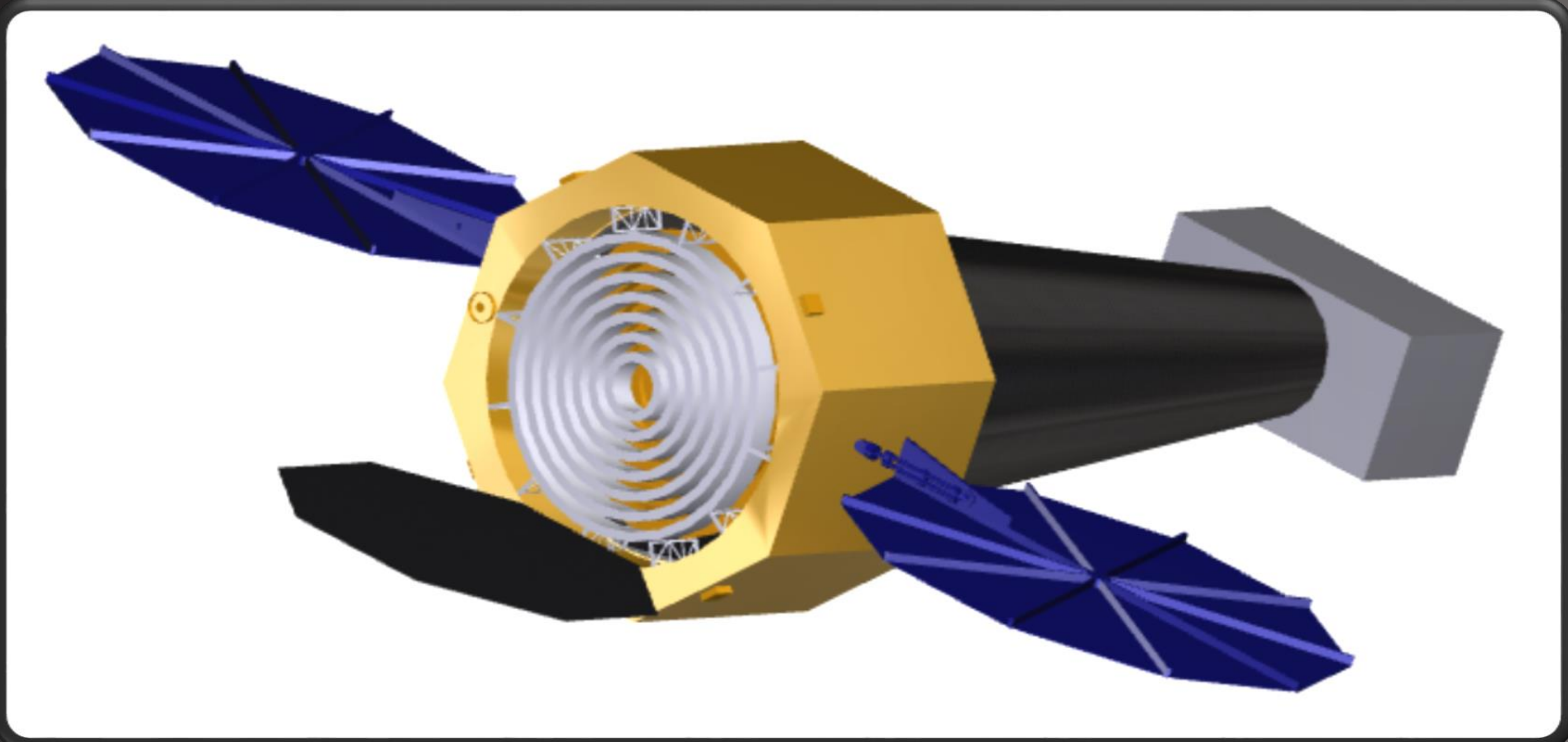
The X-ray Surveyor

Mission concept, strawman mission design, and preliminary cost estimate

Martin C. Weisskopf (MSFC)
On behalf of the X-ray Surveyor community



HEAD, June 29, 2015

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

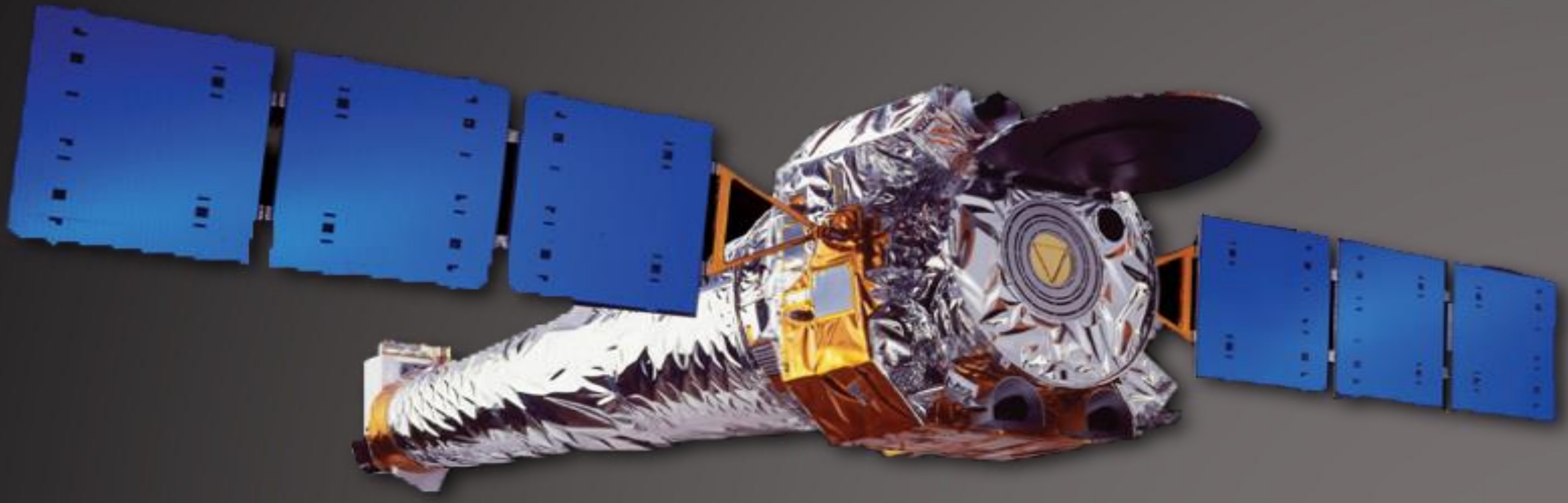
- Strawman definition: Spacecraft (structures, thermal control, mechanisms, propulsion, guidance, navigation & control, power), instruments, optics, orbit, radiation environment, launch vehicle and costing

- Performed under the guidance of the MSFC-SAO Team, tlements 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 (UChicago), 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, starbutst, 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 ½ arcsecond resolution

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

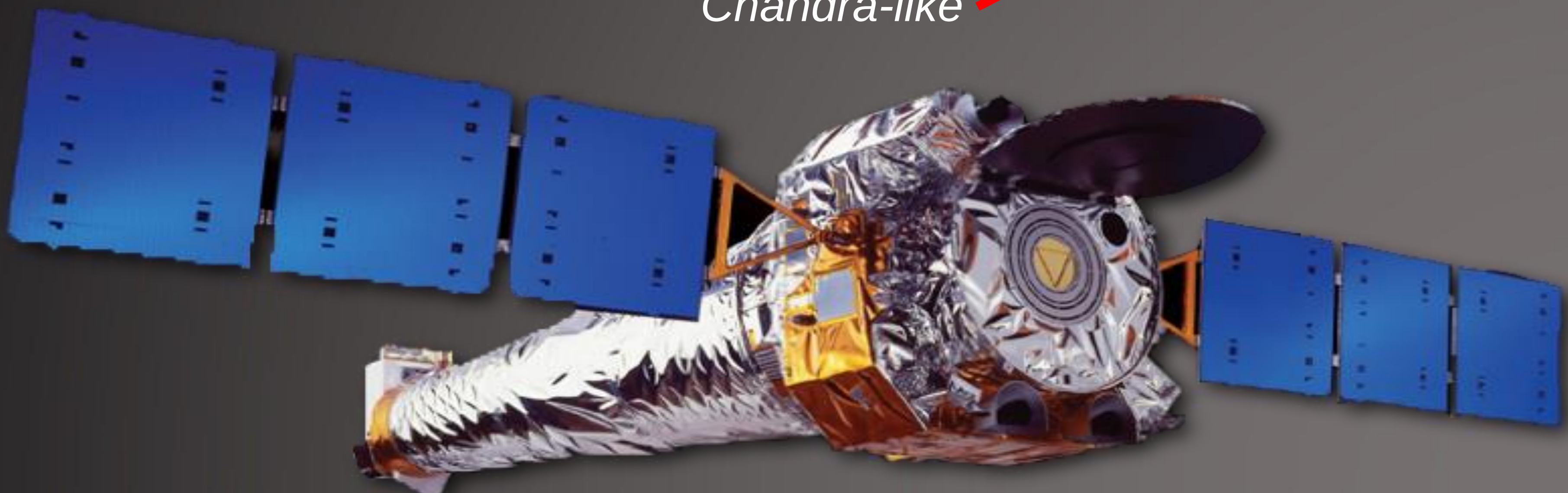
The strawman X-ray Surveyor concept is a successor to *Chandra*

- 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

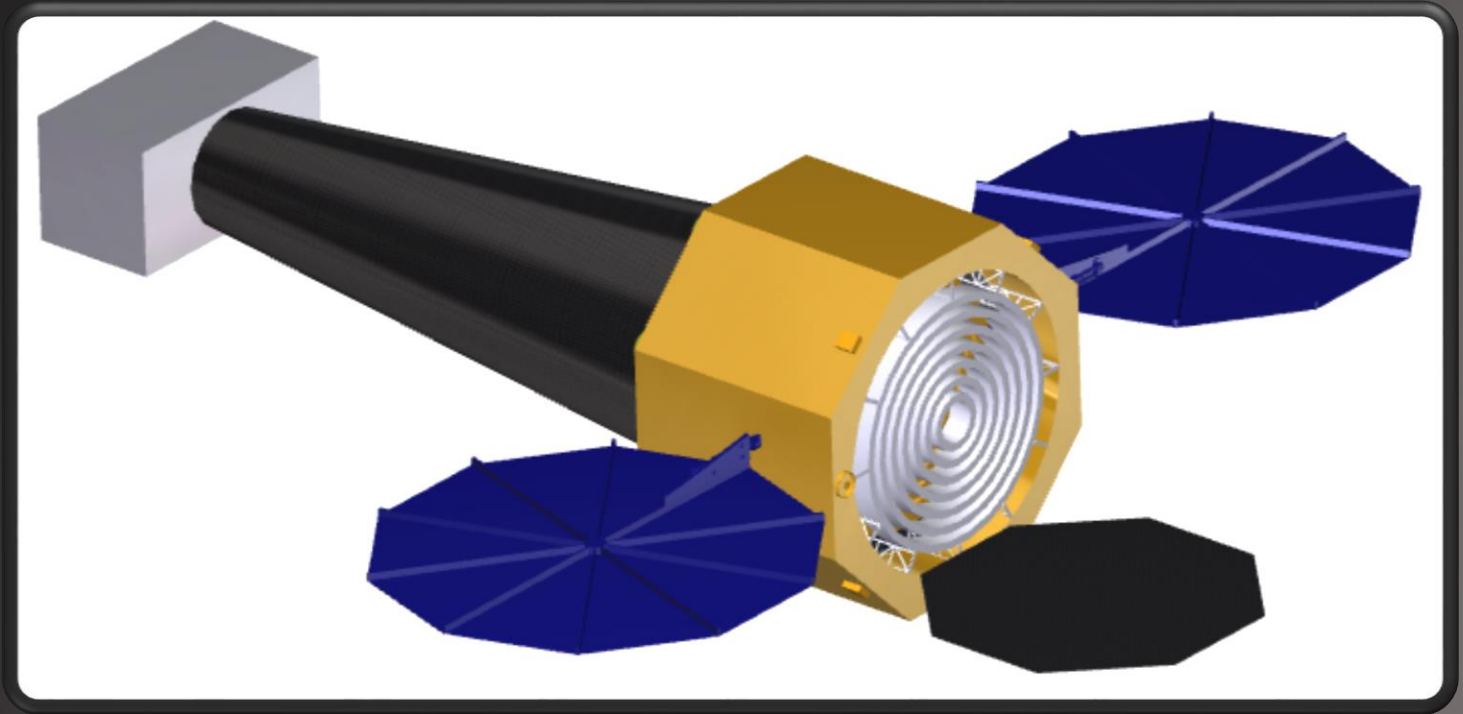
✓ Limits most spacecraft requirements to *Chandra-like*

✓ Achieves *Chandra*-like cost



The 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

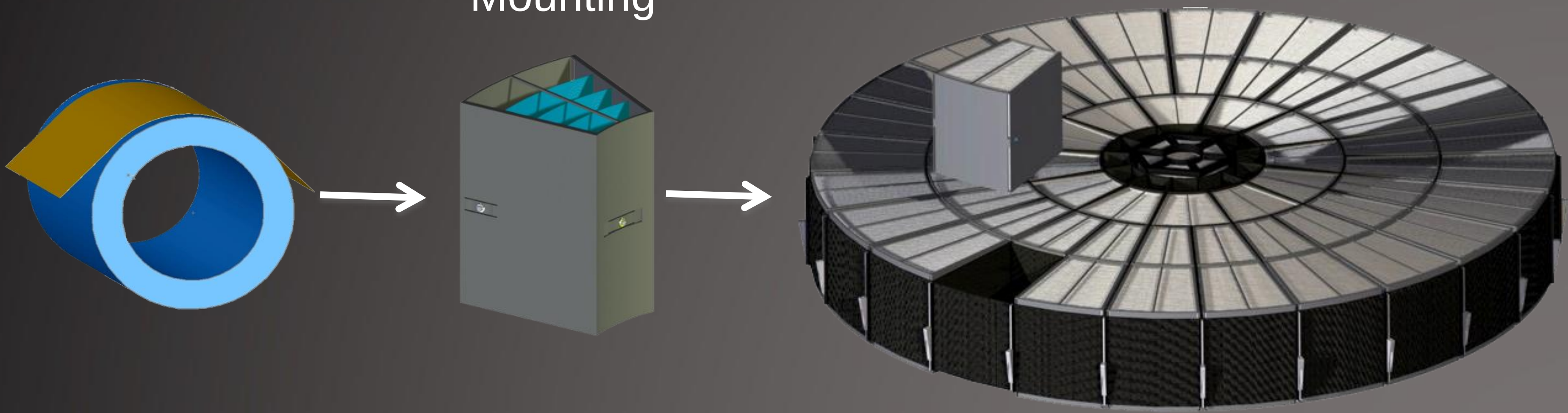
Build on Heritage

The segmented optics approach for IXO was progressing yet limited to ~10″ angular resolution

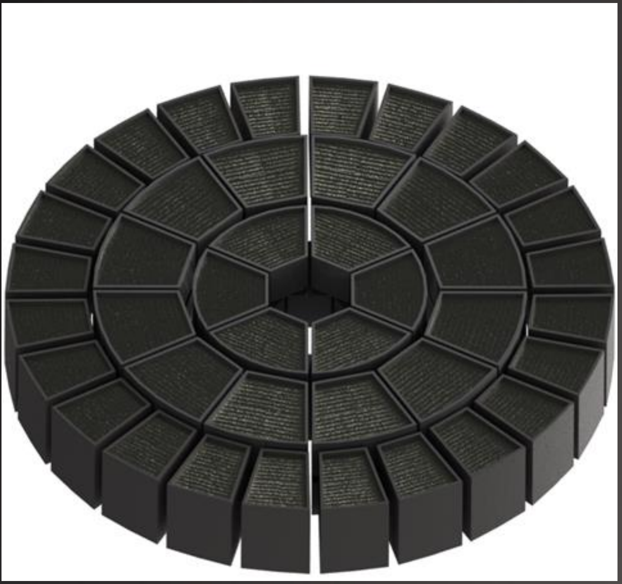
Fabrication

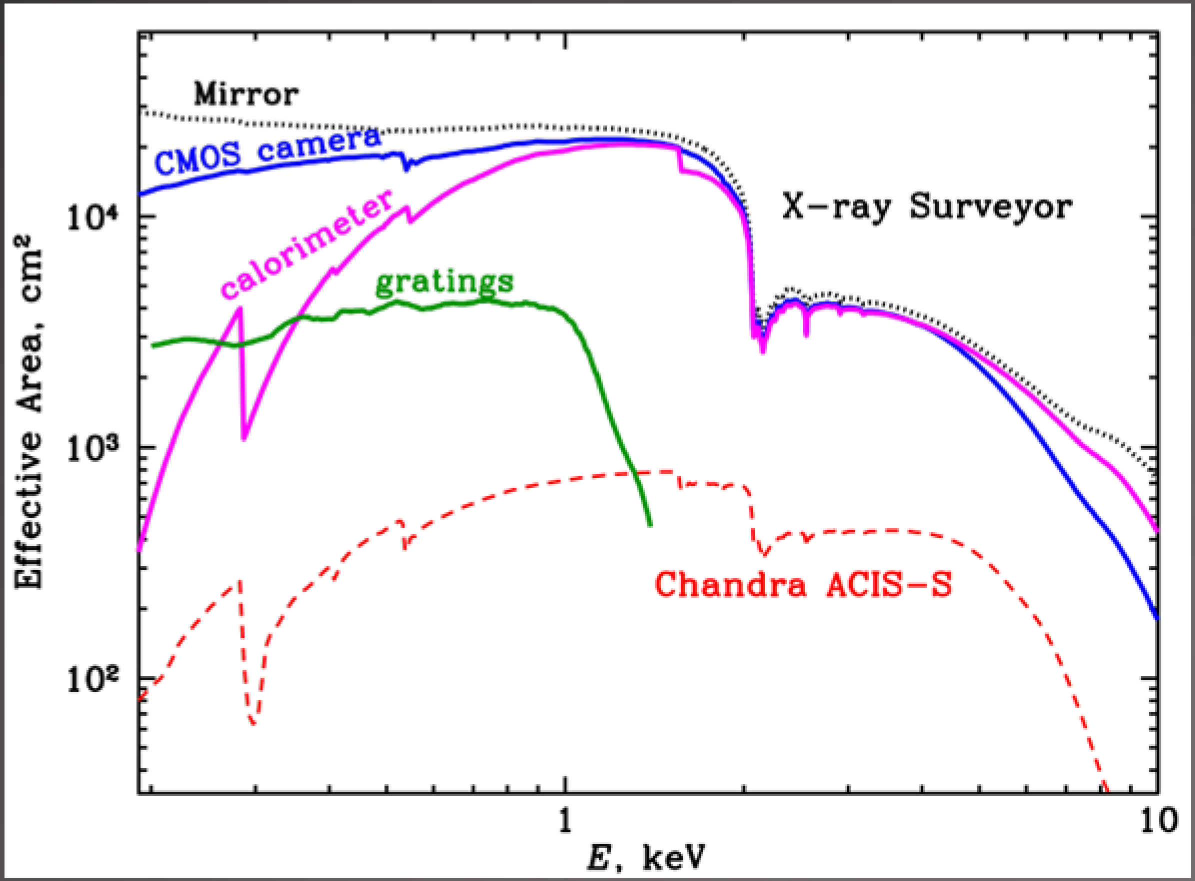
Alignment & Mounting

Integration



Optics Specifications & Performance

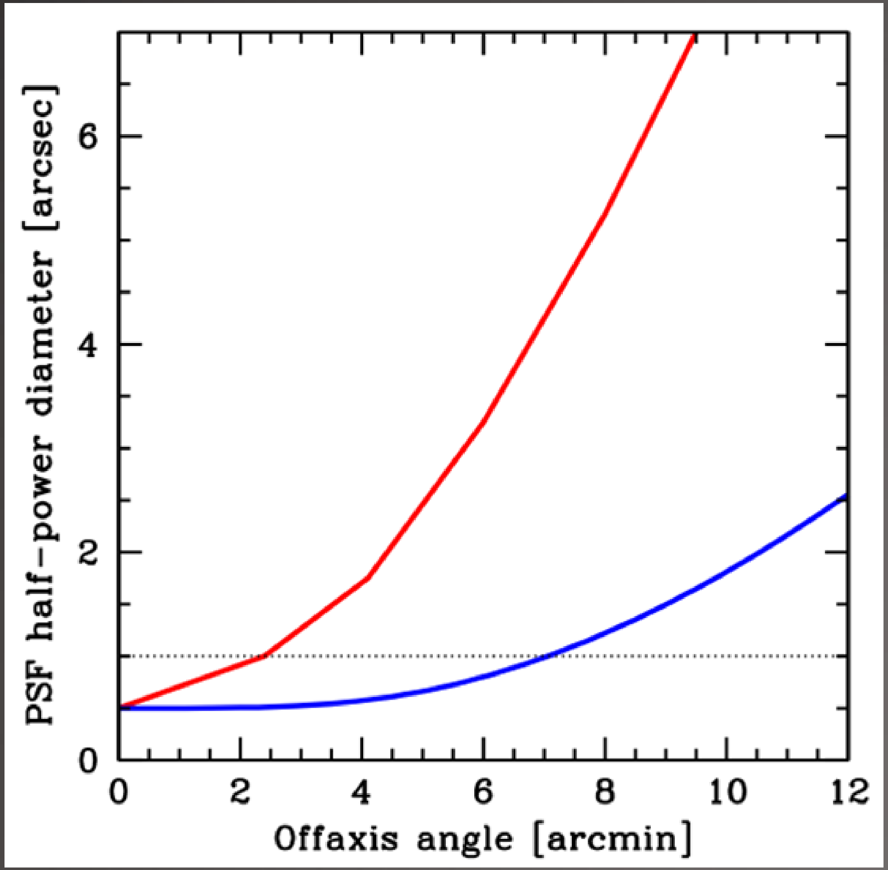




- Wolter-Schwarzschild optical scheme
- 292 nested shells, 3m outer diameter, segmented design
- 50 × more effective area than Chandra
- 4-Msec detection limits below 1×10^{-19} erg/s/cm^2 (0.5–2 keV)

Angular Resolution Versus Off-Axis Angle

Short segments and Wolter-Schwarzschild design lead to excellent wide-field sensitivity



- 10-16 × larger solid angle for sub-arcsecond imaging
- 500-800 × higher survey speed at the CDFS limit

Obtaining the Sub-Arcsecond Elements

APPROACHES

- Differential deposition
    - Fill in the valleys (MSFC/RXO)

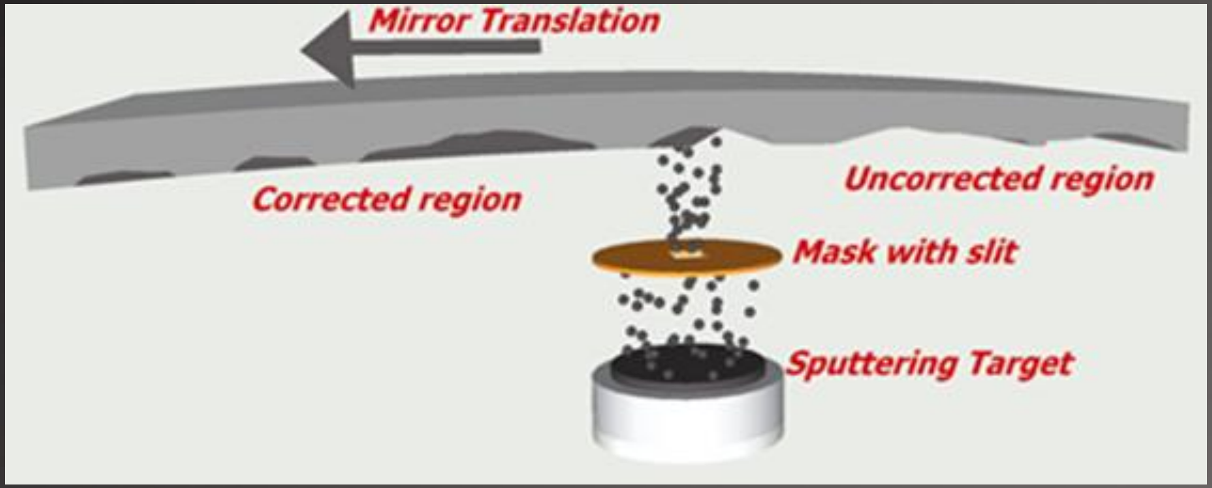
- Adjustable optics
    - Piezoelectric film on the back surface (SAO/PSU)
    - Magneto-strictive film on the back surface (Northwestern)

ALSO WATCH

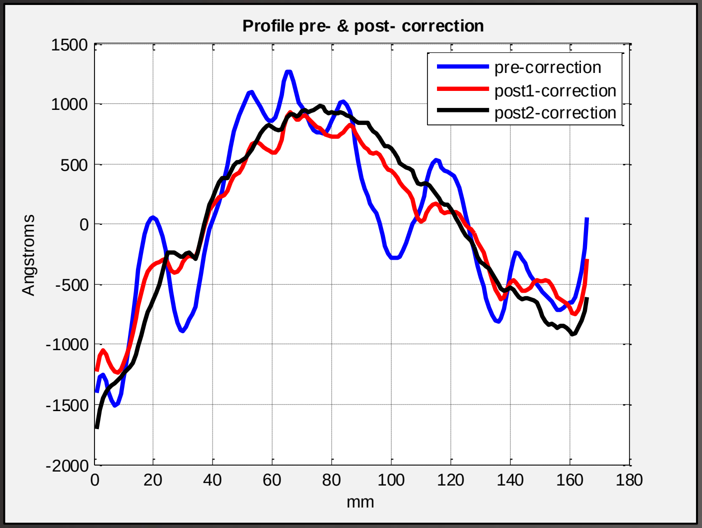
- Figuring, polishing, and slicing silicon into thin mirrors (GSFC)
- Direct polishing of a variety of thin substrates (MSFC/Brera)

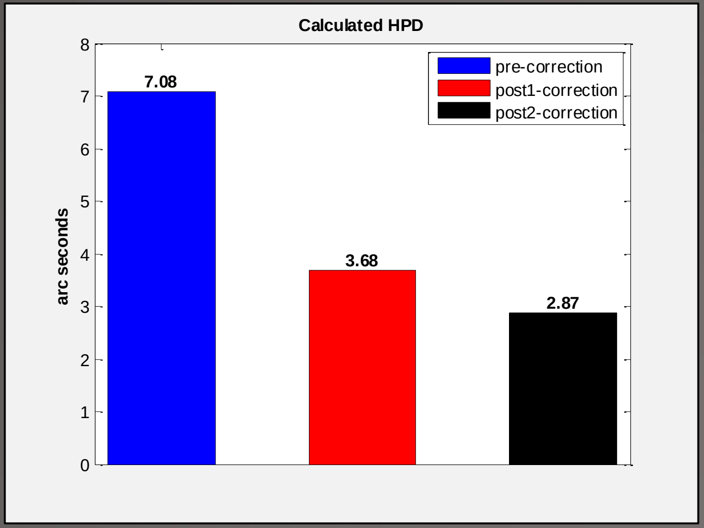
Final approach may well be a combination of the above

Differential Deposition (MSFC/RXO)



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





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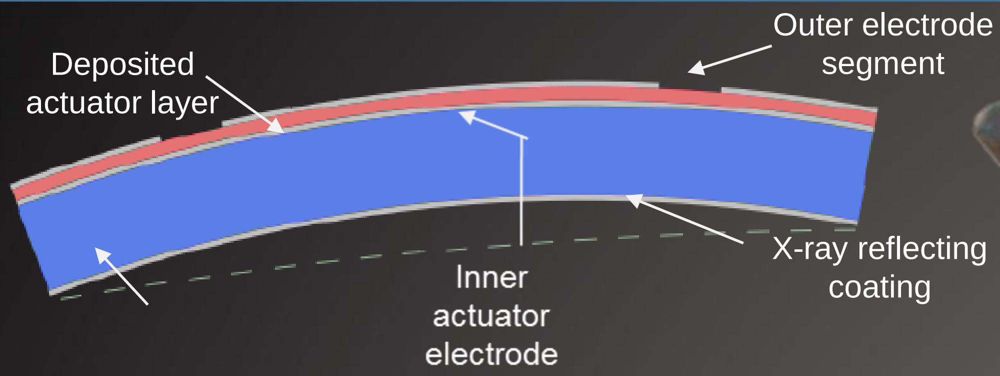
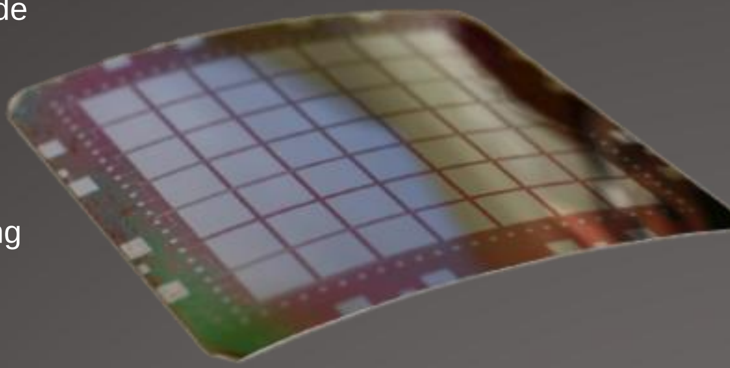
Adjustable Optics – Piezoelectric (SAO/PSU)





- 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 — ~5% on curved segments demonstrated
- 2D response of individual cells is a good match to that expected
- Uniform stress from deposition can be compensated by coating
- Row/column addressing
    - Implies on-orbit correction feasible

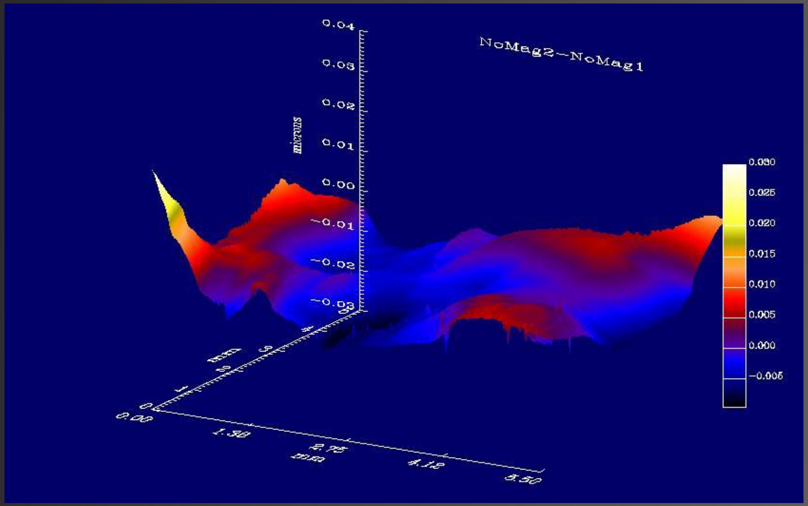
Adjustable Optics - Magnetostrictive (NW)

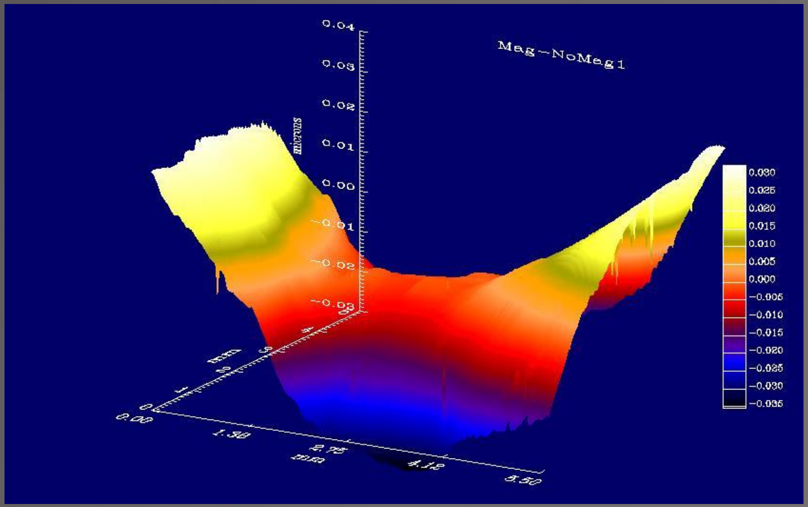
Magnetic smart material applied to NiCo, a magnetically hard substrate 5 mm x 20 mm x 100 µm, showed:

- The material responds to the external field and bends
- Once the external field is removed the piece stays bent

Magnetic field applied to magnetostrictive-coated glass substrate 50 mm x 50 mm x 100 µm showed:

- Capability of bending the piece
- Repeatability on sub-micron scales





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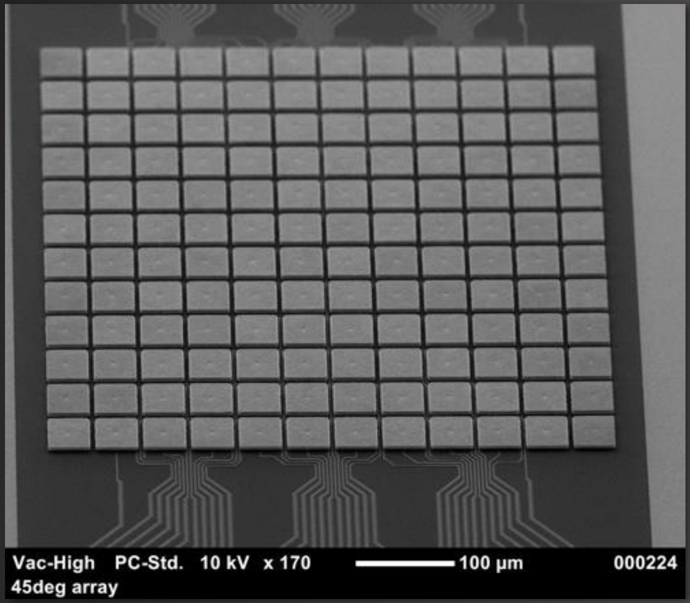
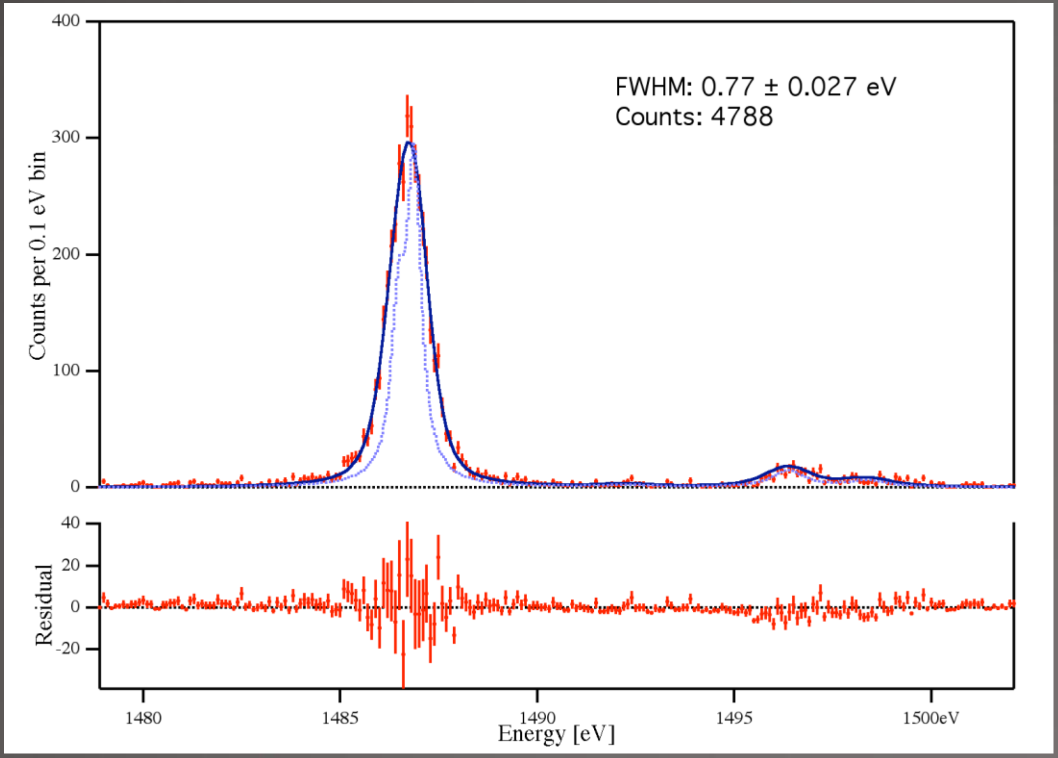
Instrument Technologies and Challenges
The Microcalorimeter Imaging Spectrometer

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





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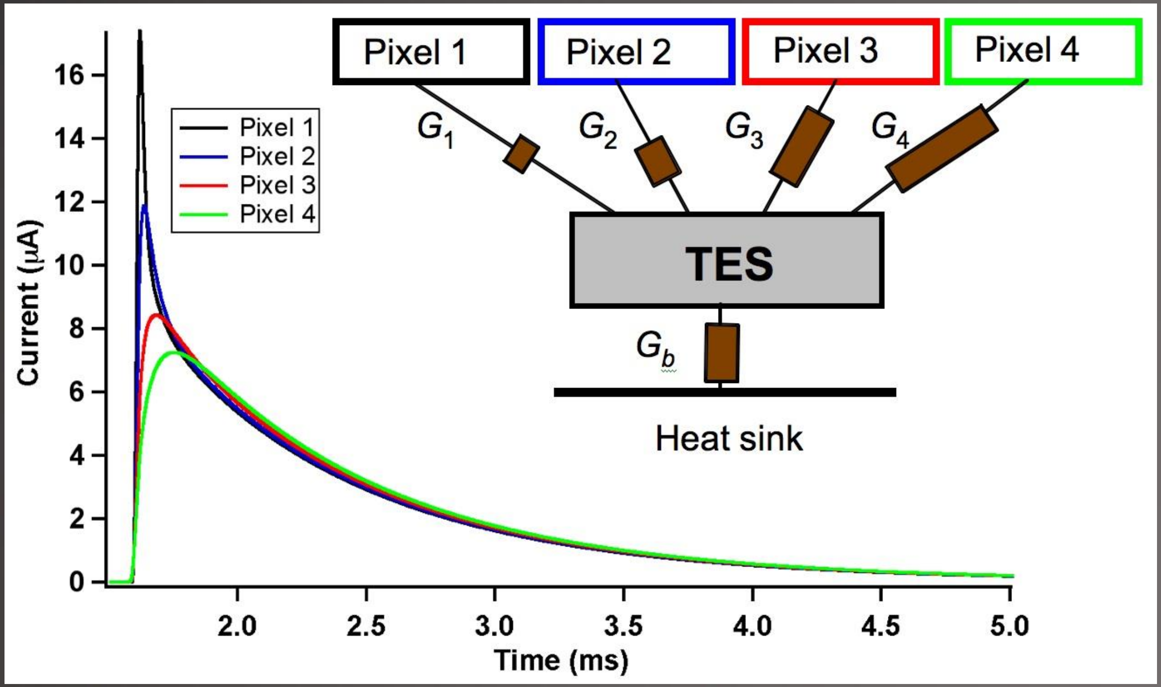
Microcalorimeter Imaging Spectrometer

Progress with respect to multiplexing

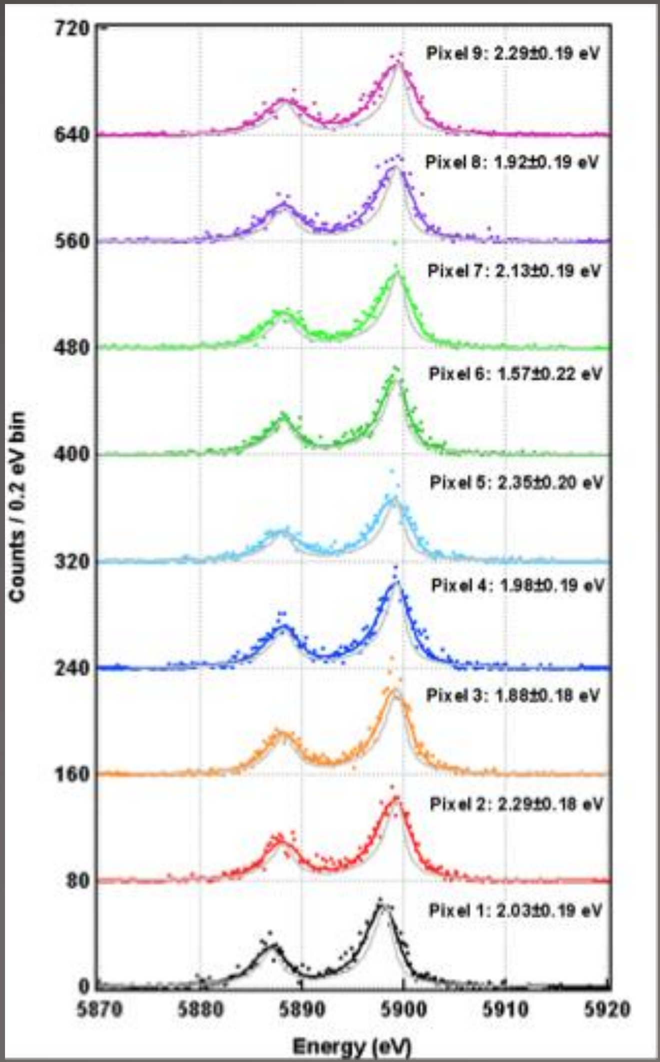
- Conceptual design by S. Bandler et al. (GSFC & NIST):
- Transition Edge Sensors with SQUID readout.
- Multiple absorbers per one TES ("Hydra" design)



Microcalorimeter Imaging Spectrometer

Energy Resolution (w 3 x 3 Hydra)

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

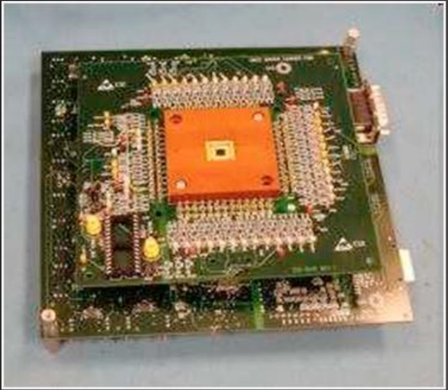


Instrument Technologies and Challenges
High Definition X-ray Imager

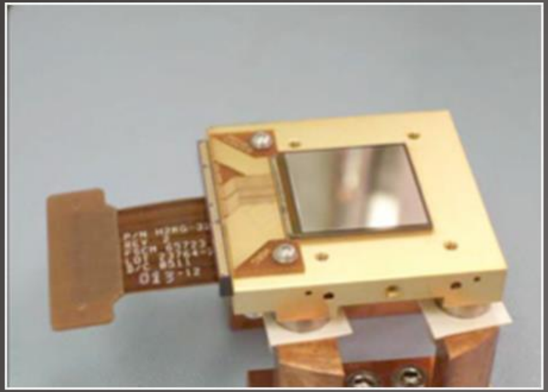
Requirements:

- 16 μm (=0.33 arcsecond) pixel size or smaller
- 4k × 4k array (22′ × 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)

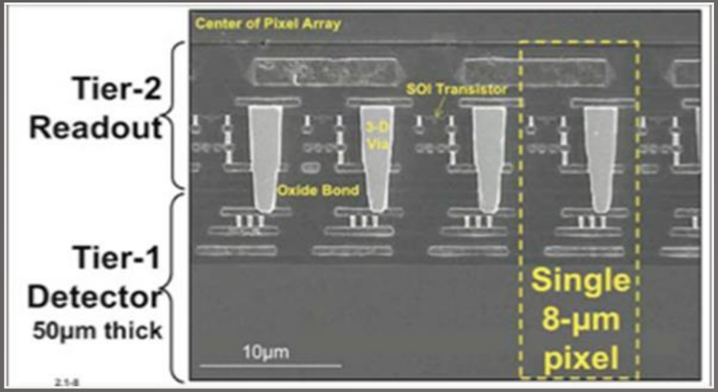
All have been demonstrated individually



SAO/Sarnoff



PSU/Teledyne



MIT/Lincoln Lab

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

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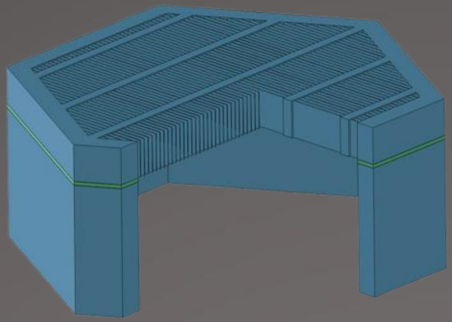
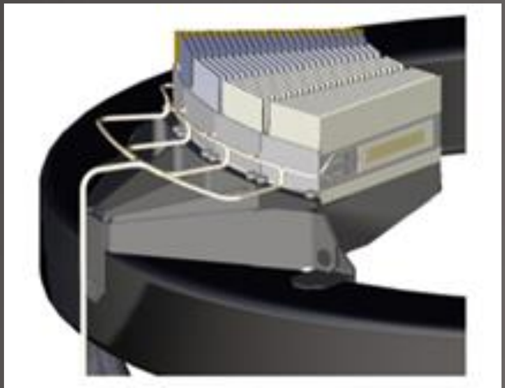
Instrument Technologies and Challenges
Gratings

- Resolving power = 5000 & effective area = 4000 cm^2
- 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 robotic assembly

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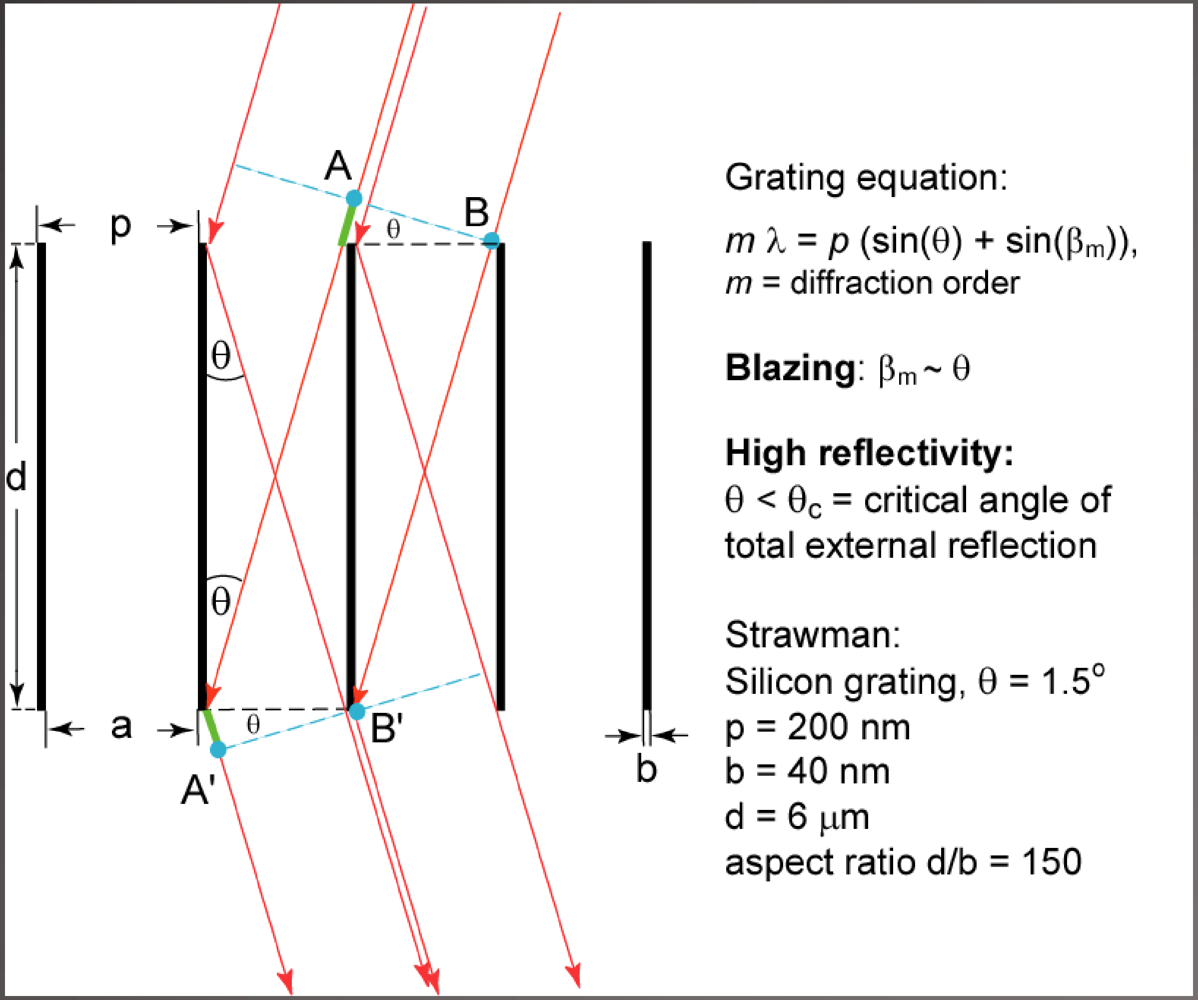
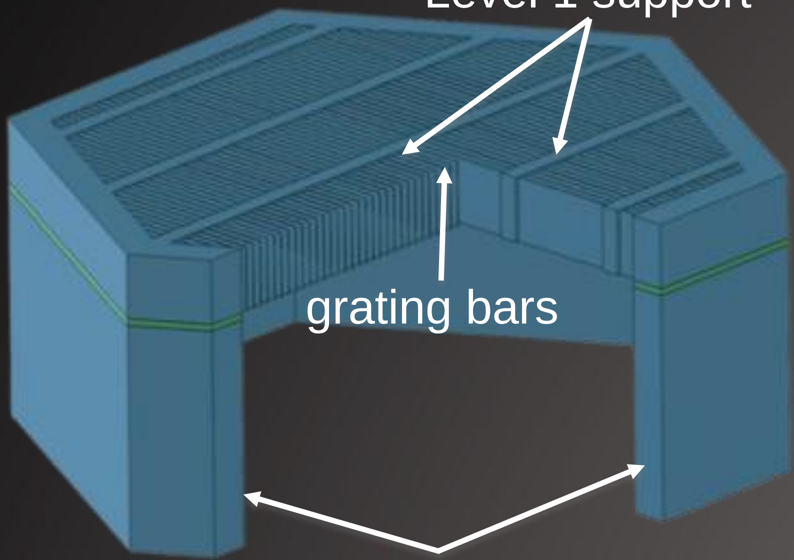
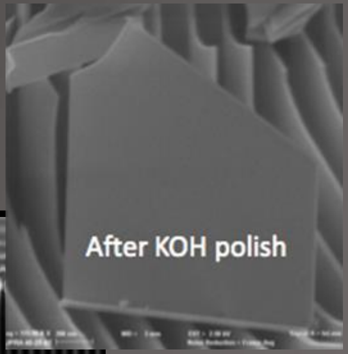
Critical Angle Transmission Grating: Principle

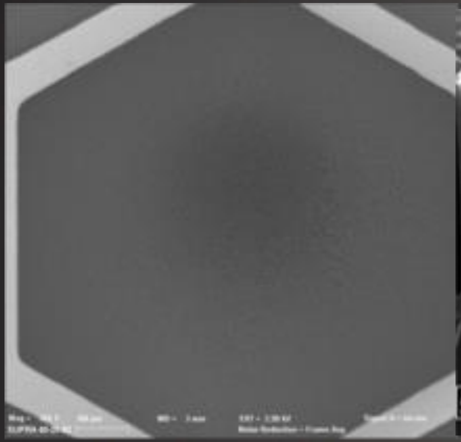
- Combines transmission and blazed grating
- Blazing achieved via reflection from sidewalls at graze angles below the critical angle
- High energy X-rays contribute to effective area at focus

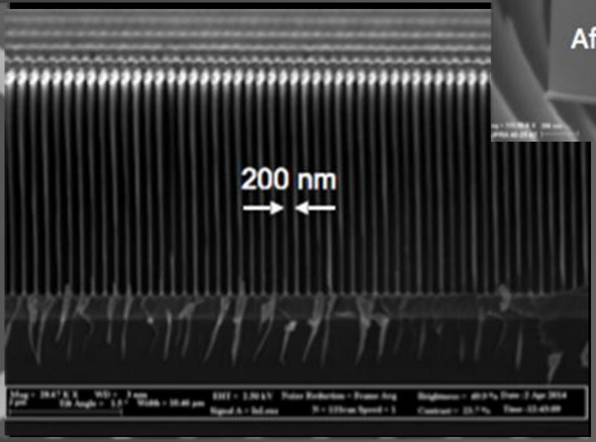


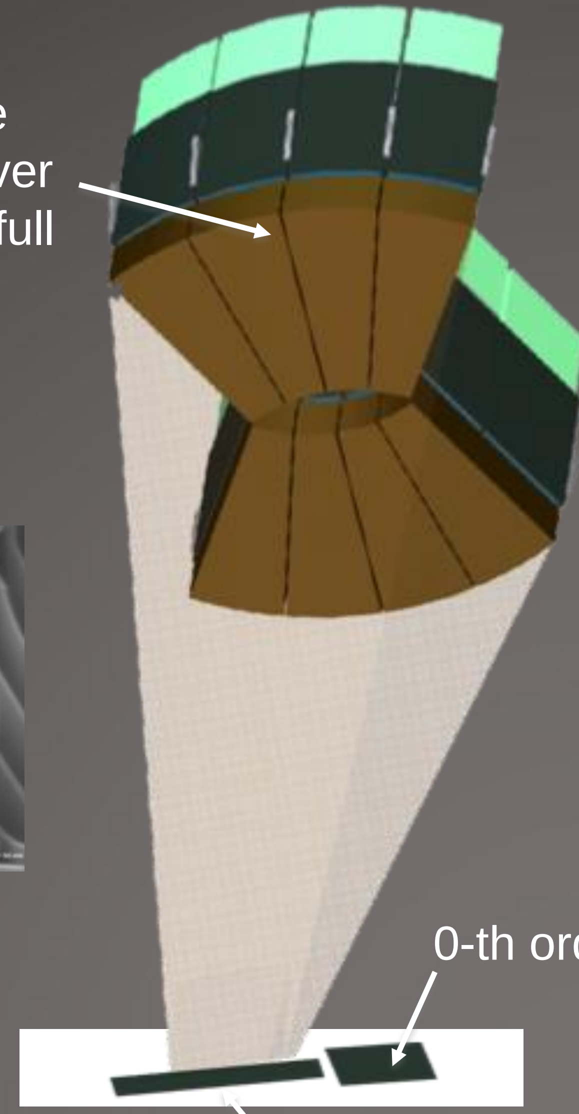
Critical Angle Transmission Gratings (MIT)











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

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

Cost Estimates
Ground Rules and Assumptions -1

- Where applicable, take advantage of *Chandra* heritage or its derivatives
- ***<u>All elements of the Mission are assumed to be at TRL 6 or better prior to phase B</u>***
  - This is a fundamental difference from *Chandra* with regards to the optics and science instruments
- Atlas V-551 launch vehicle (or equivalent)
- L2 orbit & 5 year lifetime
- Mass and power margins set to 30%
- Cost margins set to 35% except for instruments
  - Conservative considering the Chandra heritage
- Instruments costs at 70% confidence
- 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.
- Contractor fee and NASA program support are 10% each
- Integration with the launch vehicle is 5%
- Costs for the optics assembly is a bottom's up input from the MSFC/SAO Team
- Aspect camera based on a ROM quote from Ball Aerospace
- The Instruments are costed at 70%-confidence according to the NASA Instrument Cost Model (NICM)

Costing: Ingredients

Spacecraft

- Structure and mechanisms
- Propulsion
- Thermal systems
- Guidance, Navigation, and Control
- Power
- Science instrument table (aka SIM for Chandra)
- Overall S/C management of all subsystems
  - Power switching for instruments
  - Communication interfaces
  - Data storage
- Master Equipment List constructed with power and mass margins set at 30%

No technology challenges were identified for the S/C

Costing: Ingredients

Instruments

- X-ray microcalorimeter
- High definition X-ray Imager
- Critical angle transmission gratings with readout
- Master Equipment List established with mass & power margins set at 30%

Optics

- High resolution mirror assembly
- Master Equipment List established with mass & power margins set at 30%

Technology challenges were identified in previous slides

Costing: Ingredients

Mission Profile

- Sun-Earth L2 halo orbit Thermal systems
- Mission duration = 5 years
- Consumables sized for 20 years
- Launch vehicle Atlas V-551 (or similar)

No technology challenges were identified for the Mission

Cost Estimates

• S/C	$1,650M
• Launch Vehicle (Atlas 551)	$ 240M
• Scientific Instruments	$ 466M
• Optics	$ 438M
• Pre-Launch Operations, Planning & Support	$ 196M
• Total	$2,990M

• Mission Operations	$70M/yr

Backup Slides

- Technical (specifications) Comparison to Athena?
- Chandra costs in today's era?