Study of Instrumental and Scientific performances of the Athena's X-ray Integral Field Unit

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1. Context

- Athena is an ESA large mission dedicated to the study of the Hot and Energetic Universe [1]:
  - *how does ordinary matter assemble to create the large scale structures ?*
  - *how do black holes grow and shape their surrounding Universe ?*
- Two X-ray focal plane instruments:
  - the **Wide Field Imager (WFI)** optimised for surveys
  - the **X-ray Integral Field Unit (X-IFU)** [2] optimised for spatially resolved high resolution spectroscopy
- The X-IFU is a **cryogenic imaging spectrometer**:
  - made with superconducting microcalorimeters: **Transition Edge Sensors (TES)**, operated at **50 mK**
  - composed of an array of **2376 pixels** with **5" pixel-size** in a **field-of-view of 5'** (equivalent diameter)
  - with a unprecedented spectral resolution of **2.5eV up to 7keV** in the soft X-ray energy band (**0.2-12keV**)

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

2. Objectives

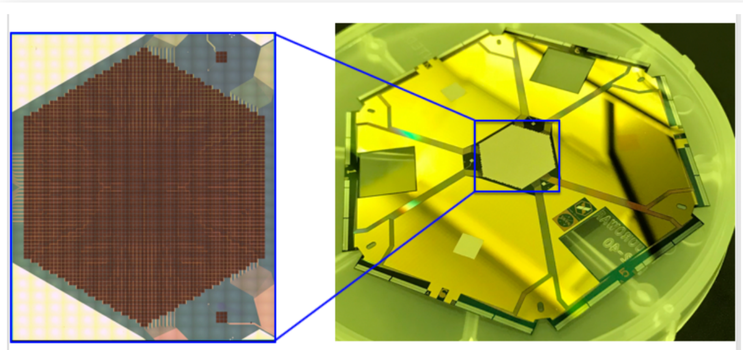

Figure 2: *(Left) Prototype TES microcalorimeter array and (Right) its supporting wafer (NASA/GSFC)*

- The X-IFU is at the end of its **preliminary definition Phase (Phase B)**. In this context, we need to test and assess the capabilities of the X-IFU by the study of:

Instrumental Performances of the X-IFU
Verifying the instrumental performance by undertaking an end-to-end demonstration of the detection chain of the X-IFU thanks to a cryogenic test bench

Scientific Performances of the X-IFU
Assessing the feasibility of the core science objectives of the mission via numerical end-to-end simulations of X-IFU observations

3. Cryogenic Test bench

Figure 3: *(Left) Nb shield enclosing the TES detectors connected to the cold electronics card (Right) the CNES / IRAP 50mK test bench*

- The **50mK test bench at IRAP**, in collaboration with CNES, composed of a commercial cryostat from Entropy GmbH and a **representative cold electronics** and TES array from NASA/GSFC and NIST, has been developed to demonstrate the **X-IFU baseline readout electronics**.
- **Characterisation of the test bench** has already been performed with a NASA/GSFC and NIST **validation readout electronic chain** [3].

4. Numerical Simulations

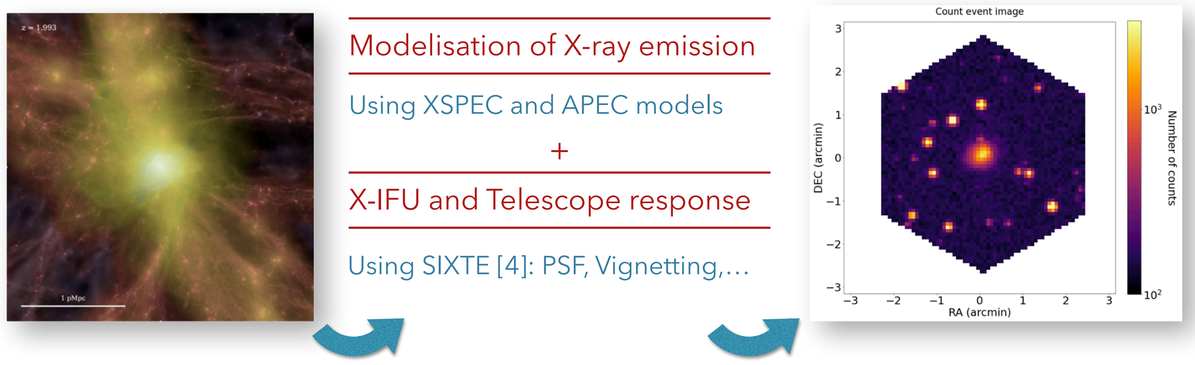

Figure 4: *Illustration of the end-to-end numerical simulation pipeline, starting from a cosmological simulation (HYDRANGEA [5]), modelling the X-ray emission of the Intra Cluster Medium and extracting a realistic mock observation of the distant group of galaxies by the X-IFU instrument*

- **Realistic mock observations** of a distant ($z = 2$) groups of galaxies (Mass = $7\ 10^{13}\ M_{\odot}$) have been produced for a 1Ms exposure time. We used SIXTE [4] to simulate the X-IFU detectors, taking into account astrophysical and instrumental background.
- **Spectral analysis** allows to extract **temperature or chemical abundance** 2D projected profiles.
- We perform **Bayesian analysis using a forward-modelling** approach to retrieve the **thermodynamical structure** of the intra-cluster gas.

5. Results and Perspectives

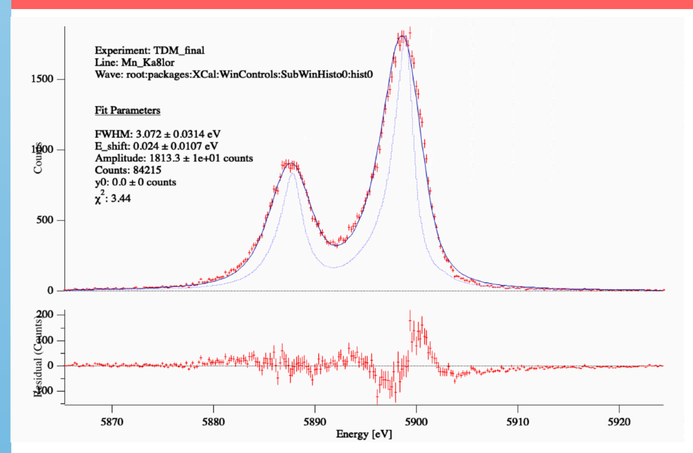

Figure 5: *Spectrum of the Mn_Ka complex measured on 50mK test bench*

- We have **successfully validated** the design of the 50mK test bench by measuring a 3.1eV energy resolution at 5.9keV for a **Time-Division Multiplexing (TDM)** scheme [6]

➡ *We plan to operate and validate the first bloc of X-IFU baseline readout electronics, the **Digital Readout Electronics (DRE)** developed at IRAP, in the 50mK test bench this year*

- Our preliminary results illustrate the capability of the X-IFU to **characterise the first groups of galaxies** in the Universe

➡ *Synergy studies with **WFI** instrument to improve surface brightness resolution are ongoing*

➡ *We will quantify the relative error between the **retrieved thermodynamical profiles** and input profiles*

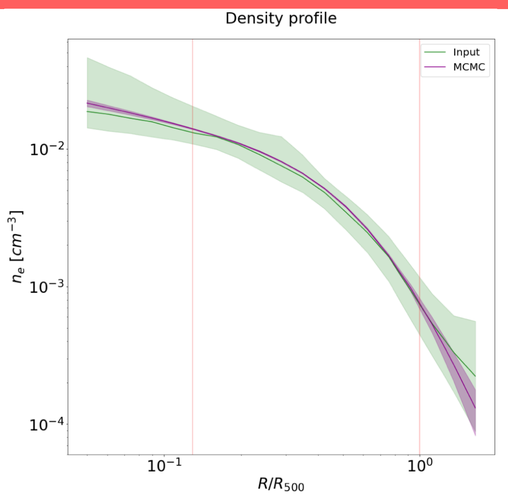

Figure 6: *Best model for the gas density distribution (purple) compared to the input profile (green line and envelope representing 1σ dispersion)*

[1] Nandra et al., "The Hot and Energetic Universe: A White Paper presenting the science theme motivating the Athena+ mission", 2013
[2] Barret et al., "The Athena X-ray Integral Field Unit: a consolidated design for the system requirement review of the preliminary definition phase", 2022
[3] Betancourt-Martinez et al., "A test platform for the detection and readout chain for the Athena X-IFU", 2020
[4] Dauser et al., "SIXTE: a generic X-ray instrument simulation toolkit", 2019. doi:10.1051/0004-6361/201935978.
[5] Bahé et al, "The Hydrangea simulations: galaxy formation in and around massive clusters", 2017. doi:10.1093/mnras/stx1403.
[6] Castellani et al., "A 50 mK test bench for demonstration of the readout chain of Athena/X-IFU", 2022