Spectroscopy for Red Shifts and Doppler Shifts:

Elihu Boldt's role in the the next experiment in non-dispersive x-ray spectroscopy

Richard Kelley
GSFC
November 6, 2009

The next experiment…

Frank McDonald, head of the LHEA, learned in 1982 that the AXAF AO was imminent and informed Elihu Bolt.

Elihu held a meeting of the x-ray group (much smaller than it is now!) and, characteristically, asked *each* of the members what sort of instrument they thought *should be* on AXAF, not what instrument they thought could be built.

Richard Mushotzky made a strong case for a non-dispersive spectrometer with high quantum efficiency, and the idea was to improve the resolution by employing a semiconductor with lower band-gap energy than Si (more e^--h pairs per x-ray ➔ higher energy resolution.)

Richard then eventually contacted Harvey Moseley, said to be familiar with such materials. After an hour or so of discussing the problem and requirements, Harvey said that he did not want a semiconductor device, but a bolometer, and proceeded to write down the Mather *et al* formula for energy resolution.

Building the next experiment…

Elihu then asked Richard to start developing the instrument.

After a few months of Richard trying to interact with GSFC engineering, something had to be done!

Elihu had a very high opinion of Prof. Dan McCammon (U. Wisconsin), and invited him to Goddard to in the summer of 1983 to develop the technology. Note that what mattered here was the caliber of the physicist, not the resident institution!

Dan, Harvey and Dale Arbogast worked like crazy together to prove the concept in time for the AXAF proposal:

> The theory said that a resolution of a few eV was possible and the proposal promised < 10 eV…

AXAF/XRS Proposal (Feb 1984)

A PROPOSAL FOR AN X-RAY SPECTROSCOPY INVESTIGATION FOR THE AXAF OBSERVATORY

Volume 1: Technical Proposal

Instrument Principal Investigator:

S. S. HOLT
GODDARD SPACE FLIGHT CENTER

Lead Co-investigator:

D. McCAMMON
UNIVERSITY OF WISCONSIN

with Additional Collaborators at the Goddard Space Flight Center and the University of Wisconsin

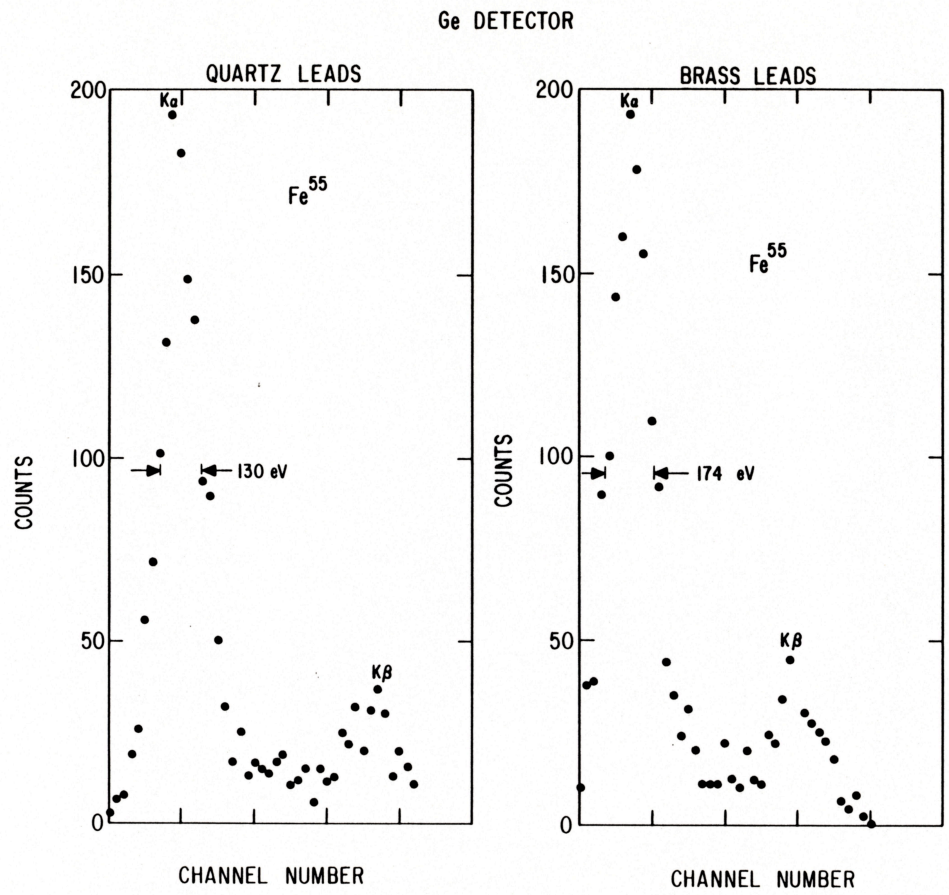
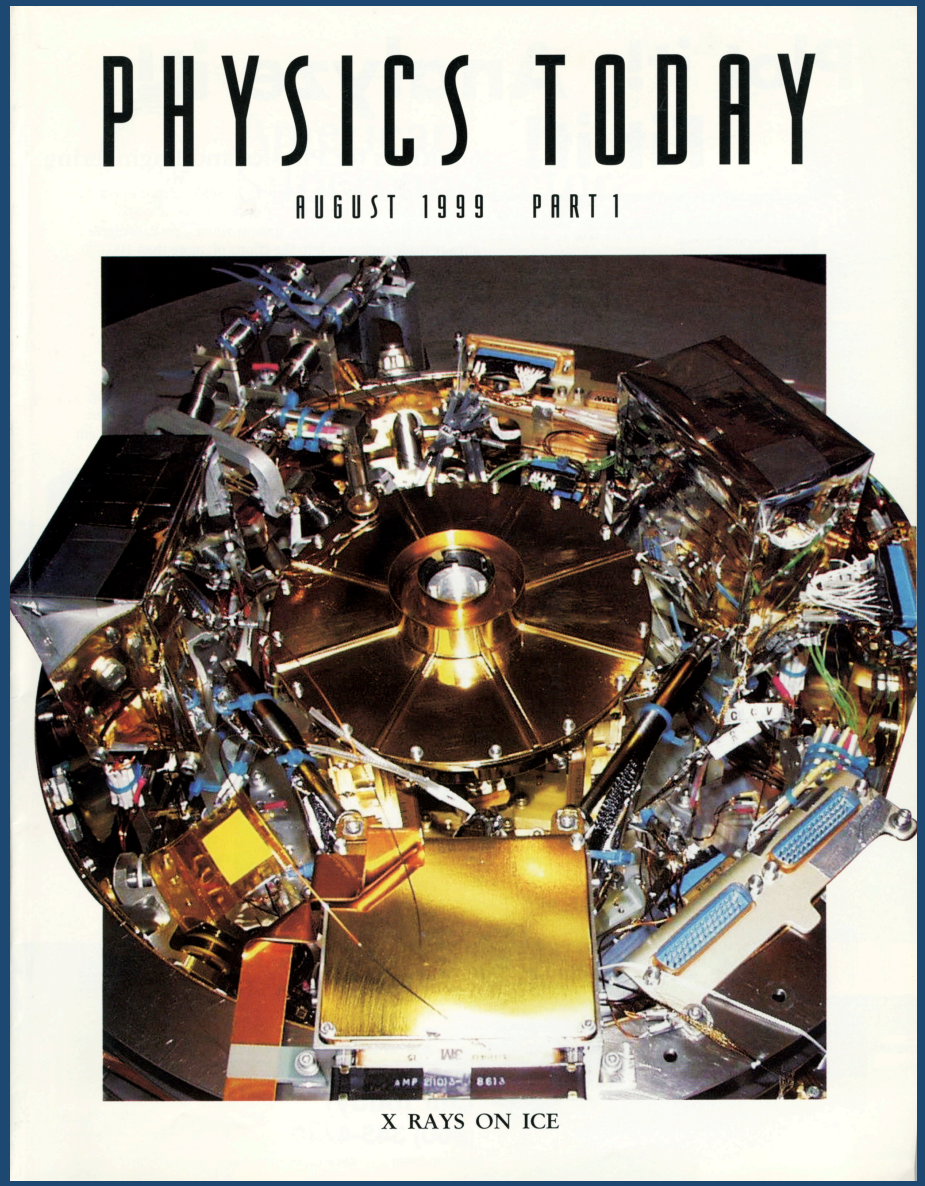
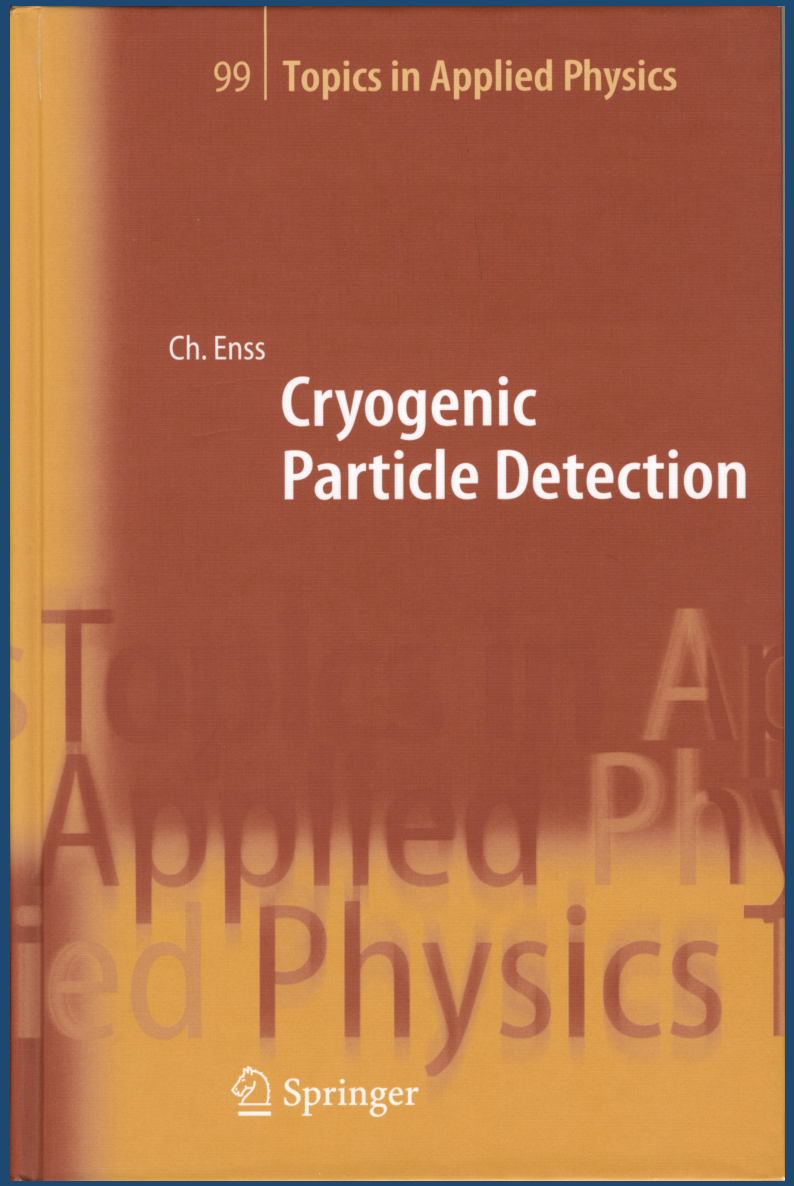


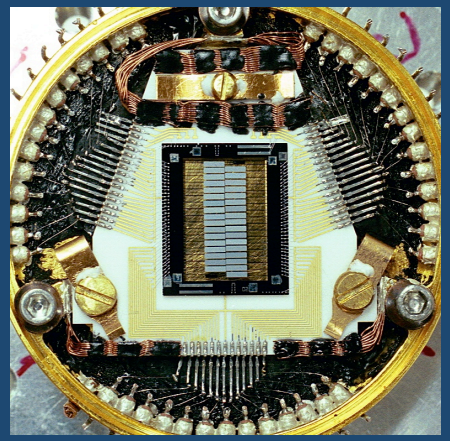
Fig. 7. Calorimeter results

An established field for quantum detection

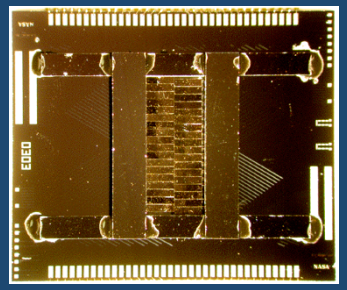




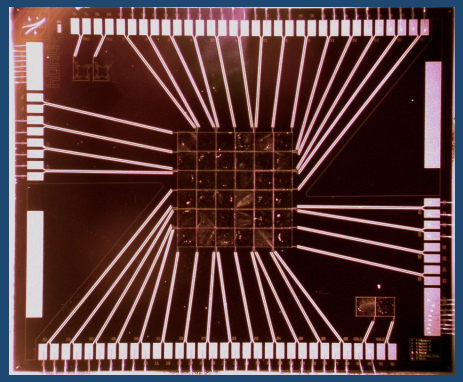
Extensive Record of Producing X-Ray Calorimeter Arrays at GSFC



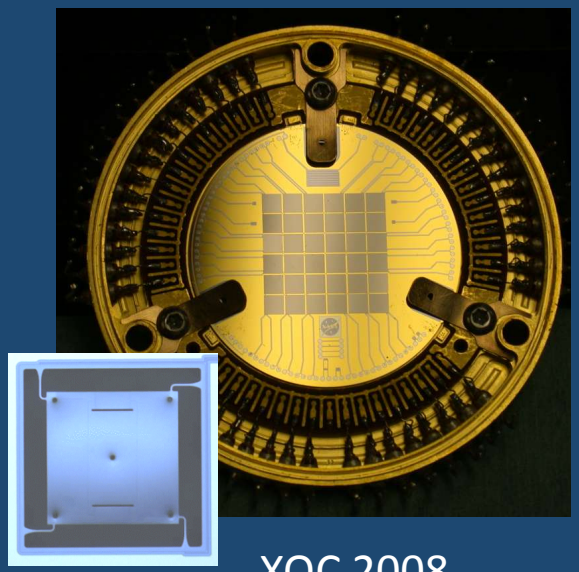
XQC 1995



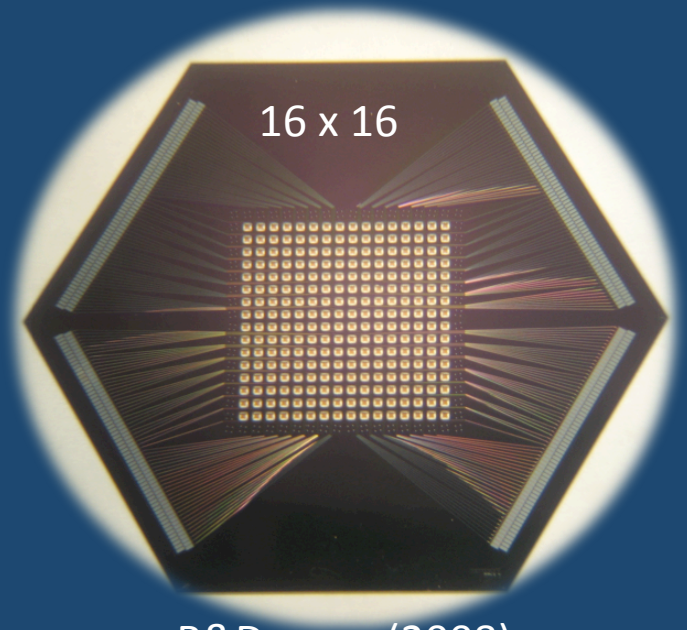
Astro-E 2000



Suzaku 2005



XQC 2008

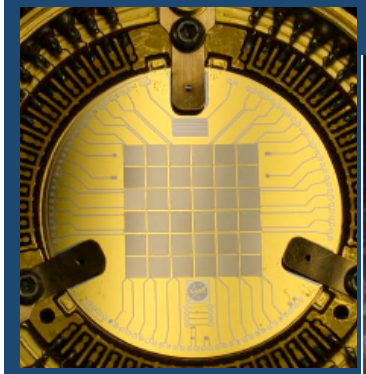


R&D array (2008)

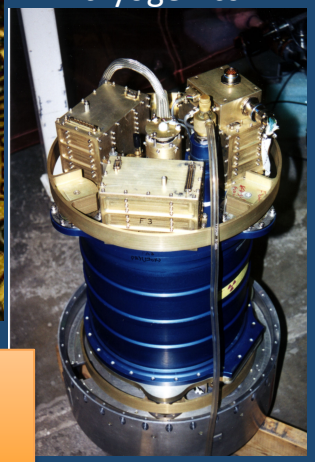
Under development!

Astro-H 2014

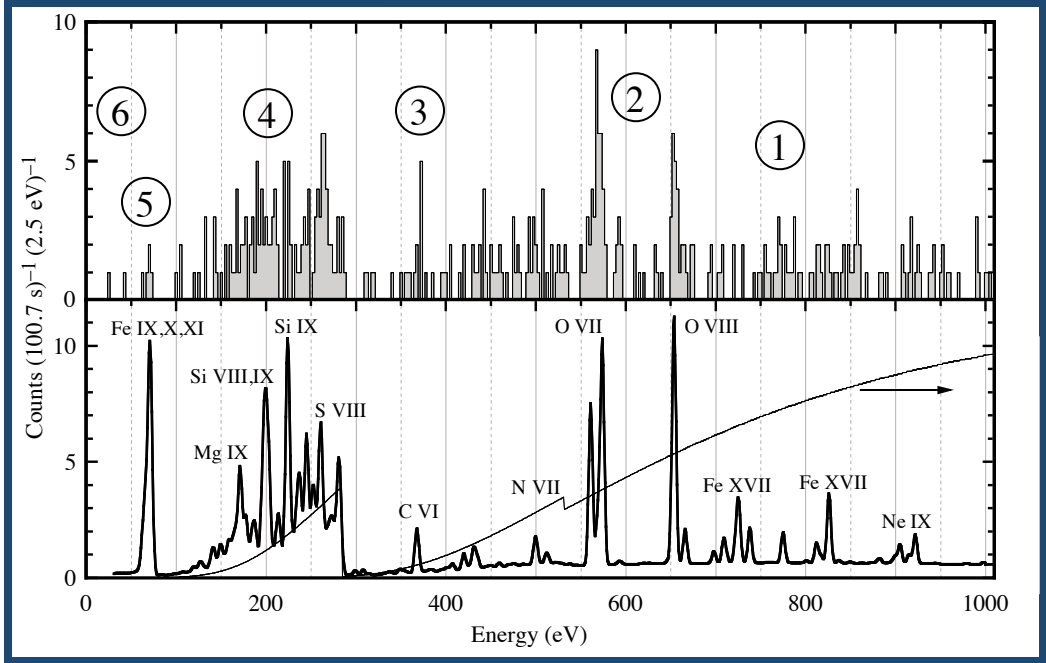
The first x-ray calorimeters in space: The *X-Ray Quantum Calorimeter* (XQC)



50 mK space cryogenics

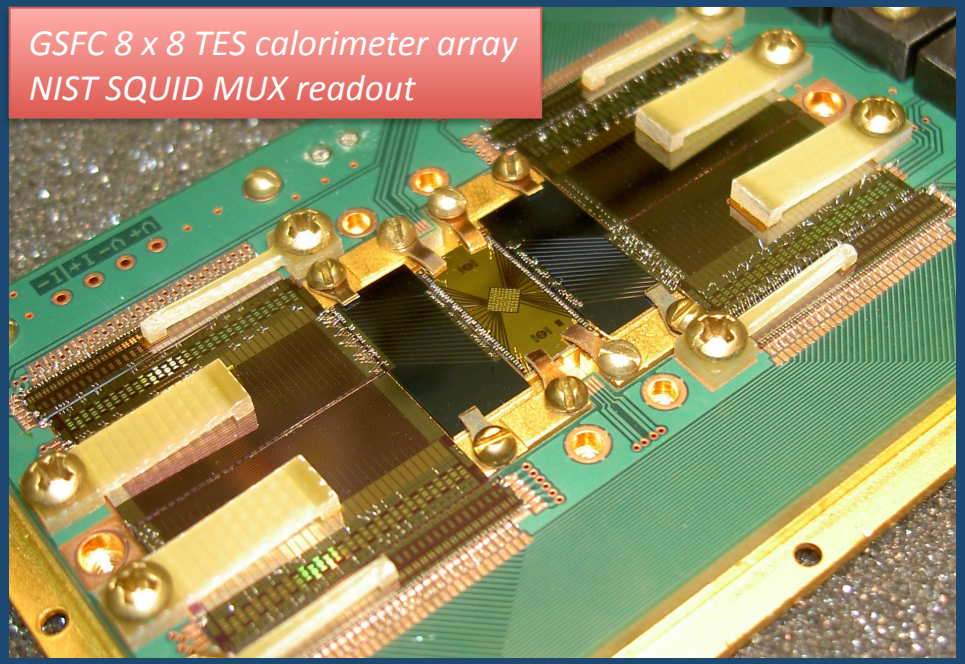


First launched in 1990Results:

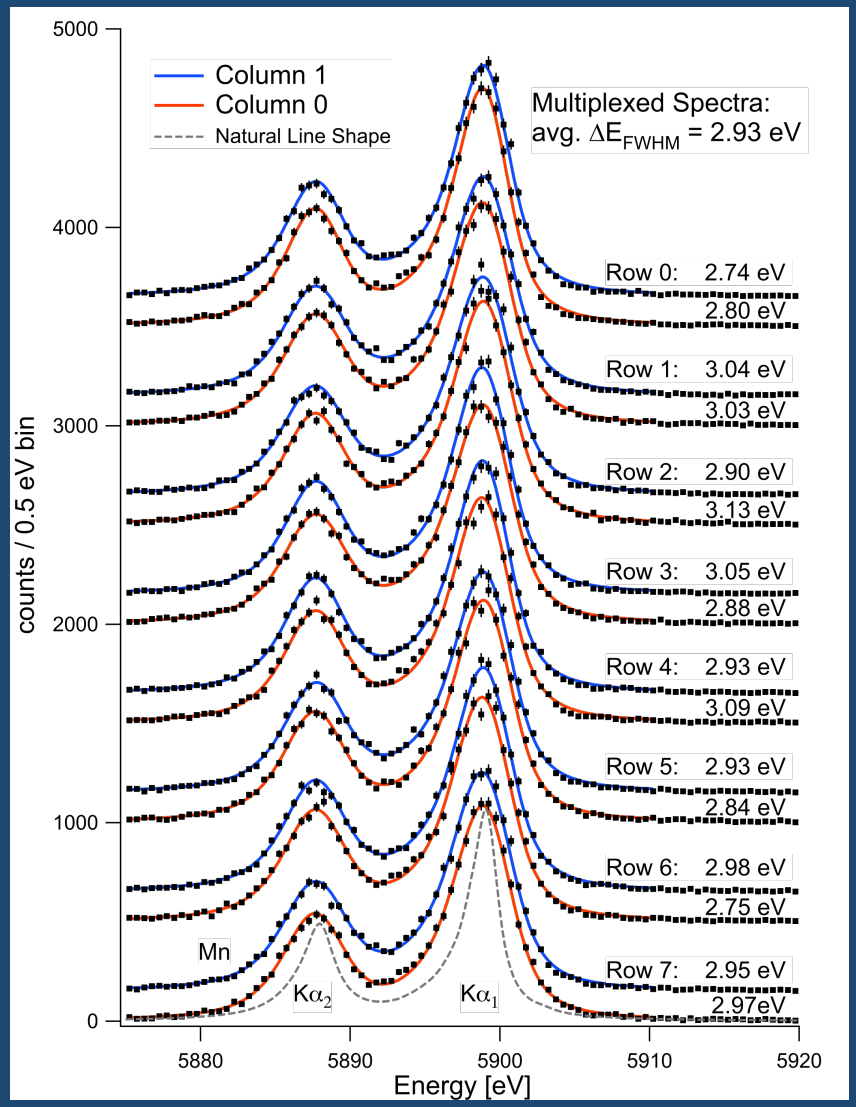


- <u>Published Science Results</u>
  - 1. Weak Iron lines show that most Fe is missing from Galactic hot gas.
  - 2. Bright lines with redshift <.005 show that most of thermal radiation is **not** from a hot IGM
  - 3. CVI lines could be used to determine contributions from charge exchange on solar wind heavy ions
  - 4. Plasma line diagnostics on hot gas in bubble surrounding the Sun
  - 5. First detection of long-sought Iron M-lines
  - 6. Lack of counts below 50 eV rules out Strongly Interacting Dark Matter candidates.

State-of-the-art in X-ray Calorimeters

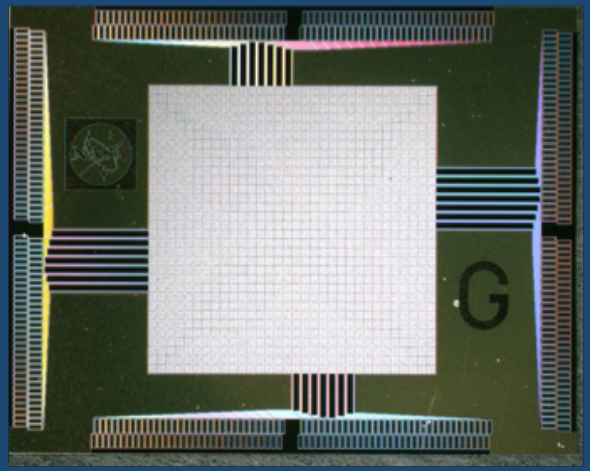


16 channels read out simultaneously



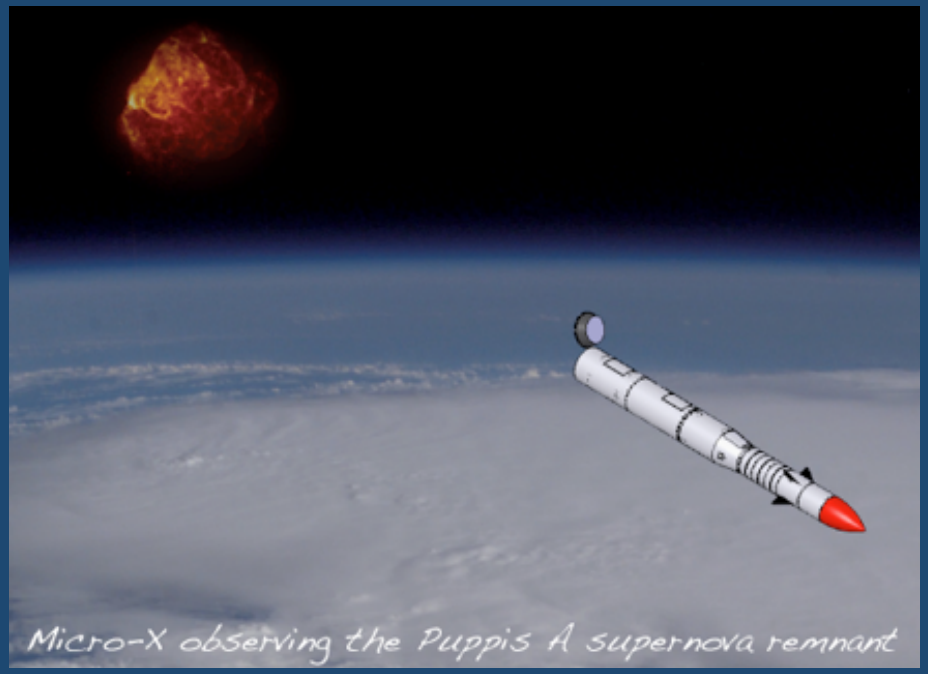
Next step:

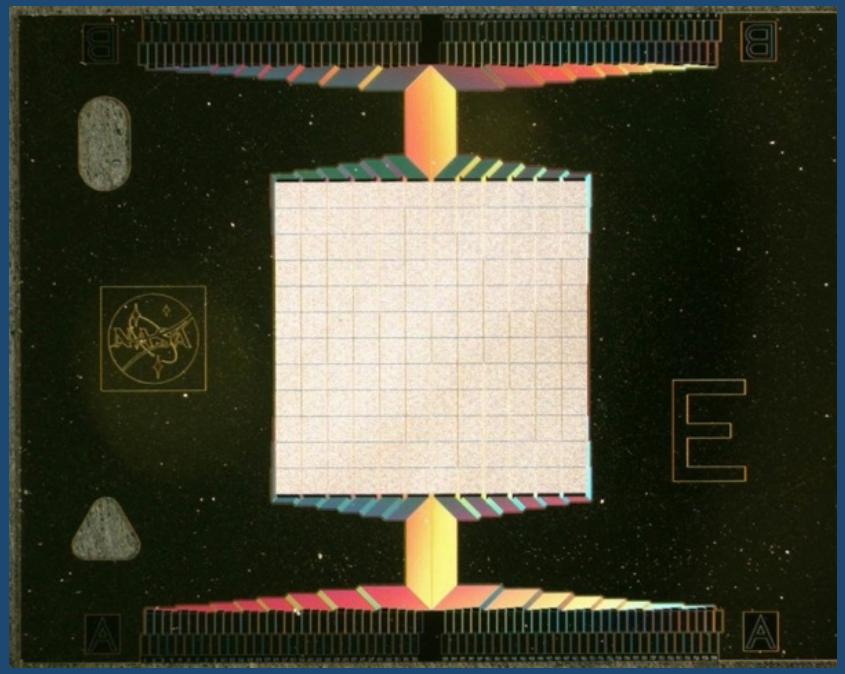
32 x 32 arrays



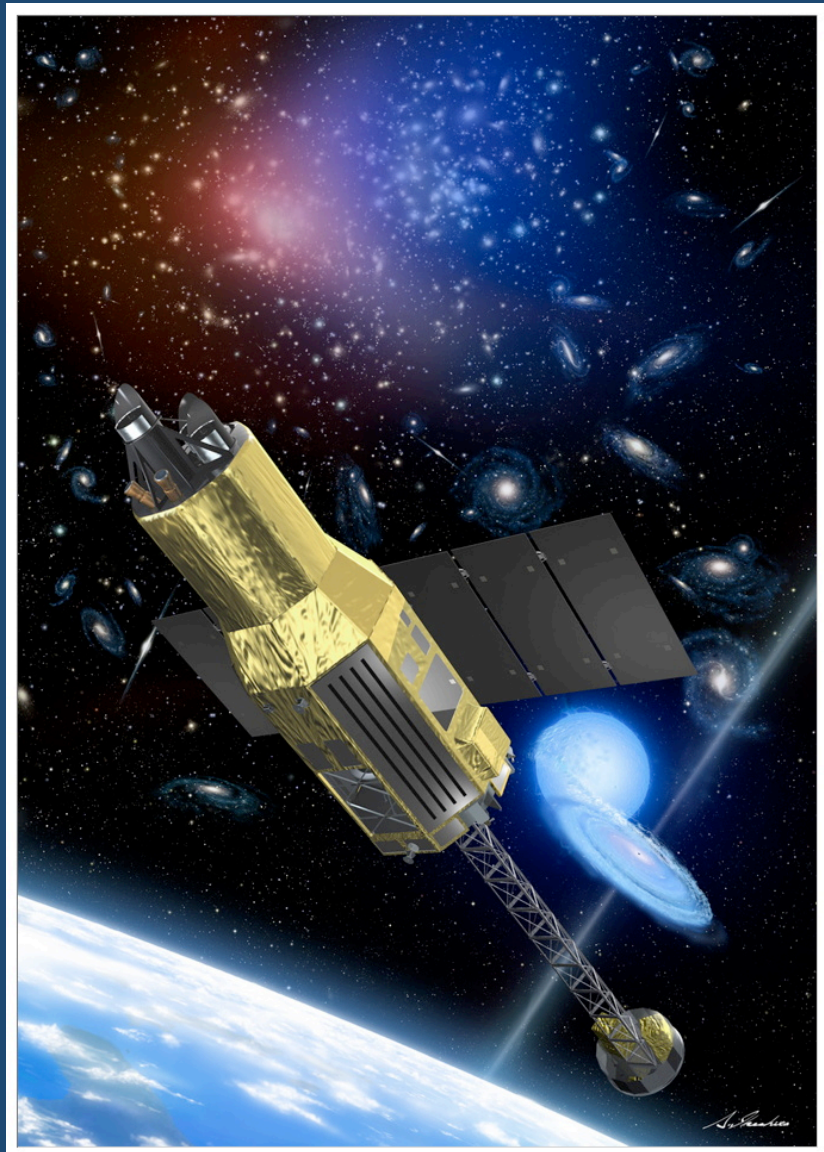
Micro-X

- Suborbital payload to study large SNR's
- 12 x 12 array
- Launch planned for 2011
- MIT/GSFC/NIST/U. Wisconsin/U. Miami/U. Florida

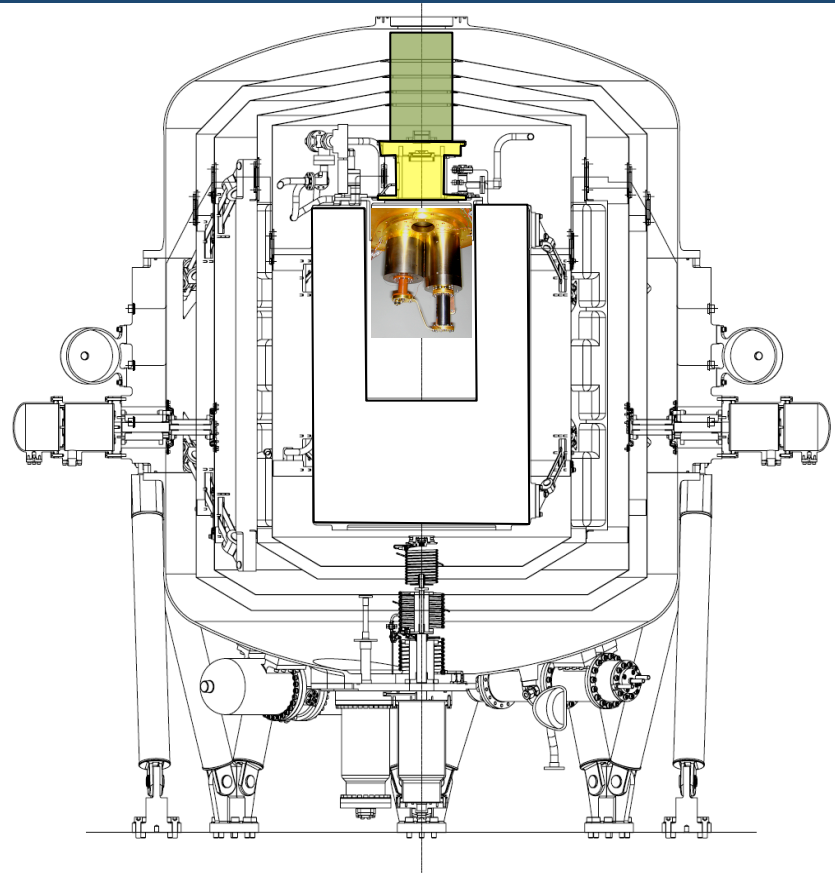




The Astro-H *Soft X-Ray Spectrometer*



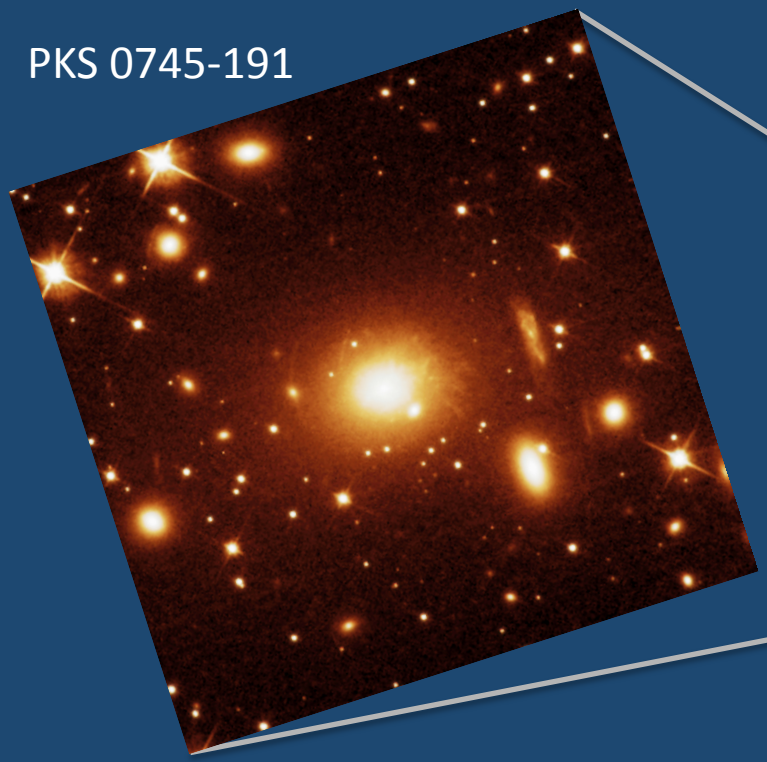
- NASA/JAXA collaboration
- Hybrid cryogen/cryocooler dewar for long life
- Launch in 2014



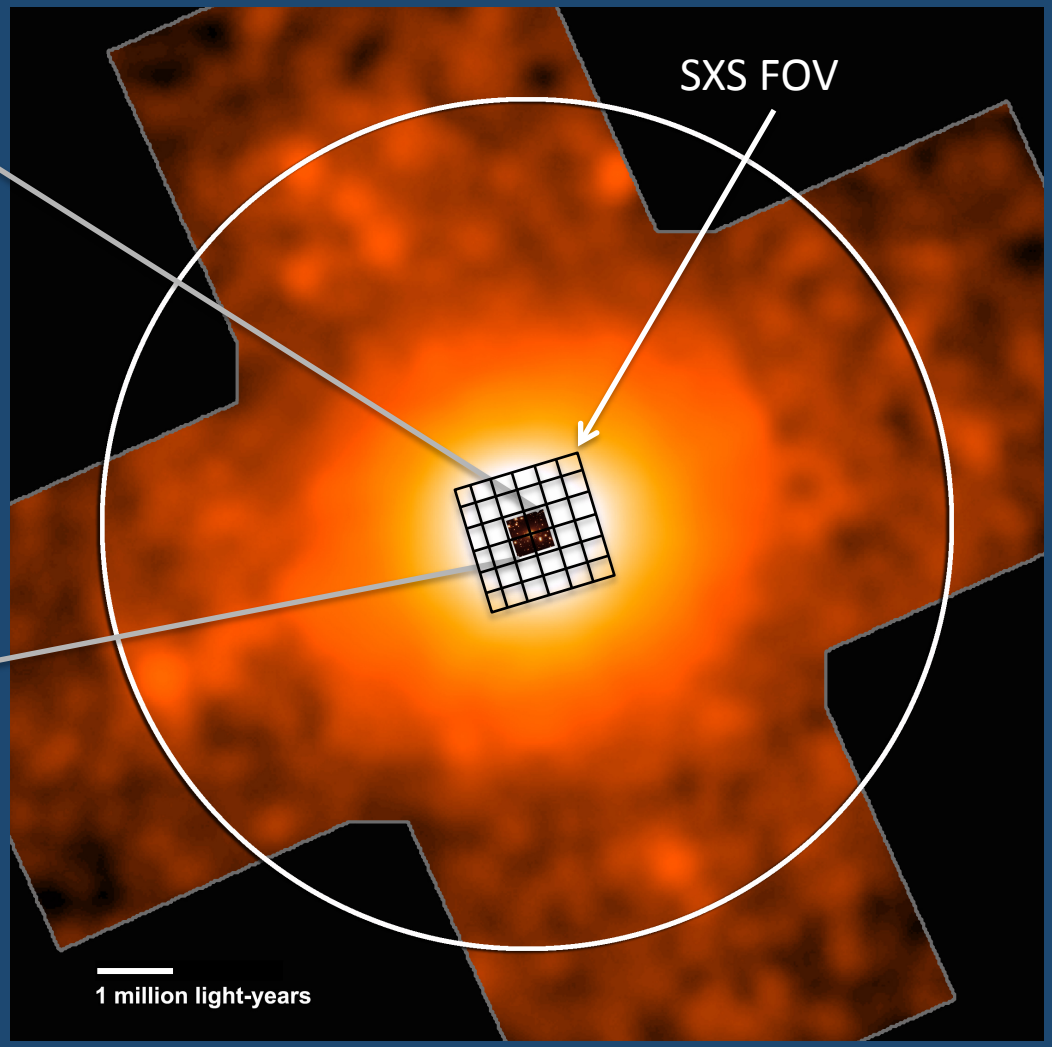
The power of non-dispersive spectroscopy: Clusters of Galaxies

Suzaku Snaps First Complete X-ray View of a Galaxy Cluster

PKS 0745-191

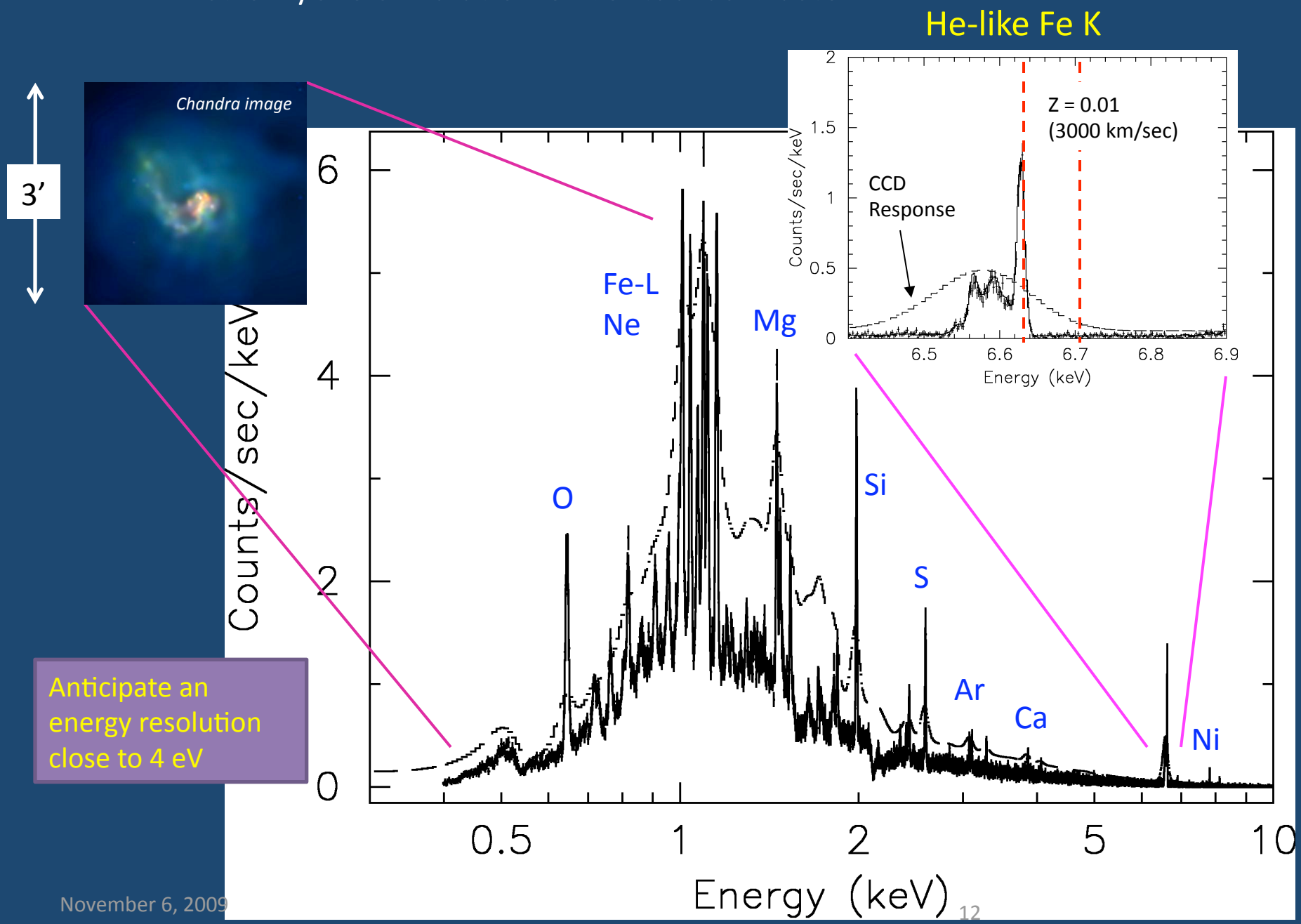


Credit: NASA/STScI/Fabian, et al.



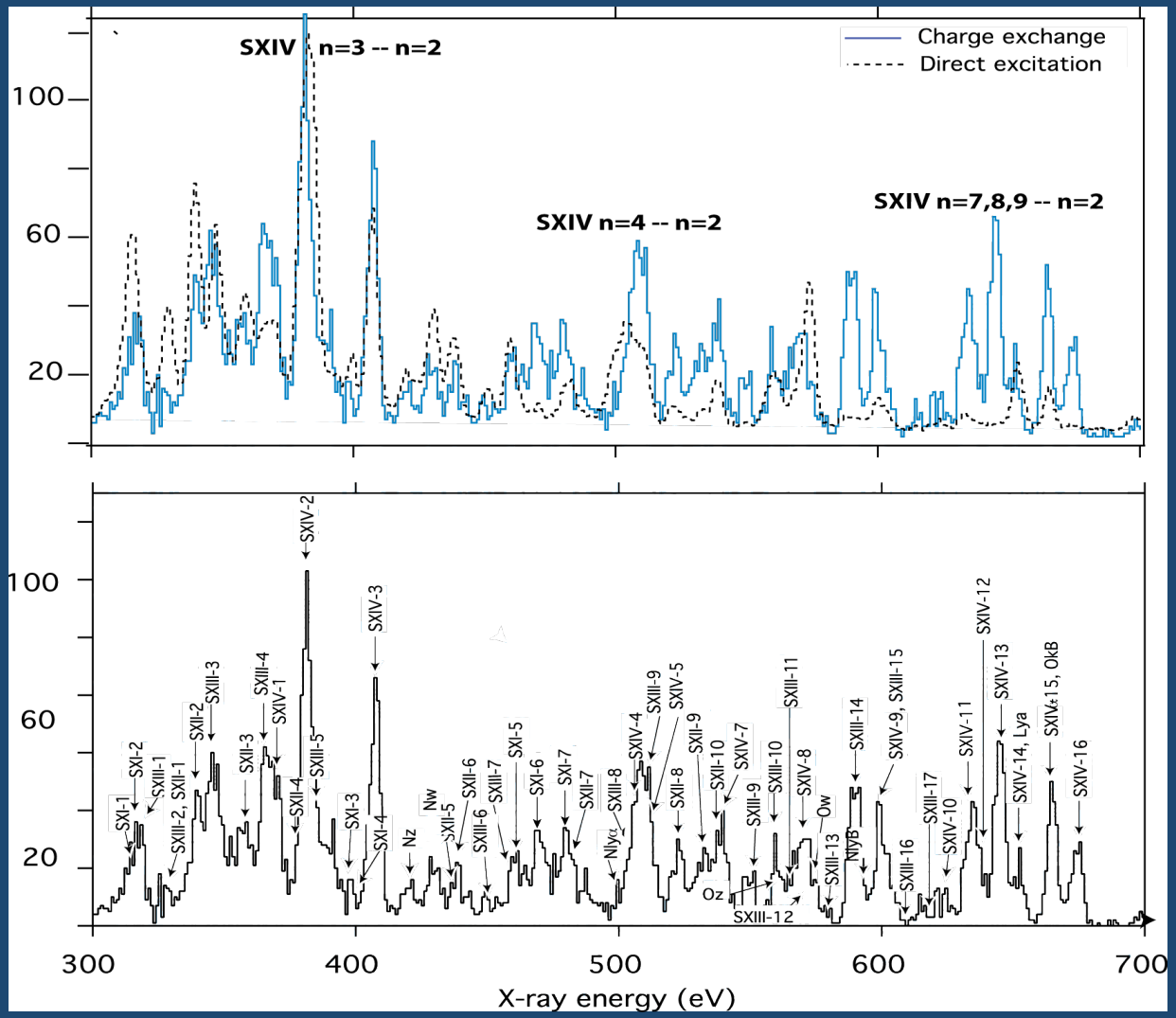
Credit: NASA/ISAS/Suzaku/M. George, et al.

Astro-H/SXS Simulation of *Centaurus* Cluster



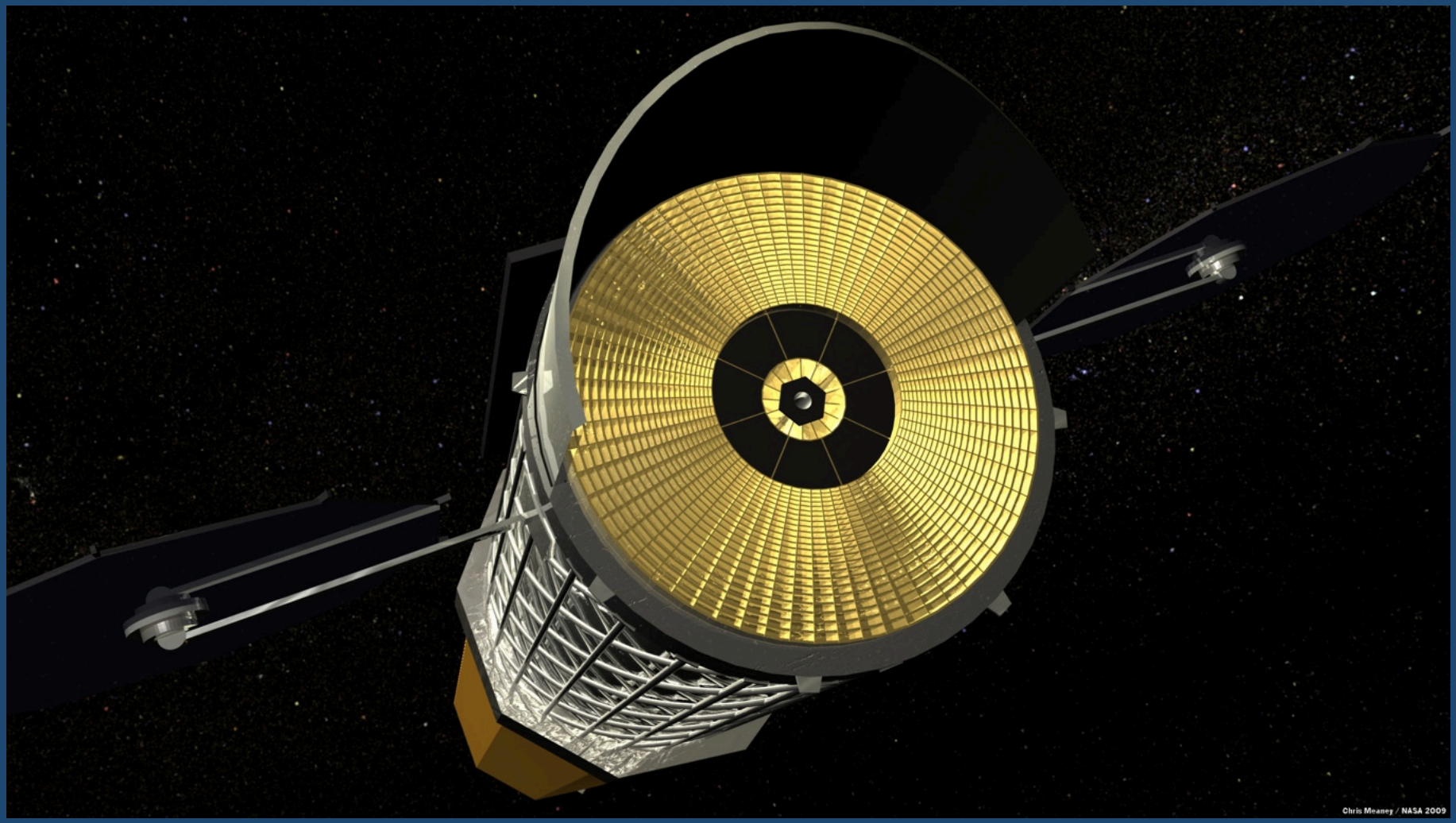
Anticipate an energy resolution close to 4 eV

X-ray calorimeters for atomic physics measurements

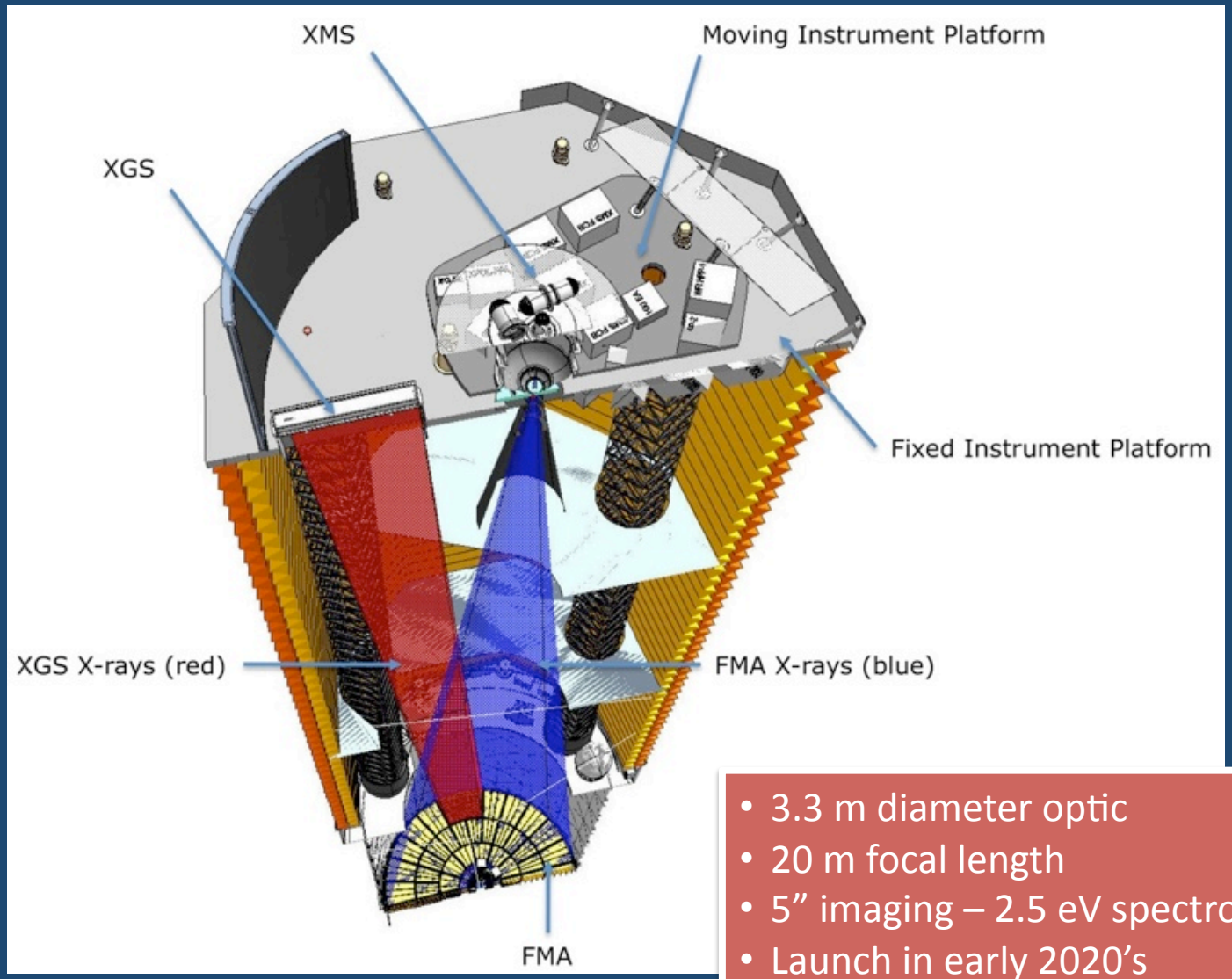


Measurements obtained using GSFC x-ray calorimeter with LLNL electron-beam ion trap

The International Observatory

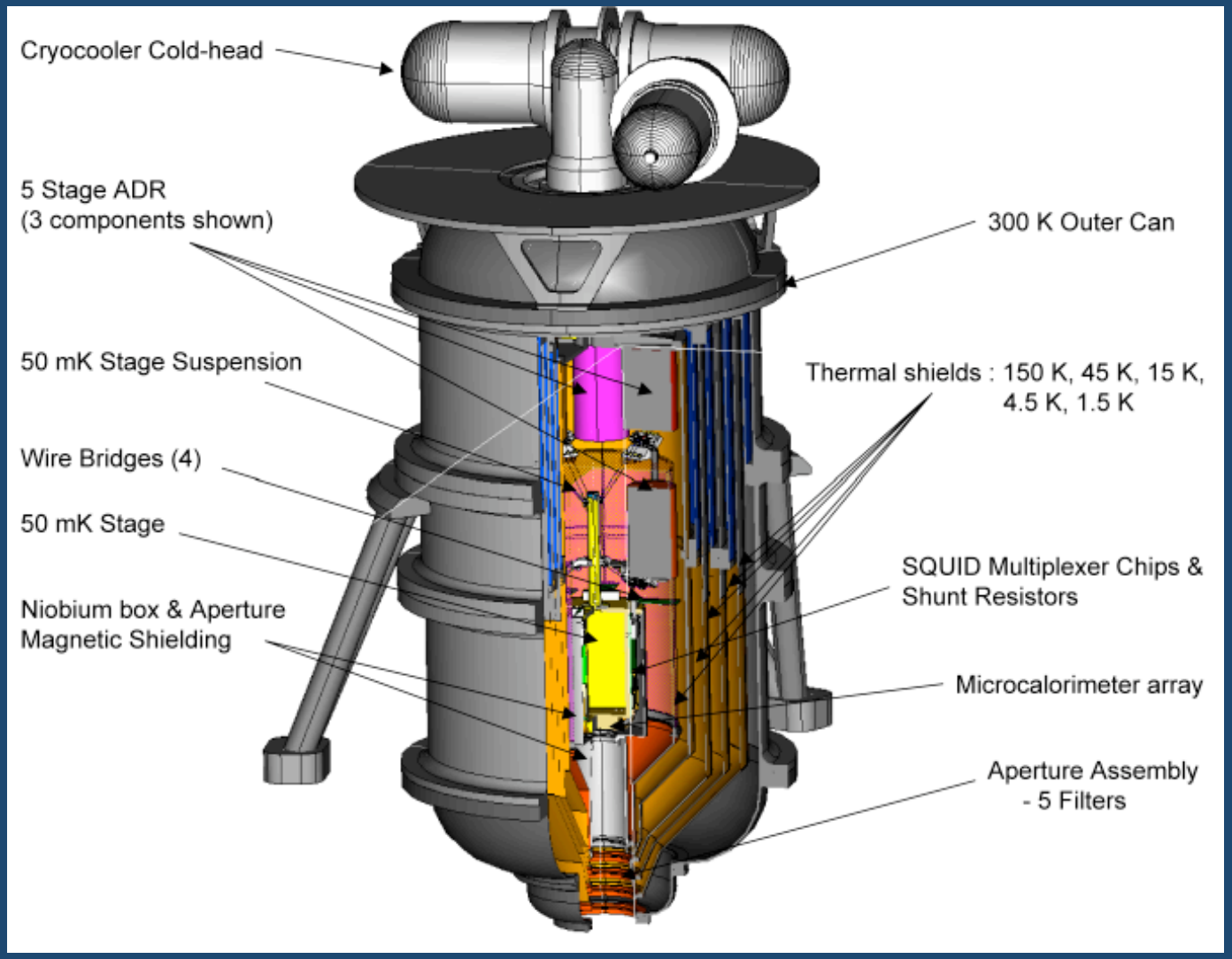


IXO Instruments



- 3.3 m diameter optic
- 20 m focal length
- 5” imaging – 2.5 eV spectroscopy
- Launch in early 2020’s

The IXO X-Ray Microcalorimeter Spectrometer



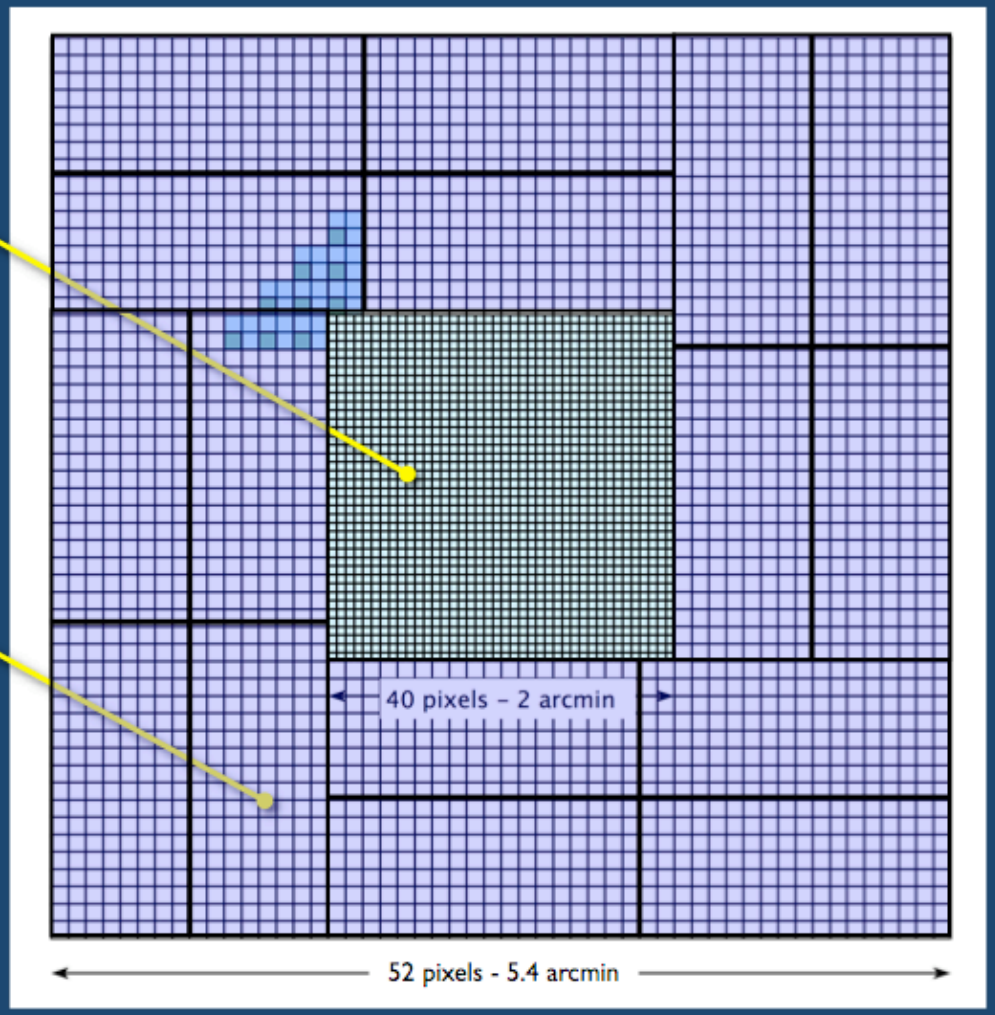
Thousands of Pixels

Central, core array:

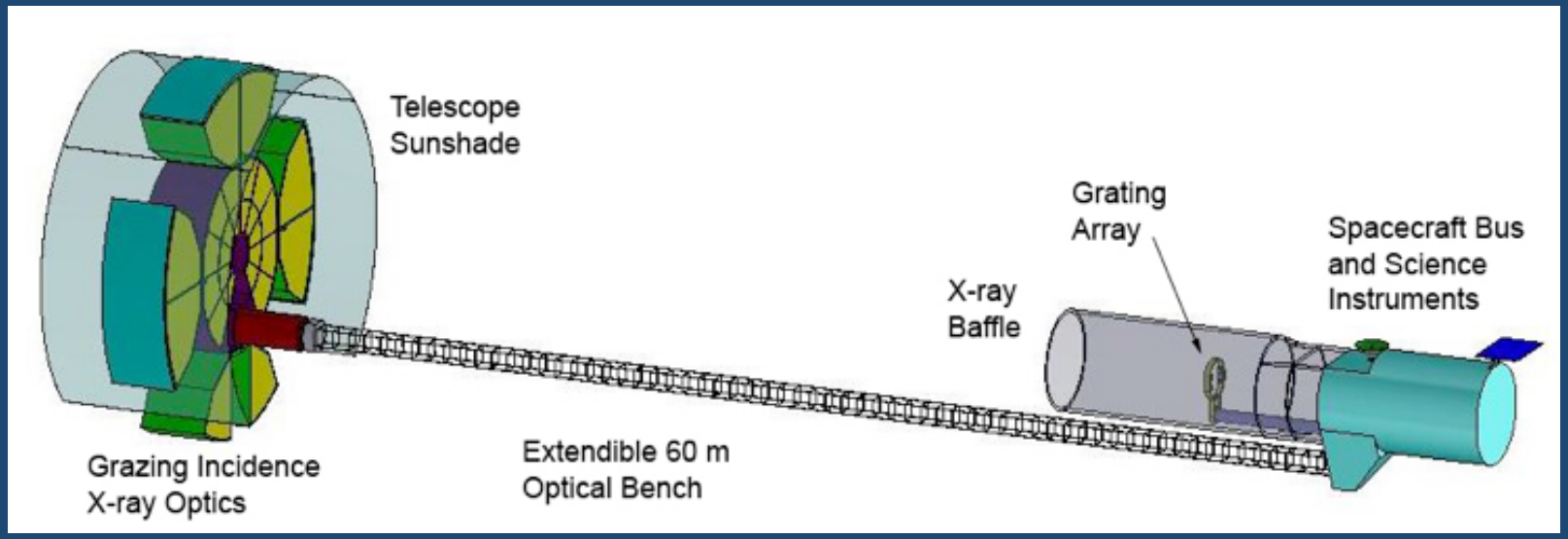
- Individual TES - one absorber/ TES (40 x 40 pixels)
- 300 x 300 μm pixels (2 arcmin FOV)
- 2.5 eV resolution (FWHM)
- Speed < 300 μsec (time constant)

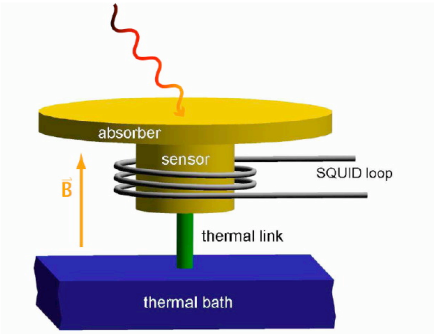
Outer, extended array

- Four absorbers/TES
- 52 x 52 pixels (total of 2176 readout channels)
- 600 x 600 μm pixels (5.5 arcmin FOV)
- < 10 eV resolution
- ~ 2 msec time constant



Gen-X: A million calorimeter pixels?





operation at low temperatures (T<100mK)

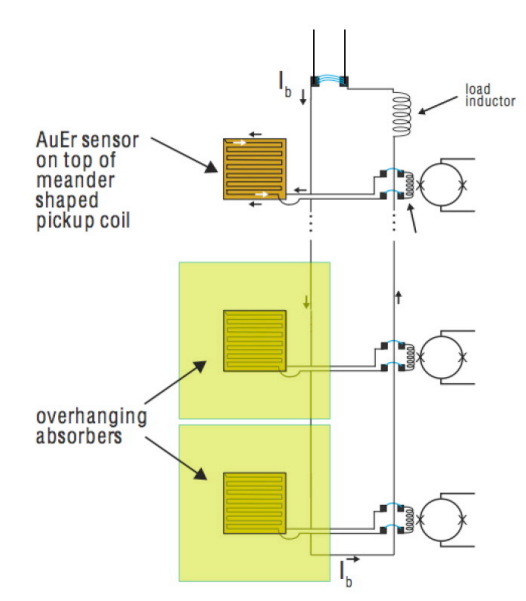
small heat capacity

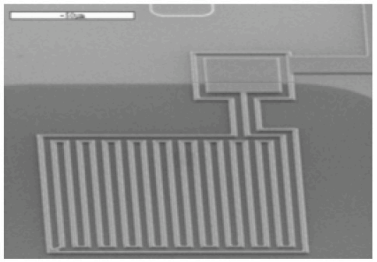
large temperature change

small thermal noise

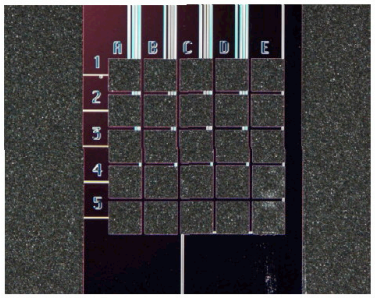
main differences to resistive calorimeters

no dissipation in the sensor





5x5 array :



Elihu's Legacy…

High resolution x-ray spectroscopy, with imaging, using calorimeters will enable breakthroughs in astrophysics.

Elihu Boldt helped to launch this new frontier.