X-ray Imaging Micro-Calorimeter Spectrometer

Piet de Korte

On behalf of an emerging calorimeter collaboration
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Mirror Driven Specifications

• Angular Resolution

5 arc sec resolution = 485 - 606 μm for 20 – 25 m focal length

Proposed Pixel size between 250 – 300 μm

• Field of View

7 arc min radius = 71 mm

• Countrate

1mCrab ~ 125 c/sec (May 2008, NASA IXO mirror concept with f = 20 m)
TES-based Micro-Calorimeter

SRON PIXEL DESIGN

Side view             Top view
part of 5 x 5 array
TES-based Micro-Calorimeter

SRON ARRAYS

5 x 5 array with Cu stems

5 x 5 array with Cu/Bi absorbers

Close-up of 32 x 32 array
TES-based Micro-Calorimeter

PERFORMANCE for SRON PIXELS from 5 x 5 arrays

$\Delta E_{TDL} \approx 3.1 \text{ eV } T_C = 105 \text{ mK}$

Cu-absorber

$\Delta E = 1.6 \text{ eV @ 250eV}$

100 $\mu$s fall time

$\Delta E_{TDL} \approx 3.6 \text{ eV } T_C = 116 \text{ mK}$

Cu/Bi-absorber 0.3/3 $\mu$m

$\Delta E = 2.5 \text{ eV at 5.9 keV}$

$\Delta E = 3.1 \text{ eV @ 5.9 keV}$
GSFC TES approach

250 µm

Facility Science Team - GSFC
Multiplexed TES calorimeter array

GSFC 8 x 8 array
NIST SQUID MUX readout

Also developed de-MUX software and we are now working on implementing real-time pulse height analysis
2 x 8 pixels read out with SQUID MUX

~30,000 counts per pixel from $^{55}\text{Fe}$ source

~500,000 total

$$\tau = 280 \mu\text{ s}$$

(critically damped)

$$2x8 \text{ MUX:}$$

$$\langle \Delta E_{\text{FWHM}} \rangle = 2.93 \pm 0.02 \text{ eV}$$
FREQUENCY DOMAIN MULTIPLEXING
CURRENT SUMMING TOPOLOGY

- AC-bias of TES; so that it acts as AM-modulator
- LC noise blocking filter per TES
- One SQUID per column
- Base-band feedback to decrease common impedance, to linearize SQUID response, and to increase dynamic range

1 – 10 MHz frequency range
200 - 300 kHz separation will enable multiplication of 32 – 45 pixels/channel

400 kHz AC-bias: 3.7 eV @ 5.9 keV and 3.5 eV baseline; data is drift corrected
BBFB electronics board realization
Amplitude and Phase measurements/model of BBFB
On a commercial Xilinx breadboard

Amplitude: red-data blue-model  Phase: red-data blue-model
Gain-bandwidth of 35 kHz for 200 kHz spacing and 830 ns delay

FLL-gain of 3.5x at highest signal frequency (10 kHz) and 22 x at 1.6 kHz (100 μs pulse decay time)
Focal Plane Array Layout (from Con-X to IXO)

Central, core array:
- Individual TES - one absorber/TES (40 x 40)
- 2 arcmin FOV
- 2.5 eV resolution (FWHM)
- Fast (< 300 µ sec time constant)

Outer, extended array
- 4 absorbers/TES
- Extends array to 52 x 52 pixels for a total of 2176 readout channels
- 5.0 arcmin FOV
- < 10 eV resolution
- ~ 2 msec time constant
Multi Absorber TES - 1 TES, 4 absorbers

Simple approach:
Separate absorbers (e.g., 4) connected to a single TES, each with a different thermal conductance.

Rise times easily distinguished
5-6 eV already obtained!
Optimized high-speed array (GSFC)

- 20 x 20 array of 1 arcsec pixels
- Distribute counts over ~ 10 times more pixels
- Use direct coupling to Si substrate for higher speed (~ 10’s of micro-sec.)
<table>
<thead>
<tr>
<th>Cooler</th>
<th>1ST (100K)</th>
<th>2ST (20K)</th>
<th>2ST+⁴He JT (4K)</th>
<th>2ST+³He JT (2K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2W@80K 50W, 4.2kg</td>
<td>325mW@20K 90W, 9.5kg</td>
<td>20mW @4.5K 120W, 23kg</td>
<td><a href="mailto:16mW@1.7K">16mW@1.7K</a> 190W, 25kg</td>
<td></td>
</tr>
<tr>
<td>Life time test &gt; 5 years (still running)</td>
<td>Life time test &gt; 4 years (still running)</td>
<td>1 year test was done. A new lifetime test in preparation</td>
<td>Lifetime test in preparation</td>
<td></td>
</tr>
<tr>
<td>Suzaku, in orbit 3.1 years</td>
<td>Akari, in orbit 2.5 years</td>
<td>FM for SMILES assembled</td>
<td>EM for SPICA &amp; Astro-H(NeXT) assembled</td>
<td></td>
</tr>
</tbody>
</table>
Last stage cooler developments in Europe

Interface with satellite cryostat at 2.5 K with 10 mW cooling power

Options under development:

He-3 sorption/1-stage ADR (CEA Grenoble)
30 W and 31 kg for 1 μW during 30 hours

2-stage single shot ADR (Astrium/MSSL or JAXA)
30 W and 31 kg for 1 μW during 30 hours

He-3 sorption/1-stage ADR (CEA Grenoble)
25 W and 5 kg for 1 μW during 30 hours

Closed cycle dilution refrigerator (Air Liquide, Institute Neel)

XEUS - NFI X-ray experiment
- requires 1 μW at 50 mK for ADR
  - CCDR meets requirement with $i_3 = 30 \mu\text{mole/s}$, $i_4 = 120 \mu\text{mole/s}$
  and a heat exchanger of $L = 9$ m
  and $d = 0.4$ mm
  - better thermalization of wiring reduces required cooling power for CCDR
- precooling stage of XEUS delivers 10 mW at 2.5 K
  - CCDR needs 5 mW at 1.5-1.8(?) K
  - solution: $^3\text{He}$ Joule-Thompson expansion from 15 K or with SPICA technology
Cryostat design adopted for recent IDL study at GSFC

Facility Science Team - GSFC

Kevlar Suspension System

ADR Stage 1

ADR Stage 4

ADR Stage 5

ADR Stage 3

ADR Stage 2

Detector Package

Telescope focal Point

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Si-doped X-ray Micro-calorimeter at CEA-Saclay

Herschel heritage: Developments by CEA-Saclay and LETI, Grenoble
Contributed paper by Claude Pigot
Fully integrated sensor with read-out multiplexer

Results: - Impedance of 8X8 sensor matrix in the right range with good sensitivity
- Integration of absorber matrix onto sensor matrix promising

Next steps: April 2008: First 8X8 array with freed Sensor & Absorber
End 2008: 1st Iteration Cold Electronics

Pro: Fully integrated system with multiplexed read-out
Con: Till now no X-ray performance data, use of Ta-absorbers by other teams failed, potentially slow response, developments late for XEUS.
Focal Plane Array Layout for XEUS → IXO

Field of View: 2.75 x 2.75 arcmin

Central pixels: 1.37 x 1.37 arcmin
2.5 x 2.5 arcsec pixels
2 eV @ 2 keV
100μs decay time

Surrounding pixels:
5 x 5 arcsec pixels
4 eV @ 2 keV
400μs decay time