The Athena X-ray Integral Field Unit

François Pajot
Institut de Recherche en Astrophysique et Planétologie

on behalf of Didier Barret, Thien Lam Trong, Jan-Willem den Herder, Luigi Piro, Massimo Cappi and the X-IFU team
Athena in a nutshell

- Advanced Telescope for High Energy Astrophysics, for the study of the hot and energetic universe
- Second Large (L) mission of the ESA Cosmic Vision 2015-2035
- Launch year: end of 2028
  - with the newly developed Ariane 6 (64)
- A 7 ton spacecraft to be placed in a L2 (L1) orbit
- Unprecedented collecting area in X-rays:
  - 2 m\(^2\) goal at 1 keV and 0.17 m\(^2\) at 7 keV
  - 5'' angular resolution
- Two focal plane instruments with a movable mirror assembly
  - The Wide Field Imager (WFI) optimized for surveys
  - The X-ray Integral Field Unit (X-IFU) optimized for spatially resolved spectroscopy
## The X-ray Integral Field Unit

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Requirements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy range</td>
<td>0.2 — 12 keV</td>
</tr>
<tr>
<td>Energy resolution $^1$: $E &lt; 7$ keV</td>
<td>2.5 eV</td>
</tr>
<tr>
<td>Energy resolution: $E &gt; 7$ keV</td>
<td>$E/\Delta E = 2800$</td>
</tr>
<tr>
<td>Field of View</td>
<td>5’ (equivalent diameter)</td>
</tr>
<tr>
<td>Effective area @ 0.3 keV</td>
<td>$&gt; 1500$ cm$^2$</td>
</tr>
<tr>
<td>Effective area @ 1.0 keV</td>
<td>$&gt; 15000$ cm$^2$</td>
</tr>
<tr>
<td>Effective area @ 7.0 keV</td>
<td>$&gt; 1600$ cm$^2$</td>
</tr>
<tr>
<td>Gain calibration error (peak, 7 keV)</td>
<td>0.4 eV</td>
</tr>
<tr>
<td>Count rate capability nominally bright point sources $^2$</td>
<td>1 mCrab ($&gt; 80%$ high-resolution events)</td>
</tr>
<tr>
<td>Count rate capability brightest point sources</td>
<td>1 Crab ($&gt; 30%$ throughput)</td>
</tr>
<tr>
<td>Time resolution</td>
<td>10 µs</td>
</tr>
<tr>
<td>Non X-ray background (2 — 10 keV)</td>
<td>$&lt; 5 \times 10^{-3}$ counts/s/cm²/keV ($80%$ of the time)</td>
</tr>
</tbody>
</table>

$^1$ goal 1.5 eV, $^2$ goal 10 mCrab ($> 80\%$ high-resolution events) events

- Consortium led by CNES/IRAP-F, with SRON-NL, INAF-IT and other European partners, NASA and JAXA.
Spectroscopic capabilities

Effective area comparison between X-IFU and other facilities

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Effective area (cm$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$10^1$</td>
</tr>
<tr>
<td>10</td>
<td>$10^4$</td>
</tr>
<tr>
<td>X-IFU</td>
<td>$10^2$</td>
</tr>
<tr>
<td>EPIC PN</td>
<td>$10^3$</td>
</tr>
<tr>
<td>SXS</td>
<td>$10^4$</td>
</tr>
<tr>
<td>NuSTAR</td>
<td>$10^5$</td>
</tr>
</tbody>
</table>

Figure of merit for spectroscopy measurements

<table>
<thead>
<tr>
<th>Energy (keV)</th>
<th>Figure of merit (m keV$^{-1/2}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>25</td>
</tr>
<tr>
<td>Athena X-IFU</td>
<td></td>
</tr>
<tr>
<td>Hitomi SXS</td>
<td></td>
</tr>
<tr>
<td>Gratings</td>
<td></td>
</tr>
</tbody>
</table>
**X-IFU simulations: spectroscopy on clusters**

- 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

- Simulated X-IFU spectrum of a $z = 1$ galaxy group with $kT = 3$ keV and $L_X = 1 \times 10^{44}$ erg/s for 50 ks. Emission lines from elements which are key to understand chemical evolution can be clearly seen.
X-IFU design

- Microcalorimeter array
- MXS
- Filter wheel
- Thermal filters
- Door
- Focal plane assembly
- Cryo anti coincidence
- Dewar
- Readout electronics

17th International Workshop on Low Temperature Detectors
Kurume, Fukuoka, Japan, July 16th-21st 2017
X-IFU key design driving items (1)

- Detectors
  - Allocation 2.1 eV -> X-IFU energy resolution budget
  - Detector speed /event record -> X-IFU count rate capability
  - 3840 microcalorimeter array with Mo/Au TES from NASA-Goddard (SRON backup) under AC bias
  - Intrinsic energy resolution
  - Operation of TES under AC bias
  - Extreme sensitivity to EMI/EMC, magnetic field, microphonics

X-IFU key design driving items (2)

- Readout chain
  - Allocation 1.2 eV -> X-IFU energy resolution budget
  - Frequency domain multiplexing 1-5 MHz range with 40 pixels for each 96 chains
  - Cryogenic two stage SQUID amplification and low noise amplifier at ambient temperature
  - Base Band Feedback implementation to linearize SQUID operation
  - Event processor based on optimal filtering and pulse templates
  - Digital to Analog Converter
  - Crosstalk
  - Gain/thermal stability and monitoring with Modulated X-ray Source -> X-IFU energy scale

(Prêle+ O-59, Akamatsu+ O-60, Bruijn+ O-75, den Hartog +PB-3, van der Kuur+ PB-13, DeNigris+ PC-14, Cucchetti+ PE-49)
X-IFU key design driving items (3)

- Cryogenic chain and aperture cylinder
  - Allocation 0.6 eV -> X-IFU energy resolution budget
  - Rejection of IR-visible-UV photons and EMI
  - 50 mK base temperature with 0.9μK rms thermal stability
  - Thermal filters including mesh insuring EMI immunity
  - Impact of Cosmic Ray on thermal stability of the detector
  - Preserving the X-ray Quantum Efficiency
    (Yamasaki+ PD-17, Sciortino+ O-82, Barbera+ PE-62)

- Cryogenic anti-coincidence detector
  - Rejecting non X-ray events (cosmic rays, ...) to 5 \(10^{-3}\) counts/s/cm\(^2\)/keV -> low brightness capability
  - Active 4 TES pixels Cryo AC below the X-ray detector array
  - Secondary electrons/back scattering on array
    (Biasotti+ PE-47, D'Andrea+ PE-52, D'Andrea+ PE-53)
High count rate and defocussing

- Mirror defocus capability up to 35 mm is now in the baseline
- Spreading of the PSF over an increasingly larger number of pixels
  - Allows enhanced throughput on point sources
    (at the cost of a loss of imaging capabilities of these point sources)

![Image of PSF spreading with increasing defocus from on focus to 35 mm].

Courtesy of D. Willingale
Count rate capability

- Exceeds goal requirement at 10 mCrab (high resolution) and 1 Crab (10 eV resolution)
- Even higher count rate in the 5-8 keV band with use of a beryllium filter

(See Peille+ PE-45)
Cryochain and dewar

Present baseline, a simplified cryochain is being studied.
X-IFU design status

- Current status: a ~800 kg instrument
  - Optimization in progress (mass, power consumption, margins)
  - Progressing well towards TRL 5 in key technologies
- Phase A until end of 2018 (might evolve)
- Phase B1 up to mission adoption in June 2020
Conclusion

- Thanks to challenging and innovative technologies in microcalorimeters operated at low temperature, X-IFU will provide breakthrough capabilities in high resolution X-ray spectroscopy for the study of the hot and energetic Universe.