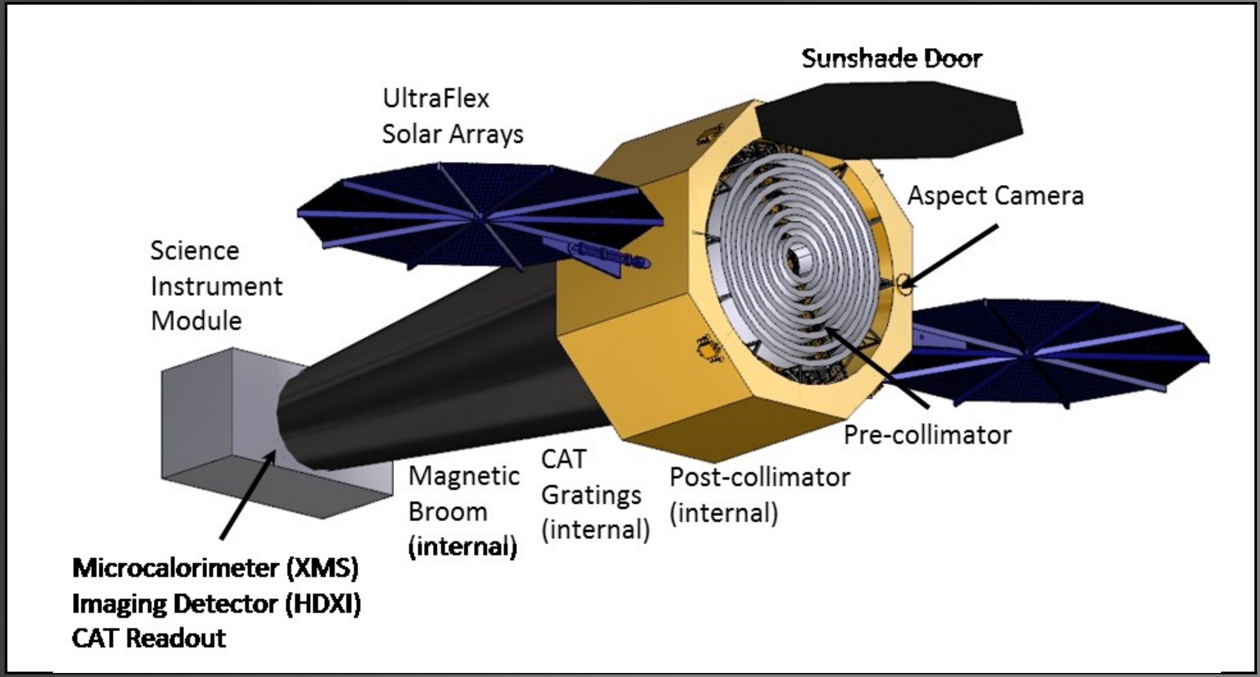
The X-ray Surveyor Mission: A Concept Study

Jessica A. Gaskin (MSFC)
On behalf of the X-ray Surveyor community



2020 Decadal Prioritization

- NASA Astrophysics Division white paper: Planning for the 2020 Decadal Survey
  - ✔ Provided an Initial list of missions drawn from 2010 Decadal Survey and 2013 Astrophysics Roadmap that includes the X-ray Surveyor
  - ✔ The three NASA Program Analysis Groups (PAGs) to coordinate community discussion to review and update list of missions
  - PAG reports will be sent to the Astrophysics Subcommittee and then to the Astrophysics Division for selection of mission concepts to study
  - Will result in a call for Science and Technology Definition Teams and assignment of lead NASA Center for each study

Planning for the 2020 Decadal Survey
An Astrophysics Division White Paper

POC: Paul Hertz, Astrophysics Division Director (paul.hertz@nasa.gov)
January 4, 2015

Background

The next Decadal Survey in Astronomy and Astrophysics will be conducted by the National Research Council (NRC) in response to a charge set by NASA and NSF, and possibly DOE. Nominally this survey will be carried out in the years 2018-2020.

One of the important tasks of the 2020 Decadal Survey will be to prioritize large missions to follow JWST (the highest priority large space mission of the 2000 Decadal Survey) and WFIRST (the highest priority large space mission of the 2010 Decadal Survey). To enable this prioritization, NASA will provide information on several candidate large mission concepts for consideration by the 2020 Decadal Survey Committee.

A well informed prioritization by the 2020 Decadal Survey Committee requires that any large mission be studied sufficiently to provide, at a minimum, the following information for the consideration of the 2020 Decadal Survey Committee:

- Science case
- Design reference mission with strawman payload
- Technology development needs
- Cost requirements assessment

In the 2010 Decadal Survey, a large mission was defined as one having a total cost exceeding $1B. For the purpose of this white paper, NASA adopts the same definition.

The 2020 Decadal Survey Committee will consider a broad range of activities in addition to large space missions; these activities will certainly include medium-size, or probe-class, space missions. This white paper only addresses the plans for providing information to the 2020 Decadal Survey Committee regarding large mission concepts. No decision has been made by NASA at this time on how to provide input to the 2020 Decadal Survey Committee regarding probe-class missions, technology development, or other programmatic areas.

This white paper presents the Astrophysics Division's plans for providing the appropriate information on a small set of large mission concepts to the 2020 Decadal Survey Committee.

Overall Process

The process of developing the necessary science case and technical information for candidate large mission concepts may be described as a two-part process:

- Part A: Identification of a small set of candidate large missions, and
- Part B: Development of the science case and technical information for each member of the small set of candidate large missions.

White Paper - 1

http://cor.gsfc.nasa.gov/copag/rfi/

X-ray Surveyor Goals

- ***Leaps in Capability:*** large area with high angular resolution for 1–2 orders of magnitude gains in sensitivity, large field of view with subarcsec imaging, high resolution spectroscopy for point-like and extended sources

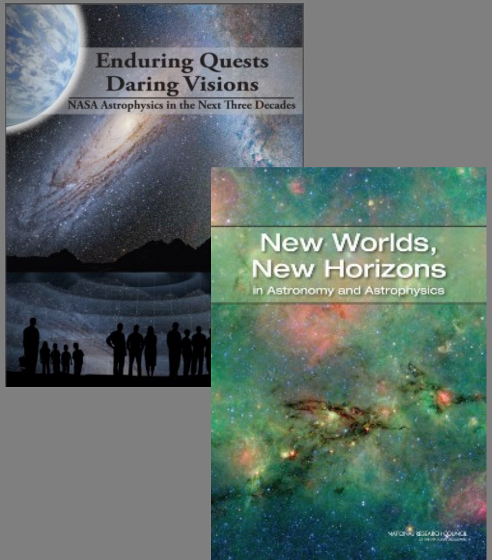
- ***Feasible:*** *Chandra*-like mission with regards to cost and complexity with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B

- ***Scientifically compelling:*** frontier science from Solar system to first accretion light in Universe; revolution in understanding physics of astronomical systems

Consistent with:

NASA Astrophysics Roadmap: Enduring Quests, Daring Visions

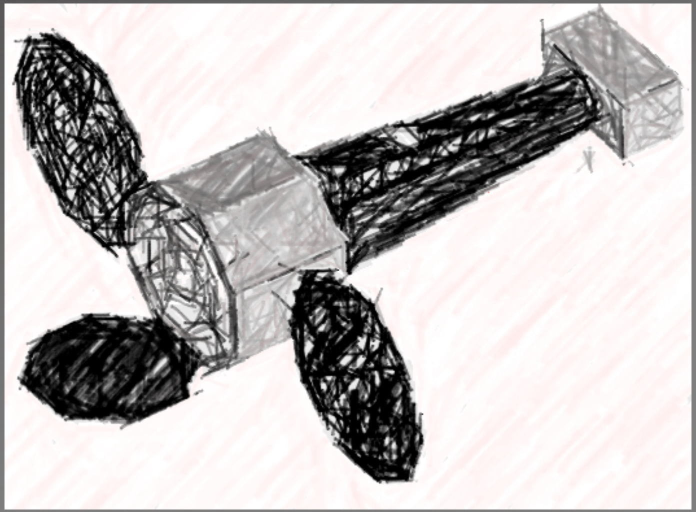
201 Astrophysics Decadal Survey: New Worlds, New Horizons

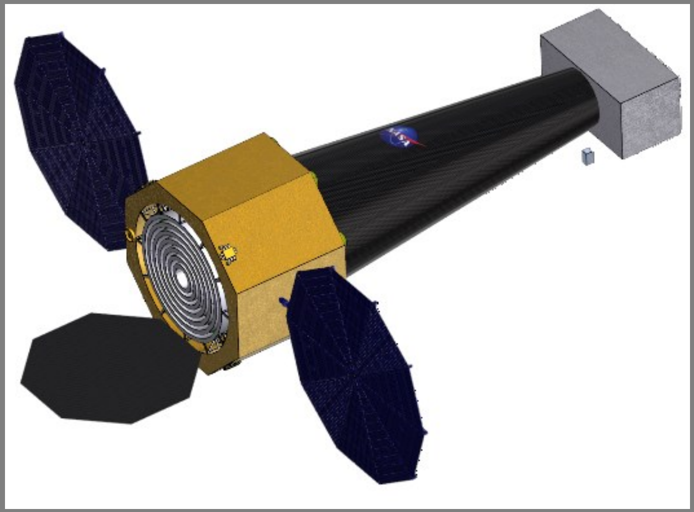


X-ray Surveyor Mission Concept

- MSFC ACO Team Led by Randall Hopkins & Andrew Schnell
- Strawman definition:
  Spacecraft, instruments, optics, orbit, radiation environment, launch vehicle and costing
- Performed under the guidance of an informal mission concept team comprising the following:

J. A. Gaskin (MSFC), A. Vikhlinin (SAO), M. C. Weisskopf (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)





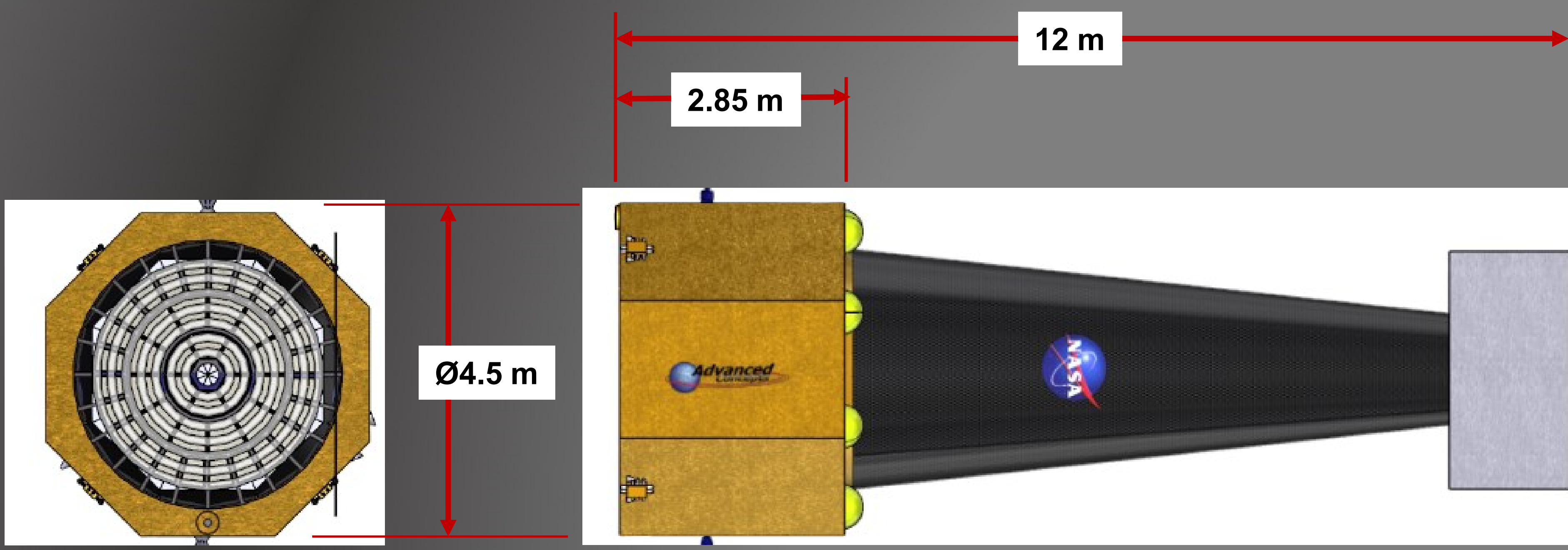
X-ray Surveyor: A Successor to *Chandra*

- Angular resolution at least as good as *Chandra*
- Much higher photon throughput than *Chandra* (observations are photon-limited)

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

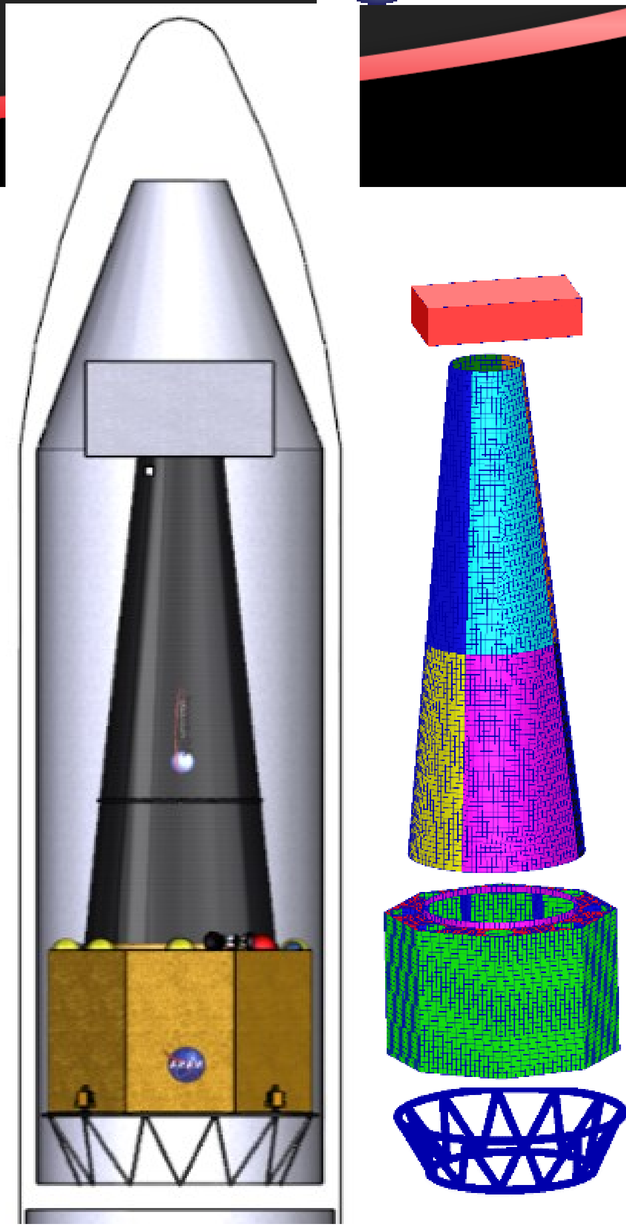
✓ Limits most spacecraft requirements to *Chandra-like*

✓ Achieves *Chandra-like* cost



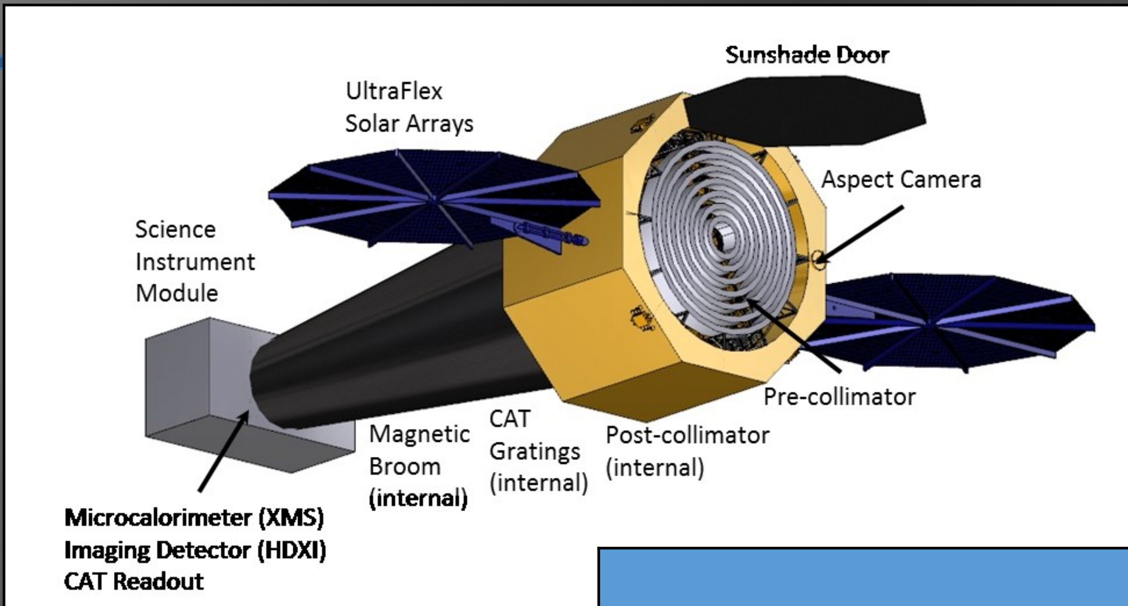
ACO Study Participants

Study Lead	**Andrew Schnell (ED04)**
Study Lead *Emeritus*	**Randy Hopkins (ED04)**
Mission Analysis	Dan Thomas (ED04)
	Randy Hopkins (ED04)
Configuration	Mike Baysinger (ED04)
Propulsion	Dan Thomas (ED04)
Power	Leo Fabisinski (ED04)
C&DH	Ben Neighbors (ES12)
Communications	Ben Neighbors (ES12)
GN&C	
Thermal Analysis	Andrew Schnell (ED04)
Structural Analysis	Jay Garcia (ED04)
Mechanisms	Alex Few (ES21)
Environments	Joe Minow (EV44)
Cost	Spencer Hill (CS50)



AtlasV 5m Long Shroud

Optics & Instruments



- High-resolution X-ray telescope
- Critical Angle Transmission XGS
- X-ray Microcalorimeter Imaging Spectrometer
- High Definition X-ray Imager

Concept Payload for:
- Feasibility (TRL 6)
- Mass
- Power
- Mechanical
- Costing

NOT THE FINAL CONFIGURATION

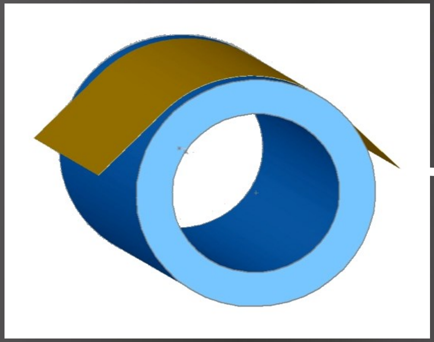
	Chandra	X-Ray Surveyor
Relative effective area (0.5 – 2 keV)	1 (HRMA + ACIS)	50
Angular resolution (50% power diam.)	0.5”	0.5”
4 Ms point source sensitivity (erg/s/cm^2)	5×10^{-18}	3×10^{-19}
Field of View with < 1” HPD (arcmin^2)	20	315
Spectral resolving power, R, for point sources	1000 (1 keV) 160 (6 keV)	5000 (0.2-1.2 keV) 1200 (6 keV)
Spatial scale for R>1000 of extended sources	N/A	1”
Wide FOV Imaging	16’ x 16’ (ACIS) 30’ x 30’ (HRC)	22’ x 22’

Light-Weight, Sub-Arcsecond Optics

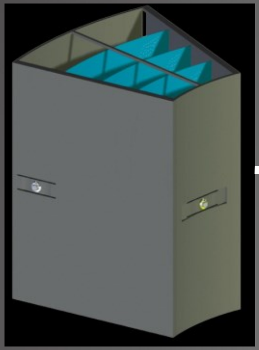
- Build upon segmented optics approaches considered for Con-X, IXO, AXSIO
  - -The segmented optics approach for IXO was progressing and a ~10″ angular resolution was demonstrated

- Follow <u>multiple</u> technology developments for the reflecting surfaces

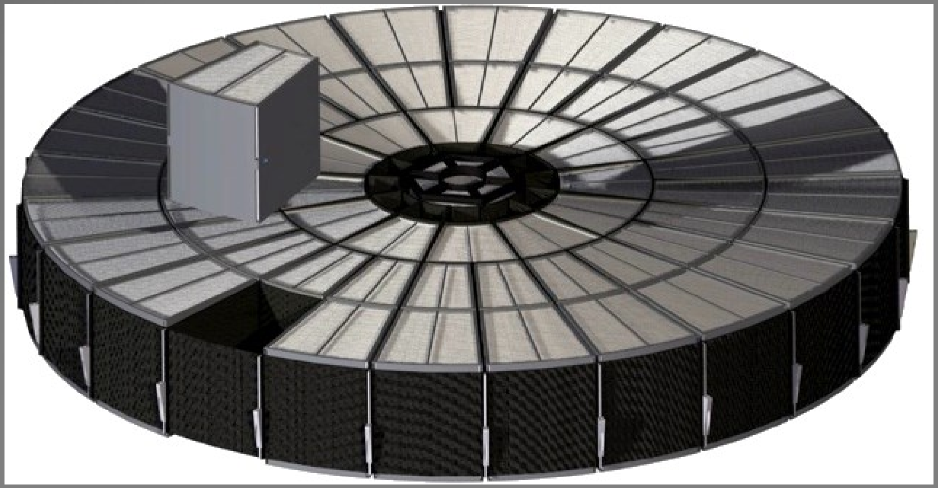
Fabrication



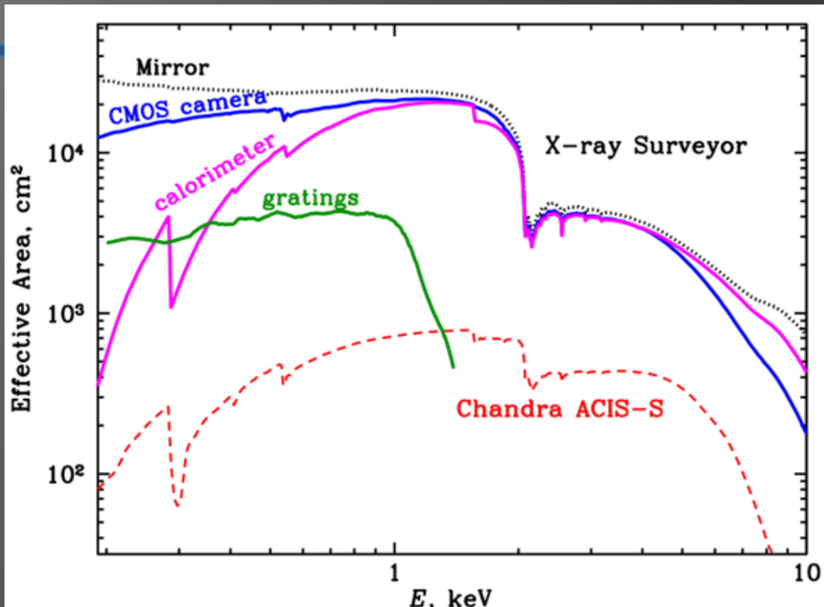
Alignment & Mounting



Integration

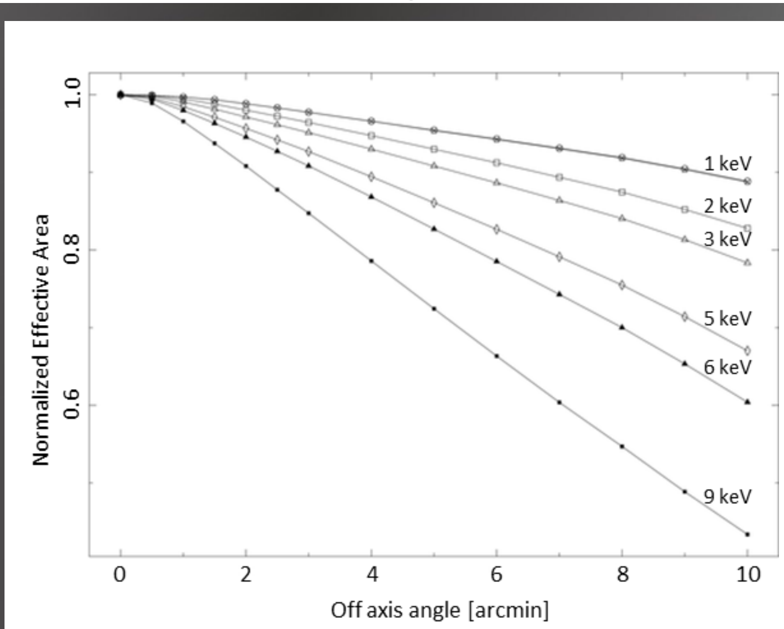


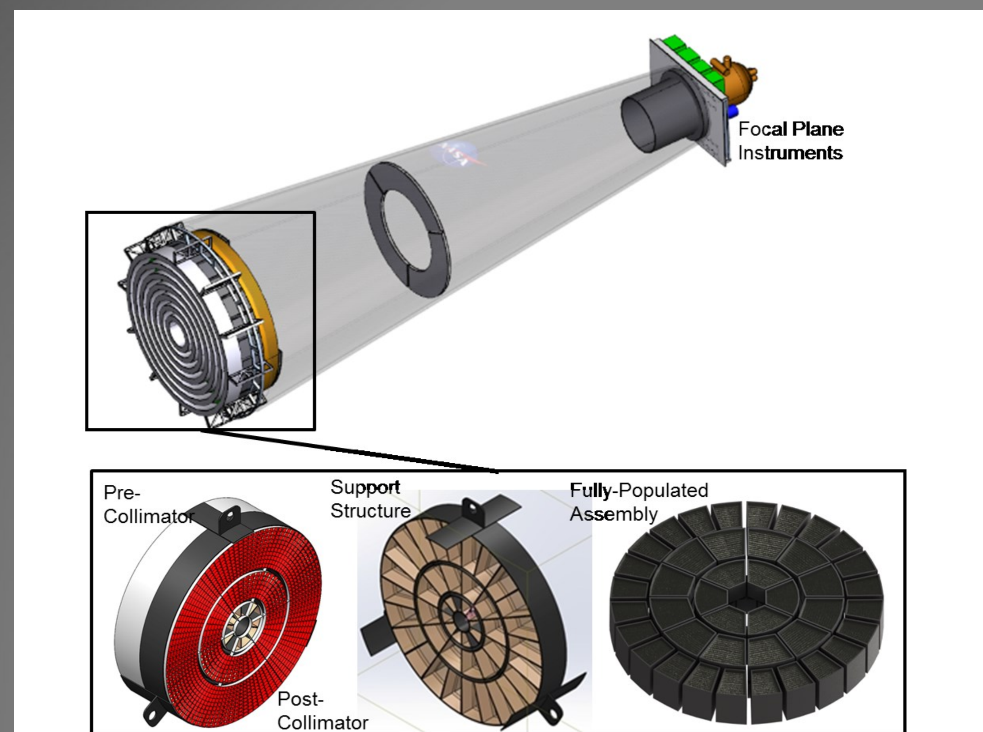
Optics – Specifications & Performance



- Wolter-Schwarzschild optical scheme
- 292 nested shells, segmented design
- 3m outer diameter
- 30x more effective area than Chandra HRMA

  -(2.3 m^2 @ 1 keV)
- 4Msec survey limit ~3×10^{-19} erg/s/cm^2 (0.5–2 keV)





Obtaining Sub-Arcsecond Elements

APPROACHES

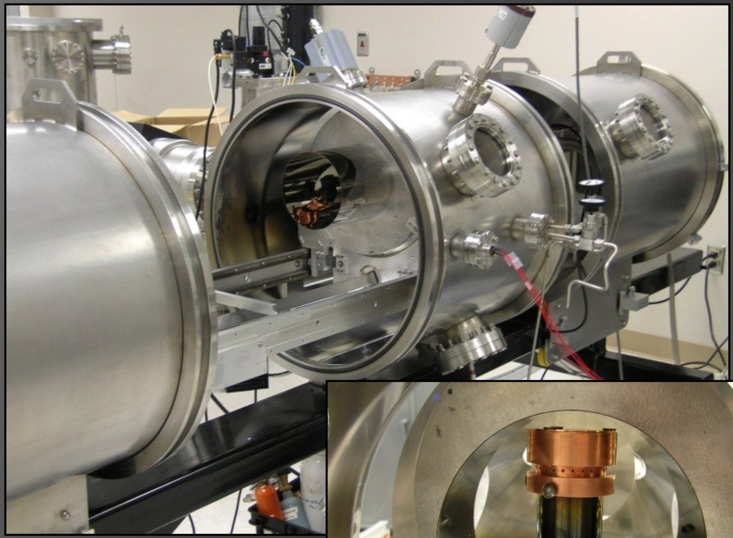
- Differential deposition
    - Fill in the valleys (MSFC/RXO)

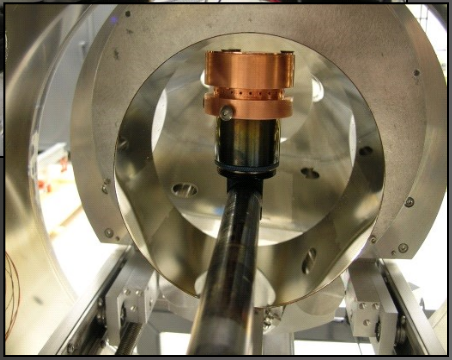
- Adjustable optics
    - Piezoelectric film on the back surface (SAO/PSU)

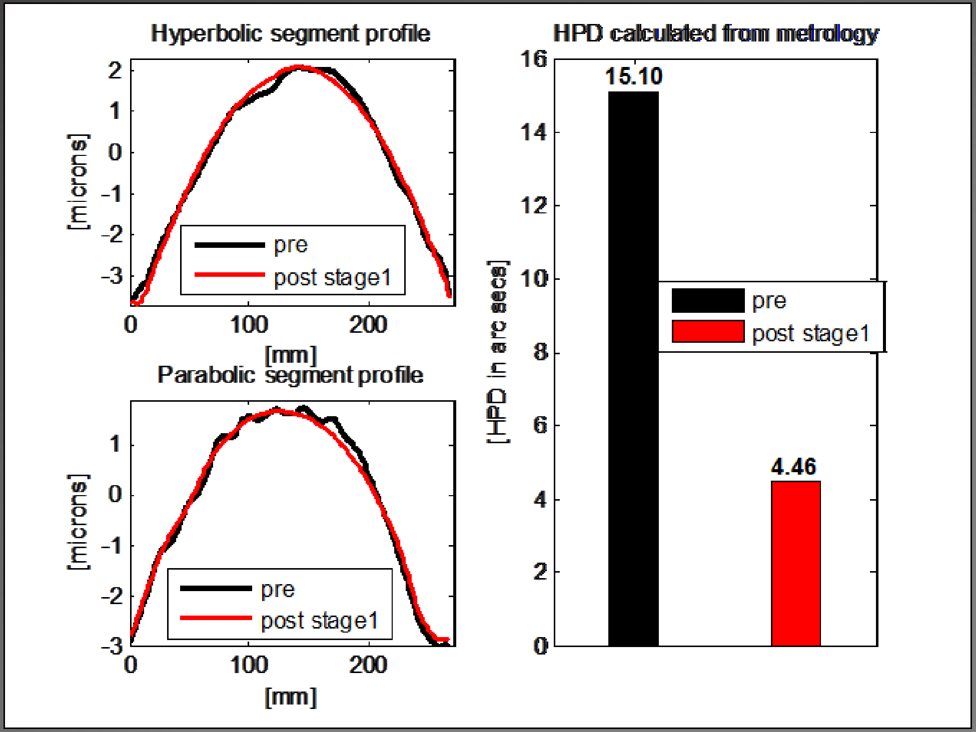
ALSO WATCH

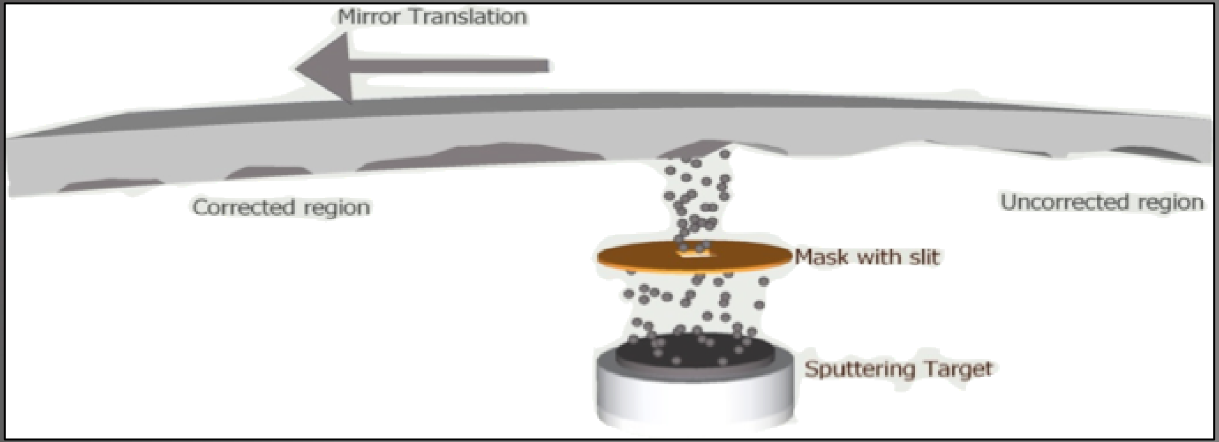
- Figuring, polishing, and slicing silicon into thin mirrors (GSFC)
- Magnetostrictive film on the back surface (Northwestern)
- Direct polishing of a variety of thin substrates (MSFC/Brera)
- Ion Implantation

Differential Deposition (MSFC, RXO)

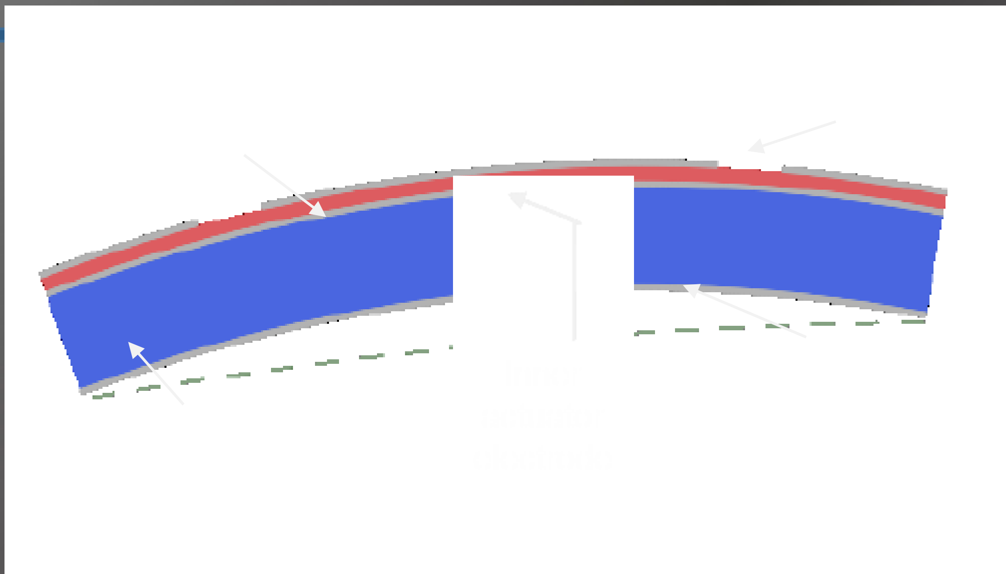


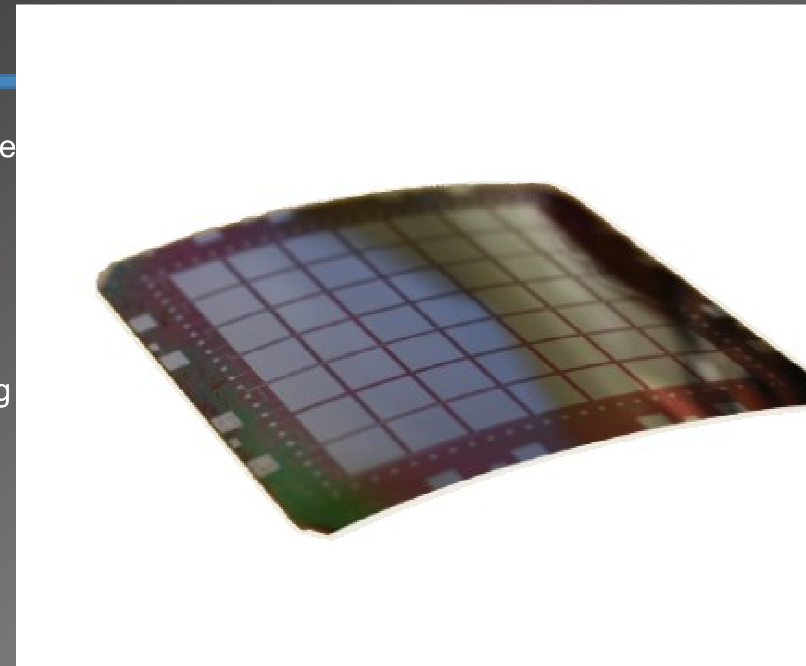






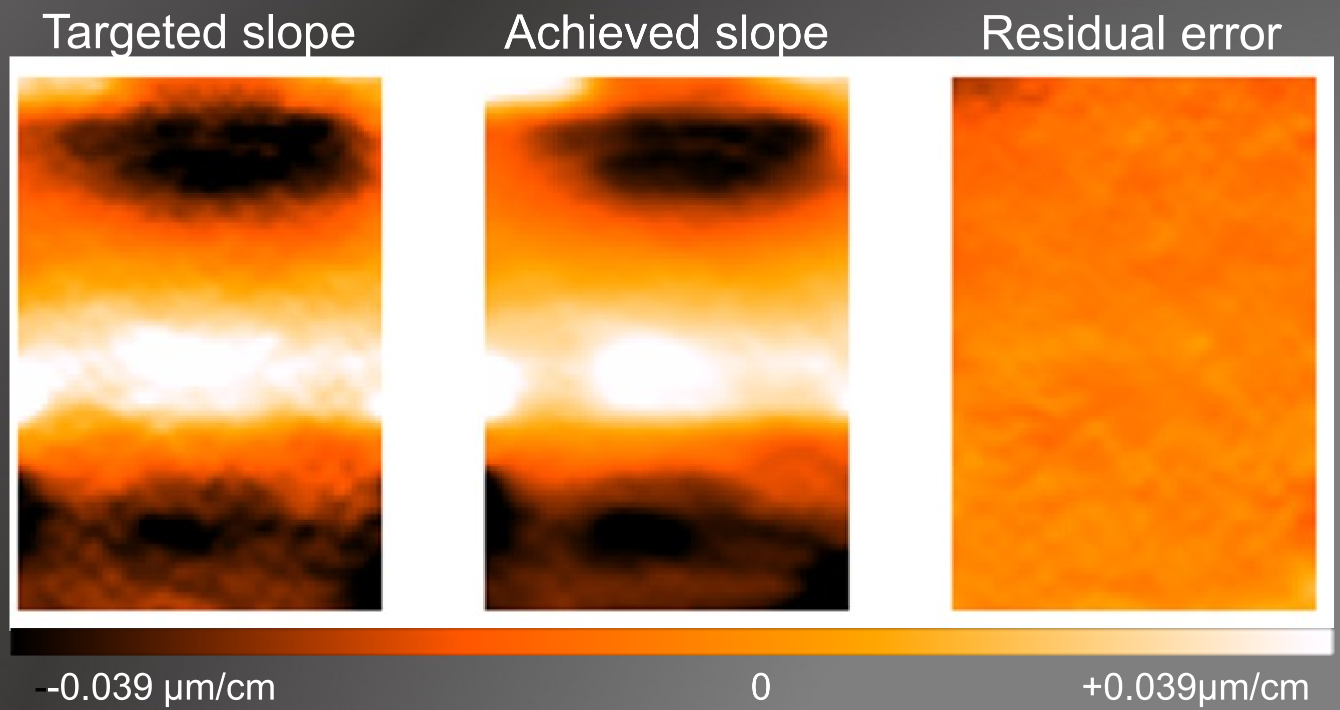
Adjustable Optics – Piezoelectric (SAO/PSU)





- 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
- 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

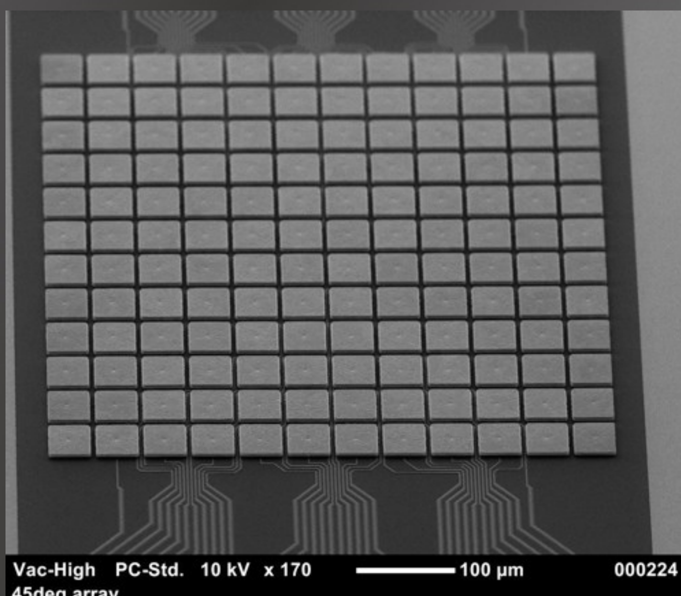
Adjustable Optics – Piezoelectric (SAO/PSU)

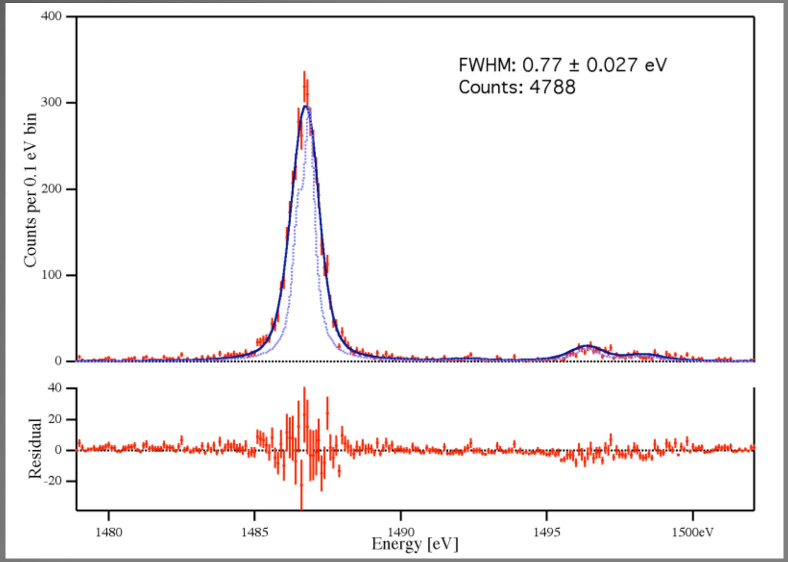


- 10 cm diameter flat mirror, 86 10 × 5 mm cells operated together to apply a deterministic figure in a 75 × 50 mm region
- Target correction (left) is approximated (middle) giving residuals shown on right
- Residuals converted to HPD for 2 reflections correspond to 3 arcseonds

X-ray Microcalorimeter Imaging Spectrometer (XMIS)

Parameter	Goal
Energy Range	0.2 – 10 keV
Spatial Resolution	1 arcsec
Field-of-View	5 arcmin x 5 arcmin (min)
Energy Resolution	< 5 eV
Count Rate Capability	< 1 c/s per pixel
Pixel Size / array size (10-m focal length)	50 μm pixels / 300 x 300 pixel array



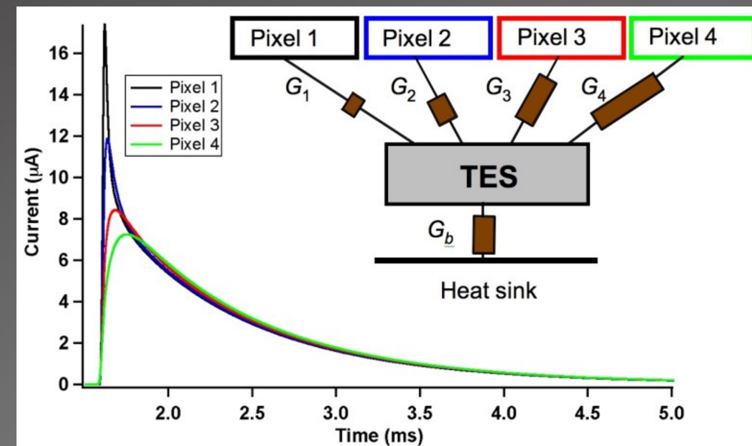


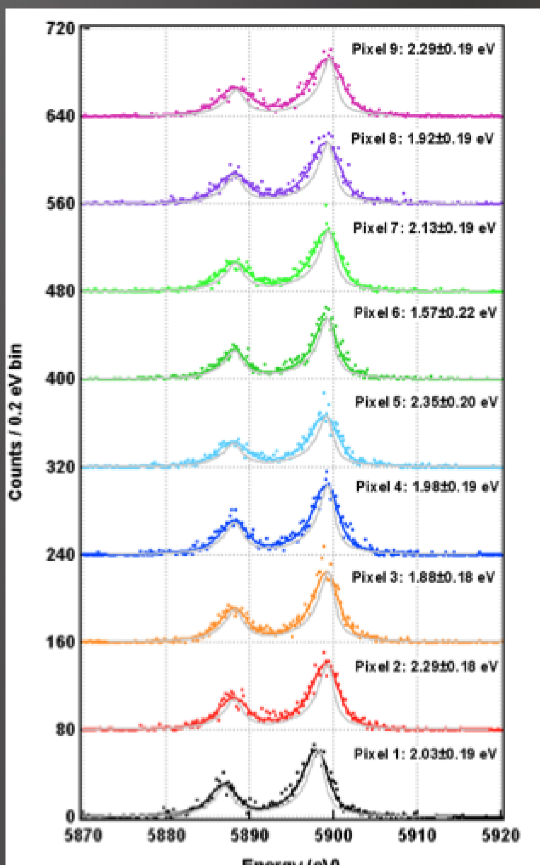
Challenge: Develop multiplexing approaches for achieving ~10^5 pixel arrays

X-ray Microcalorimeter Imaging Spectrometer (XMIS)

Progress with respect to multiplexing:

- Transition Edge Sensors (TES) with SQUID readout.
- Multiple absorbers per one TES (“Hydra” design)





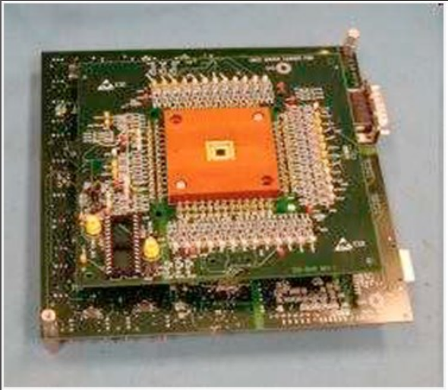
- Current lab results with 3 × 3 Hydra, 65μm pixels on 75 μm pitch shows 2.4 eV (FWHM) resolution at 6 keV
- ΔE ~ N for N × N Hydras, so current results imply ~5 × 5 Hydras with 50 μm pixels and < 5eV energy resolution are achievable

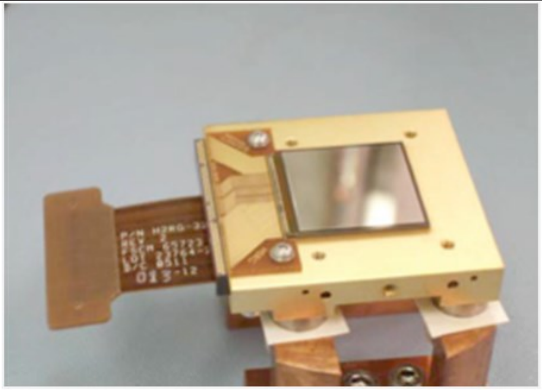
Smith, S.J., et al., IEEE Trans. on Appl. Superconductivity, 2009
Kilbourne, C., et al, A response to RFI : Concepts for the Next X-ray Astronomy Mission submission, 2011

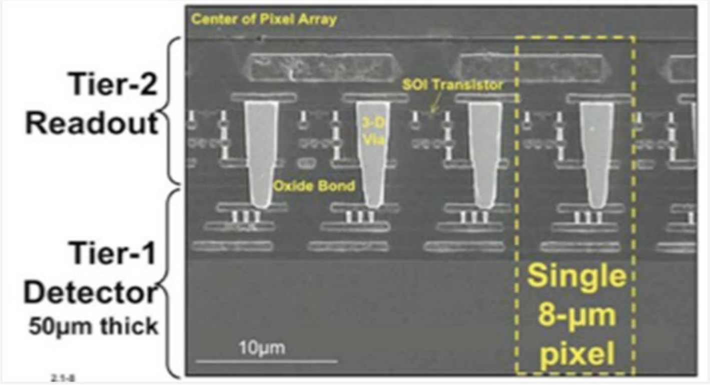
High Definition X-ray Imager

Parameter	Goal
Energy Range	0.2 – 10 keV
Field of View	22 arcmin x 22 arcmin
Energy Resolution	37 eV @ 0.3 keV, 120 eV @ 6 keV (FWHM)
Quantum Efficiency	> 90% (0.3-6 keV), > 10% (0.2-9 keV)
Pixel Size / Array Size	<16 µm (< 0.33 arcsec/pixel) / 4096 x 4096 (or equivalent)
Frame Rate	> 100 frames/s (full frame) > 10000 frames/s (windowed region)
Read Noise	< 4e^- rms

All have been demonstrated individually



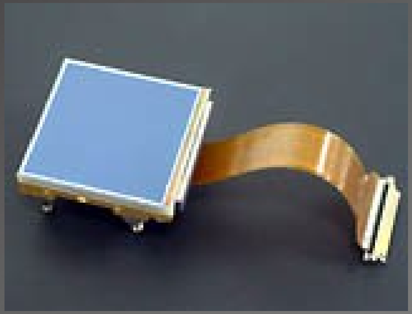




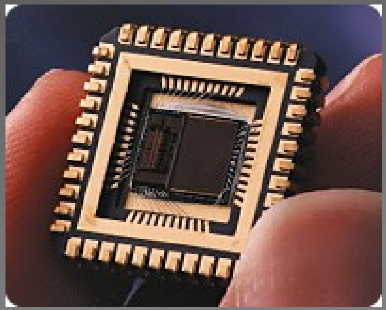
Challenges: Develop sensor package that meets all requirements, and approximates the optimal focal surface

Advantages of Active Pixel Sensors

- Random-access pixel readouts
- Silicon-based devices:
  - Similarities to CCDs
    - Photoelectric absorption in silicon
    - Energy resolution comparable to CCDs
    - Large arrays like CCDs
  - High count rate capability with low pile-up
    - Arbitrary window readout vs entire device readout for CCD, and multiple output lines boosts full frame rate
  - Radiation hard (charge is not transferred across the device)
  - Low power (<100 mW for some devices)
  - On-chip integration of signal processing electronics (lower noise)
  - Some devices have >200 μm depletion depths = Good QE over soft X-ray band
  - Large formats (up to 4k × 4k abuttable devices)
  - Pixel sizes from 8 μm to 100 μm

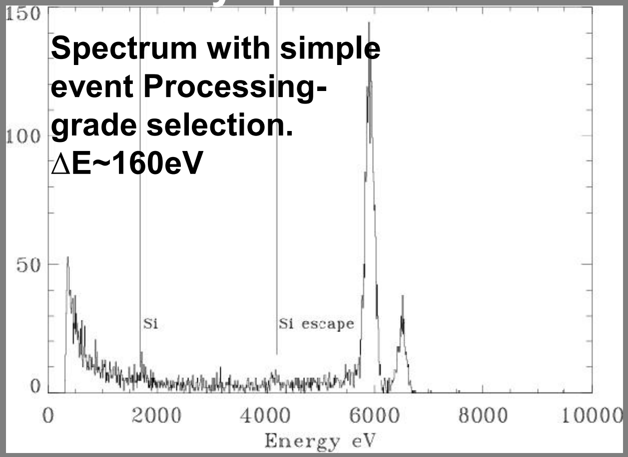


Hybrid
– Multiple bonded layers, with layers for photon detection and readout circuitry optimized independently
– MIT/LL and PSU/Teledyne



Monolithic
– Single Si wafer used for both photon detection and read out electronics
– SAO/Sarnoff and MPE

55Fe x-ray spectrum. T=300K



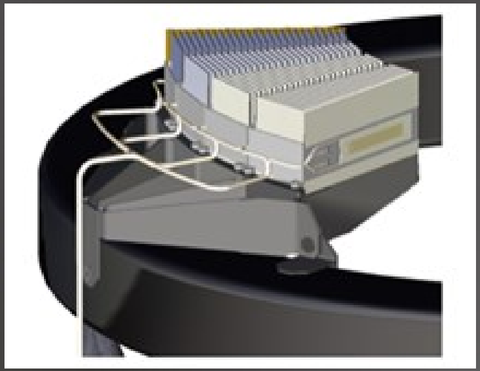
Kenter, A., et al., Proc. SPIE 9154, 2014

Grating Spectrometer

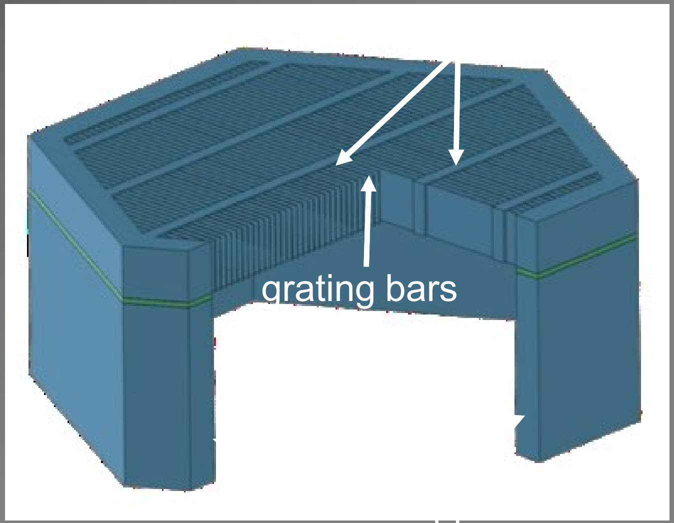
- Resolving power = 5000 & effective area = 4000 cm^2
- Energy range 0.2 – 2.0 keV

Blazed Off-Plane Reflection gratings

(Univ. of Iowa)



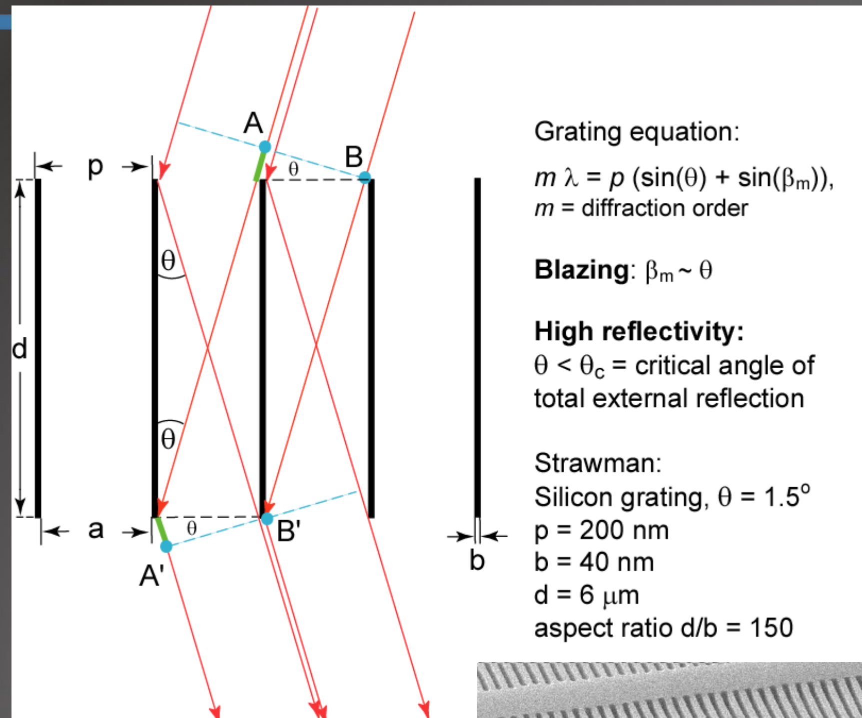
Critical Angle Transmission (CAT) gratings (MIT)

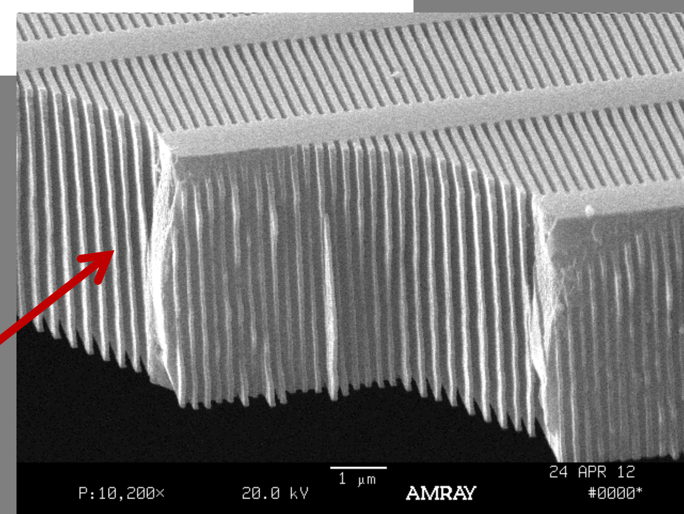


Challenges: improving yield, developing efficient assembly processes, and improving efficiency

Critical Angle Transmission Gratings (MIT)

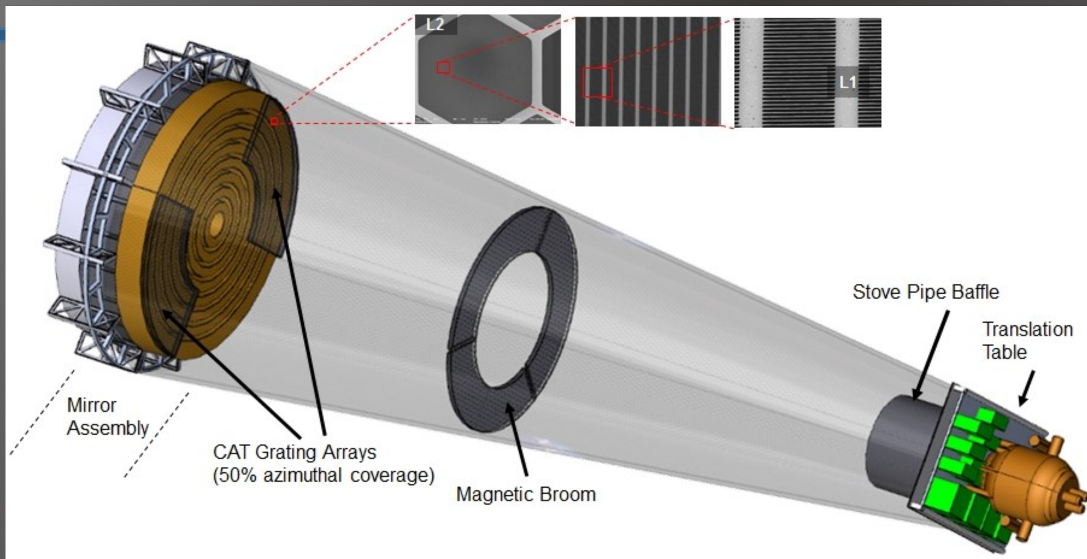
- CAT grating combines advantages of transmission gratings (relaxed alignment, low weight) with high efficiency of blazed reflection gratings.
- Blazing achieved via reflection from grating bar sidewalls at graze angles below the critical angle for total external reflection.
- High energy x rays undergo minimal absorption and contribute to effective area at focus.





200 nm pitch
CAT grating bars

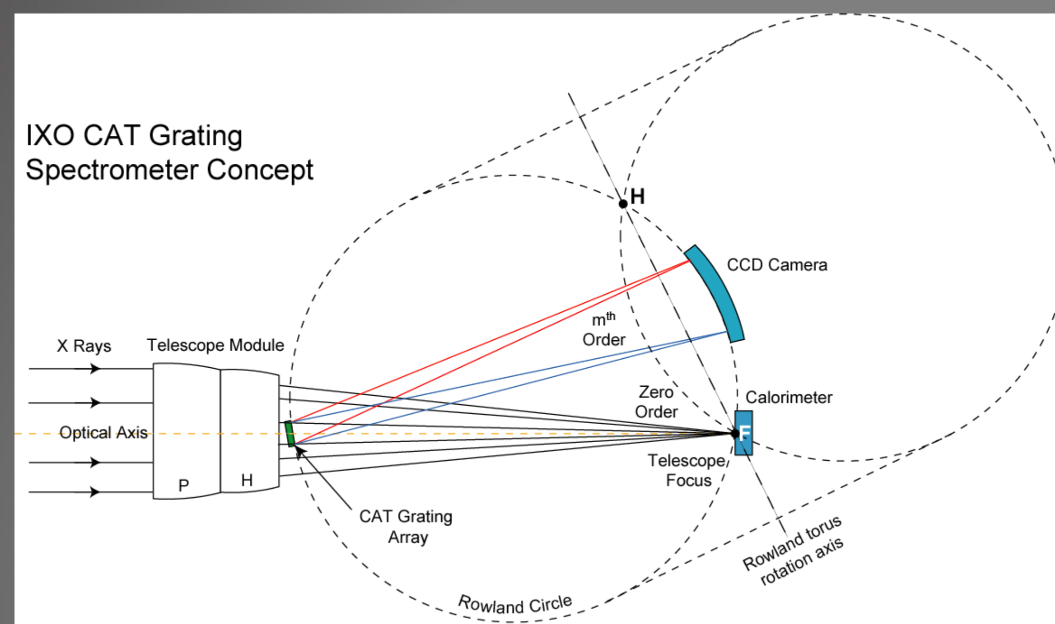
Critical Angle Transmission Gratings (MIT)



Advantages:

- low mass
- relaxed alignment & figure tolerances
- high diffraction efficiency
- up to 10X dispersion of Chandra HETGS
- no positive orders (i.e., smaller detector)

- Gratings, camera, and focus share same Rowland torus.
- Blazed gratings; only orders on one side are utilized.
- Only fraction (50%) of mirrors is covered: "sub-aperturing" boosts spectral resolution.



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

- All elements of the Mission are assumed to be at TRL 6 or better prior to phase B
- 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$

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

THANK YOU!

Science Organizing Committee:
Jessica A. Gaskin (MSFC), Martin C. Weisskopf (MSFC), Harvey Tananbaum (SAO), Alexey Vikhlinin (SAO), Fabbiano Giuseppina (SAO), Christine Jones (SAO), Eric Feigelson (PSU), Neil Brandt (PSU), Leisa Townsley (PSU), Dave Burrows (PSU), Priya Natarajan (Yale), Maxim Markevitch (GSFC), Andrey Kravtsov (Chic.), Steve Allen (Stanford), Sebastian Heinz (Wisc.), Chryssa Kouveliotou (GWU), Roger Romani (Stanford), Feryal Ozel (Ariz.), Richard Mushotzky (UMD), Mike Nowak (MIT), Rachel Osten (STSCI)