PE-46 The Design of the *Lynx* X-ray Microcalorimeter

Abstract:
Lynx is an x-ray telescope, one of four large satellite mission concepts currently being studied by NASA to be the next astrophysics flagship mission after WFIRST. One of Lynx's three instruments is an imaging spectrometer consisting of an x-ray microcalorimeter behind an X-ray optic with an angular resolution of 0.5 arc-seconds and approximately 3 m^2 of area at 1 keV. This instrument will provide unparalleled diagnostics of distant extended structures and in particular will allow the detailed study of the role of cosmic feedback in the evolution of the Universe. We discuss the design and read-out of the of the array configuration including a number of sub-array options for increasing the capabilities to maximize the scientific return of the Lynx observatory.

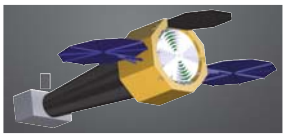
NASA/GSFC:
Simon Bandler, Michael Dipirro, Megan Eckart, Kazuhiro Sakai, Stephen Smith, Wonsik Yoon

NIST/Boulder:
Douglas Bennett, Vincent Kotsubo, Benjamin Mates, Daniel Swetz, Joel Ullom

Kent Irwin, Stephen Kuenster - Stanford University
Dan McCammon - University of Wisconsin
Enectali Figueroa-Feliciano - Northwestern University

Kevin Ryu – MIT Lincoln Laboratories
Benjamin Zeiger – Luxel
Jeffrey Olson – Lockheed Martin
Douglas Swartz – NASA/MSFC

Lynx: Revealing the Invisible Universe



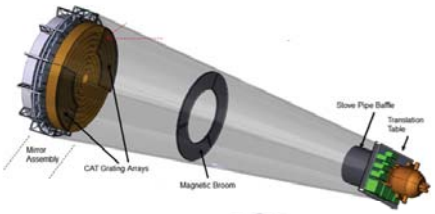
Lynx: Many Science Drivers:

- First Black Holes in the Universe and their co-evolution with Galaxies
- Cycles of (Hot) Baryons in and out of Galaxies
- Feedback from Stars, Supernovae, and Black Holes, in all settings
- Stellar Lifecycles
- X-ray counterparts of GW events and multi-wavelength phenomena
- Physics of Accretion and Compact Objects

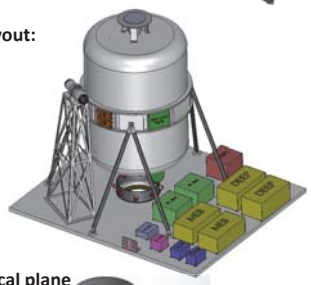
- A symbol of great insight
- Ability to see through rocks and trees to reveal the true nature of things.

- The historic Accademia dei Lincei (Academy of the Lynx)
- Name based on ability to perform incisive and penetrating investigations of the natural world.
- Galileo was a proud member
- Coined the term telescope for marvelous device for peering into the cosmos.

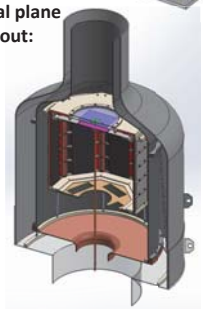
Telescope layout:



Cryostat layout:

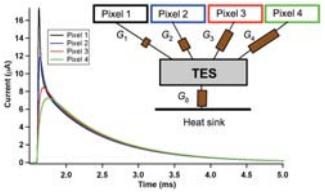


Notional focal plane assembly layout:

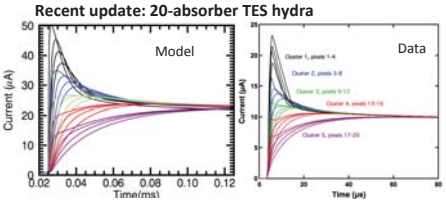


Hydras:

Extensive use of hydra concept with up to 25 absorbers per TES in main array:

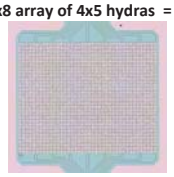


Recent update: 20-absorber TES hydra



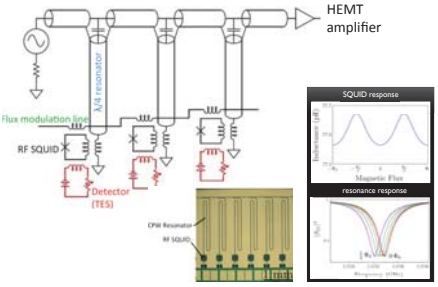
– absorbers on 50 μm pitch
– 3.4 eV demonstrated at 5.4 keV
– see poster P-59: S. Smith et al.

8x8 array of 4x5 hydras = 1280 pixels



Read-out:

Microwave (GHz) SQUID Resonators are advancing rapidly, have the most potential, and the baseline read-out for Lynx calorimeter



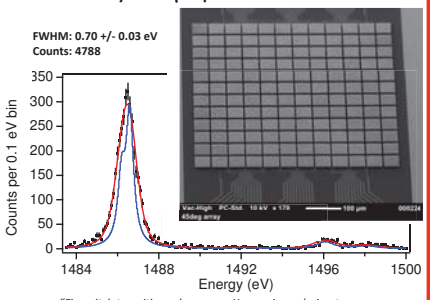
- NIST has demonstrated a slew rate of 3A/s with spacing with a resonator design sufficient to read out pixels with a frequency spacing of ~ 10 MHz. See presentation O-53: Mates et al.
- GSFC has demonstrated microwave SQUID read-out of X-ray microcalorimeters with almost no energy resolution degradation. – See poster PB-28 Yoon et al.

Suggested initial *Lynx* microcalorimeter requirements from earlier study:

- Pixel size: 1″
- Field-of-View: At least 5′ x 5′
  - 5′ field-of-view with 1″ pixels =>300 x 300 array
    => 90,000 pixels
- Energy resolution [FWHM]: < 5 eV
- Count rate capability: < 1 count per second per pixel
- For a focal length of optic of 10 m,
  - 1″ corresponds to 50 μm pixels

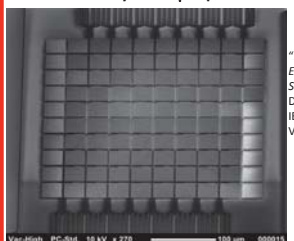
Small-pixel designs

12 x 12 array on 35 μm pitch:

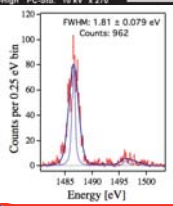


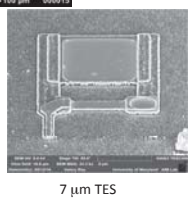
"Fine pitch transition-edge sensor X-ray microcalorimeters with sub-eV energy resolution at 1.5 keV", S. J. Lee et al., App. Phys. Lett. **107**, 223503 (2015).

10 x 10 array on 35 μm pitch:



"Reduced-Scale Transition-Edge Sensor Detectors for Solar & X-Ray Astrophysics", Datesman et al., IEEE Trans. on Appl. Sup., Vol 27, (4), (2017).

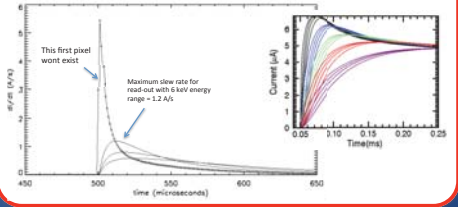




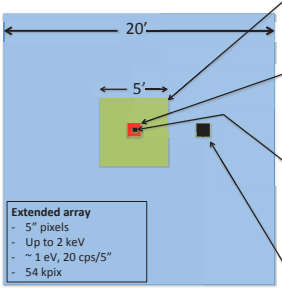
7 μm TES

Optimization of hydra design for read-out

- Introduction of optimal Nyquist inductor to minimize slew rate & maintain position discrimination.
- Assume first pixel is removed, and its heat capacity added to TES sensor



Focal plane design - still being refined



Main array
- 1″ pixels, 5′ FOV
- ~ 3 eV, 10 cps/hydra (5″)
- up to 7 keV
- 86.4 kpix

Enhanced main array
- 0.5″ pixels, 1′ FOV
- ~ 1.5 eV, 40 cps/hydra-25 (2.5″)
- up to 7 keV (baseline mode)
- 12.8 kpix

Hi-res inner array
- 0.5″ pixels, 20″ FOV
- ~ 1.5 eV, 20 cps/hydra-4 (1″)
- up to 7 keV
- 1.6 kpix

Extended array
- 5″ pixels
- Up to 2 keV
- ~ 1 eV, 20 cps/5″
- 54 kpix

Ultra-hi-res array
- 1″ pixels, 1′ FOV
- 0.3-0.4 eV (up to ~ 0.75 keV)
- Count rate ~ 80 cps/1″
- 3.6 kpix

Conclusions/outlook

- A new instrument has been designed representing a new generation in scale of X-ray microcalorimeter arrays
- Over 100,000 pixels
- New wiring schemes suitable for these arrays are being developed.
- Design exists for flight implementation of microwave SQUID read-out, assuming microwave read-out slew-rate capabilities already demonstrated.