The Constellation X-ray Mission

Harvey Tananbaum
Nicholas White
Robert Petre
Jay Bookbinder
Mike Garcia
Ann Hornschemeier
Paul Reid
Mark Freeman
Will Zhang
Richard Kelley

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CHANDRA BRINGS X-RAY ASTRONOMY to FOREFRONT

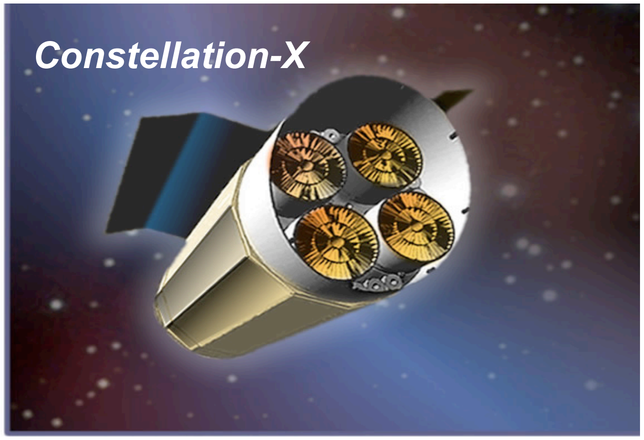
Chandra imaging 0.5-1" comparable
to typical ground-based O/IR telescopes

More than 2000 Chandra investigators to date
publishing nearly 500 refereed papers per year

Most X-ray SPECTRA still colors like U/B/V

Grating exposures show richness of data - but only for
brightest sources with long exposures

CONSTELLATION-X OPENS WINDOW of X-RAY SPECTROSCOPY



Throughput: 50-100x Chandra and
XMM gratings

Resolution: 300-1500 (3000 goal)

Good spectra (>~ 1000 cts at $f_x \sim 10^{-15}$)
for 1000's of sources

THE PHYSICS IS IN THE SPECTRA
X-ray Astronomy becomes X-ray Astrophysics

CONSTELLATION-X SCIENCE OBJECTIVES

Black Holes

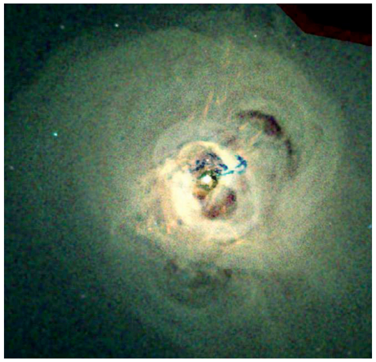
- Observe matter spiraling into **Black Holes** & test the predictions of General Relativity
- Study distant/faint sources to trace the evolution of **Black Holes** with cosmic time

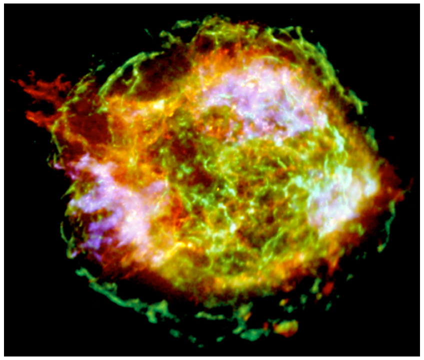
Dark Matter and Dark Energy

- Use clusters of galaxies to trace dark matter and as probes for amount and evolution of dark energy

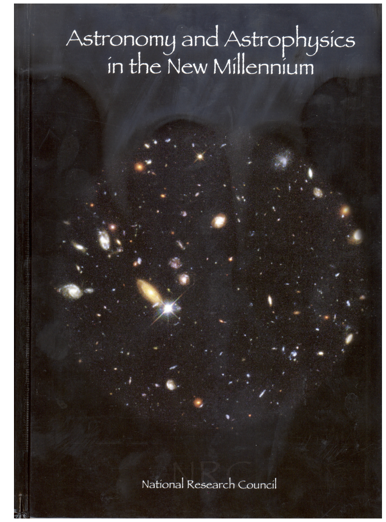
Cycles of Matter and Energy

- Investigate the influence of **Black Holes** on galaxy formation
- Search for the hot missing matter in the Cosmic Web
- Study behavior of matter at extreme densities & magnetic fields using **neutron stars**
- Measure production of heavy elements in **Supernovae**

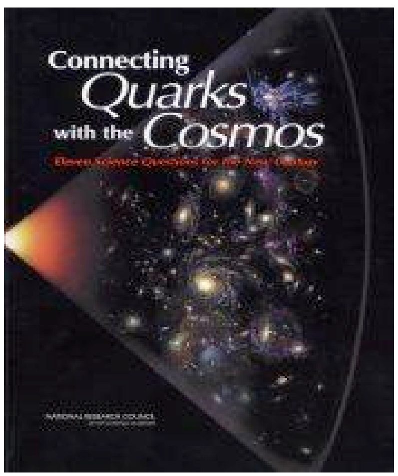




SCIENCE PRIORITY (reviews by National Academy)



The Astronomy and Astrophysics in the New Millennium (2000) decadal survey ranked Constellation-X priority next after JWST among large new space observatories

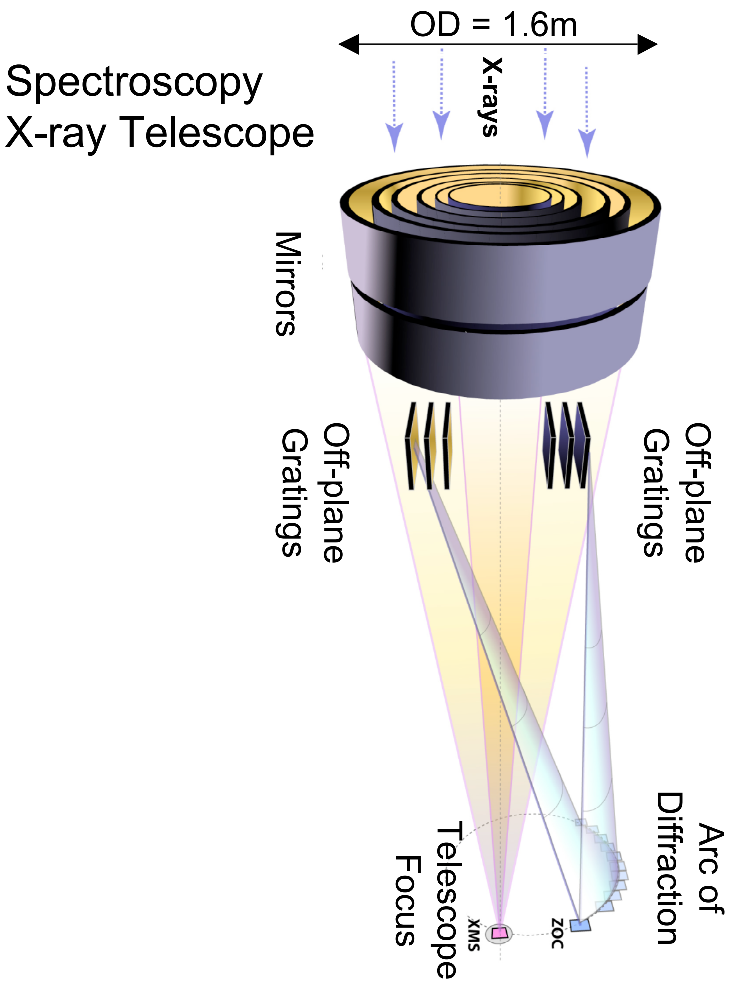


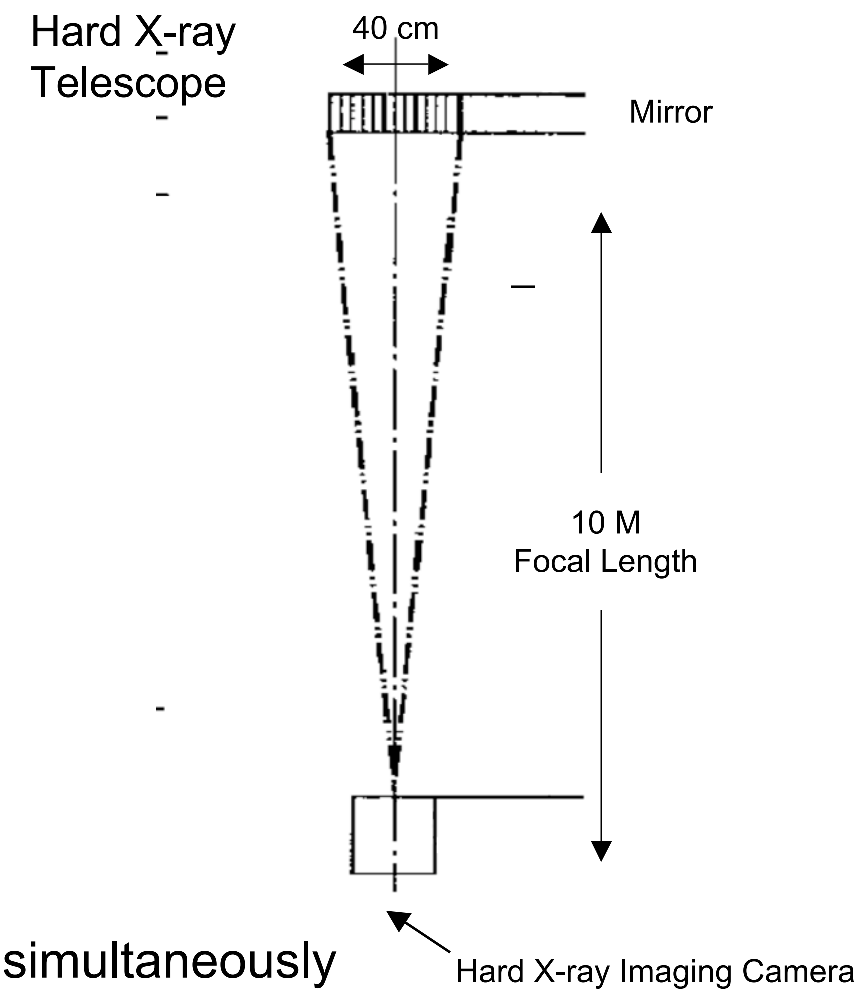
The NRC study Connecting Quarks with the Cosmos strongly endorsed the Constellation-X mission and provided a context for the overall Beyond Einstein program.

The National Academy Mid-Course Review (2005) Endorsed Decadal plan

CONSTELLATION-X PAYLOAD

Baseline configuration of 4 SXT and 12 HXT divided across four spacecraft





All instruments operate simultaneously

SHORT HISTORY of CONSTELLATION-X

- Merger of 2 proposals selected in 1995 for concept studies
- Ranked immediately after JWST in AANM Decadal Survey
- Approved as new start in FY04 NASA Budget (along with LISA)
- Funding reduced in FY05 with announcement of Exploration Initiative
- Funding reduced mid-2006 with release of FY07 budget request
- Future budget projections for NASA Astrophysics "tight"
- Slips for any mission add ~3-3.5% per year due to inflation
- Launch costs have escalated substantially

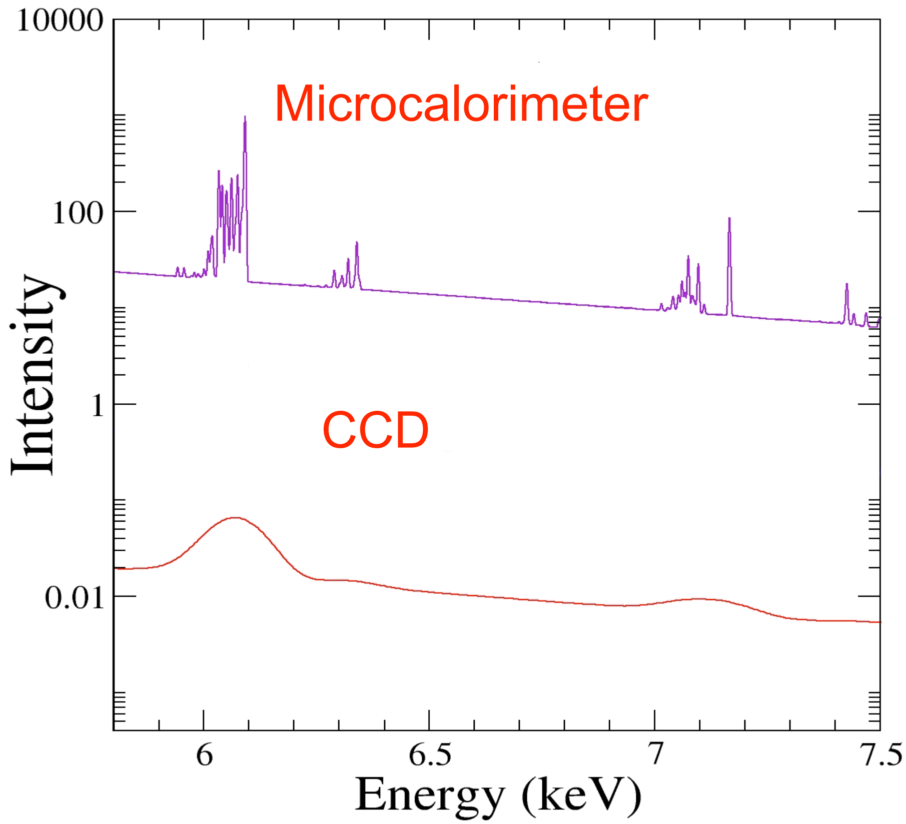
Can we simplify the mission and reduce its cost?

A STREAM-LINED CONFIGURATION

- Retain effective area over 0.6-10 keV band (Fe K lines)
- Reduce mass and envelope to fit within single Atlas V 551
- Requires dropping Reflection Grating Assembly and Hard X-ray Telescope and either fewer or smaller Spectroscopy X-ray Telescopes with Calorimeters
- Significant cost reductions - $720 Million RY$ less than 2 launch 4 satellite TRIP configuration
- Launch in 2017. Possibly 2016 with increase in early year $$
- Estimated cost of streamlined mission - $1946 Million RY$
  - $100 Million Science Enhancement Package included
  - $480 Million MO&DA for pre-launch and five year life time

X-RAY SPECTROSCOPIC TECHNIQUES: WHY CALORIMETERS

Grating spectrometers have very high resolution at low energies, which degrades with increasing energy. Lower efficiency (typically 20%) and not well-suited for extended sources.



X-ray CCDs are excellent for imaging over large fields of view, but have comparatively low spectral resolution with count rate limitations due to pile-up for brighter sources.

X-ray micro-calorimeters provide high throughput (close to 1) across a broad energy band, 2-4 eV energy resolution, and ability to handle count rates ranging to 1000 c/s per pixel. Most importantly they image extended sources such as supernova remnants, galaxies, and clusters.

IMPACTS TO SCIENCE WITH SXT AND CALORIMETER ONLY

Core Science Objectives	Capability
1.1 GR	1—0.9
1.2 BH properties	1—0.9
2.1 DE/DM	1.0
2.2 ICM Shocks	1.0
2.3 DM,abundances	1.0
2.4 WHIM	0.5
3.1 CXRB CDF	1.0
3.2 AGN evolution	1.0
3.3 outflows, AGN+	0.5
Observatory Science	
4.1 SNR	1.0
4.2 X-ray Binary f(m)	1.0
4.3 Accretion dynamics	1.0
4.4 NS EOS	0.9
4.5 stars	0.8
4.6 comets	1.0

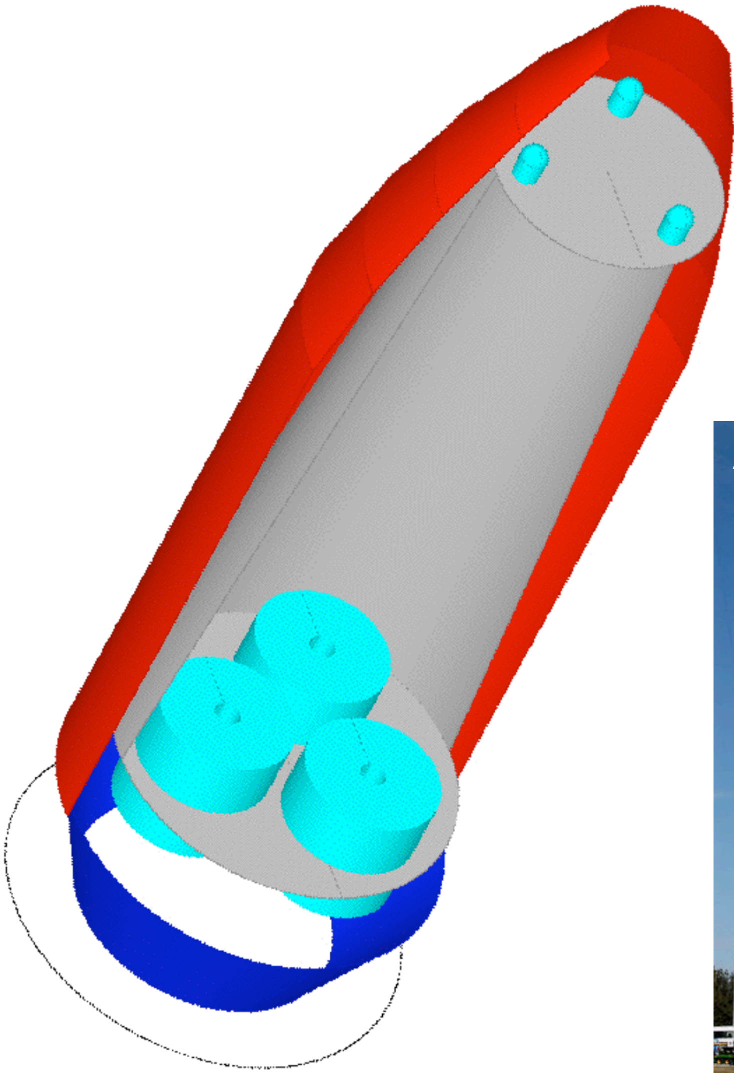
- BH/GR studies utilize HXT
  - Assess options for measuring underlying continuum needed for Fe line shapes
- WHIM/AGN outflow studies utilize RGS
  - Assess trades involving throughput below 1 keV, energy resolution, exposure time, and science achievable with Ne as well as O lines.

POSSIBLE SCIENCE ENHANCEMENT CONCEPTS

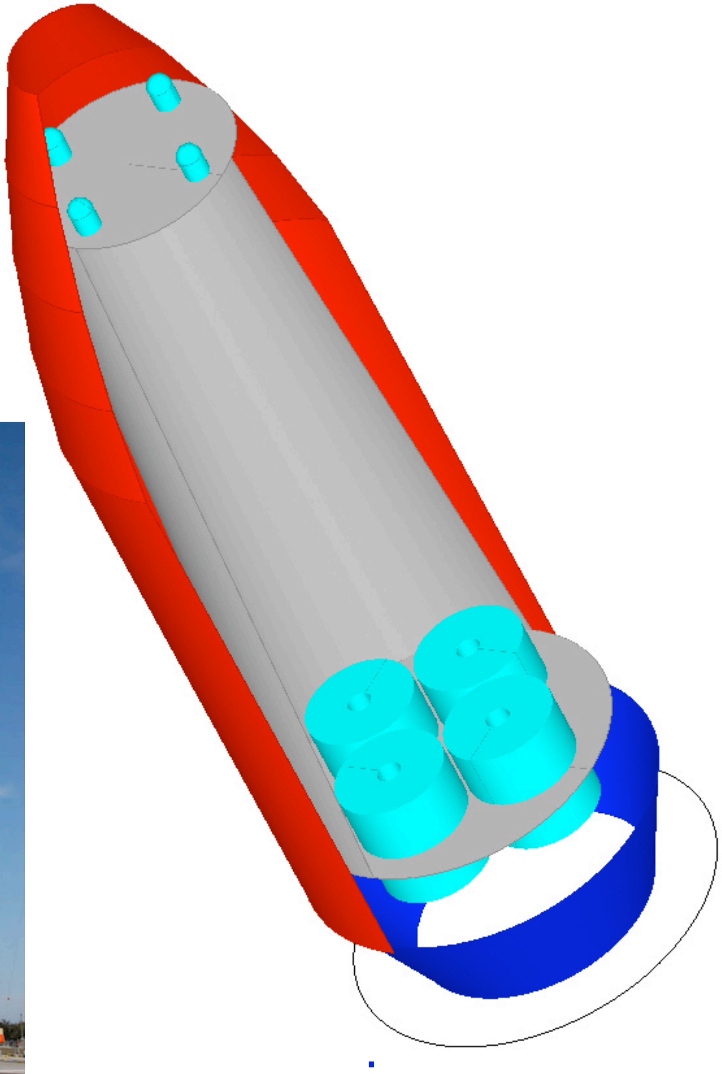
100 kg of mass and $100M budgeted for science instrument(s) to be added to basic SXT/Calorimeter to achieve Con-X science objectives

- High Energies (> 10keV):
  - ✓ Ir or Multi-layers on inner mirrors
  - ✓ Calorimeter to higher Energies
  - ✓ A limited number of HXT telescopes
- Lower Energies (< 1keV):
  - ✓ Hybrid Calorimeter with some pixels providing 1-2 eV resolution below 1 keV
  - ✓ Simplified grating/detector system

CON-X SINGLE ATLAS-V LAUNCH WITH 3 or 4 SXTs and 1 SPACECRAFT



ATLAS V 551



3 vs 4 TELESCOPES

3 telescopes

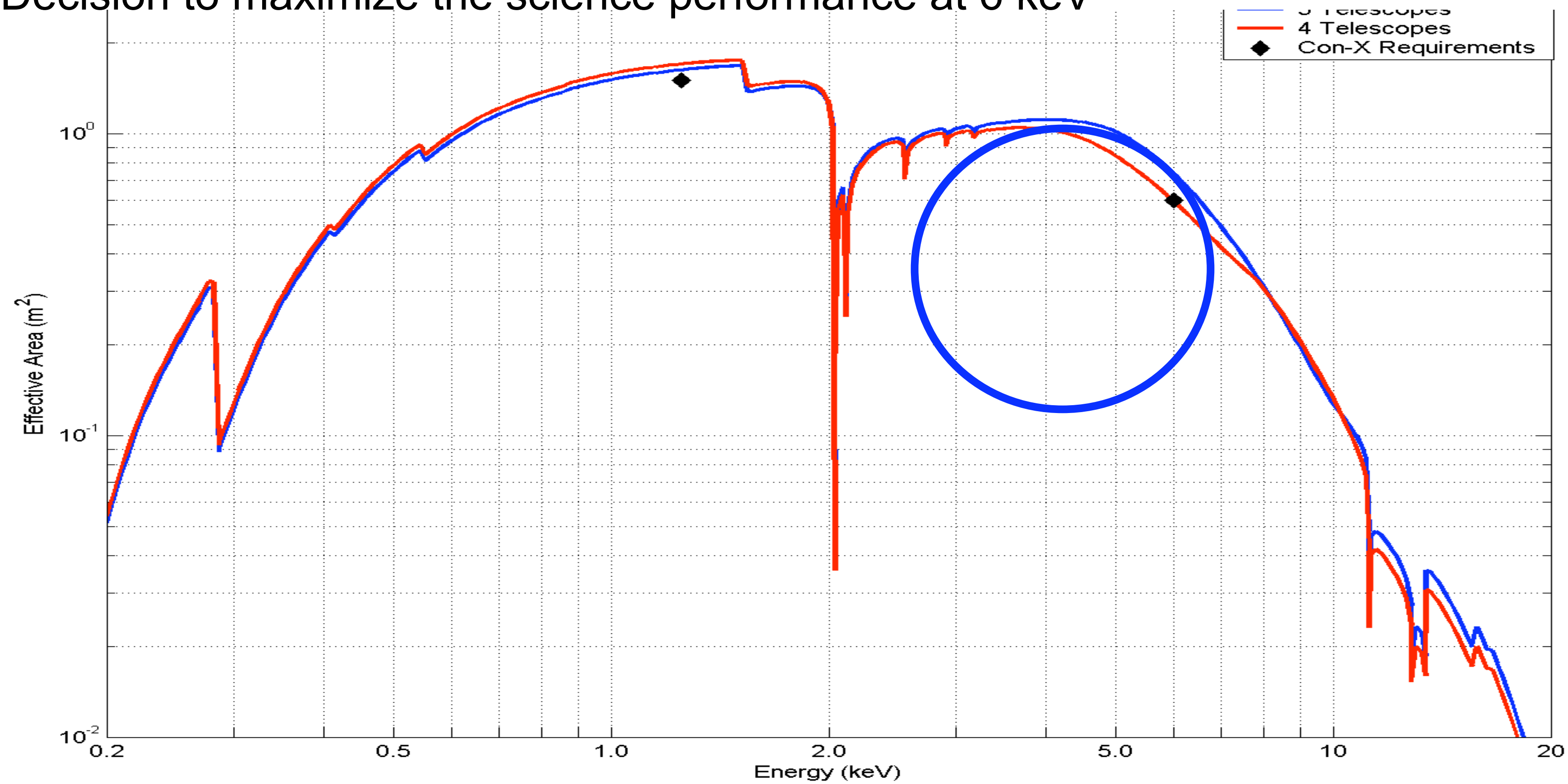
- Characteristics
  - OD = 1.5m, ID = 0.3m, 204 shells each
  - 10116 mirror segments and 54 modules total
- Possibly less expensive
- Only 3 calorimeters
  - lower cost
  - reduced build schedule (although mirrors are critical path)
- Only 3 SEP units if they use SXT
- Optical bench simpler and lighter
- Potentially lower mass
- Less tightly constrained in fairing

4 telescopes

- Characteristics
  - OD = 1.3m, ID = 0.3m, 163 shells each
  - 13040 mirror segments and 40 modules total
- Higher throughput 3-10 keV
- Fewer mandrels needed
  - lower up front cost
  - less time to make mandrels
- FMA design may be simpler
- Needs full cost trade of fewer mandrels against additional instrument and optical bench complexity

Maximizing the science performance

- Top level issue:
  - 4 SXT: Maximize the science performance of the SXT+XMS at 6 keV
  - 3 SXT: Minimize cost and mission mass
- Decision to maximize the science performance at 6 keV

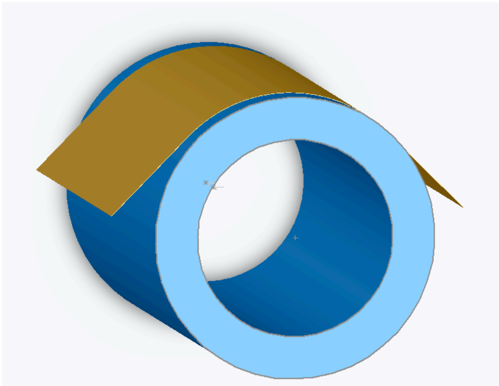


PRELIMINARY MASS TABLE

Major Component	Mass (kg)
Mirror End	2179
Optical Bench/Metering Structure	1011
Detector End	1366
Science Enhancement	100
Launch Vehicle Interface	198
Propellant	214
Total Wet Mass	5068
Atlas Capability to L2 (TRIP)	6498
Contingency	~30%

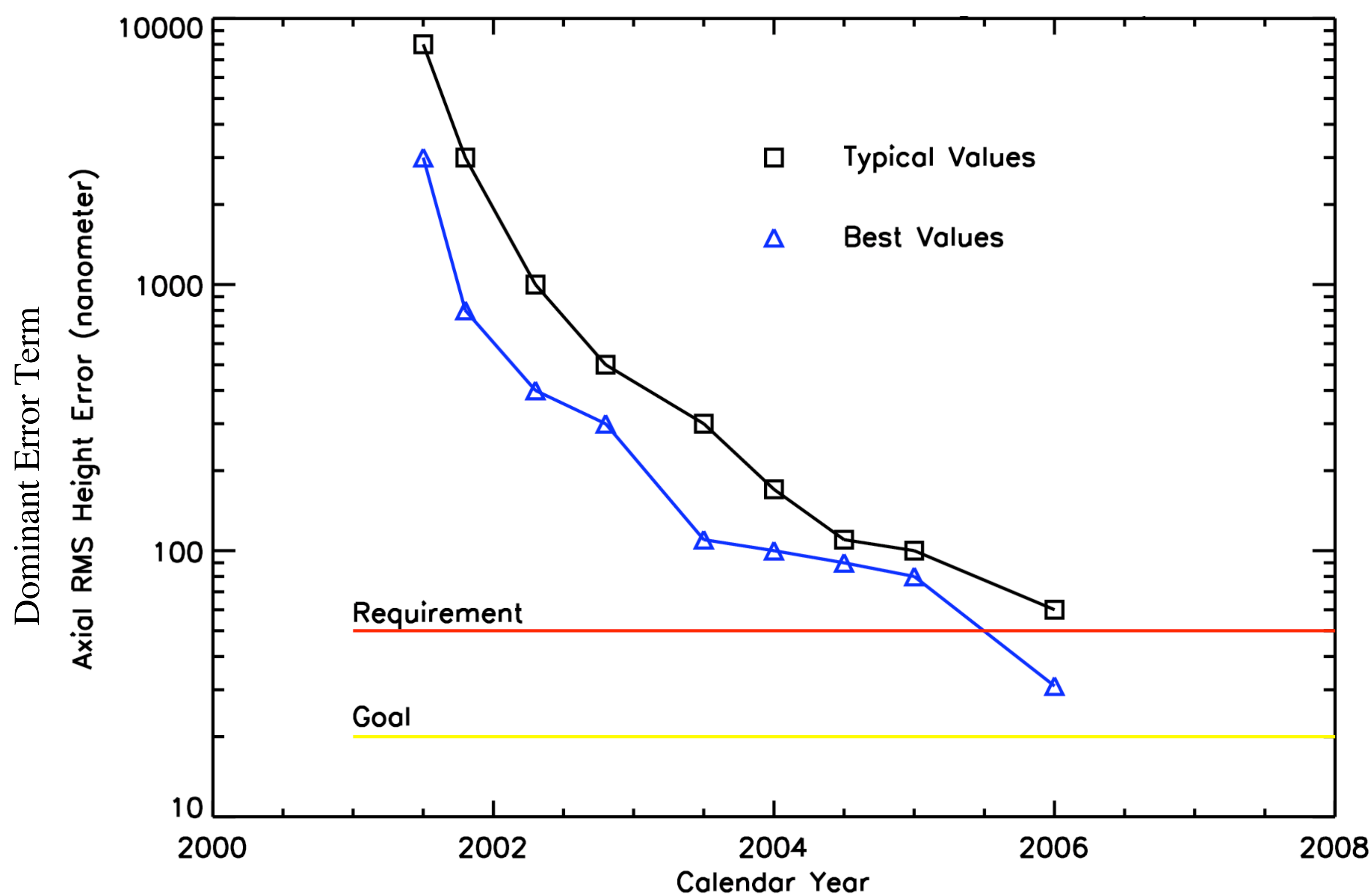
SXT Mirror Segment Progress

Substrate Fabrication



- **Accurate mirror surfaces are the key to attaining the SXT 5 arc sec HPD goal**
- **Substrate**
  - **Thermally formed thin float glass: 0.4mm**
  - **Excellent figure at low spatial frequencies (<0.1 cycle/mm)**
  - **Conforming to forming mandrel to better than 40 nm RMS**
- **Forming mandrels for technology development**
  - **Fabricated by GSFC using fused quartz and by Zeiss using both fused quartz and Keatite**
- **Replication mandrels for technology development**
  - **Fabricated by Zeiss of electroless Ni and Zerodur**
  - **7.5 arc second HPD**
- **Replicated segment performance**
  - **Current performance at better than 20” HPD level, within a factor of 2 of requirements.**
  - **Next generation segments will incorporate forming process improvements, precise forming mandrels, and should approach 10” HPD.**

SPECTROSCOPY X-RAY TELESCOPE REFLECTOR PROGRESS

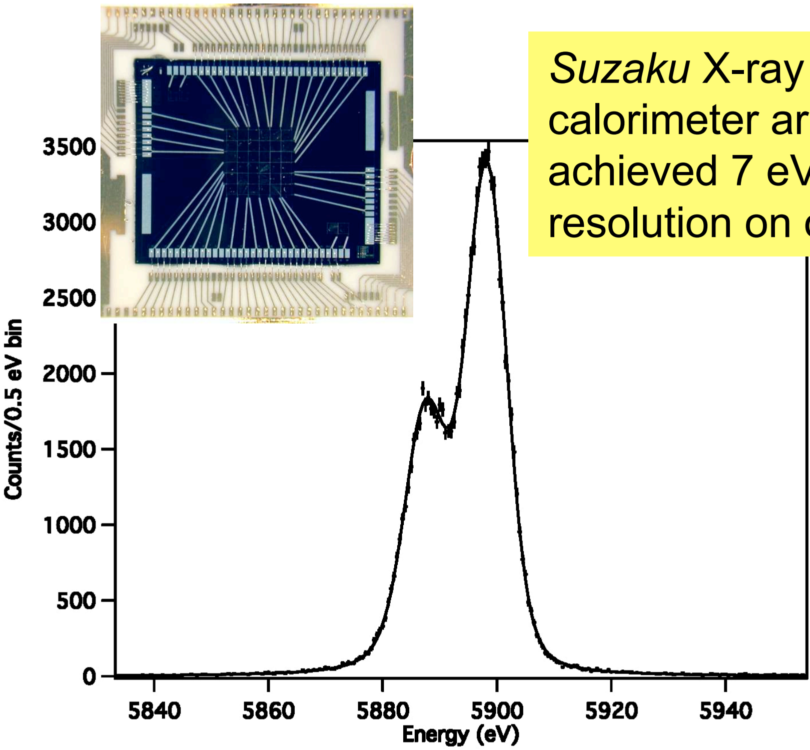


X-RAY MICRO-CALORIMETER SPECTROMETERS

Thermal detection of individual X-rays gives 20-40x better spectral resolution than Chandra CCDs

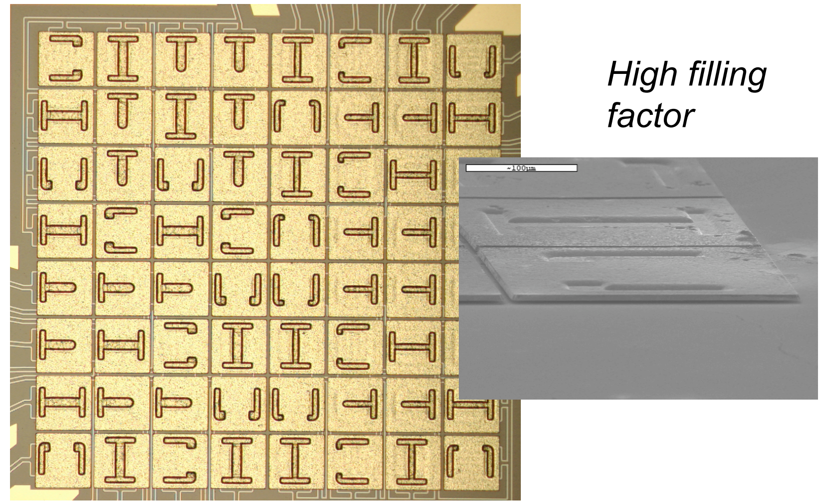
Arrays have been successfully demonstrated on sounding rockets and *Suzaku* (Astro-E2)

XRS: 32 pixels, 640 μm pixels



Suzaku X-ray calorimeter array achieved 7 eV resolution on orbit

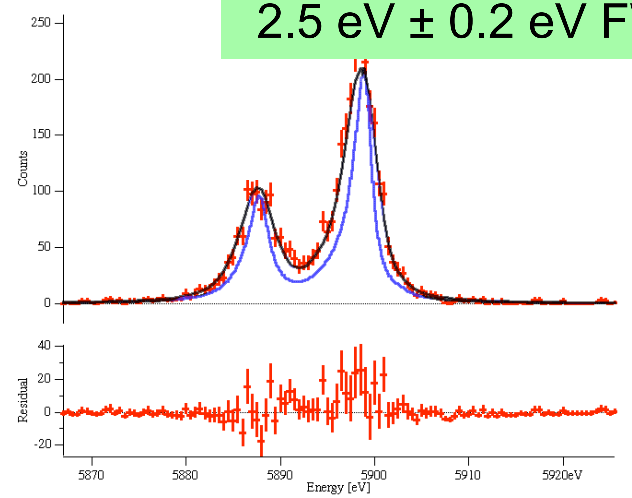
Con-X arrays under development and approaching goal of 2 eV at 6 keV.



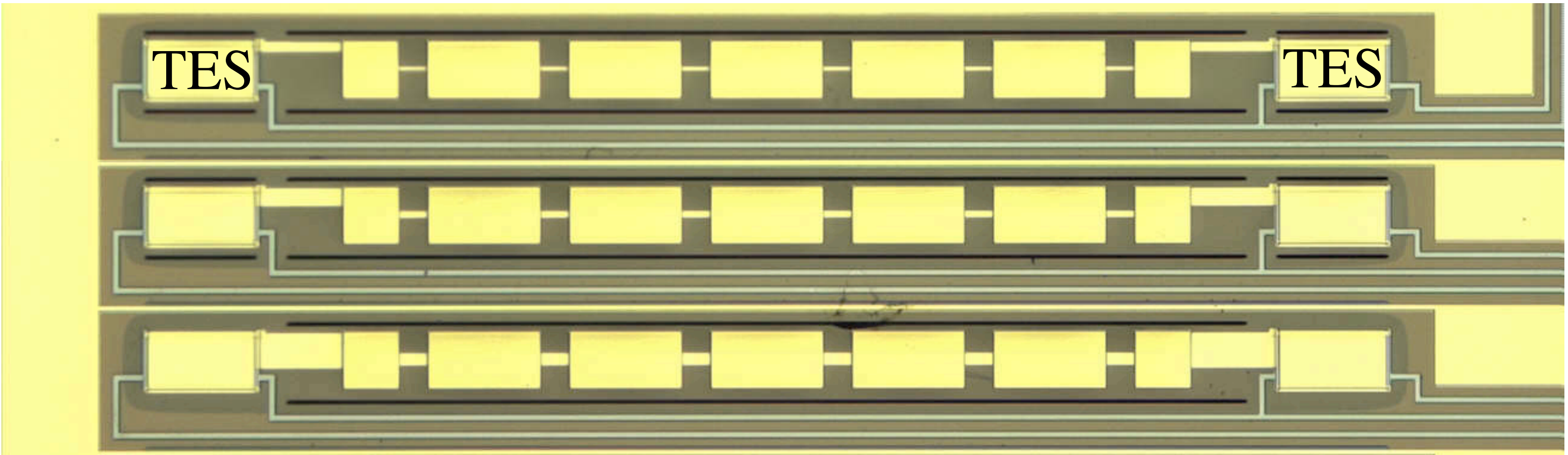
High filling factor

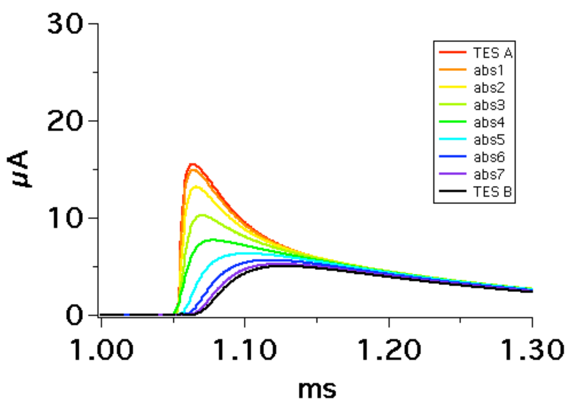
8x8 development TES array for Con-X with 250 μm pixels

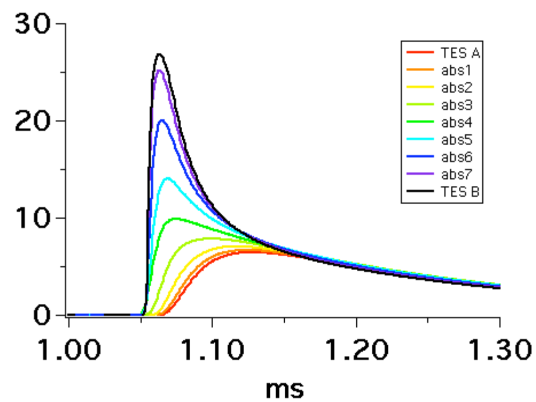
2.5 eV ± 0.2 eV FWHM

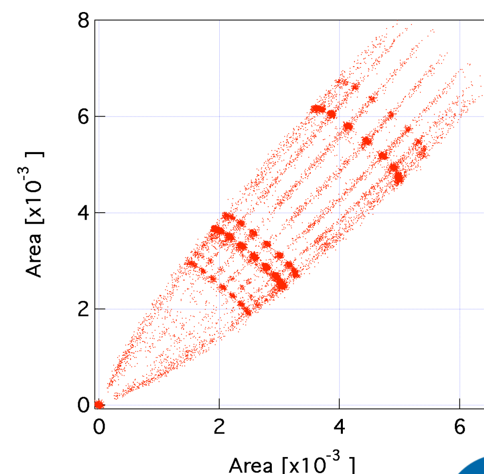


Extended FOV - Position-Sensitive TES (“PoST”)



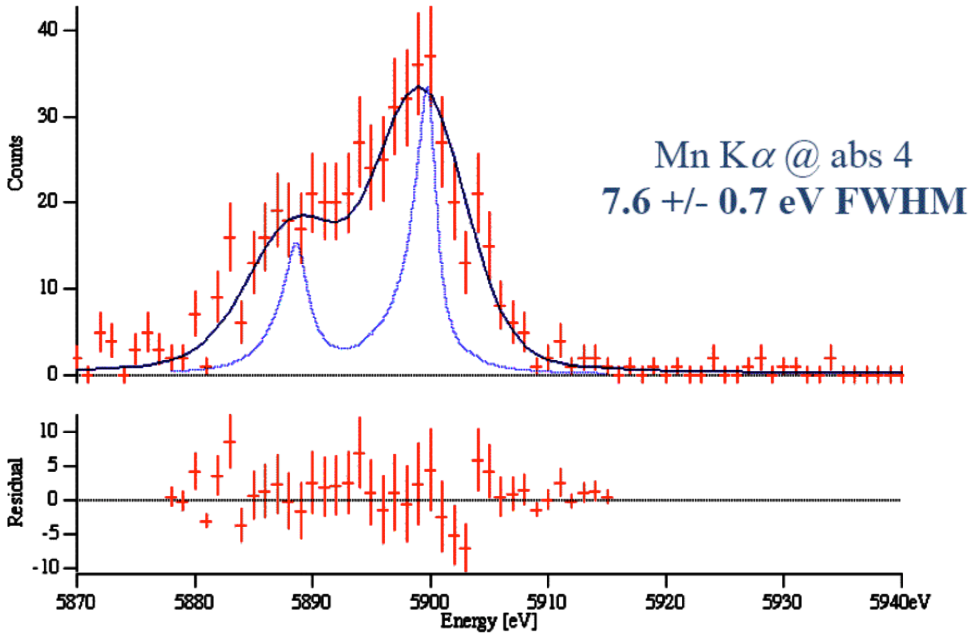


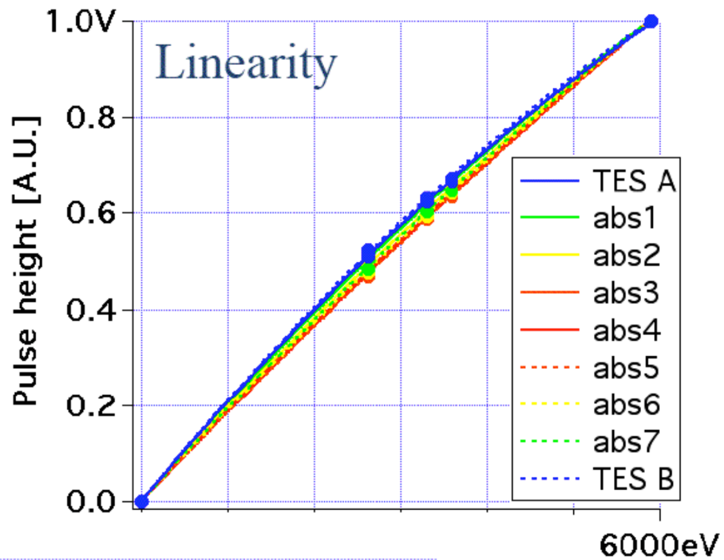


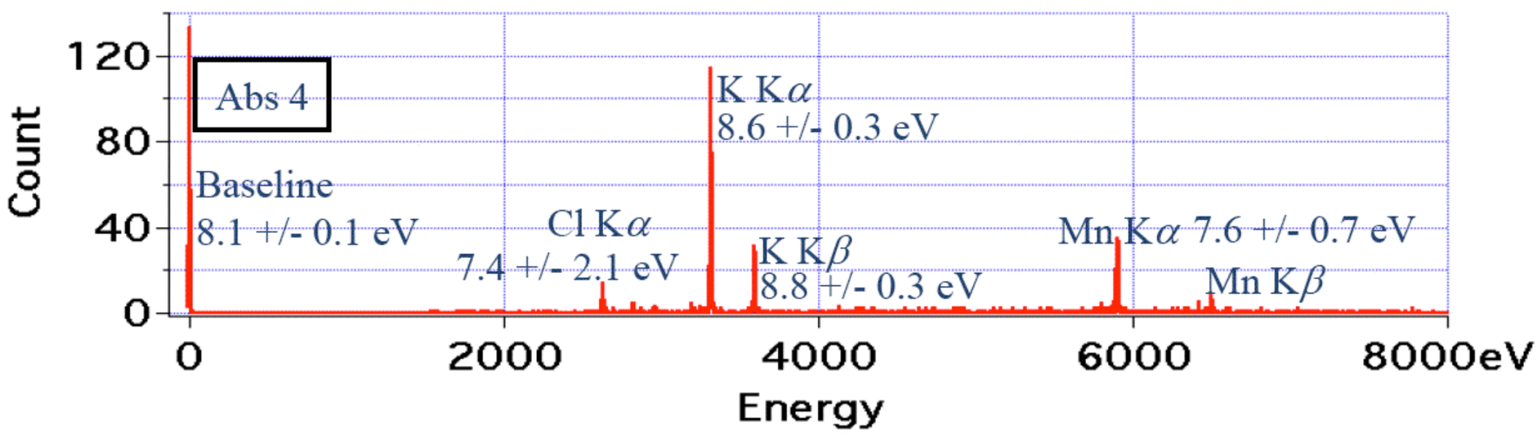


Thermal diffusion gives rise to different pulse responses and hence position; summing signals gives x-ray energy. “PoST” provides path to larger fields of view without significantly increasing electronics.

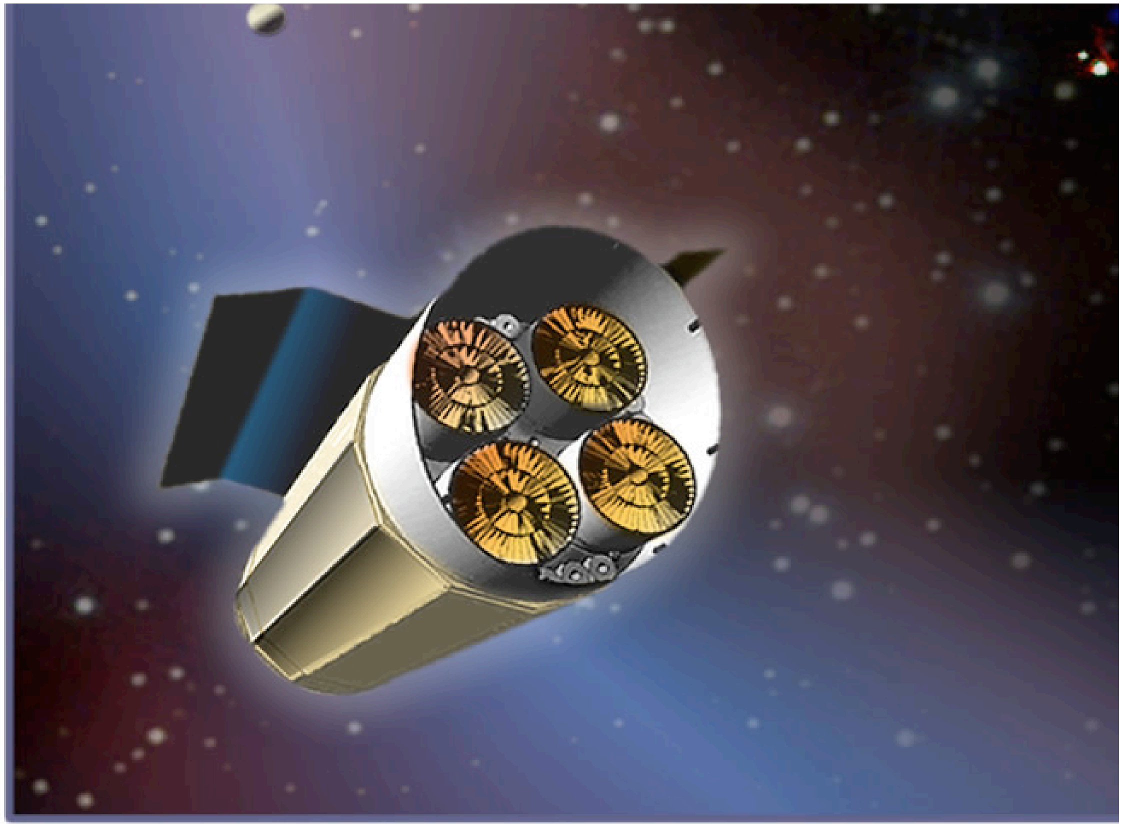
BEST POST RESOLUTION SO FAR:







SUMMARY



Constellation-X opens the window of X-ray spectroscopy to address compelling and high priority science questions on Black Holes, Dark Matter and Dark Energy and the Cycles of Matter and Energy

The technology development continues to make substantial progress

Con-X launched on a single ATLAS V is now our focus, with further simplification and cost savings under study

http://constellation.gsfc.nasa.gov

Effective Area vs Energy (Pt Coating)