Advanced multi-pixel transition-edge sensors (MPTE), although originally referred to as “hydra”, are a type of position sensitive microcalorimeter that resistively couple a large area detector to a transition-edge sensor (TES). The design uses a pass thermistor that allows for a different characteristic pulse shape for a group of pixels in each of the multi-pixel arrays. In this contribution we report on the experimental results from hydra consisting of up to 25 pixels per 72. We discuss the design trade-offs between energy resolution, position discrimination and number of pixels and investigate future design-optimizations specifically targeted at meeting the readout technology considerations for Lynx.

3) 4 and 9 pixel hydra:

- Arrays presented here are small-pixel designs < 75 μm pitch for high angular resolution.
- 8 x 8 arrays of 4 and 9 pixel hydrams have been developed.
- 35±35 μm Mo/Au bilayer TES.
- 65±65 μm electroplated Au x-ray absorbers, 5 μm thick. Provides 98% absorption at 6 keV.
- Absorbers are cantilevered above substrate and TES for high fill factor.
- Fabricated on thick Si wafers with embedded Cu heat sink layer.
- ~ 500 nm Au thick, few μm wide links couple the TES to the absorbers.

4) 4 and 9 pixel hydra Energy Resolution:

- AE scales approximately with (number of pixels).
- \( \Delta E_{\text{hydra}} \equiv 0.9 \text{ eV at 1.5 keV.} \)
- 9 pixel hydra \( \Delta E_{\text{hydra}} \equiv 2.2-3.4 \text{ eV at 9 pixels for } E = 1.5 \text{ keV.} \)
- 4 pixel hydra \( \Delta E_{\text{hydra}} \equiv 1.4-2.2 \text{ eV at } 4 \text{ pixels for } E = 1.5 \text{ keV.} \)
- Excellent resolution consistent across all pixels and consistent with expectations.

5) Position Sensitivity:

- Position determined from rise-time.
- Thermal links designed using a finite element model to calculate the pulse shapes and noise.
- Position sensitivity decreases as energy decreases (\( \alpha \approx 1/E \)).
- Position discrimination demonstrated down to ~ 1 keV for both 4 and 9 pixel designs.
- Simulations suggest sensitivity should be down to a few 0.1 eV.
- Pulse shapes match well with numerically simulated.
- Hits in exposed links between absorbers have been identified.
- Low \( T_0 \) resulted in excellent AE but relatively low decay times (ms). Thus these particular detectors are excellent for lower count-rate X-ray astronomy applications.

6) 20-pixel hydra designs:

- Extending designs to the first prototype 20-pixel hydra.
- These designs utilize a hierarchical structure using trunks and branches that make it easier to design and lay out, but require more complex position discrimination algorithm.
- Pixel design iteration consisting of 5 clusters of 4 absorbers, where each cluster is individually coupled to the TES (schematic below).
- The absorbers are 4.2 μm Au on a 50 μm pitch.
- TES is ~25,000 μm^2.
- \( T_{\text{c}} = 80 \text{ mK.} \)

Simulated pulse shapes for a 20-pixel hydra design. Pulses are color-coded to match the pixel colors in schematic.

- \( T_{\text{c}} = 55 \text{ mK.} \)
- \( C = 0.4 \text{ pC/K for 4 pixels.} \)
- \( C = 1.0 \text{ pC/K for 9 pixels.} \)

7) 20-pixel hydra results:

- Measured average pulse shapes (right) qualitatively agree with simulations.
- The 5 clusters each with 4 pixels have different characteristic pulse shapes.
- Additional pole in rise time requires 2nd metric for parameterizing pre-equilibrium signal.
- Different algorithms under study for determining optimum position.
- Example shown here uses 2 rise time metrics: \( r_1 \), determined from 5-50% and \( r_2 \), from 50-95% of the pulse peak. Two x-ray data rates run at different energies:
  - \( \Delta E_{\text{K (6 keV) and C (5.4 keV).}} \)
  - \( \Delta E_{\text{K (1.5 keV) and C (277 eV).}} \)
- Good position discrimination demonstrated on most pixels down to \(< 1.5 \text{ keV.} \)
- However, due to very fast rise time and low sampling rate (only 4 data points on rise of fastest pixels), position discrimination between fastest pixels (cluster 1).
- \( \Delta E_{\text{K (steel) evaluated a C-K (steel) using crystal monochromator.}} \)
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8) Future plans include:

- Extend design to 25 pixels for Lynx baseline design.
- Optimize design to match fastest pixel with readout mux readout bandwidth.
- Test large scale arrays with multiplexed microwave mux readout.
- Design hydrams with 25 μm pixel pitch to better match Lynx 0.5 arc-second goal.

9) X-ray absorber

10) 5x5 array

11) Close-up photograph of single hydra, the metal links are visible in between absorbers.

12) Photograph of 20x20 array of 20 pixel hydrams, with a total of 1280 pixels.