A 50mK test bench for the demonstration of the readout chain of Athena/X-IFU

Florent Castellani[1,2], Sophie Beaumont[1,3,5], François Pajot[1], Gilles Roudil[1], Joseph Adams[3,5], Simon Bandler[3], James Chervenak[3], Christophe Daniel[2], Edward Denison[6], William Doriese[6], Michel Dupieux[1], Malcolm Durkin[6], Hervé Geoffray[2], Gene Hilton[6], David Murat[1], Yann Parot[1], Philippe Peille[2], Damien Prêle[4], Laurent Ravera[1], Carl Reintsema[6], Kazuhiro Sakai[3,5], Robert Stevens[6], Joel Ullom[6], Leila Vale[6], Nicholas Wakeham[3,5]

[1]IRAP, Univ. de Toulouse, CNRS, UPS, CNES, Toulouse, France - [2]CNES, Toulouse, France - [3]NASA/Goddard Space Flight Center, Greenbelt, USA - [4]APC, Paris, France - [5]CSST, Univ. of Maryland, Baltimore County, USA - [6]NIST, Gaithersburg,USA

1. Athena's X-ray Integral Field Unit

Figure 1: Athena spacecraft (ESA/IRAP/CNRS/UT3/CNES/Fab&Fab)

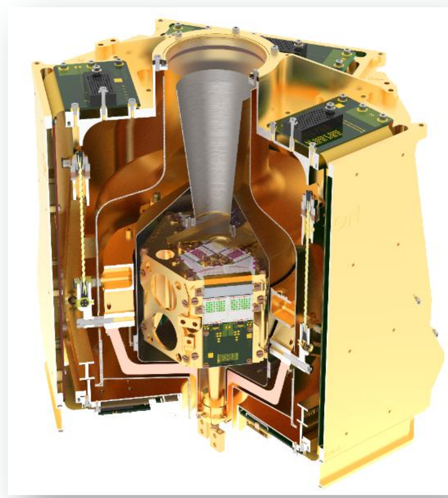

Figure 2: X-IFU focal plane assembly (Credits: SRON)

- ATHENA (Advanced Telescope for High-Energy Astrophysics) is the ESA second large mission of the Cosmic Vision science program, dedicated to the study of the Hot and Energetic Universe
- Scheduled for launch in the mid 2030's into a Lagrange point L1 orbit
- The moveable silicon pore optics X-ray mirror will able to focus photons on two different focal plane instruments:
  - the **Wide Field Imager (WFI)** optimised for surveys
  - the **X-ray Integral Field Unit (X-IFU)** optimised for spatially resolved high resolution spectroscopy [1]
- The X-IFU is a microcalorimeter spectrometer based on an array of ~2400 pixels of Transition Edge Sensors (TES), operated around 90mK. It is built under the responsibility of IRAP and CNES by a consortium of 11 European countries plus USA and Japan.

Spectral resolution	2.5 eV (E < 7 keV)
Field of view	5′ (equivalent diameter)
Pixel size	~ 5″ (~mirror PSF HEW)
Background level	<5 10^{-3} count/s/cm^2/keV
Energy band	0.2 - 12 keV
Effective area	1.4 m^2 at 1 keV 0.17 m^2 at 7 keV
Count rate capability	1mCrab (2.5 eV) up to 1 Crab (10eV)

Figure 3: X-IFU key parameters (from [2])

2. ELSA: A Cryogenic Test Bench

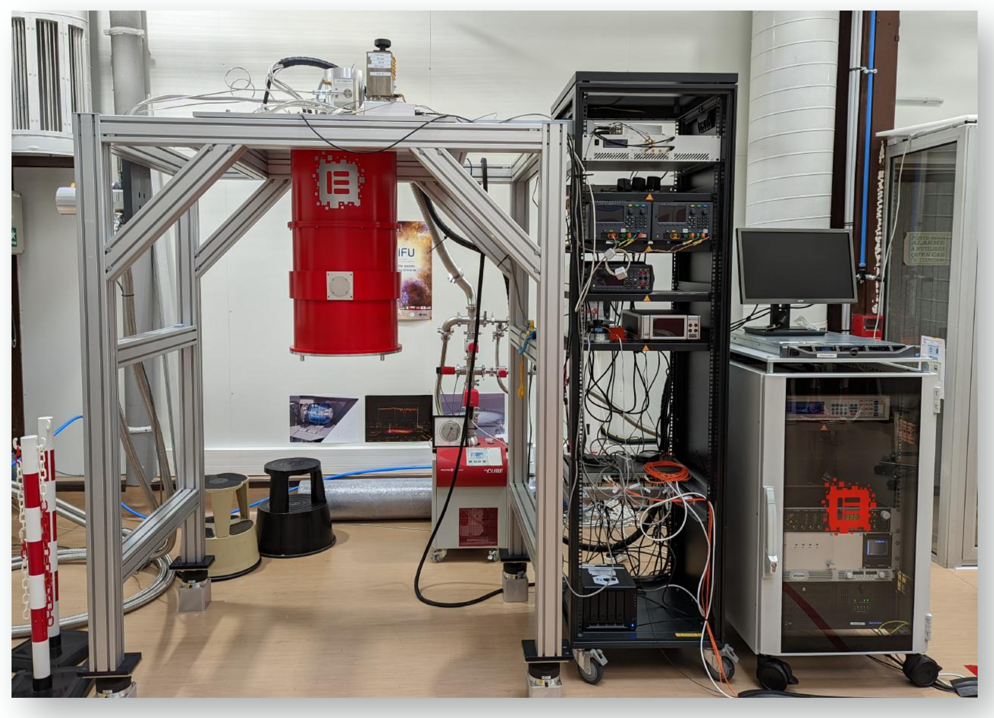

Figure 4: The CNES / IRAP 50mK cryogenic test bench (Elsa)

- To demonstrate the operation of the warm electronics blocs of the X-IFU readout chain with representative cold electronics and microcalorimeters, a cryogenic test bench has been developed at IRAP in collaboration with CNES. It is composed of:
  - A cryostat from Entropy Gmbh based on a double stage pulse tube cooler (70K and 4K) and a double stage Adiabatic Demagnetisation Refrigerator (ADR) (500mK and 50mK)
  - A focal plane assembly from NIST and GSFC made of a 1024-pixel TES array and its associated cold electronics (NIST)
- Characterisation of the thermal performances of the cryostat has been performed with the Goddard and NIST cold detection chain installed:
  - The temperature stability is ~ 5μK rms
  - The hold time for one ADR recharge ~ 15h at 55mK. It allows long enough acquisitions to make high-resolution spectra
  - In agreement with values measured during cryostat characterisation [3]

Figure 5: Nb shield attached to the 50mK plate and the 3K cold electronics

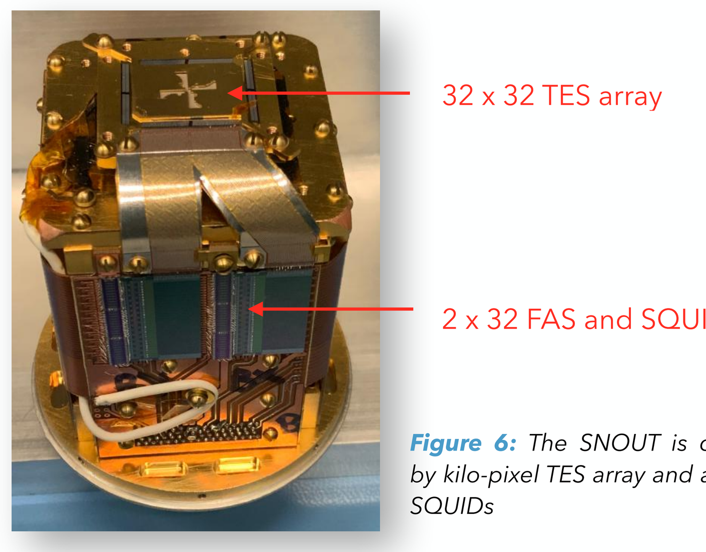

Figure 6: The SNOUT is composed by kilo-pixel TES array and associated SQUIDs

3. Characteristics and Performances of the current Readout Chain on ELSA

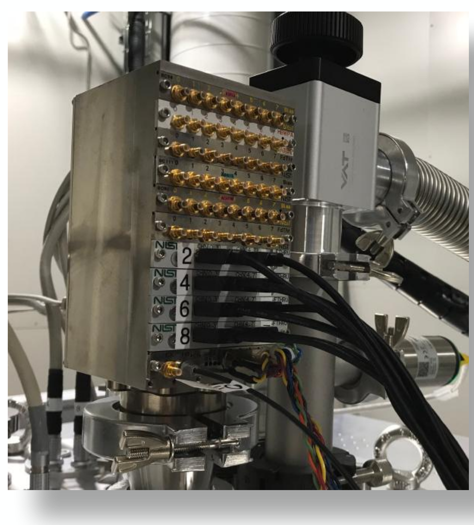

Figure 7: The Tower, connected with HDMI cables to the TDM row box

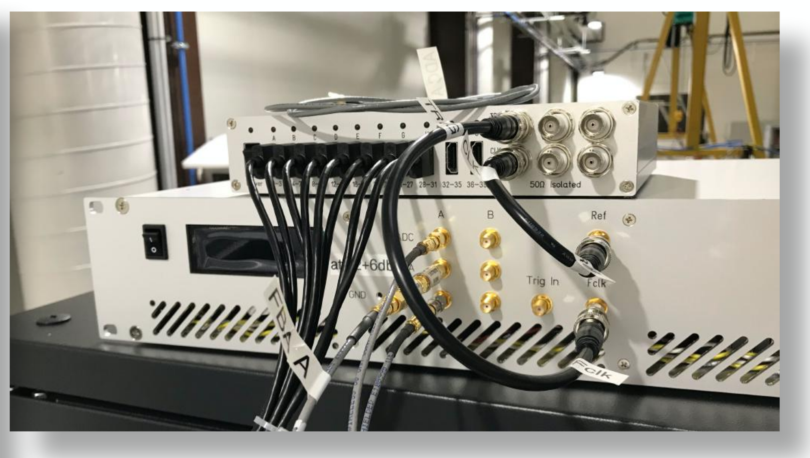

Figure 8: The TDM readout electronics (K. Sakai, NASA/GSFC) composed by the row box on top of the column box

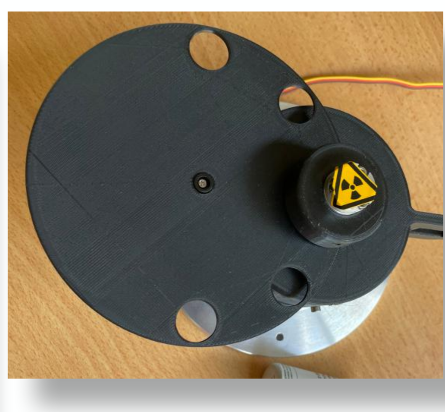

Figure 9: Radioactive Fe-55 source installed in its remote controlled filter wheel allowing to control the source flux

- A warm readout chain composed by Goddard and NIST electronics allows the characterisation of the 50mK test bench.
  - The "Tower" (NIST) includes low-noise amplifiers for TES signals, TES and SQUIDs biases, and feedthrough for feedback signals and row addressing signals (Fig. 7)
  - The TDM electronics (NASA/GSFC), is composed by the Row box that controls the row addressing and the Column box that performs the FLL (flux locked-loop) and demultiplexes the output signals (Fig. 8) up to 2 separated columns
- In order to perform a functional validation of the X-IFU warm readout chain, a 3eV or better FWHM energy resolution for a multiplexed acquisition is sufficient.
- Optimisation of the SNR is performed through a careful EMI/EMC analysis and control implementation:
  - As done on NIST and GSFC systems, a strict grounding scheme was implemented on the 50mK test bench: all measurement electronics and cryostat system electronics have been grounded through a single copper braid. A metal cable path tray was installed between cryostat structure and measurement electronic rack.
  - An isolation transformer allows to isolate the measurement electronics from any power supply disturbance.
  - High-Frequency filtering is implemented at cryostat feedthroughs: The magnet power-supply is filtered with Shaffner Single-stage Filter FN2410/FN2412 and LEMO plugs for thermometry are filtered with 560pF capacitor EEseal filter performing a low-pass filter at 100 kHz
- A radioactive Fe55 X-ray source allows the end-to-end characterisation (Mn Kα complex at 5.9 keV)
  - A remote controlled filter wheel (Fig. 10) selects a specific absorber (Mylar and Al films) to have the adequate count rate (~1 photon/pixel/sec)
  - The alignment of the TES array with the optical axis, and the Fe-55 source, has been checked (less than 1 mm deviation)
- A preliminary validation of the current NASA/GSFC and NIST detection chain performance in the Elsa test bench was performed:
  - 2.8 eV FWHM energy resolution measured on single channel
  - 3.1 eV energy resolution measured with 8 multiplexed pixels (Fig. 10)
  - These have to be compared to the performance of this detection chain in GSFC cryostat: 2.1 eV / 2.6 eV respectively [4]

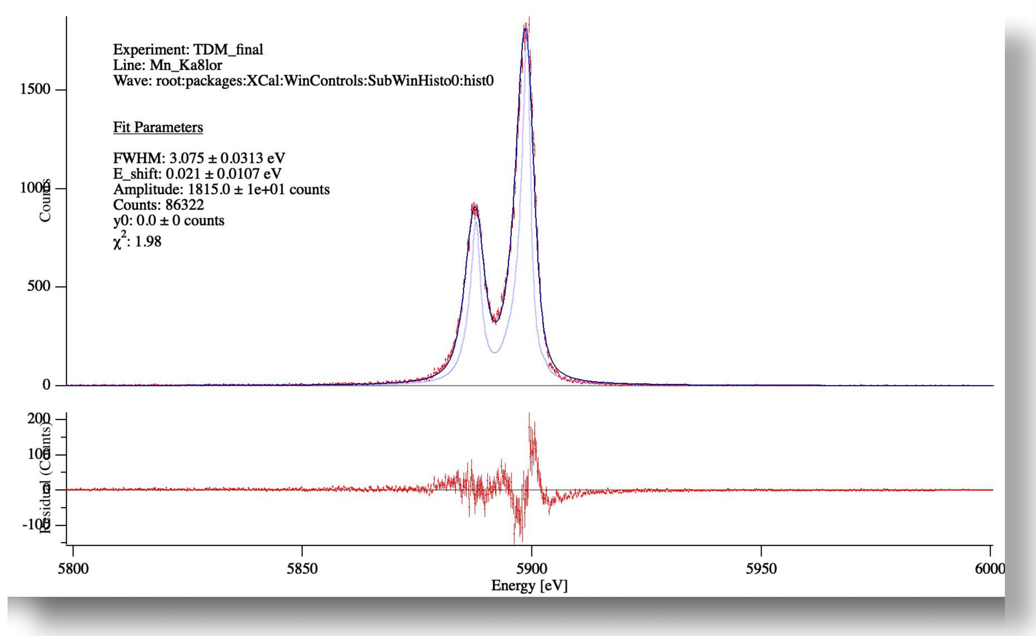

Figure 10: Mn-Kα complex spectrum on 8 multiplexed pixels after 6 hours of acquisition, processed with Goddard software

4. X-IFU warm readout chain validation

Figure 11: The Digital Readout Electronics Row Addressing and Synchronisation (DRE RAS) module

Figure 12: Demonstration model of the Warm Front-End Electronics (D. Prele, APC, Paris)

- The X-IFU detection and readout chain is composed of:
  - The TES array (NASA GSFC) [5]
  - The cold front-end electronics: Flux Actuated Switches, SQUID 1 (NIST) [6]
  - The cold amplifier: SQUID array (VTT / NIST) [7]
  - The WFEE (Warm Front-End Electronics) (APC) [8]
  - The DRE (Digital Readout Electronics) (IRAP) [9]
- The prototypes of the WFEE and DRE will replace the corresponding Goddard and NIST electronics of the 50mK test bench in order to perform the end-to-end demonstration of the X-IFU readout chain:
  - The TDM row box will be replaced by the DRE Row Addressing and Synchronisation module (Fig. 11) developed at IRAP, Toulouse (on-going)
  - The TDM column box by the DRE DEMUX (demultiplexing) module (during the current year)
  - The "Tower" will be replaced by the WFEE (Warm Front-End Electronics) (Fig. 12) developed at APC, Paris (next year)
  - WFEE and DRE are differential readout electronics: the current single-ended detection chain will be adapted by a replacement of the 3K amplifying electronics (Fig. 5) and harnesses.
- A software framework is developed by CNES, XIFUFWK, based on open-source Python, designed to analyse data from the future X-IFU instrument. XIFUFWK is currently under validation on the 50mK test bench.

References:

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