Data analysis and results for multi-absorbers TES

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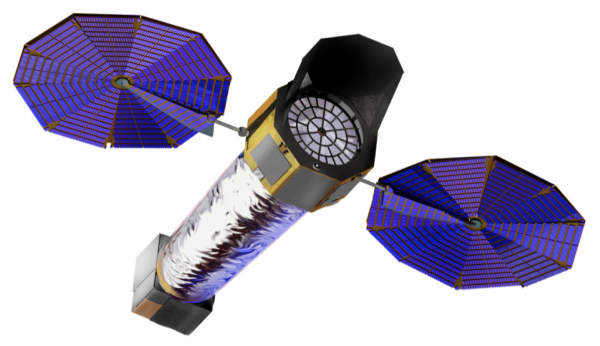
Abstract

We have been developing position-sensitive detectors, most recently for the proposed Lynx X-ray observatory currently under study for the next 2020 decadal survey. These detectors, referred to as hydras, are composed of multiple absorbers connected to a single transition-edge sensor (TES), each with a different thermal conductance. Using this technique as a form of thermal multiplexing allows the design of arrays at the scale of a hundred kilo-pixels, while keeping fairly good performance with reasonable read-out electronics. For these detectors a different pulse shape is measured by each of the pixels of the hydra when x-rays are absorbed. It is hence crucial to optimize the process of analyzing the data, to optimally discriminate the events from different pixels, and to provide the best possible energy resolution.

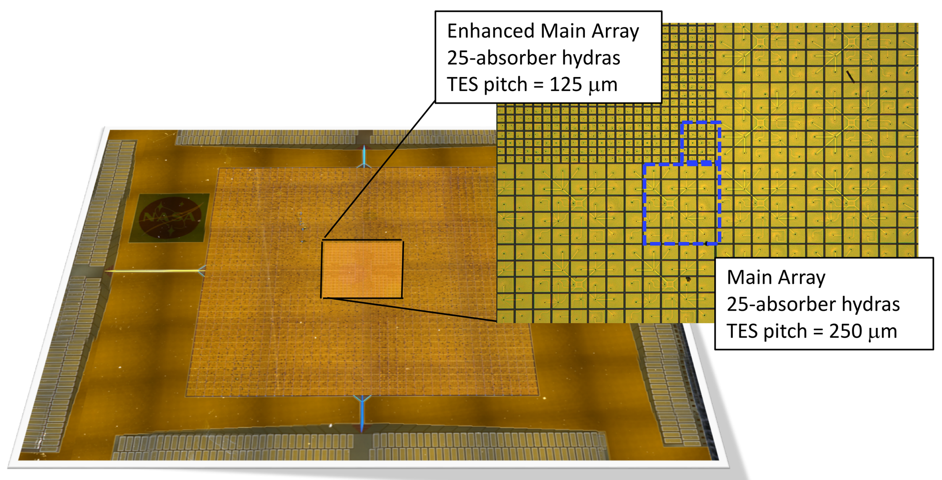
In this work we describe our studies of the characterization of our latest hydra designs. Two different designs are studied, one with 50 µm and one with 25 µm absorbers, in both cases with 25 pixels per hydra. These have demonstrated a combined (rms) energy resolution ΔE of ~1.7 eV for the small pixels and ~3.6 eV for the large ones at 1.25 keV, which is roughly in agreement with our expectations. We review the measurements performed in order to characterize the pixels and discuss how the processing had to be adapted in order to properly handle this kind of data, in particular to discriminate between X-ray events in the different pixels.

Lynx X-ray Observatory



- Lynx : one of the four mission concepts under study for the next 2020 decadal survey
- It will have 3 instruments for X-ray astrophysics, including an array of X-ray microcalorimeters (LXM), designed for 0.2-7 keV energy range
- The LXM array[3] shall present a main array (MA) and an enhanced main array (EMA)

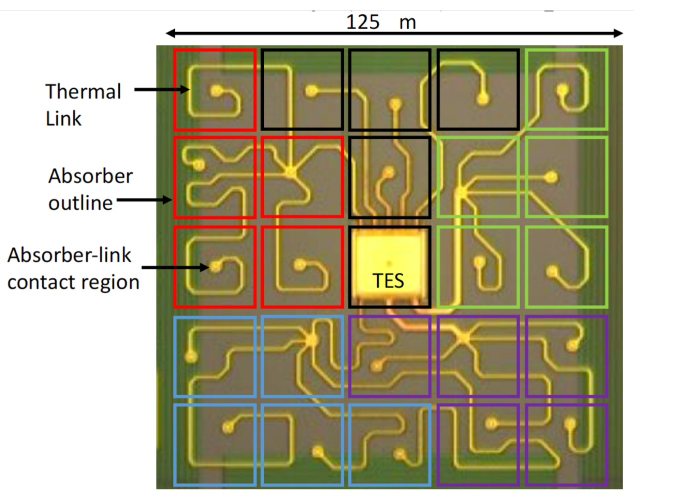
	MA	EMA
Pixel size	1"	0.5"
FOV	5'	1'
ΔE over 0.2-7 keV	3 eV	2 eV
Num. of pixels	86,400	12,800

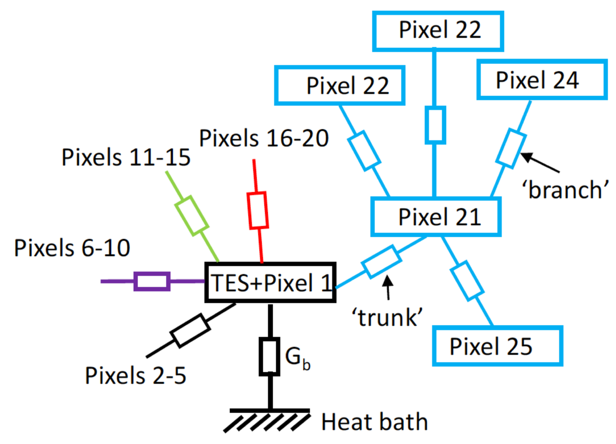


Prototype LXM array, half size of the final one

Multi-absorber TES – 'Hydras'

- Hydra : consists of multiple x-ray absorbers, each with a different thermal conductance to a single TES. Each pixel has a different characteristic pulse shape and enables position discrimination[1,2]
- We analyze hydras with 25 absorbers, organized in 5 groups (indicated in different colors below)





Example of EMA Hydra shown without absorbers

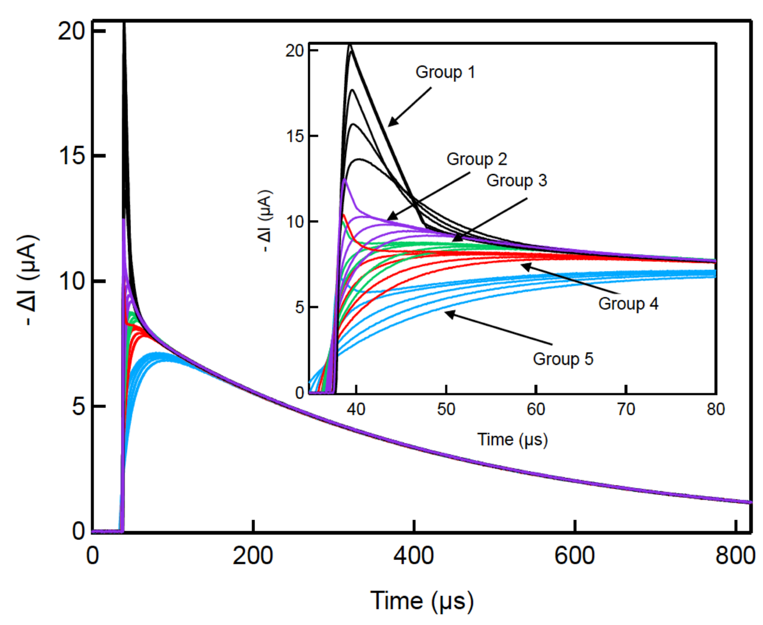
- In this work, measurements are done with Al-Kα x-rays (1.5 keV)
- ➢ For more details on Hydra design and results, see : Talk from S.J. Smith, "Towards 100,000-pixel microcalorimeter array using multi-absorber transition-edge sensors"
- ➢ For more details on LXM array fabrication, see : Poster from J.A. Chervenak, "Process development for dual-thickness, multi-absorber x-ray microcalorimeter arrays"

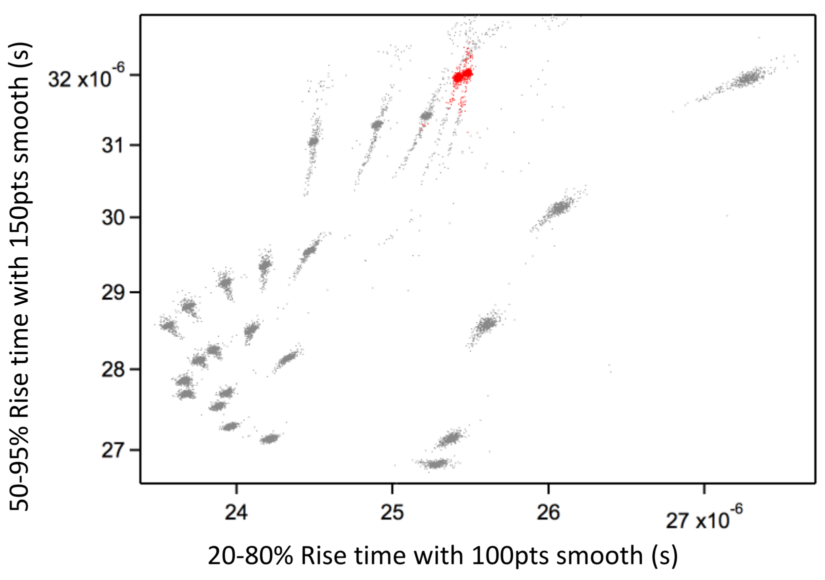
Processing steps

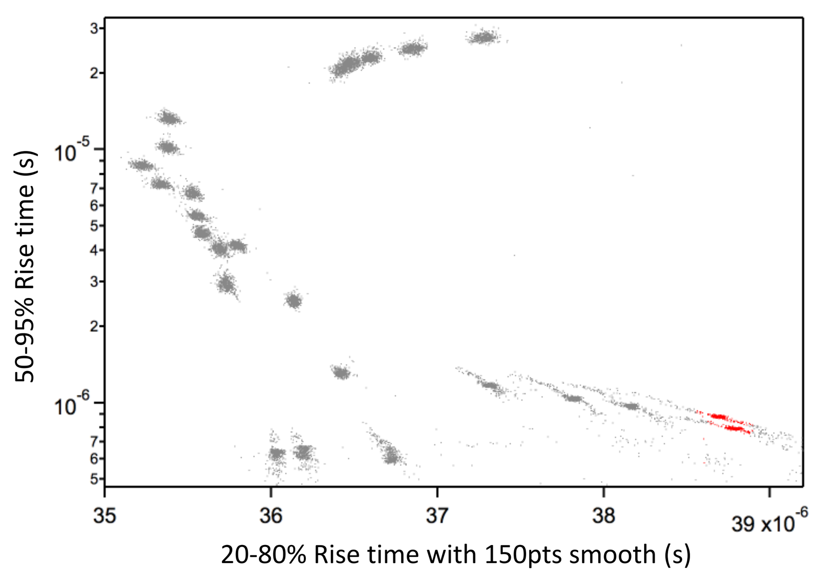
- We have 25 absorbers, how do we process everything?
  - Need to identify the 25 groups / pulses shapes, each with a different rise time due to the thermal link structures = Pulse shape discrimination
    ↳ various different approaches being studied
    ↳ still under investigation, but try to use as much information as possible about pre-equilibrium part
  - We then make an optimal filter for every individual pixel
  - We apply various corrections (baseline, gain, etc) to each pixel
  - We generate a spectra for each pixel, using the optimal filter generated with that pulse shape
  - We build the co-added spectrum for the 25 absorbers

Pulse shape discrimination – Enhanced Main Array (EMA) hydras

- Pulse shapes shown on the right for the EMA hydras
- Using 50-90% rise time with 150 points smoothing vs. 20-80% rise time with 100 points smoothing, we can clearly distinguish between 23 pixels (bottom left)
- Smoothing can help by attenuating variations in pulse shape from a same group which are due to noise
- However 2 pixels (in red) are overlapping
- We can then use 2 other metrics (50-95% rise time vs. 20-80% rise time with 150 points smoothing) to sperate them (bottom right)

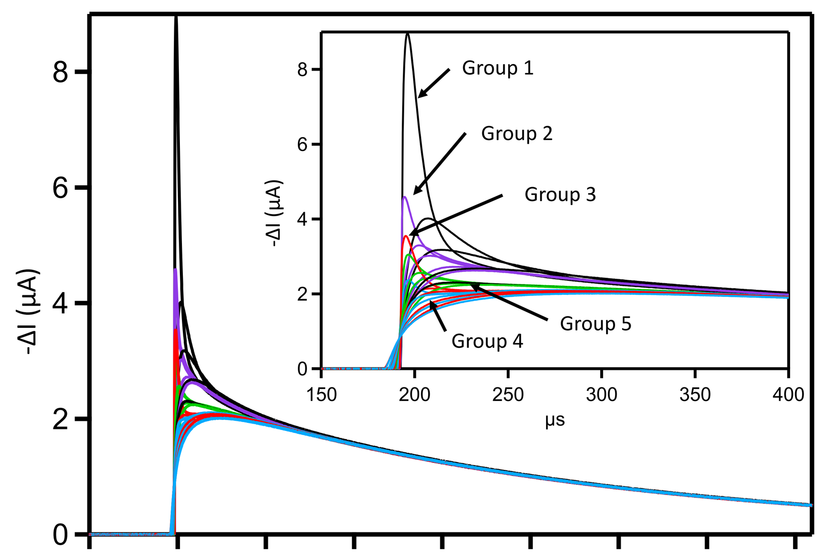


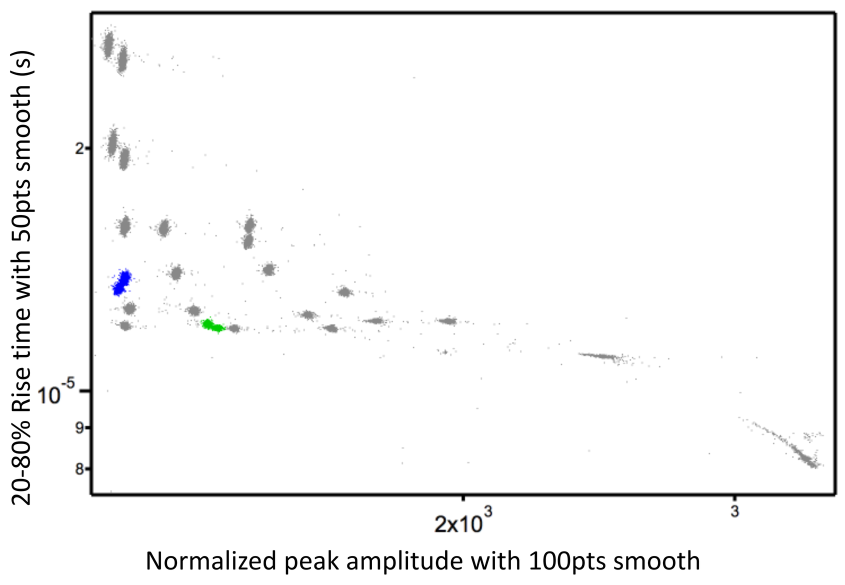


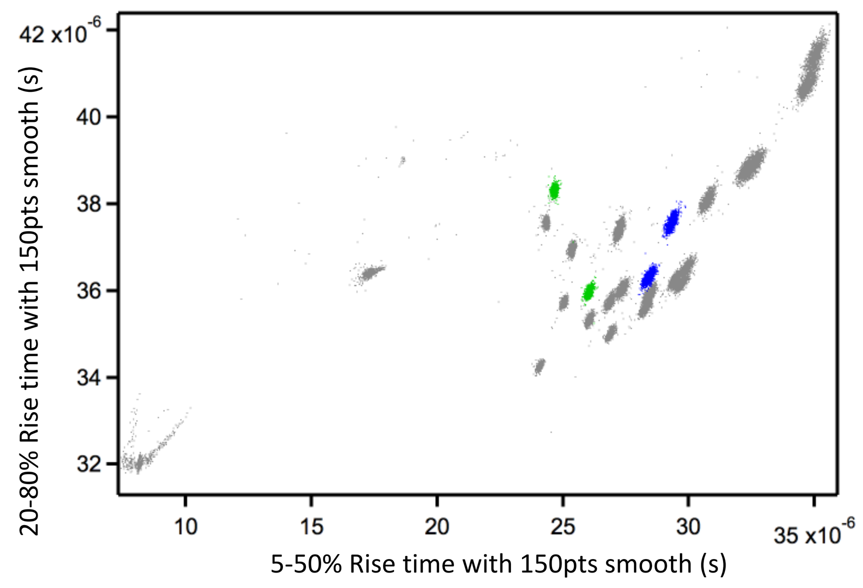


Pulse shape discrimination – Main Array (MA) hydras

- Pulse shapes shown on the right for the MA hydras
- Using 20-80% rise time with 150 points smoothing vs. the peak amplitude normalized by the area under the pulse with 100 points smoothing, we can clearly distinguish between 21 pixels (bottom left)
- However 2 groups of 2 pixels (in blue and green) are overlapping
- We can then use 2 other metrics (20-80% rise time vs. 5-50% rise time, both with 150 points smoothing) to sperate them (bottom right)



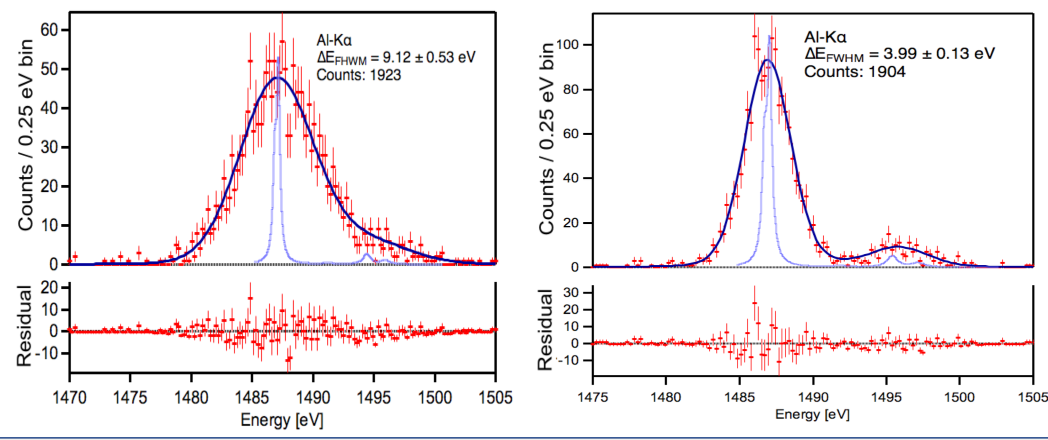




Low Pass Filtering

- For the absorber connected directly to the TES, which is strongly coupled, some spatial dependency can be observed due to the thermalization time of the absorber becoming a significant fraction of the thermalization time of the TES. This leads to high frequency content in the pulse, degrading the energy resolution
- This can be mitigated by applying a low pass filter (LPF) when generating the optimal filter

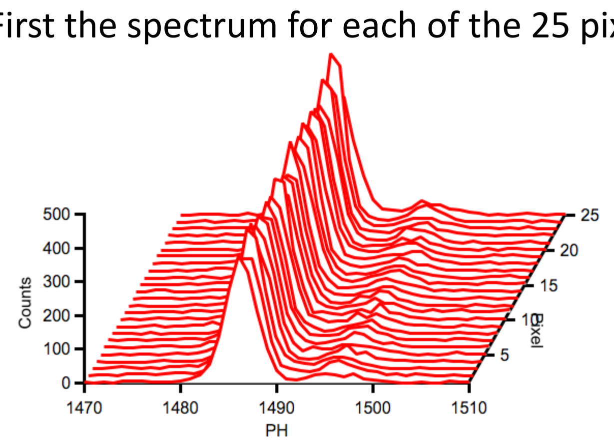
Spectra of the absorber connected to the TES without LPF



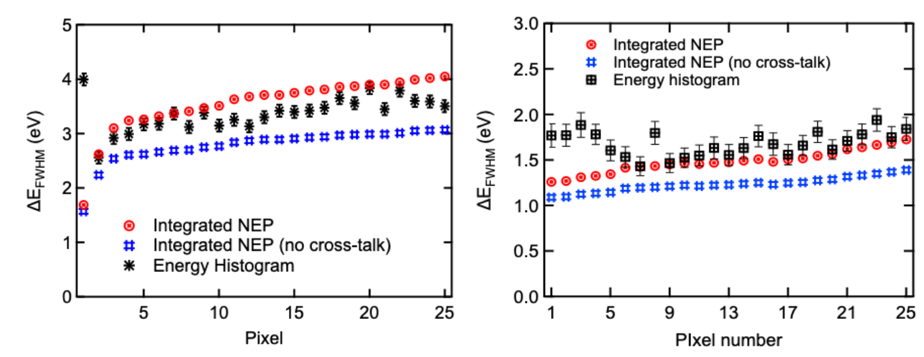
Spectra of the absorber connected to the TES with 3 kHz LPF

Spectra

- The final step of the analysis is the generation of the spectra and fit to get the energy resolution
- First the spectrum for each of the 25 pixels is generated independently (left)



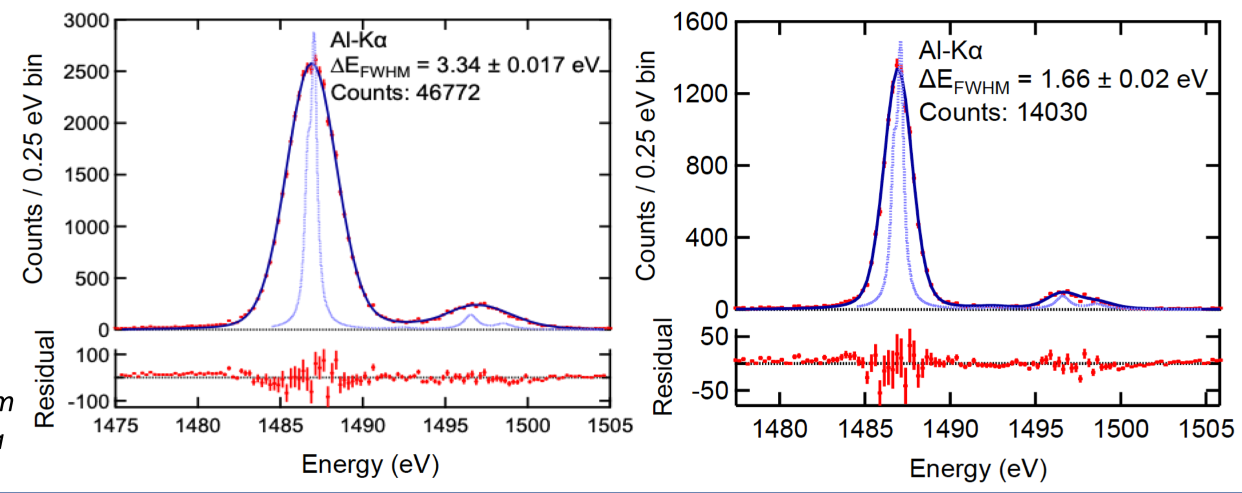
Overview of the 25 individual spectra for the MA hydra



Per pixel energy resolution and integrated NEPs for the MA (left) and EMA (right) hydras

- All the spectra are then combined together in order to build the co-added spectra for a given Hydra

Coadded spectrum for the MA hydra



Coadded spectrum for the EMA hydra

Summary & Future work

- Pulse shapes could be separated for both hydra types (EMA and MA), using different metrics
- It should however be noted that the discrimination process will likely might become more difficult for both lower and higher energies (respectively due to lower S/N and increased non-linearity)
- If multiple data sorting algorithms are necessary to separate all 25 pixels for a hydra, the pulse shape discrimination can be done in sequential steps switching to different metrics
- Other pixel discrimination algorithms are being investigated, such as using Principal Component Analysis
- The analysis presented here showed very good performance in the studied detectors, with 1.66 eV resolution for the MA hydras and 3.34 eV for the EMA hydras

References

(1) S.J. Smith et al., "Multi-absorber transition-edge sensors for x-ray astronomy", JATIS, 2019
(2) S.J. Smith et al., "Towards 100,000-pixel microcalorimeter arrays using multi-absorber transition-edge sensors", JLTP, LTD 2019
(3) S.R. Bandler et al., "Lynx x-ray microcalorimeter", JATIS, 2019