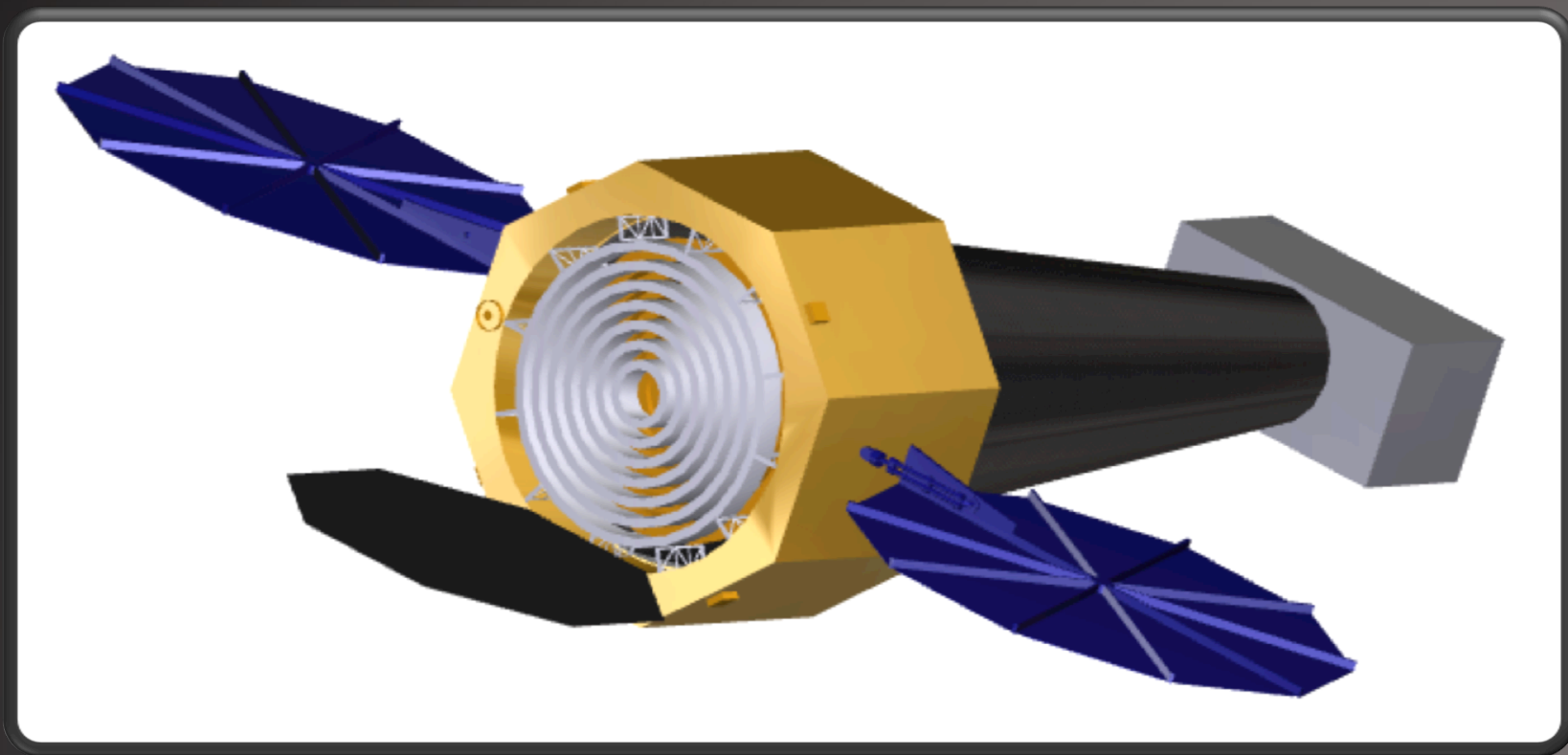


# The X-ray Surveyor

Mission concept, strawman mission design, and preliminary cost estimate

Martin C. Weisskopf (MSFC)

On behalf of the X-ray Surveyor community



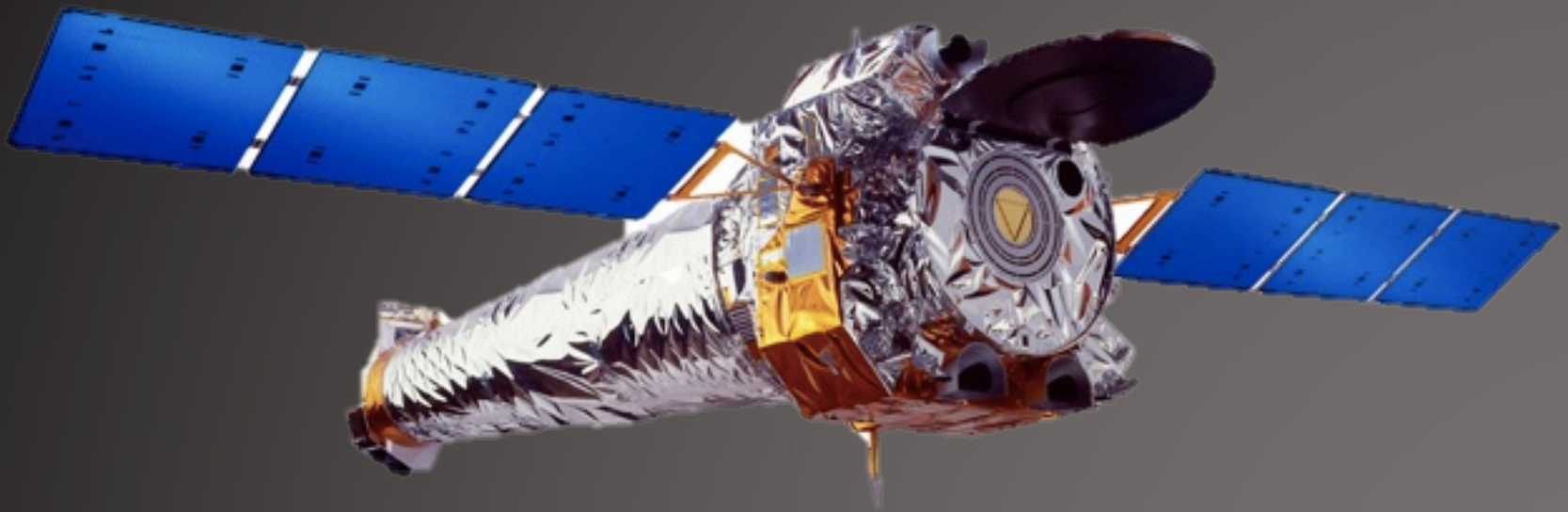
# X-ray Surveyor Mission concept developed by the MSFC Advanced Concepts Office

- Strawman definition: Spacecraft (structures, thermal control, mechanisms, propulsion, guidance, navigation & control, power), instruments, optics, orbit, radiation environment, launch vehicle and costing
- Performed under the guidance of the MSFC-SAO Team, elements of the *Chandra* Project, and the informal mission concept team comprising the following:

M. C. Weisskopf (MSFC), A. Vikhlinin (SAO), J. Gaskin (MSFC), H. Tananbaum (SAO), S. Bandler (GSFC), M. Bautz (MIT), D. Burrows (PSU), A. Falcone (PSU), F. Harrison (Cal Tech), R. Heilmann (MIT), S. Heinz (Wisconsin), C.A. Kilbourne (GSFC), C. Kouveliotou (GWU), R. Kraft (SAO), A. Kravtsov (Chicago), R. McEntaffer (Iowa), P. Natarajan (Yale), S.L. O'Dell (MSFC), A. Ptak (GSFC), R. Petre (GSFC), B.D. Ramsey (MSFC), P. Reid (SAO), D. Schwartz (SAO), L. Townsley (PSU)

# *Chandra* provides unparalleled means for exploring the high-energy universe

*Chandra* studies deepen our understanding of galaxy clusters, active, starburst, and normal galaxies, supernova remnants, normal stars, planets, and solar system objects and advance our understanding of dark matter, dark energy, and cosmology



The key to *Chandra*'s success is its  $\frac{1}{2}$  arcsecond resolution

It is also clear that many *Chandra* observations are photon-limited

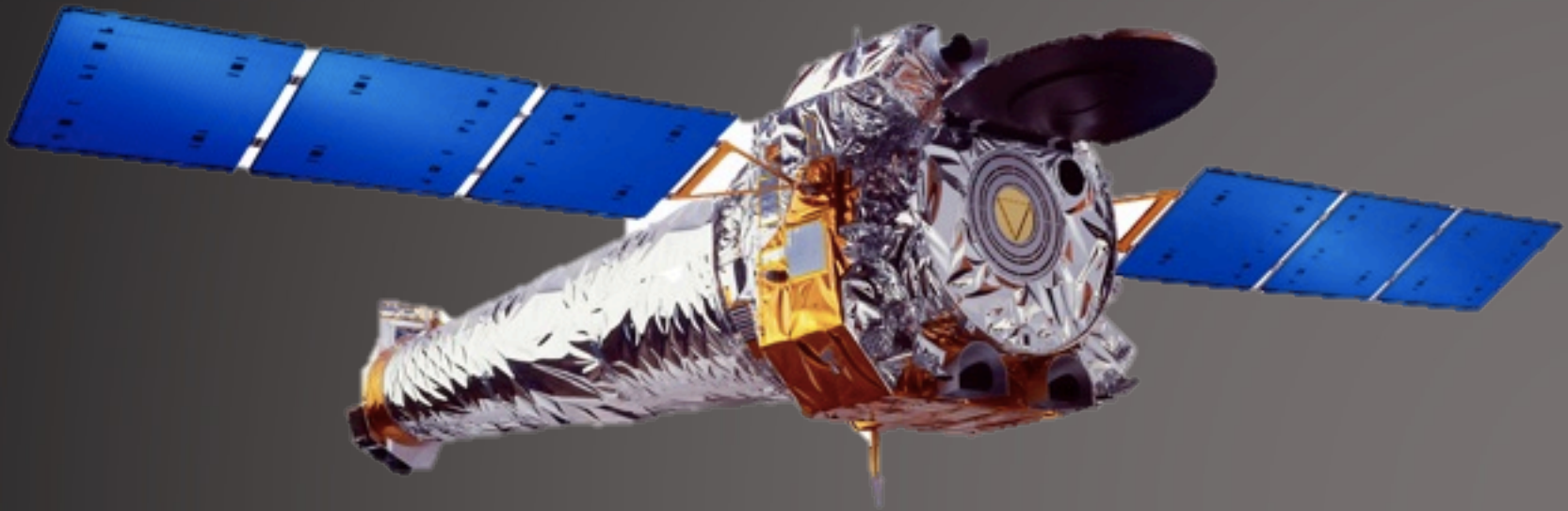
# The strawman X-ray Surveyor concept is a successor to *Chandra*

- Angular resolution at least as good as *Chandra*
- Much higher photon throughput than *Chandra*

✓ Incorporates relevant prior (Con-X, IXO, AXSIO) development and *Chandra* heritage

✓ Limits most spacecraft requirements to *Chandra*-like

✓ Achieves *Chandra*-like cost



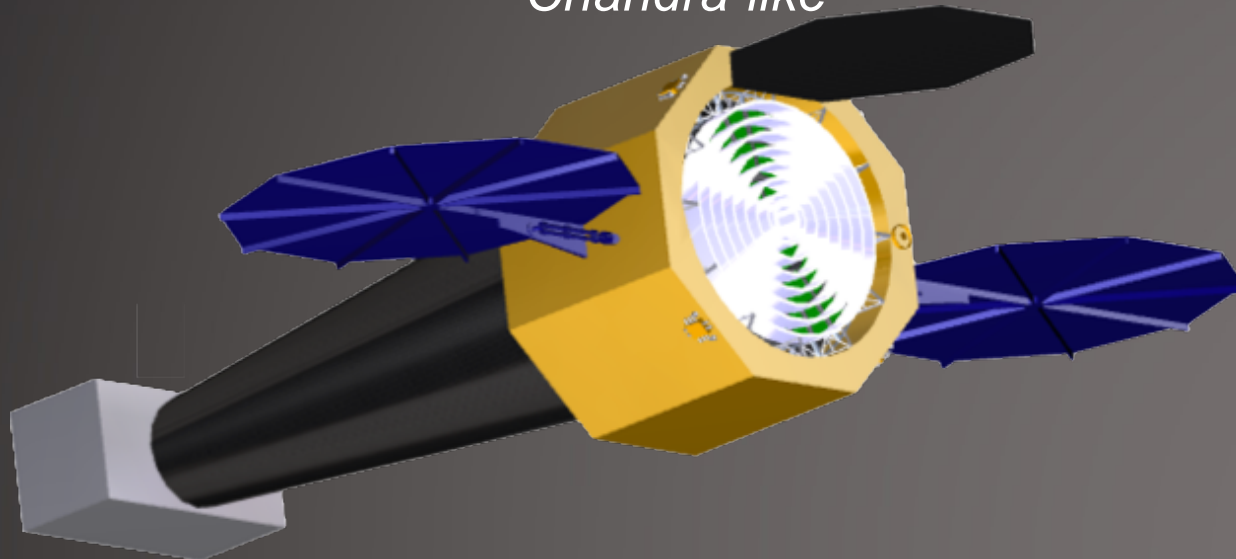
# The strawman X-ray Surveyor concept is a successor to *Chandra*

- Angular resolution at least as good as *Chandra*
- Much higher photon throughput than *Chandra*

✓ Incorporates relevant prior (Con-X, IXO, AXSIO) development and *Chandra* heritage

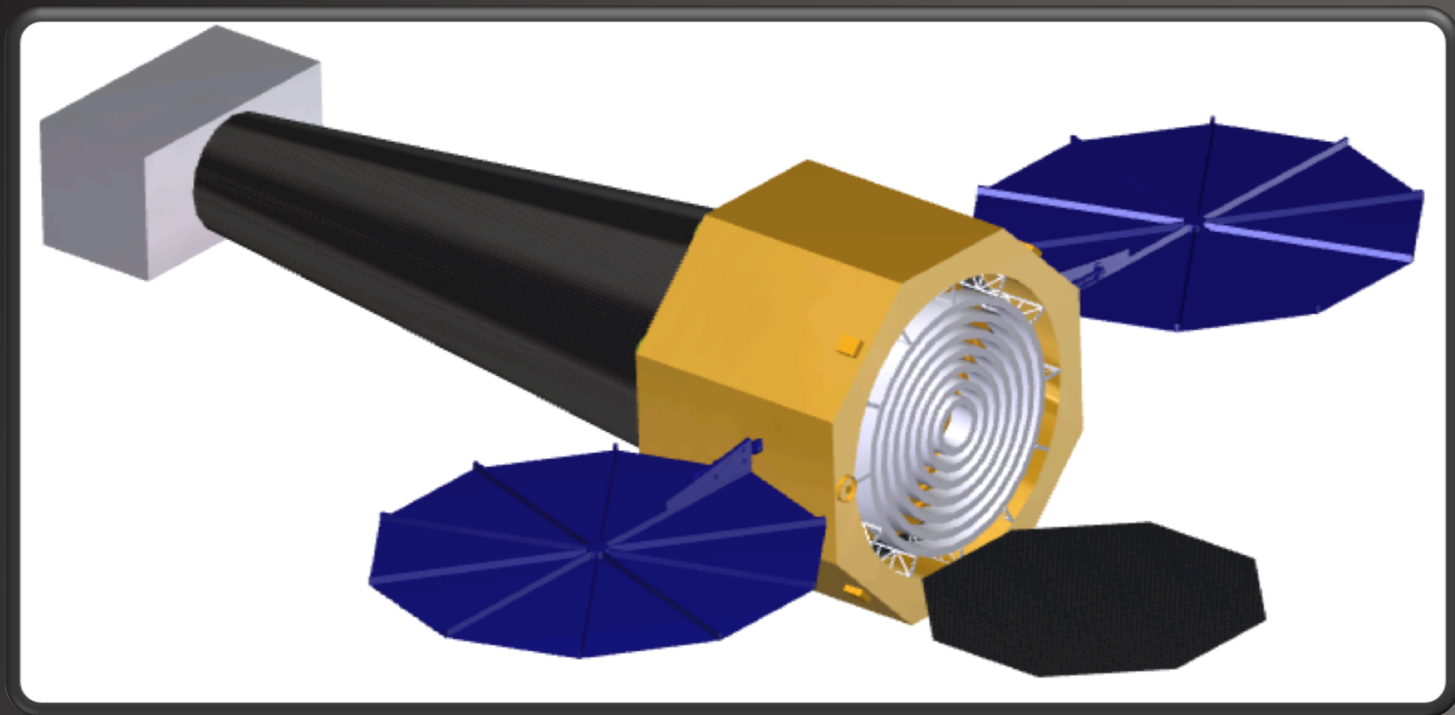
✓ Limits most spacecraft requirements to *Chandra*-like

✓ Achieves *Chandra*-like cost



# The X-ray Surveyor Instruments

Next-generation instruments that exploit the telescope's properties to achieve the science



Strawman instrument payload

5'×5' microcalorimeter, 1" pixels, 0.2–10 keV

22'×22' CMOS imager with 0.33" pixels, 0.2–10 keV

Gratings,  $R = 5000$ , 0.2–2.0 keV

# How will the optics be achieved?

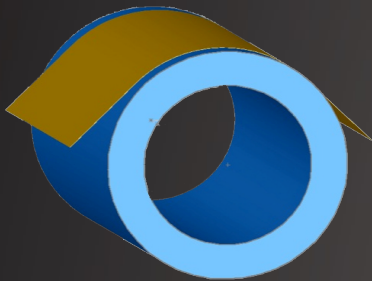
---

- Build upon segmented optics approaches that were considered for the Constellation-X, IXO, AXSIO concepts
- Follow multiple technology developments for the reflecting surfaces
  - Several look very promising
- Challenge: Demonstrate light-weight sub-arcsecond optics by 2019

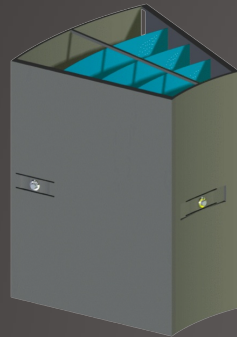
# Optics - Build on heritage

- The segmented optics approach for IXO was progressing yet limited to  $\sim 10''$  angular resolution
- We shall exploit the segmentation in combination with advanced reflecting elements

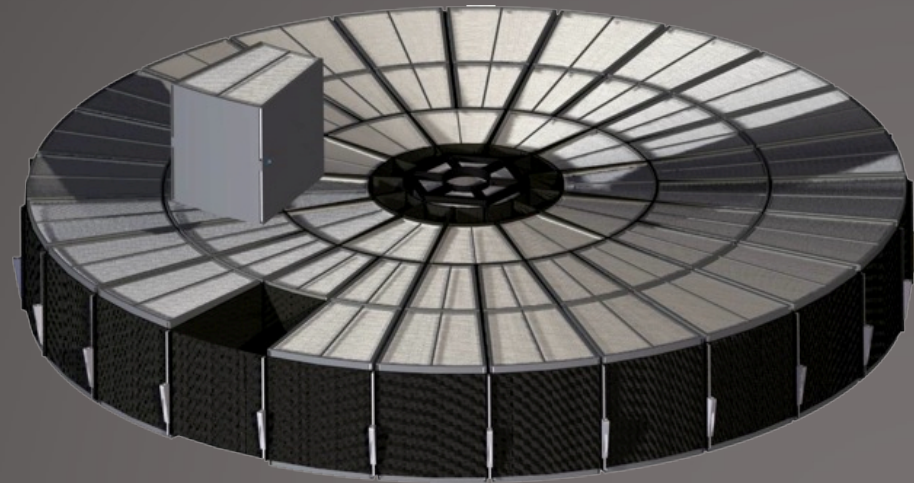
Fabrication



Alignment & Mounting

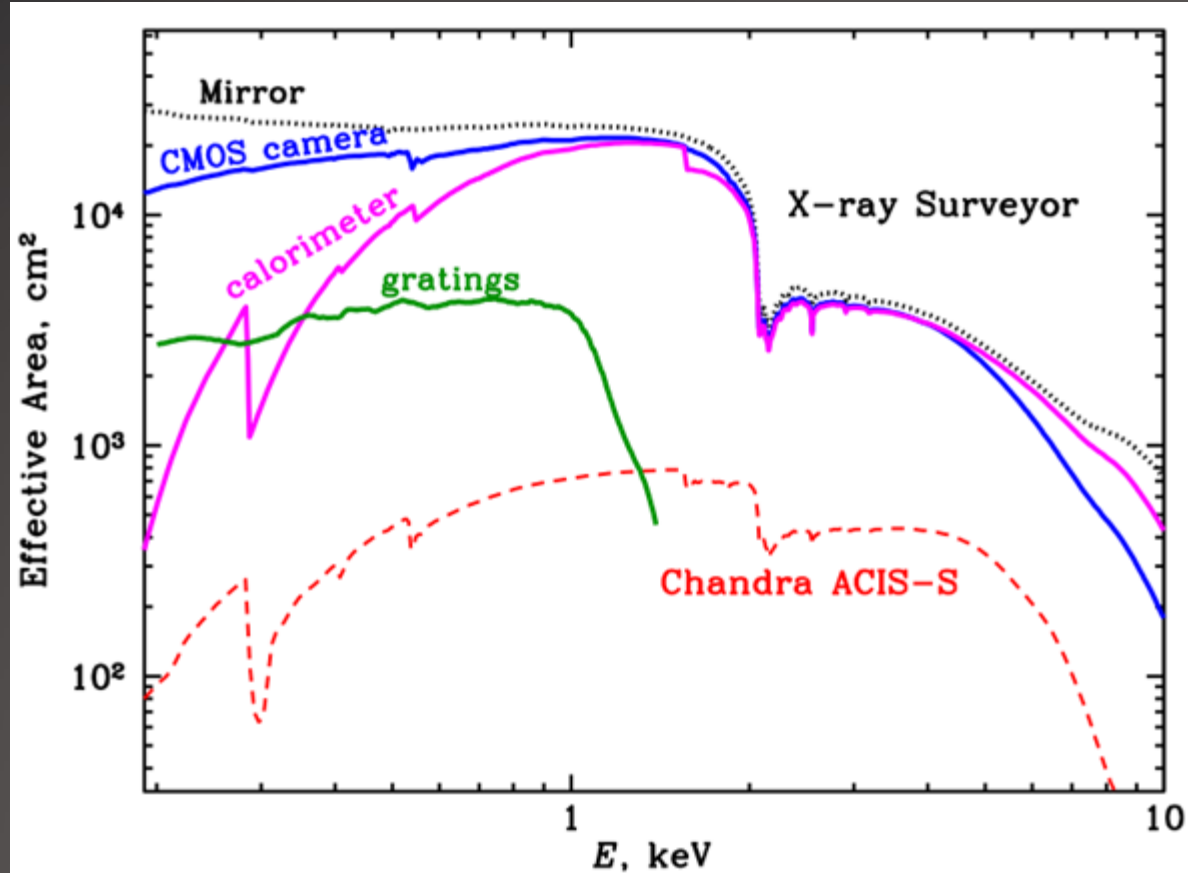
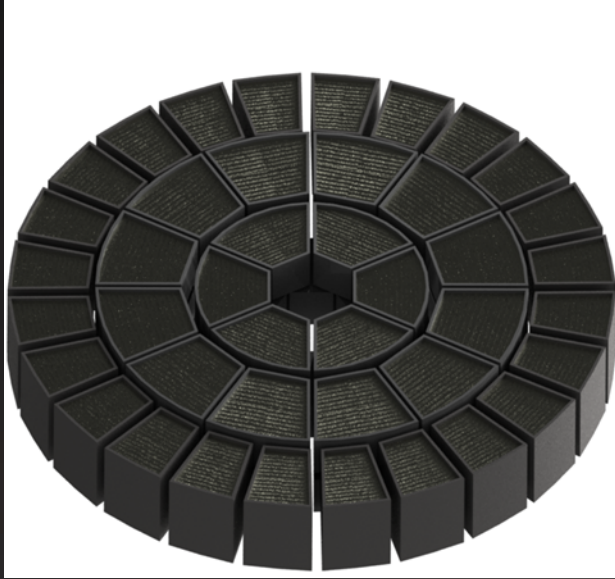


Integration





# Optics - Specifications & performance

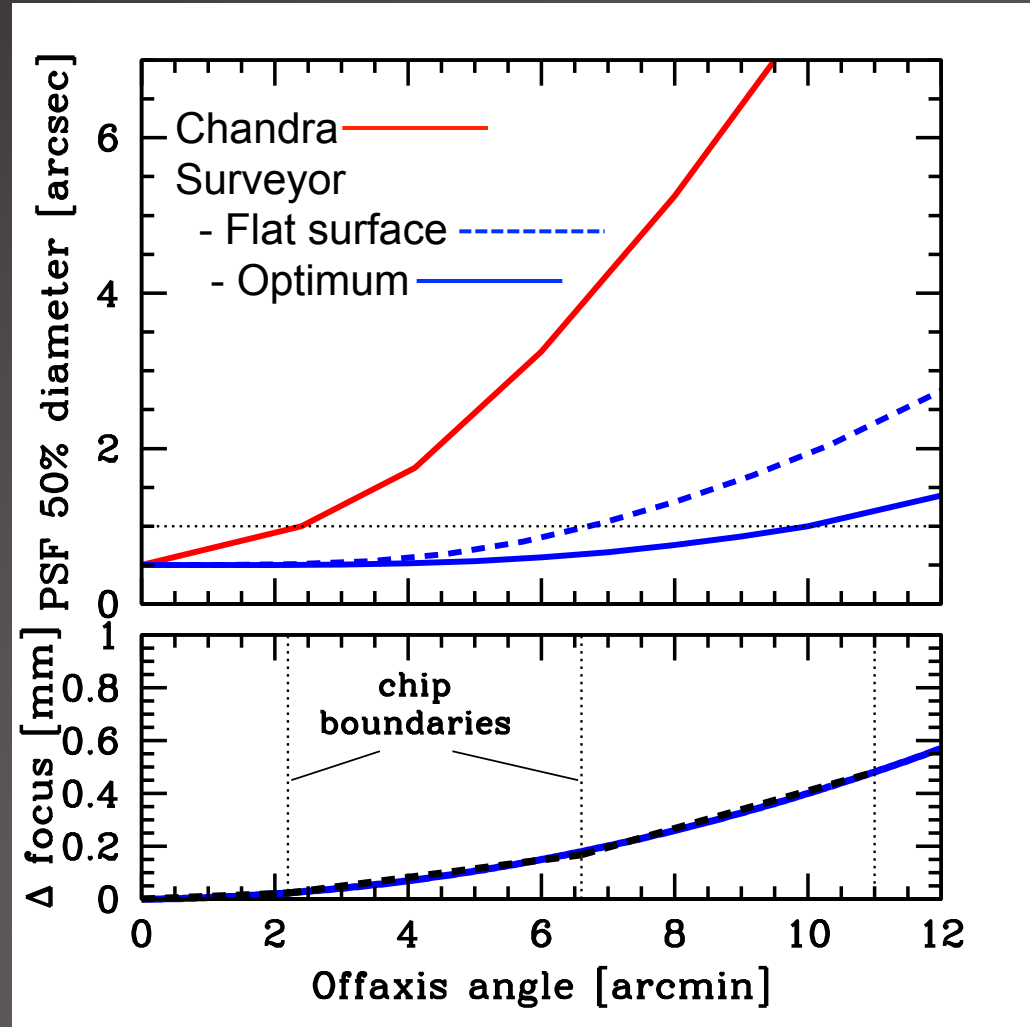


- Wolter-Schwarzschild optical scheme
- 292 nested shells, 3m outer diameter, segmented design
- 50× more effective area than Chandra
- 4-Msec survey limit  $\sim 3 \times 10^{-19}$  erg/s/cm<sup>2</sup> (0.5–2 keV)

# Angular resolution versus off-axis angle

## $E < 2$ keV

Short segments and Wolter-Schwarzschild design yields excellent wide-field performance



- 16×larger solid angle for sub arcsecond imaging
- 800×higher survey speed at the CDFS limit

# Obtaining the Sub-Arcsecond Elements

---

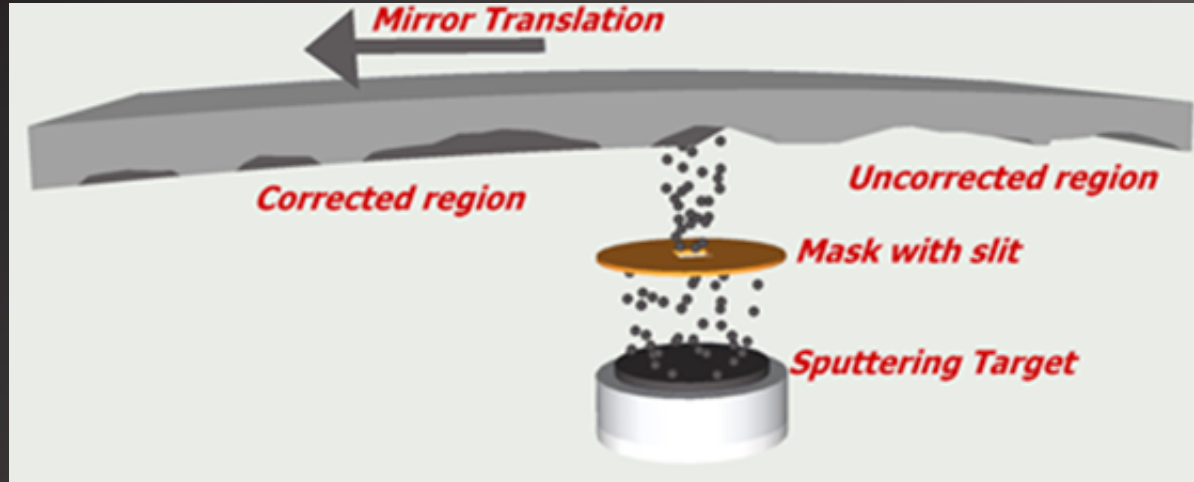
## APPROACHES

- Differential deposition
  - Fill in the valleys (MSFC/RXO)
- Adjustable optics
  - Piezoelectric film on the back surface (SAO/PSU)

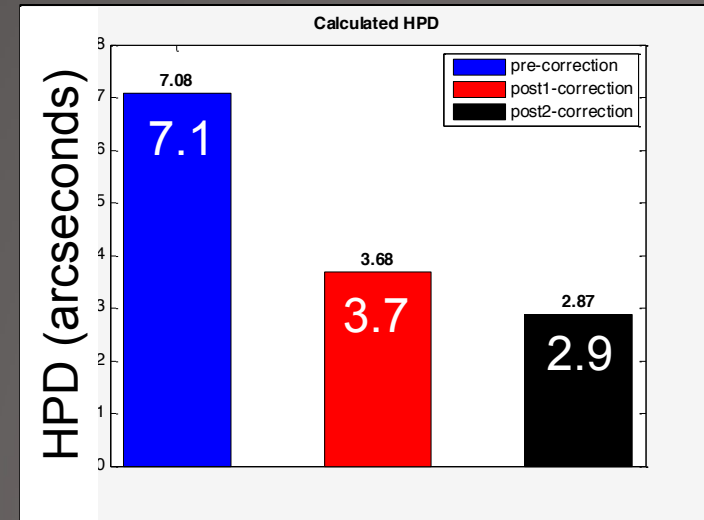
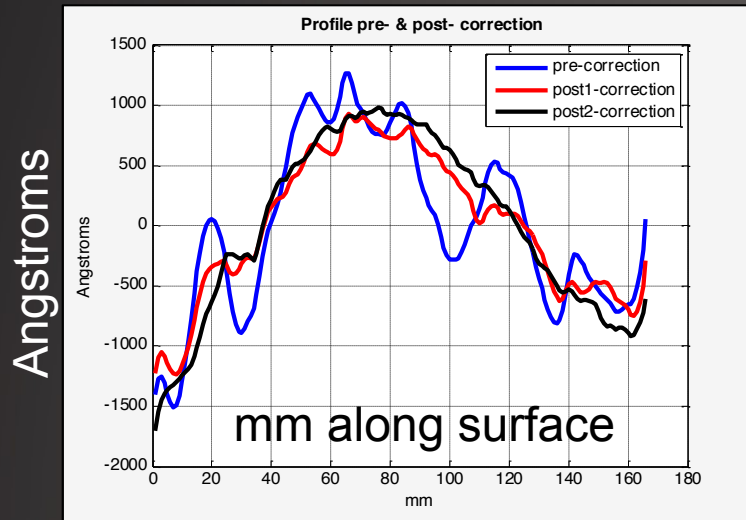
## ALSO WATCH

- Figuring, polishing, and slicing silicon into thin mirrors (GSFC)
- Magneto-strictive film on the back surface (Northwestern)
- Direct polishing of a variety of thin substrates (MSFC/Brera)

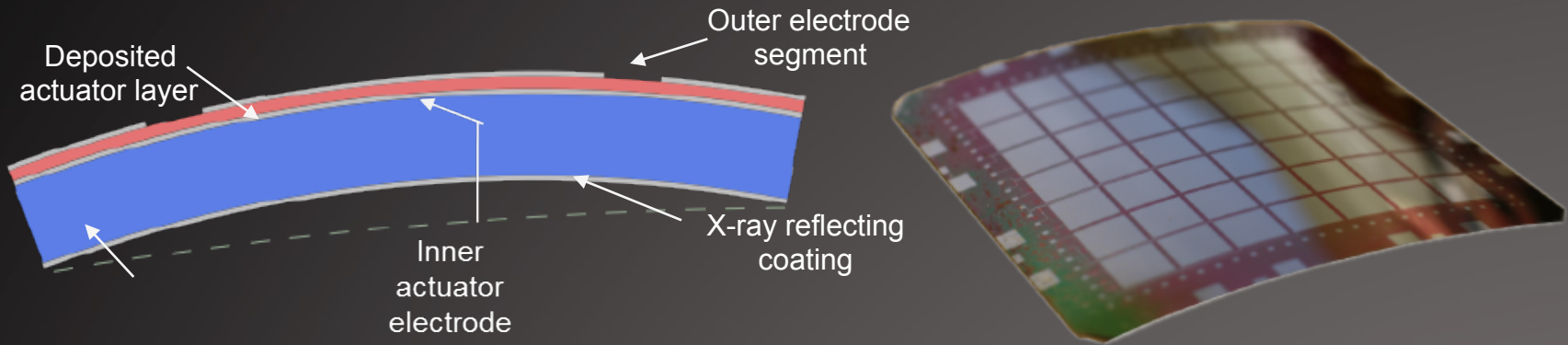
# Differential Deposition (MSFC, RXO)



7.1" to 2.9" (HPD – 2 reflections) in two passes

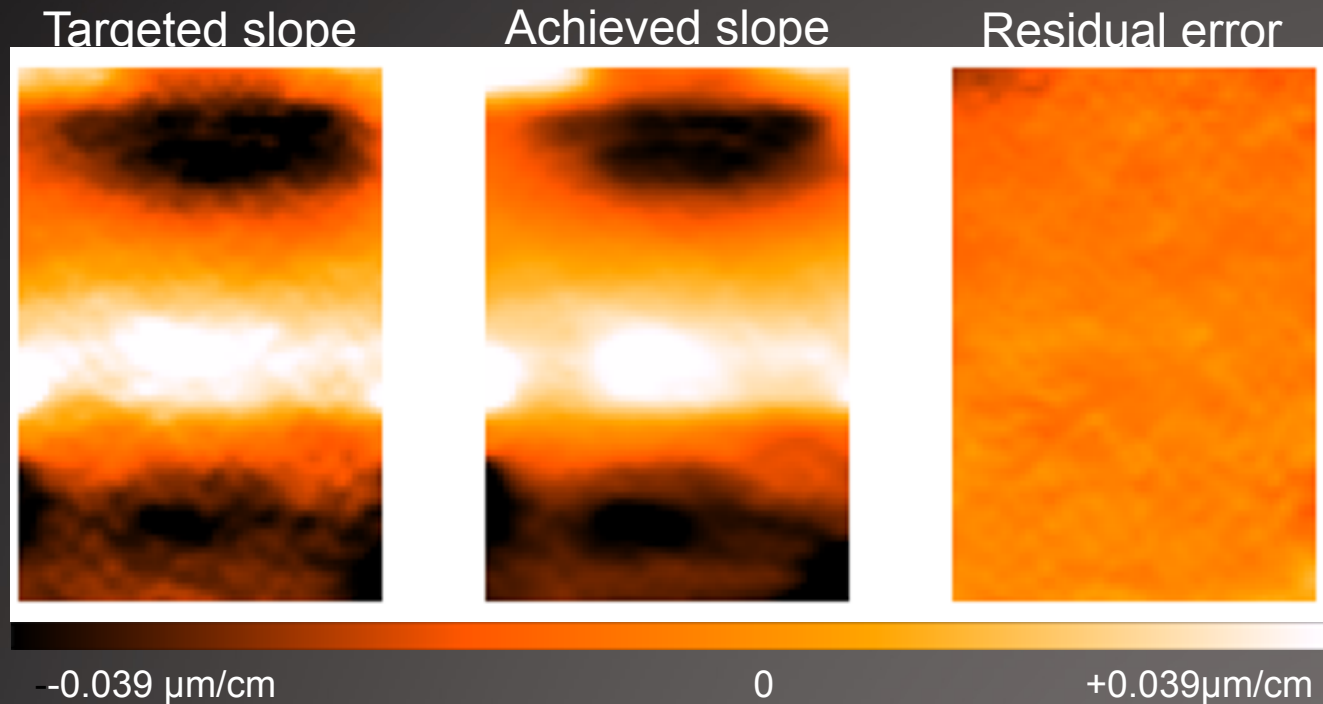


# Adjustable Optics – Piezoelectric (SAO/PSU)



- Micron-level corrections induced with  $<10V$  applied to 5–10 mm cells
- No reaction structure needed
- High yield — exceeds  $>90\%$  in a university lab
- High uniformity —  $\sim 5\%$  on curved segments demonstrated
- Uniform stress from deposition can be compensated by coating
- Row/column addressing
  - Implies on-orbit correction feasible
- 2D response of individual cells is a good match to that expected

# Adjustable Optics – Piezoelectric (SAO/PSU)



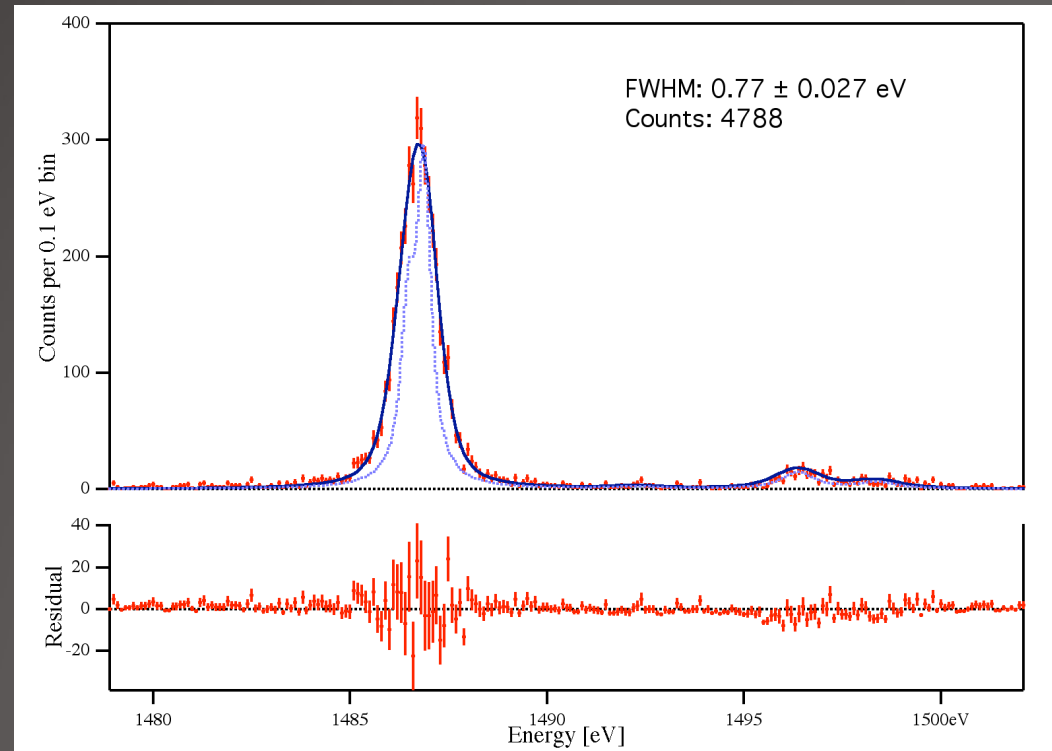
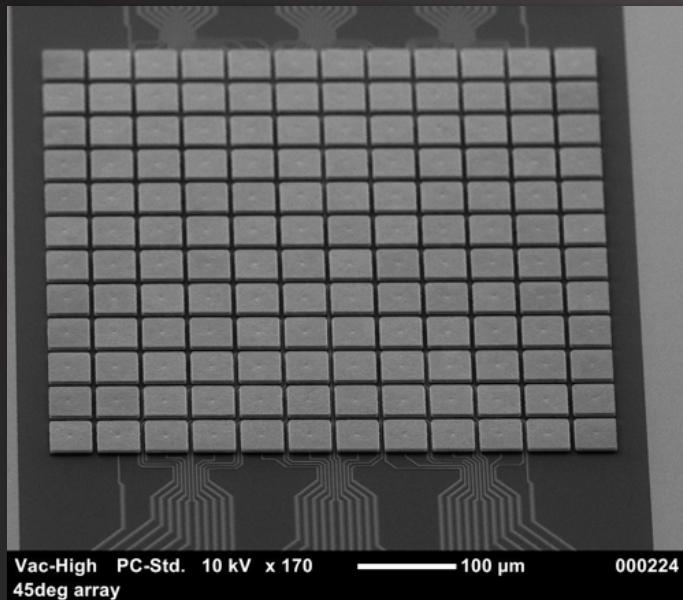
- 10 cm diameter flat mirror, 86  $10 \times 5$  mm cells operated together to apply a deterministic figure in a  $75 \times 50$  mm region
- Target correction (left) is approximated (middle) giving residuals shown on right
- Residuals converted to HPD for 2 reflections correspond to 3 arcseconds

# Instrument Technologies and Challenges

## The Microcalorimeter Imaging Spectrometer

### Requirements:

- 1" pixels and at least 5'×5' field of view (>90,000 pixels)
- < 5eV energy resolution, 1cnt/s/pixel

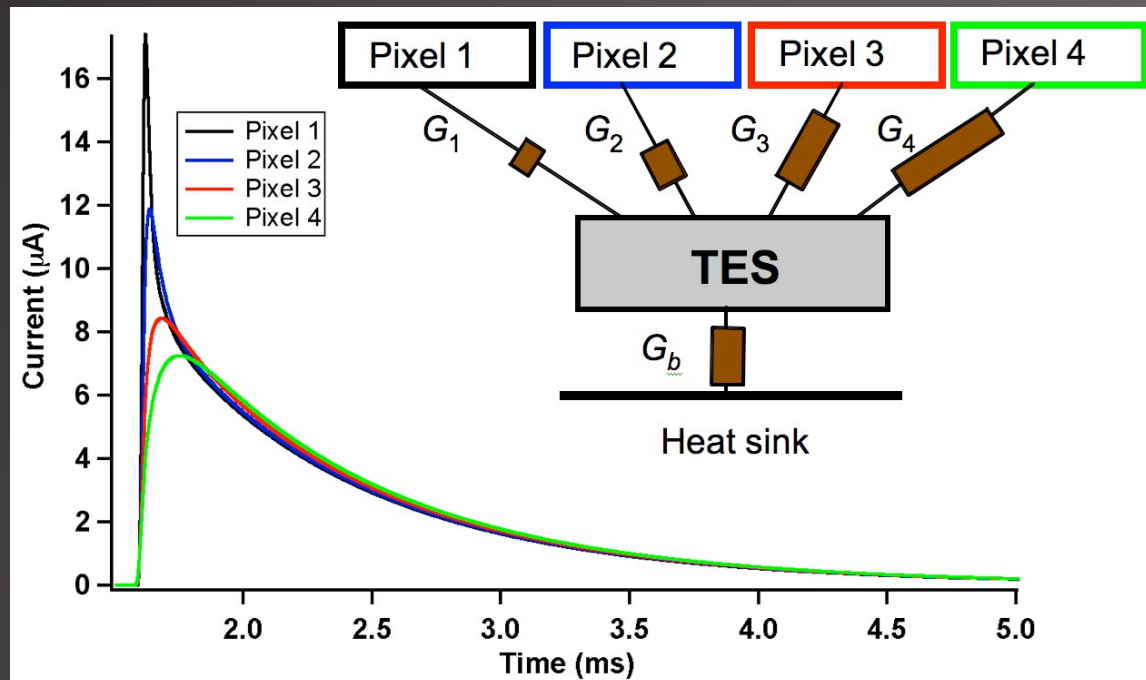


Challenge: Develop multiplexing approaches for achieving  $10^5$  pixel arrays

# Microcalorimeter Imaging Spectrometer

Progress with respect to multiplexing

- Conceptual design by S. Bandler et al. (GSFC & NIST):
- Transition Edge Sensors (TES) with SQUID readout.
- Multiple absorbers per one TES (“Hydra” design)

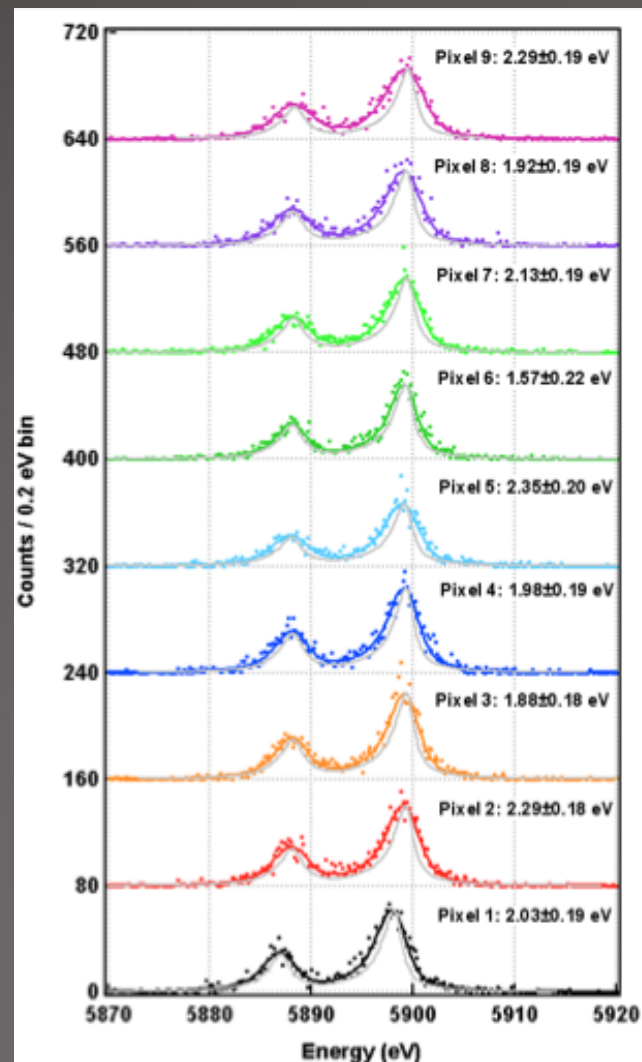




# Microcalorimeter Imaging Spectrometer

## Energy Resolution (w 3 x 3 Hydra)

- Current lab results with 3×3 Hydra, 65μm pixels on 75 μm pitch shows 2.4 eV resolution at 6 keV
- $\Delta E/E \sim N$  for N×N Hydras, so current results imply ~5×5 Hydras with 50μm pixels and < 5eV energy resolution are reachable



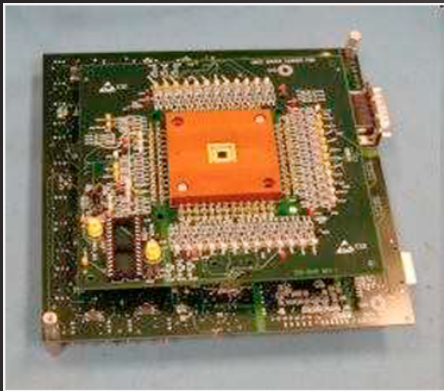
# Instrument Technologies and Challenges

## High Definition X-ray Imager

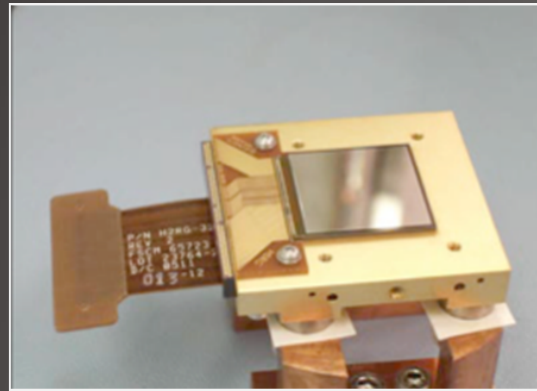
### Requirements:

- 16  $\mu\text{m}$  (=0.33 arcsecond) pixel size or smaller
- 4k $\times$ 4k array (22' $\times$ 22' FOV) or bigger
- Energy resolution (33 eV @ 0.5 keV, 48 @ 1.0 & 120 @ 6.0)
- Quantum efficiency > 90% (0.3-6.0 keV)

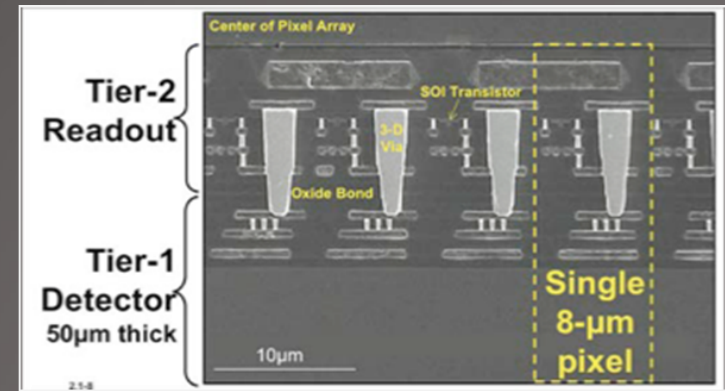
All have been demonstrated individually



SAO/Sarnoff



PSU/Teledyne



MIT/Lincoln Lab

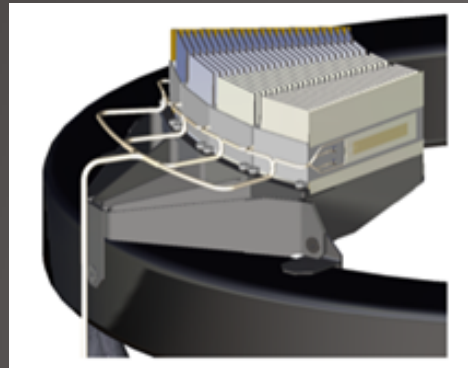
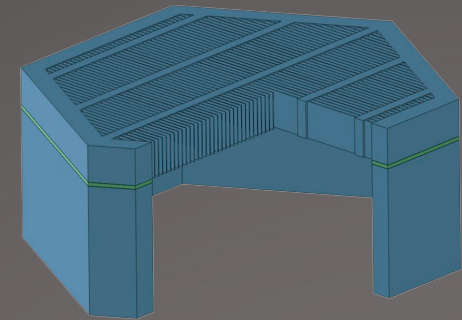
Challenges: Develop sensor package that meets all requirements, and possibly approximates the optimal focal surface

SEE POSTER 24

# Instrument Technologies and Challenges

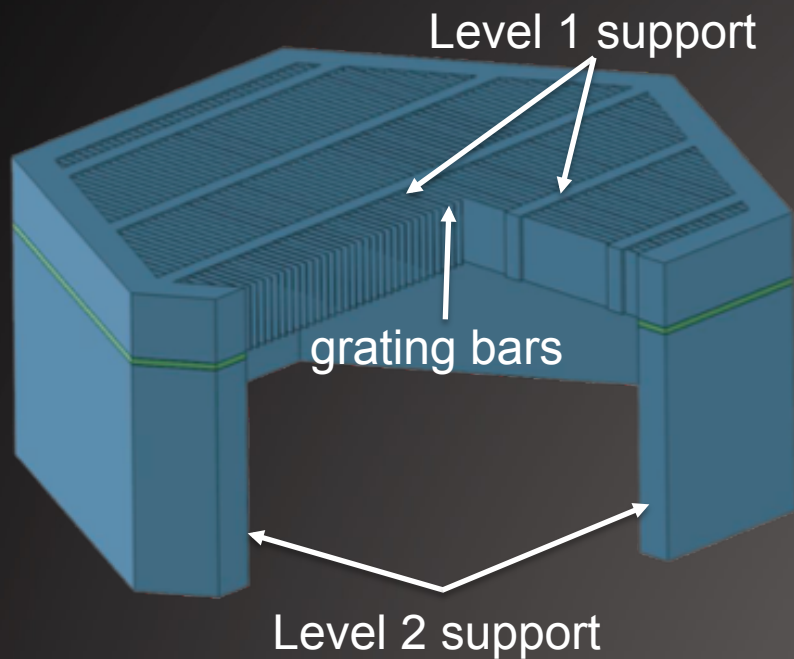
## Gratings

- Resolving power = 5000 & effective area = 4000 cm<sup>2</sup>
- Energy range 0.2 – 2.0 keV
- Two approaches --- both are feasible in the lab
  - Critical Angle Transmission (CAT) gratings (MIT)
  - Blazed Off-Plane Reflection gratings (Univ. of Iowa)

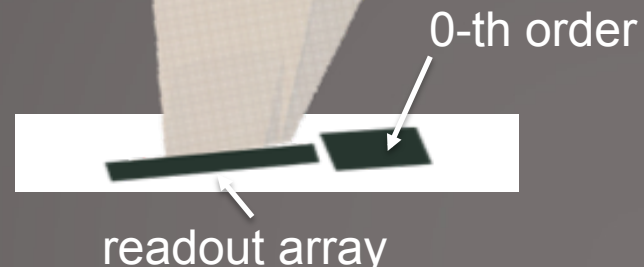
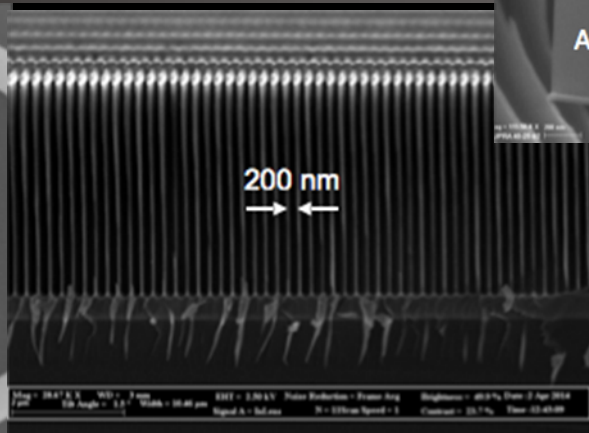
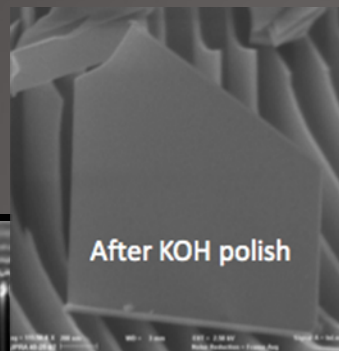
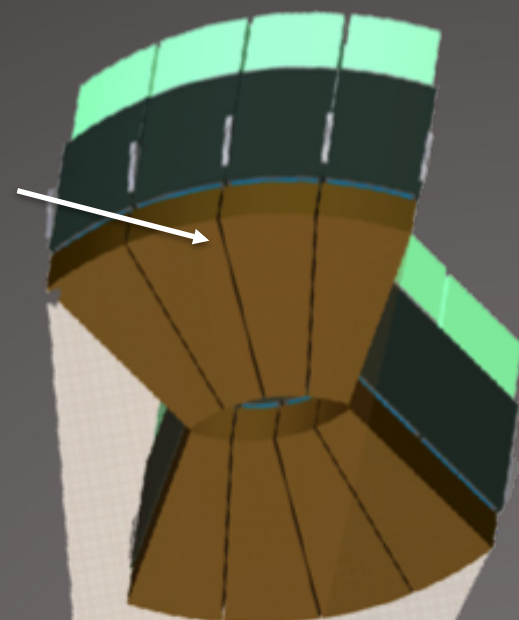


*Challenges:* improving yield, developing efficient assembly processes, and improving efficiency

# Critical Angle Transmission Gratings (MIT)



Insertable gratings cover 50% of the full aperture



# Costing: Surveyor's *Chandra* Heritage

## Identical requirements

- Angular resolution
- Focal length
- Pointing accuracy
- Pointing stability
- Dithering to average response over pixels and avoid gaps
- Aspect system & fiducial light system
- Contamination requirements and control
- Translation and focus adjust capability for the instruments
- Shielding for X-rays not passing through the optics
- Mission operations and data processing

## Somewhat different requirements

- Magnetic broom (larger magnets)
- Pre and post telescope doors (larger)
- Telescope diameter (larger)
- Grating insertion mechanisms (similar)

No S/C technology challenges

# Cost Estimates

## Ground Rules and Assumptions -1

- *All elements of the Mission are assumed to be at TRL 6 or better prior to phase B*
  - This is a fundamental difference from *Chandra* with regards to the optics and science instruments
- Atlas V-551 launch vehicle (or equivalent)
- L2 halo orbit & 5 year lifetime
- Expendables sized for 20 years
- Mass and power margins set to 30%
- Cost margins set to 35% except for instruments
- Instruments costed at 70%-confidence using NASA Instrument Cost Model (NICM)
- Costs in FY 15\$

# Cost Estimates

## Ground Rules and Assumptions - 2

---

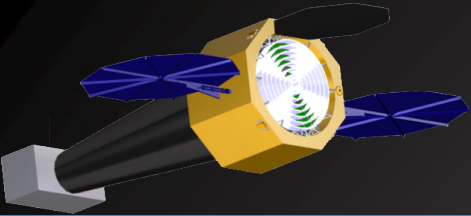
- Individual S/C subsystems contain all hardware, engineering and manufacturing costs related to the subsystem
- No single point failures
- Contractor fee and NASA program support are 10% each
- Integration with the launch vehicle is 5%
- Costs for the optics assembly is a bottoms up input from the MSFC/SAO Team
- Aspect camera based on a ROM quote from Ball Aerospace

# Cost Estimates

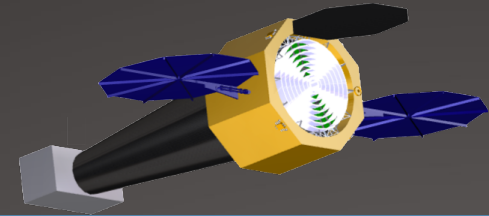
---

• Spacecraft	\$1,650M
• X-ray Telescope Assembly	\$ 489M
• Scientific Instruments	\$ 377M
• Pre-Launch Operations, Planning & Support	\$ 196M
• Launch Vehicle (Atlas 551)	\$ 240M
• Total	\$2,952M
• Mission Operations	\$45M/yr
• Grants	\$25M/yr





# X-ray Surveyor



- ***Leaps in Capability:*** large area with high angular resolution for 1–2 orders of magnitude gains in sensitivity, field of view with subarcsec imaging, high resolution spectroscopy for point-like and extended sources
- ***Scientifically compelling:*** frontier science from Solar system to first accretion light in Universe; revolution in understanding physics of astronomical systems
- ***Feasible:*** *Chandra*-like mission with regards to cost and complexity with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B

***Unique opportunity to explore new discovery space and expand our understanding of how the Universe works and how it came to look the way we see it***