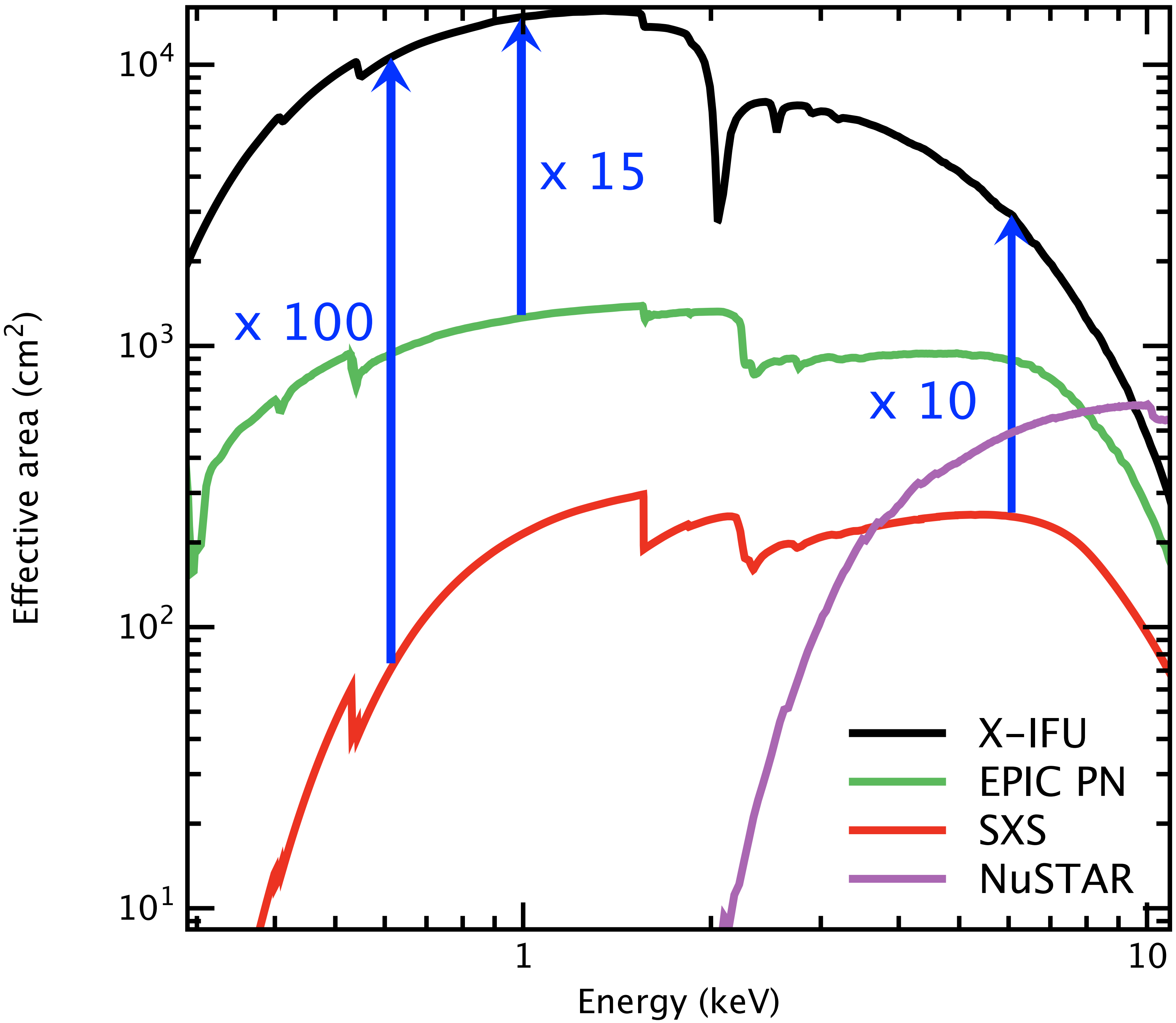






Courtesy of the e2e simulator team led by J. Wilms (Ph. Peille & T. Dauser)

Effective area comparison



On-going activities

- Consolidate the baseline design of the instrument (thermal budgets, mass and power budgets…)
- Work on reducing the costs to ESA of the Athena mission
  - ✓ by reducing the number of coolers that are currently provided by ESA to X-IFU (15 K PT, 2K JT)
    - ➡ Simplifying the cryogenic chain
    - ➡ Considering JAXA as the baseline provider of the 2K coolers
  - ✓ by taking responsibility for downstream integration and testing activities of the flight model of the X-IFU
  - ✓ by considering a larger role in the Athena Science Ground Segment in coordination with the SOC
  - ✓ by providing ESA with system engineering support for X-IFU accommodation

Conclusions

- The X-IFU is approaching the end of its feasibility study phase when its overall design is now settling down with the top level performance requirements preserved
  - ✓ Many preparatory technologies are being developed with significant progresses in key areas (e.g. cryogenic chain)
- The X-IFU remains a major technological challenge, but the X-IFU consortium carries the expertise to face it, with strong heritage from previous astronomy high-energy missions
- The X-IFU team is fully engaged in bringing Athena with its cost cap, with the prime objective of maximizing the scientific capabilities of the mission (e.g. mirror size)

Thanks to you and to them !