The X-ray Integral Field Unit (X-IFU) is a cryogenic imaging spectrometer on board of Athena (2028).

- Consortium of 11 countries, led by IRAP (PI) and CNES (project management & integration). Phase A.

The X-IFU will probe the hot and energetic Universe [1]:
- How does ordinary baryonic matter assemble?
- How do Black Hole grow and shape the Universe?

The X-IFU will have an array of 3840 superconductive Transition Edge Sensors. A current pulse is generated for each photon impact (calorimetric detection). The pulse is then multiplexed [3] and filtered [4].

Effective area: $2m^2 @ 1keV$
Spatial resolution: 5"
Field of View: $19.3arcmin^2$
Energy bandwidth: [0.2-12]keV
Spectral resolution: 2.5eV up to 7keV
A KE in energy scale: 0.4eV

Table 1: Current specifications of the X-IFU

<table>
<thead>
<tr>
<th>Technique</th>
<th>Resolution (eV)</th>
<th>Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear correction</td>
<td>25 eV</td>
<td>2 keV</td>
</tr>
<tr>
<td>Non-linear correction</td>
<td>4 eV</td>
<td>7 keV</td>
</tr>
<tr>
<td>Multi-linear correction</td>
<td>10 eV</td>
<td>10 keV</td>
</tr>
</tbody>
</table>

Figure 1: The X-IFU on board Athena [2028].

Split view: (Top) Dewar and electronic boxes (Middle) Focal Plane Array (Bottom) Detector array (2)

Figure 2: Principle of detection of the superconductive Transition Edge Sensors (TES). A current pulse is generated for each photon impact (calorimetric detection). The pulse is then multiplexed [3] and filtered [4].

Figure 3: Output maps from the E2E simulation. From top left to bottom right: Surface brightness, temperature (keV), bulk-motion (km/s), Fe, O and Ni abundances (to solar [8]). Inset: abundance ratios within R500.

- Next steps:
  - Improve fit (optimal fit, selective fit)
  - Improve physical prescriptions with finer inputs
  - Include background and instrumental perturbations

Reference:
[1] Nandra et al., 2013, Athena White Paper

Abstract: The X-ray Integral Field Unit (XIFU) onboard Athena (2028) is a cryogenic X-ray spectrometer operated at 50mK. With its array of 3840 superconductive Transition Edge Sensors, it will enable breakthrough science by providing spatially resolved high-resolution spectroscopy (2.5 eV FWHM up to 7 keV) between 0.2 and 12 keV. The XIFU is in the early stages of development; End-To-End numerical simulations are therefore required to assess its scientific performances and verify its current specifications. The achievement of the XIFU’s science goals also relies on a fine characterization of perturbing instrumental effects (e.g. cross-talk, background) and an accurate ground-in-flight calibration strategy. We present in this contribution several results achieved with the End-To-End simulator in the observation of extended sources and the calibration of the detectors’ energy scale function.

Figure 7: Residuals of the correction (eV) as function of energy (keV) for two of the techniques in a case of a 1000gpm drift in TES bias voltage

The multi-parameter gain drift correction technique offers promising results to accurately recover the energy scale. Further improvements are under study (include statistics and ultimately real-life tests).

Cross-talk mechanisms impact the energy resolution of the detectors. This impact remains moderate for extended sources, but is driving for the observation of bright point sources.

Figure 4: Illustration of cross-talk mechanisms. In red the signal and in blue (thermal) and purple (electrical) the induced cross-talk in “victim” pixels

Figure 5: Fraction of events influenced by a cross-talk level higher than 0.2eV as function of count rate of the source (electrical).

Results:
- Less than 20% of the events impacted by cross-talk
- Electrical cross-talk dominates for extended sources

Figure 6: Principle of the non-linear drift correction. Three energy scale functions for different temperatures. Finding the effective temperature of the perturbation

Table 2: Cross-talk parameters

<table>
<thead>
<tr>
<th>Cross-talk type</th>
<th>Fraction of events</th>
<th>Impacted energy range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical</td>
<td>0.2%</td>
<td>0.2 - 1.0 eV</td>
</tr>
<tr>
<td>Thermal</td>
<td>1%</td>
<td>1.0 - 3.0 eV</td>
</tr>
<tr>
<td>Optical</td>
<td>2%</td>
<td>3.0 - 5.0 eV</td>
</tr>
</tbody>
</table>

Cross-talk: parasitic signal contamination between pixels

- Degrades energy resolution. Cross-talk types:
  - Electrical (carrier overlap, common impedance)
  - Thermal (neighbours)
  - Non-linear (read-out chain non-linearities)

- Depends on:
  - Time/frequency difference between pulses
  - Energy of “victim”/”parapetator” photon

- Determining abundance ratios and discriminate between various star formation models [7]

- Investigating the level 1 requirement on the chemical enrichment of galaxy clusters.

Full End-To-End tools are now available. Moving to larger and more accurate galaxy cluster samples to investigate X-IFU capabilities to study chemical enrichment.

Evaluating the Effect of Cross-Talk on the Detectors

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