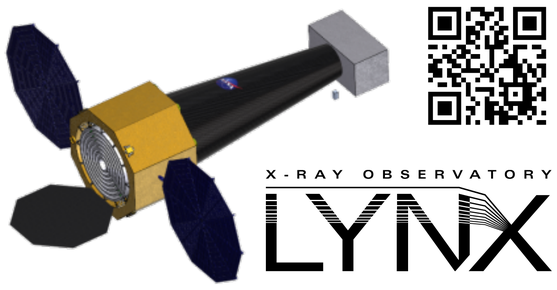
Demonstration of fine-pitch high resolution X-ray transition-edge sensor microcalorimeters optimized for energies below 1 keV

Kazuhiro.Sakai@nasa.gov

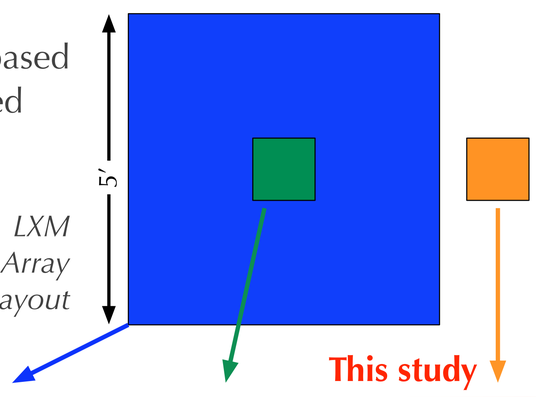
Kazuhiro Sakai (UMBC & NASA/GSFC), J.S. Adams, S.R. Bandler, S. Beaumont, J.A. Chervenak, A.M. Datesman, F.M. Finkbeiner, R.L. Kelley, C.A. Kilbourne, A.R. Miniussi, F.S. Porter, J.S. Sadleir, S.J. Smith, N.A. Wakeham, E.J. Wassell (NASA/GSFC), M.E. Eckart (LLNL), Kevin Ryu (MIT Lincoln Lab), F. Jaeckel, D. McCammon (UW-Madison)

Lynx - Revealing the Invisible Universe



Lynx is…
- 1 of 4 large mission concepts currently studied at NASA (2020 Decadal Survey)
- Next astrophysics flagship mission after WFIRST if selected
- https://lynxobservatory.com

Lynx instruments are…
- High Definition X-ray Imager (HDXI) - Si-based
- X-ray Grating Spectrometer (XGS) - Si-based
- **Lynx X-ray Microcalorimeter (LXM)** - μcal
  - Main Array (Hydra)
  - Enhanced Main Array (Hydra)
    → See Smith et al. (Poster 354)
  - **Ultra High Resolution Array**
    → This study

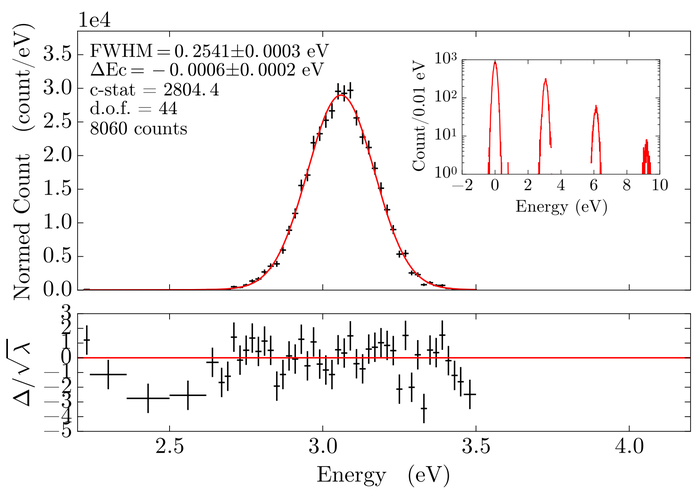


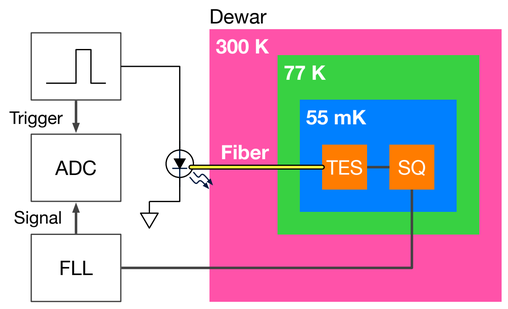
LXM TES Array Layout

		Main	Enhanced Main	Ultra Hi Res
Requirements				
Energy Range	keV	0.2 – 7	0.2 – 7	**0.2 – 0.75**
FoV	arcmin	5 × 5	1 × 1	**1 × 1**
Pixel Size	arcsec	1 × 1	0.5 × 0.5	**1 × 1**
Energy Resolution	eV	3	2	**0.3**
Count Rate	cps	10 (per Hydra)	10 – 20 (per Hydra)	**80**
Sensor Specifications				
Hydra Factor		5 × 5	5 × 5	**Non-Hydra**
# of Pixels		86,400	14,400	**3,600**
# of TES Sensors		3,456	576	**3,600**
Pixel Pitch	μm	50	25	**50**
Sensor Pitch	μm	250	125	**50**

Δ*E* Measurement with 3 eV EUV photons

- Used an optical 405 nm 'Blu-Ray' laser diode (3.06 eV per photon)
- The laser is at 300 K vacuum space and excited with 1 μs pulses
- Used an optical fiber to deliver photons to the detector
- See Jaeckel et al. (Poster 338) for more details on the measurement
- Due to difficulties in aligning the fiber, only observed 3, 6, and 9 eV lines
- **Δ*E* = 0.25 eV FWHM** at 3.06 eV



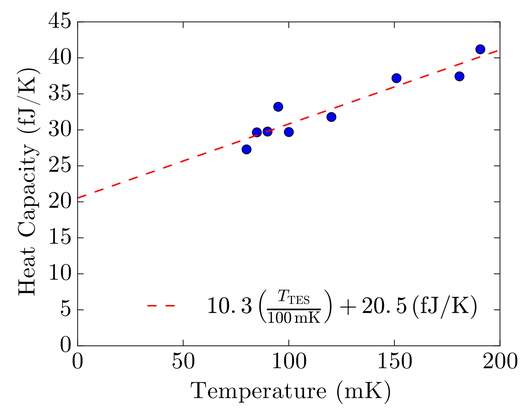


(top) *Experimental setup*
(left) *3 eV EUV photon spectrum*
(inset) *Full-range energy spectrum*

Filling the Gap between 3 eV and 1.5 keV

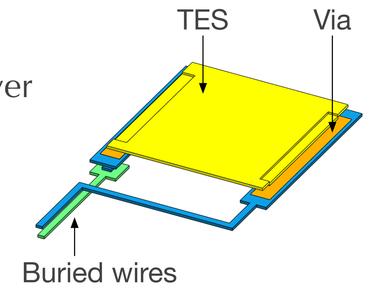
- Measured heat capacity at various bath temperatures well above Tc
- Expected 15 fJ/K at 100 mK but obtained 30 fJ/K at 100 mK
- Offset (21 fJ/K) on the measured heat capacity
  → Contaminations in absorbers?

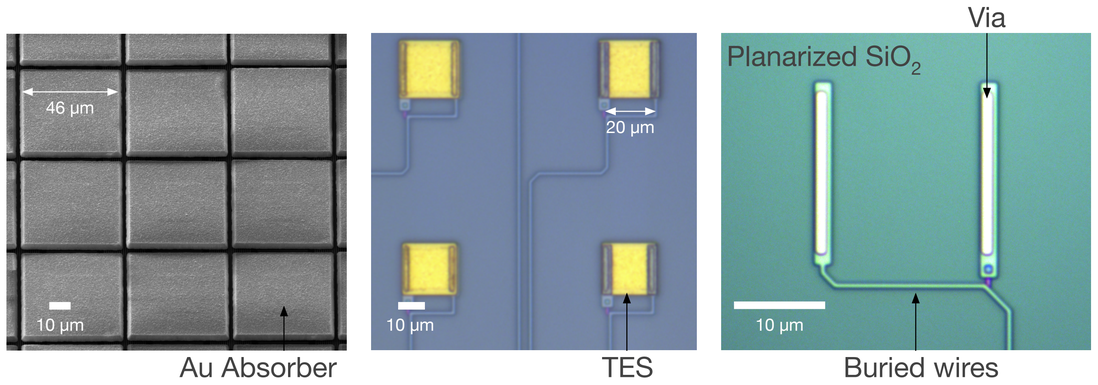
Measured heat capacity at various T_{bath} and a best-fitted linear model

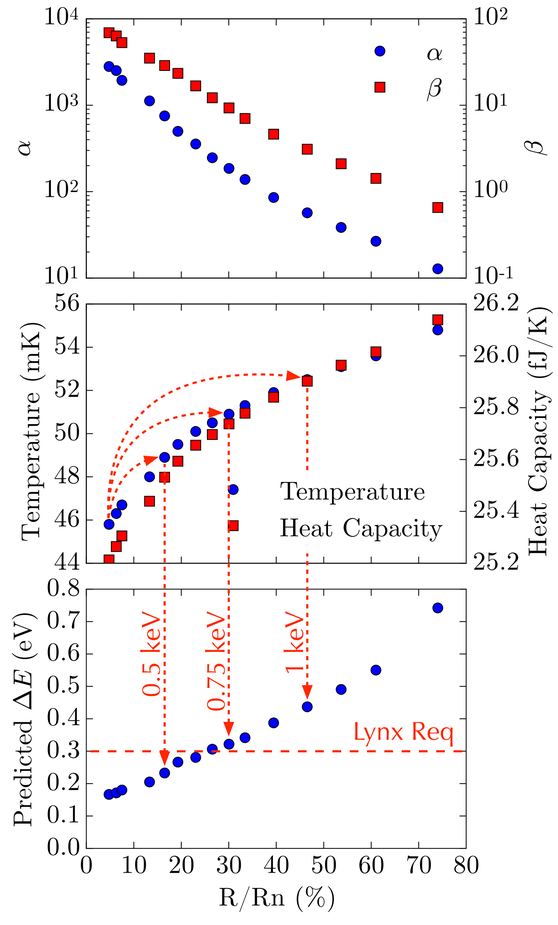


Fine-pitch TES X-ray Microcalorimeter Array with Buried Microstrip Wires

- NASA Goddard and MIT Lincoln Lab are fabricating fine-pitch TES with buried wires
- Microstrip wires are buried under SiO_2 insulation layer
- Fabricated 20-μm size TES with 50-μm pitch
- 46 × 46 × 1 μm Au absorber
- 60 × 60 sensors (internal 64 pixels are wired)
- Wire density is capable of wiring all the sensors
- See Chervenak et al. (Poster 94) for more details



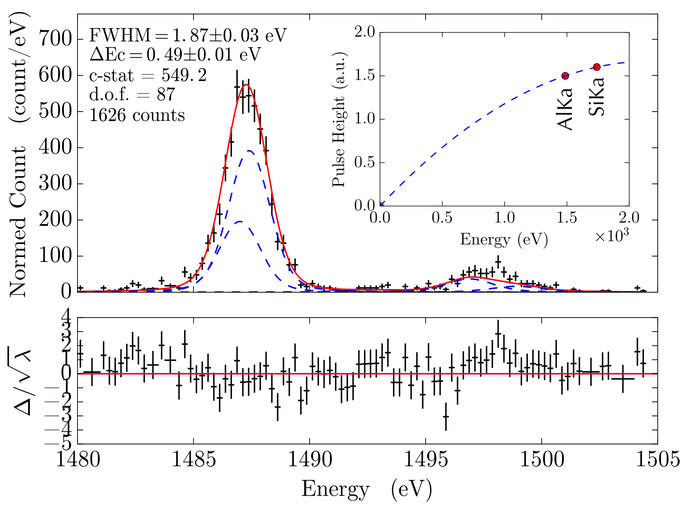


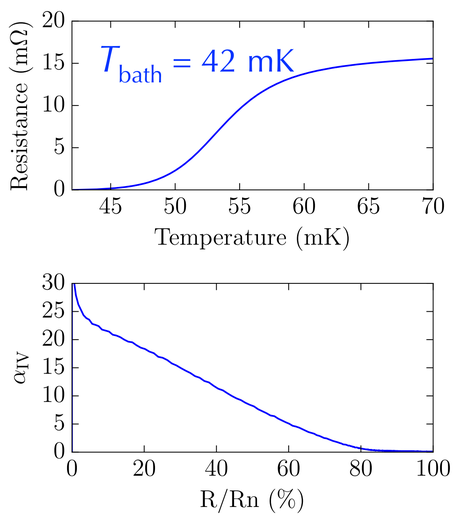


- Measured complex impedance at T_{bath} = 42 mK and obtained α and β
- Solved the thermal and electrical differential equations to reconstruct a pulse from the measured α and β
- Calculated the predicted Δ*E* in a small-signal limit using the reconstructed pulse and the measured noise
- Δ*E* < 0.3 eV FWHM for R/Rn < 25%
- For 0.5, 0.75, 1.0 keV X-ray, Δ*T* = 3, 4.7, 6.4 mK using the measured C_{TES}
- Predicted Δ*E* < 0.3 eV@R/Rn ~ 2.5% for up to 0.75 keV
- ΔE gradually degrades up to ~1 keV or higher

(top) *alpha and beta vs R/Rn obtained from complex impedance*
(middle) *TES temperature and TES heat capacity vs R/Rn*
(bottom) *Predicted energy resolution vs R/Rn*

- R_n ~ 19 mΩ
- Very smooth transition and Tc around 55 mK ± 10 mK @ 42 mK T_{bath}
- At first used commercial X-ray source with an Al target
- Significantly non-linear response at AlKa (1.5 keV) due to out of targeted band
- Δ*E* = 1.87 eV FWHM at AlKa (1.5 keV)

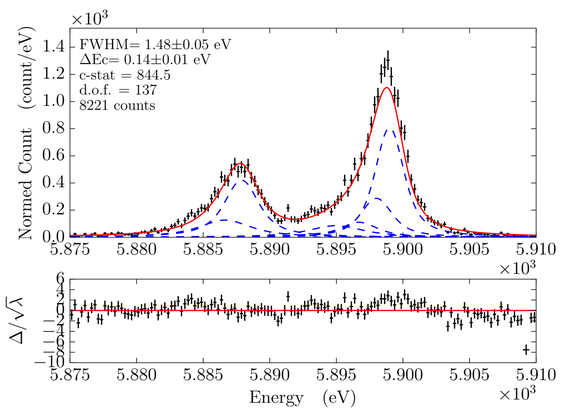




(left) *AlKa spectrum* ***(inset)*** *Energy calibration curve*
(right) *Transition curve and alpha curve derived from the transition*

Fine-pitch TES for Higher Energies (>1 keV)

Similar type fine-pitch TES:
- 12-μm size TES with 35-μm pitch
- 31 × 31 × 4 μm Au absorber
- No buried wires
- Very broad transition: 150 mK ± 40 mK
- Biased at 2% *R/Rn* where T_{TES} ~ 120 mK
- Δ*E* = **1.48 eV FWHM** at MnKa (5.9 keV)
  → Current world record?



Summary

✓ NASA Goddard and MIT Lincoln Lab are fabricating fine-pitch TES with buried microstrip wires for *Lynx* ultra-high-resolution array
✓ Fabricated 50-μm pitch 20-μm TES with buried wires and:
- Achieved Δ*E* = 1.87 eV for 1.5 keV and Δ*E* = 0.25 eV for 3 eV
- Calculated the predicted Δ*E* and obtained Δ*E* < 0.3 eV for R/Rn < 25%
- Expected Δ*E* of < 0.3 eV for up to 0.75 keV X-ray at R/Rn ~ 2.5%

✓ Fabricated 35-μm pitch 12-μm TES and achieved Δ*E* = 1.48 eV for 5.9 keV