Instrument Status at the Beginning of the Preliminary Definition Phase

1. Athena in a nutshell

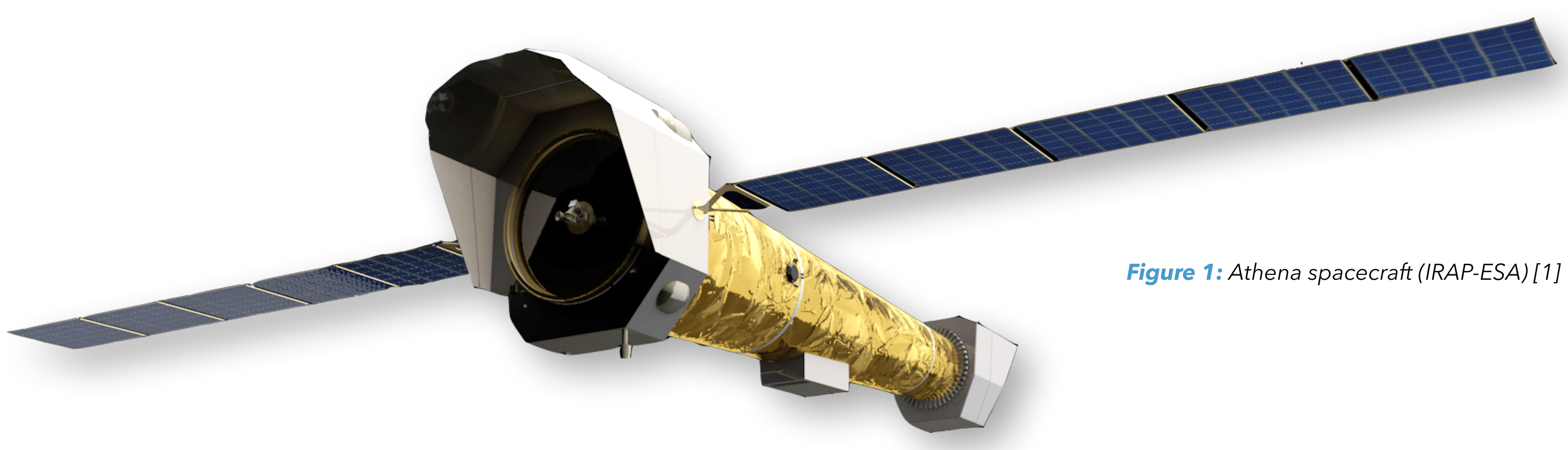
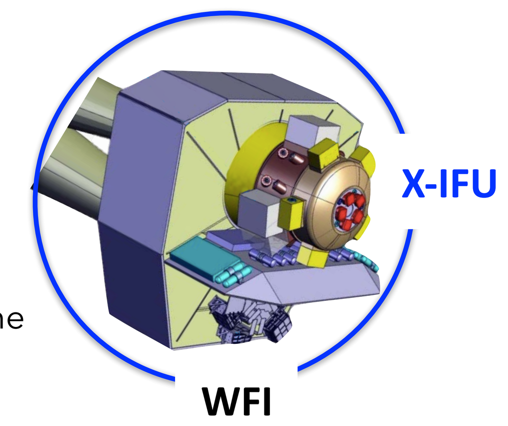


Figure 1: Athena spacecraft (IRAP-ESA) [1]

- Athena is the ESA mission dedicated to the study of the hot and energetic universe
- It will be launched in the early 2030's with the newly developed Ariane 6 (64)
- The 7 ton spacecraft will be placed in a L2 orbit
- Athena will provide an unprecedented collecting area in X-rays
  - 1.4 m² at 1 keV and 0.17 m² at 7 keV
  - 5'' angular resolution
- The movable silicon pore optics mirror assembly will allow to select one of the two focal plane instruments at a time
  - the Wide Field Imager (WFI) optimized for surveys
  - the X-ray Integral Field Unit (X-IFU) optimized for spatially resolved high resolution spectroscopy [3]

Figure 2: SIM outline ([2] and ESA study team)



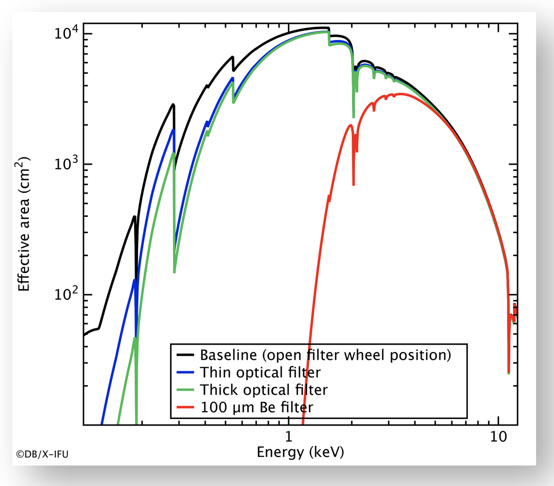


Figure 3: Athena/X-IFU Effective Area with 4 different positions of the filter wheel. Responses matrices are available at http://x-ifu.irap.omp.eu

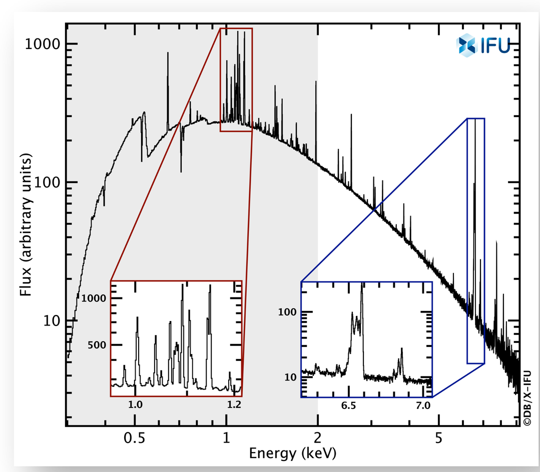


Figure 4: Perseus spectrum seen by the X-IFU simulated for a 100 ks exposure time

2. The X-ray Integral Field Unit

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 down to 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/cm²/keV	Matter assembly in clusters - Metal production and dispersal - ***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***
High-energy threshold	12 keV	Probing black hole spins and winds, ultra-fast outflows. ***Fe XXVI absorption line (0.3 c) at 8 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 - ***Observation of sources up to 1 Crab intensity levels***

Figure 5: X-IFU key performance requirements (see also [4])

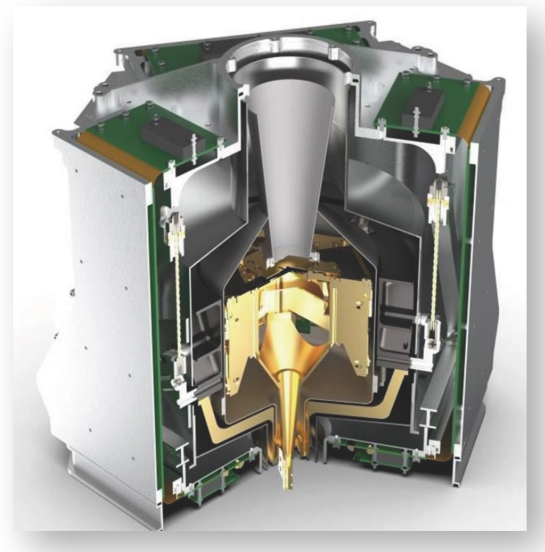


Figure 6: X-IFU Focal Plane Assembly (SRON)

- The X-IFU is built under the responsibility of IRAP and CNES by a consortium of 11 European countries plus USA and Japan
- It is a microcalorimeter instrument
  - the microcalorimeter array and cold front stage electronics are integrated in the Focal Plane Assembly, which also provides magnetic field and EMI shielding
  - optimized high transmission thermal and optical blocking filters insure high instrument QE (Fig. 3)
  - a modulated X-ray source (MXS) emitting lines allows gain monitoring during the observations
  - a filter wheel (FW) provides additional filtering for bright sources (open, Be filters, optical filters,...)
- 3168 Mo/Au Transition Edge Sensors of 275 µm pitch with absorbers of 1.7 µm of Au / 4.2 µm of Bi are operated around ~90 mK with a 50 mK bath temperature, with an anti-coincidence detector

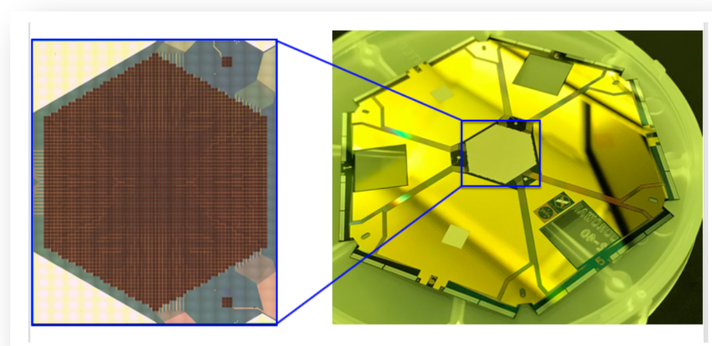


Figure 7: Prototype TES microcalorimeter array (left) and its supporting wafer (right) (NASA/Goddard)

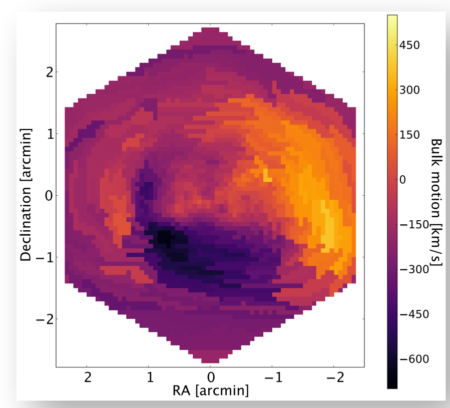


Figure 8: Reconstructed bulk motion velocity field of the hot intra-cluster gas for a 50 ks X-IFU observation of the central parts of a Perseus like cluster considered at a redshift of 0.1 [5]

3. X-IFU Detection Chain and Cryochain

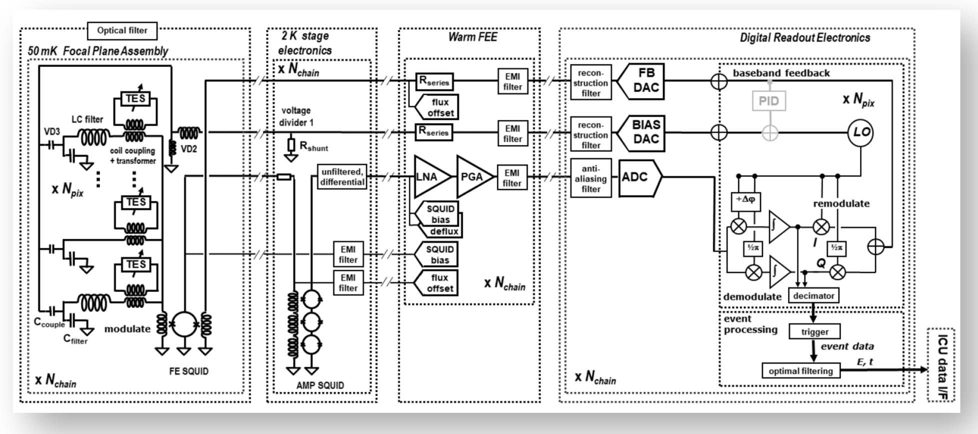


Figure 8: Detection chain schematic for one detector readout chain (or channel) [6]

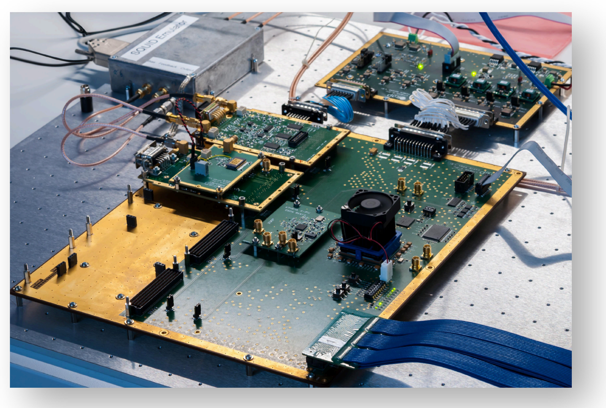


Figure 9: Prototype Digital Readout Electronics board [7]

- The array is read using FDM (Frequency Domain Multiplexing) and AC bias with carrier frequencies between 1 and 5 MHz
- The 50 mK stage is provided thanks to a multi-stage cryostat with active coolers
  - first inner shield passively cooled at 200 K by the spacecraft
  - five 15K Pulse Tubes (ESA from ALAT)
  - two 4K Joule-Thomson (JAXA)
  - two 2K Joule-Thomson (JAXA or ESA from RAL)
  - a 50 mK hybrid sorption-ADR (CEA-SBT)
- The nominal cold time is 32 hours with a regeneration time of 8 hours (80% duty cycle)
  - on-going optimization of the sub-K cooler recycling will maximize the X-IFU availability for 50 ks ToO (Target of Opportunity observations)

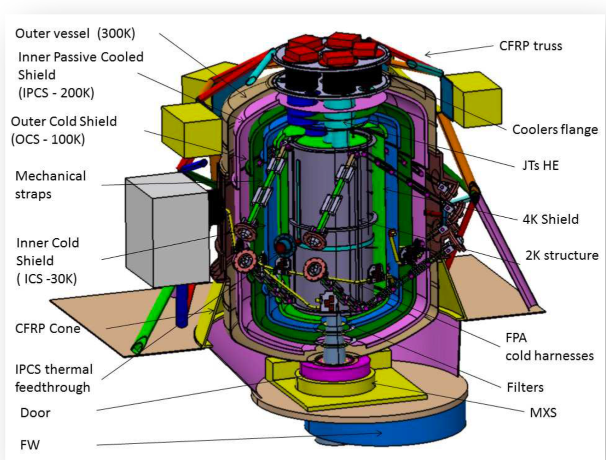


Figure 10: X-IFU dewar (CNES)

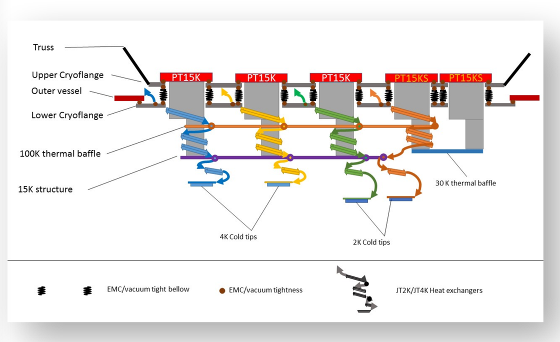


Figure 11: X-IFU cryoflange interfaces (CNES)

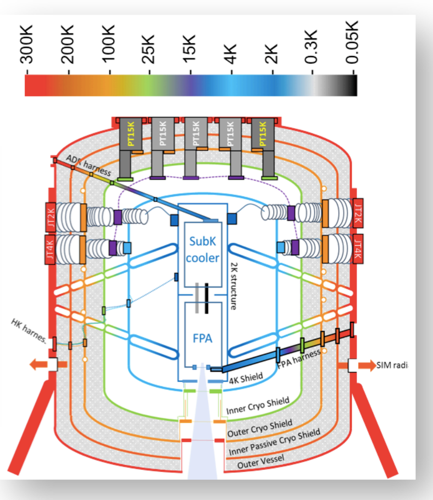


Figure 12: X-IFU cryochain (CNES)

4. On-going Optimization after IPRR

- The IPRR baseline cryochain totals 22 compressors
  - microvibrations control is challenging
  - on-going optimization reducing the number of cryocoolers without affecting the performance
- The tradeoff *number of readout channels* vs *multiplexing factor* is on-going
  - fewer channels means less connections from 300 K down to 2 K and lighter warm readout electronics
  - larger frequency spacing between channels (presently 100 kHz), corresponding to a smaller multiplexing factor (from 40 down to 34), lessens the constraints on crosstalk between pixels (carrier leakage and intermodulation effects)
- The on-going TES pixels optimization effort is continued to improve the performance under AC bias and Frequency Domain Multiplexing
- Instrument demonstration progresses well toward TRL 5 for mission adoption (11/2021)
  - *see below the multiple X-IFU team contributions to this workshop*

22-26 JULY 2019 MILANO
LTD 18 LOW TEMPERATURE DETECTORS

TES and TES Arrays

O-96 - TES pixel optimization for the ATHENA X-IFU instrument
Nicholas, A. Wakeham (NASA-GSFC / UMBC)
O-136 - Characterization of high aspect ratio TiAu TES X-ray microcalorimeters array using the X-IFU Frequency Domain Multiplexing readout
Emanuele Taralli (SRON)
P-355 - Broad-band, high-resolution, transition-edge-sensor arrays for x-ray astrophysics
Stephen Smith (NASA GSFC / UMBC)
P-140 - Quantum efficiency study and reflectivity enhancement of AuBi absorbers
Ruslan Hummatov (NASA-GSFC / UMBC)
P-176 - Characterization of a Ti/Au TES with Au/Bi absorber under AC and DC bias
Carlos Pobes Aranda (ICMA)
P-351 - Study of TES detector transition curve to optimize the pixel design for Frequency Division Multiplexing read-out
Marcel Ridder (SRON)
P-132 - Development of a TiAu TES microcalorimeter array as a backup sensor for the Athena/X-IFU instrument
Kenichiro Nagayoshi (SRON)
P-99 - Progress in the optimal TES pixel design for the X-IFU Frequency Division Multiplexing read-out
Luciano Gottardi (SRON)
P-97 - Towards a realistic resistive transition model for AC-biased TESs
Luciano Gottardi (SRON)

Readout

P-204 - Properties of the SQUID readout chain under development for the ATHENA X-IFU instrument
Jan van der Kuur (SRON)
O-358 - Updates of frequency domain multiplexing for the X-ray Integral Field Unit (X-IFU) on board the Athena mission
Hiroki Akamatsu (SRON)
0-198 - Advances in time-division SQUID multiplexing for TES X-ray-microcalorimeter arrays
Malcolm Durkin (NIST)
P-299 - A 960-pixel X-ray-TES readout platform for Athena X-IFU development
Bertrand (Randy) Doriese (NIST)

Validation - Perfo

P-81 - Thermal crosstalk measurements and simulations for X-ray microcalorimeter array
Antoine, R Miniussi (NASA/GSFC - UMBC)
P-128 - Thermal impact of cosmic ray interaction with X-ray microcalorimeter array
Antoine, R Miniussi (NASA/GSFC - UMBC)
P-258 - Thermal simulations of temperature excursions on the Athena X-IFU detector wafer from impacts by cosmic rays
Samantha Stever (Kavli IPMU, University of Tokyo)
P-249 - Quantifying the effect of cosmic ray showers on the X-IFU energy resolution
Philippe Peille (Centre National d'Etudes Spatiales)

Cryo AntiCo

O-130 - The Cryogenic AntiCoincidence detector for ATHENA X-IFU: the project status.
Claudio Macculi (INAF)
P-172 - The Demonstration Model of the ATHENA X-IFU Cryogenic AntiCoincidence Detector
Matteo D'Andrea (INAF/IAPS)
P-401 - The phonon mediated TES cosmic ray detector for focal plane of ATHENA x-ray Telescope
Michele Biasotti (GE)

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References:
[1] Athena X-IFU YouTube channel video capture
[2] Ayre et al., 2018, Proceedings SPIE, Vol 10699, 106991E
[3] Barret et al., 2018, Proceedings SPIE, Vol 10699, 106991G
[4] Pajot et al., 2018, 2018, JLTP 193, 901
[5] Barret et al., 2016, Proceedings SPIE, Vol 9905, 99052F
[6] den Hartog et al., 2018, Proceedings SPIE, Vol 10699, 106994Q
[7] Ravera et al., 2018, Proceedings SPIE, Vol 10699,106994V

François Pajot [1], Didier Barret [1], Vincent Albouys [2], Jan-Willem den Herder [3], Luigi Piro [4], Massimo Cappi [5], Juhani Huovelin [6], Richard Kelley [7], Jose Miguel Mas-Hesse [8], Kazuhisa Mitsuda [9], Stéphane Paltani [10], Gregor Rau [11], Agata Rozanska [12], Jiri Svoboda [13], Joern Wilms [14]

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