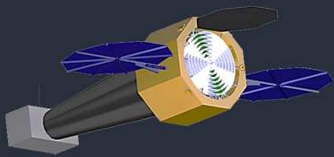
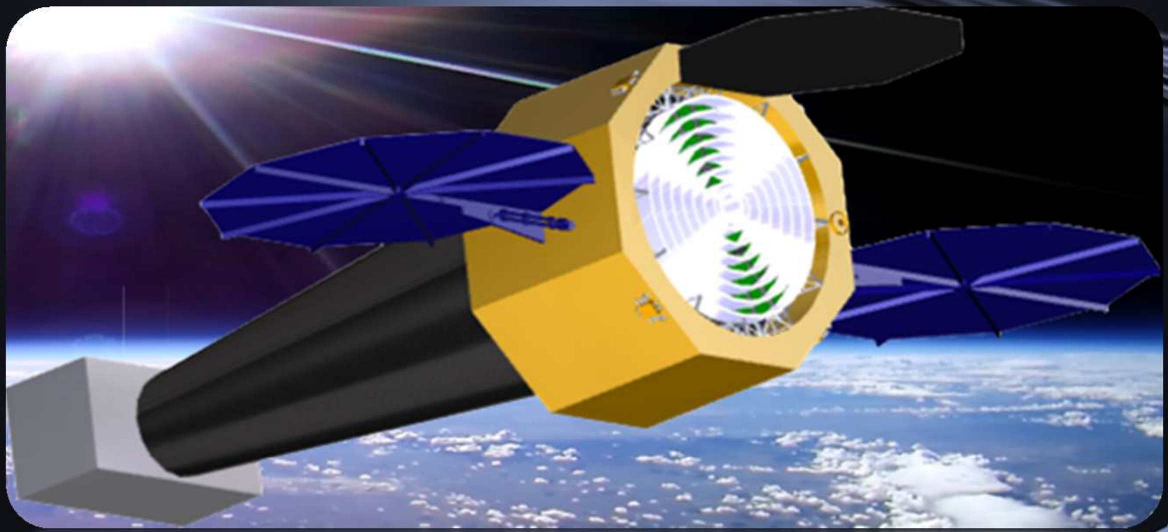


Announcements

- Free WIFI – “si-visitor’
- The Program has been posted on the website
  - http://cxc.harvard.edu/cdo/xray_surveyor/
  - DETAILS – PRESENTATION – ORAL PROGRAM
- First coffee Break is from 10:40am – 11:00am near registration table.
- Posters are in Rooms 4018-4019 next to the Patron’s Lounge
- No Food or Drink (other than bottled water) is allowed in the Rasmuson Theater
- Lunch Today is from 1:10pm-2:10pm
  - The cafeteria is on first floor and food trucks are located just outside the museum
- Please email me your talks, or provide them to me at a session break
  Jessica.Gaskin@nasa.gov
- If you have not already responded to Martin Elvis’ email regarding the breakout session Wednesday afternoon, please do so at your earliest convenience

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.

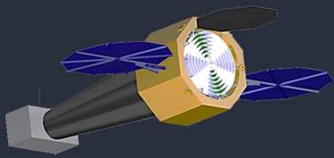
Overall Process

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/

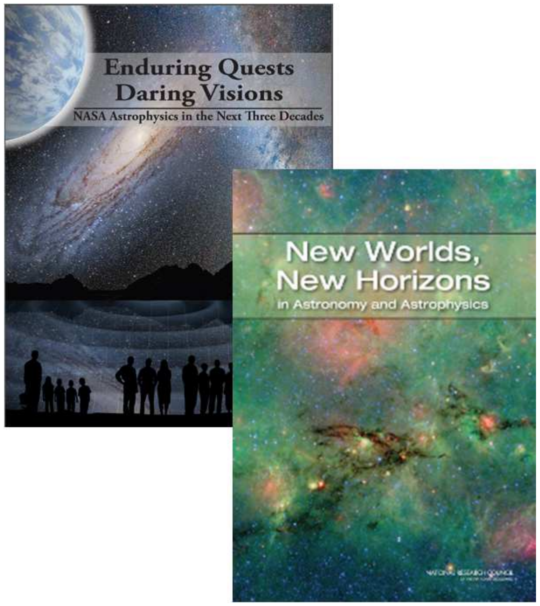


X-ray Surveyor Goals

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

- ***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



Consistent with:

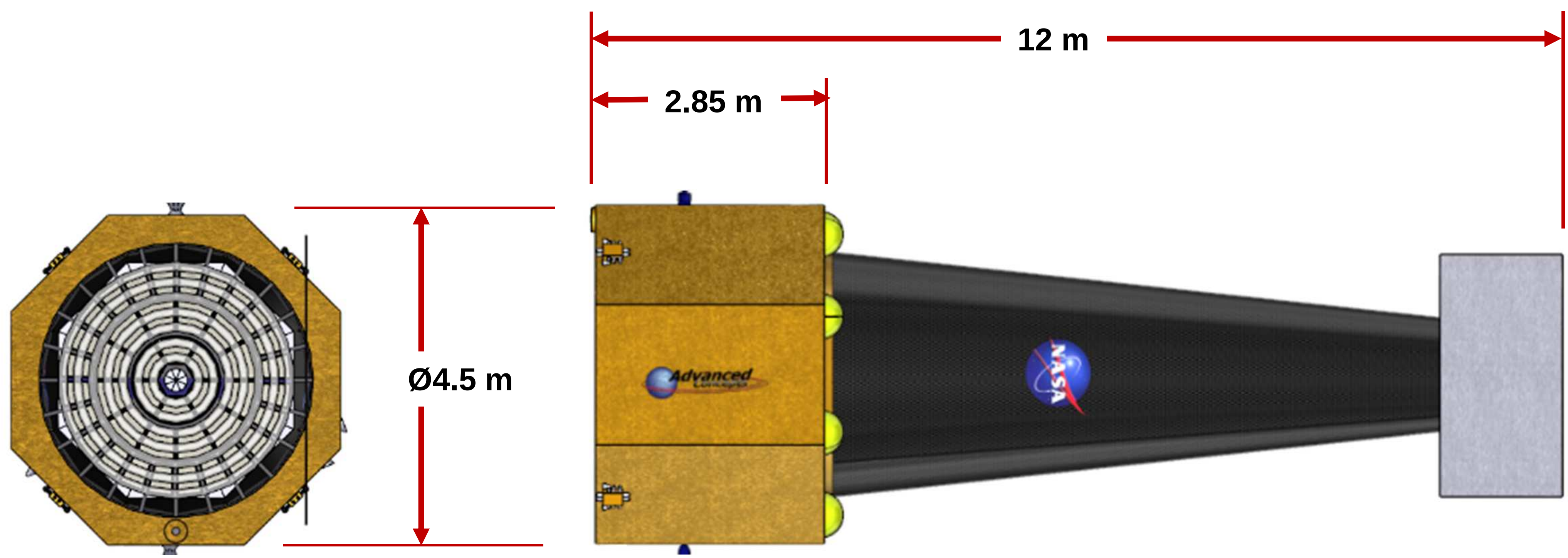
NASA Astrophysics Roadmap: Enduring Quests, Daring Visions

2010 Astrophysics Decadal Survey: New Worlds, New Horizons

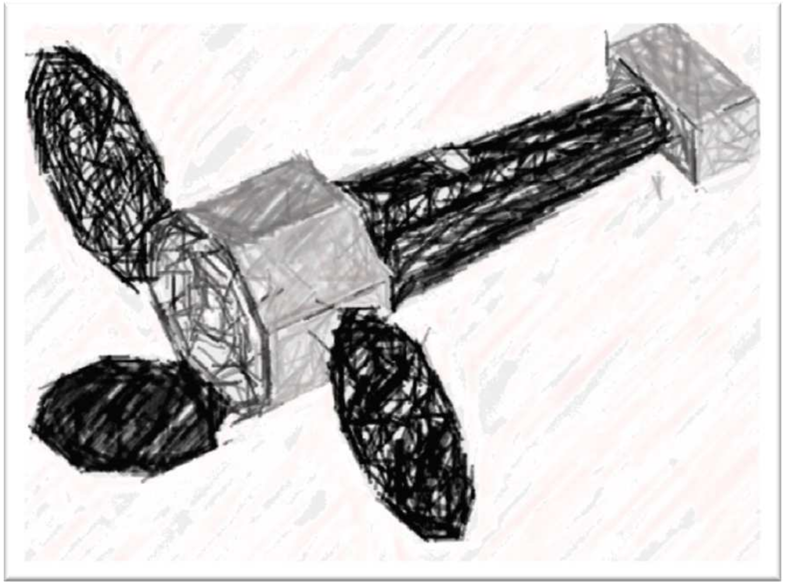
A Successor to *Chandra*

- 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 ($2.95B for Phase B through launch)

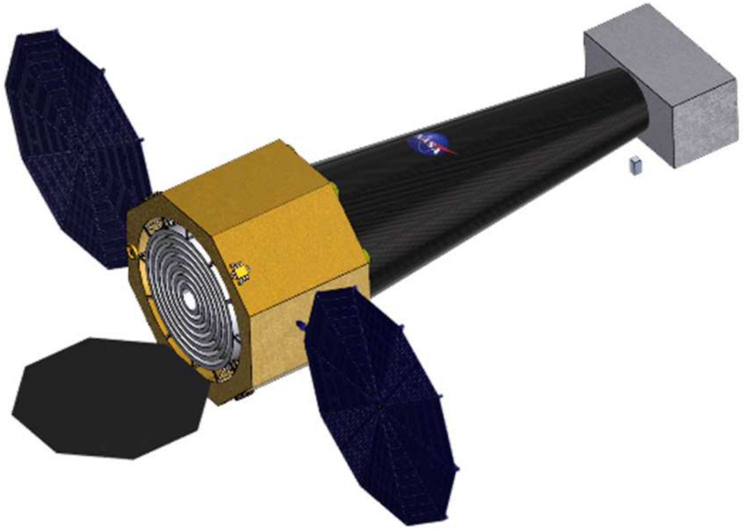


X-ray Surveyor Mission Concept



- Strawman definition:
  Spacecraft, instruments, optics, orbit, radiation environment, launch vehicle and costing
- MSFC Advanced Concept Team carried out the study
- Performed under the guidance of an informal mission concept team comprising the following:

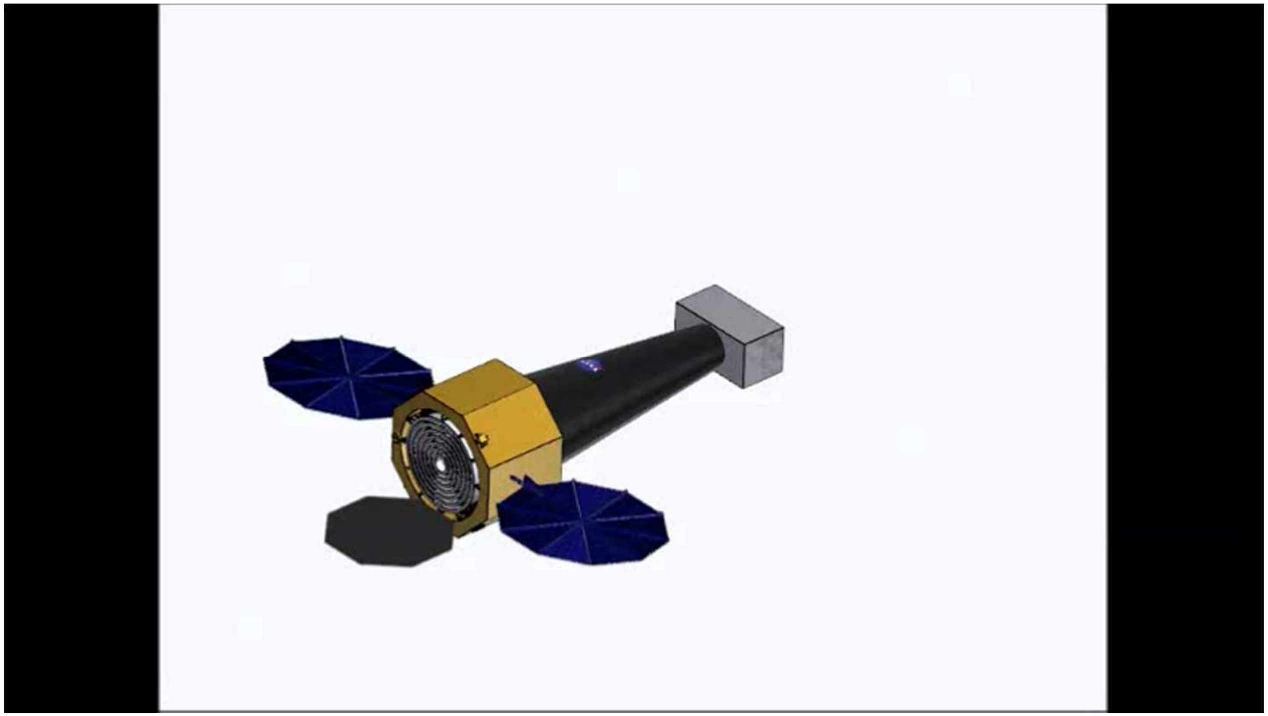
J. Gaskin (MSFC), A. Vikhlinin (SAO), M. C. Weisskopf (MSFC), H. Tananbaum (SAO), S. Bandler (GSFC), M. Bautz (MIT), D. Burrows (PSU), A. Falcone (PSU), F. Harrison (Cal Tech), R. Heilmann (MIT), S. Heinz (Wisconsin), C.A. Kilbourne (GSFC), C. Kouveliotou (GWU), R. Kraft (SAO), A. Kravtsov (Chicago), 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)

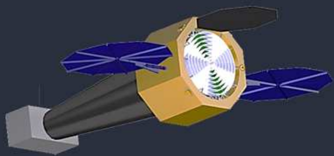


MSFC ACO Team

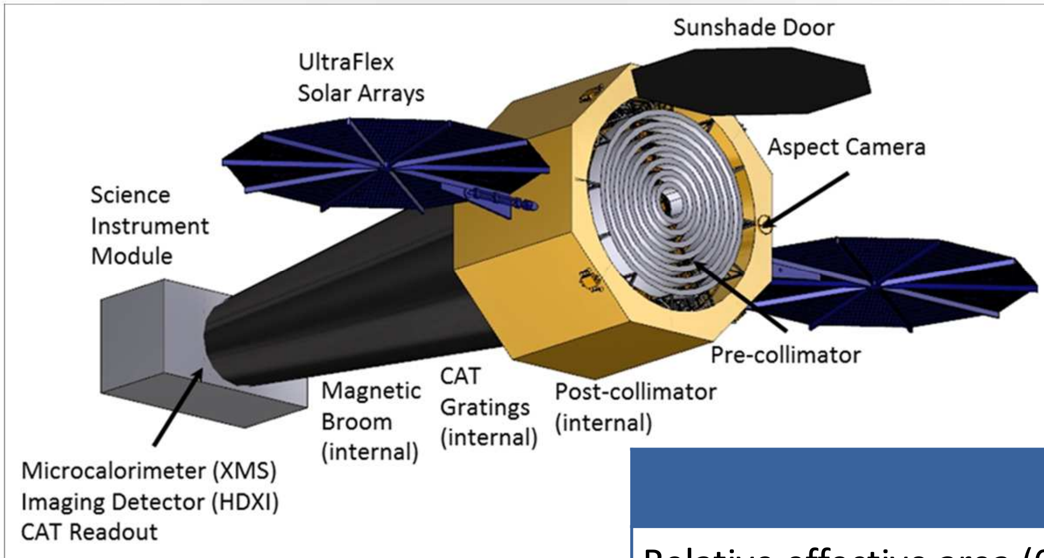
Study Leads	**Andrew Schnell (ED04)** **Randy Hopkins (ED04)**
Mission Analysis	Dan Thomas (ED04) Randy Hopkins (ED04)
Configuration	Mike Baysinger (ED04)
Propulsion	Dan Thomas (ED04)
Power	Leo Fabisinski (ED04)
C&DH	Ben Neighbors (ES12)
Communications	Ben Neighbors (ES12)
GN&C	Aerospace Corp.
Thermal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

X-Ray Surveyor Configuration





Optics & Instruments



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

Strawman Payload for Defining:

- Feasibility (TRL 6)
- Mass
- Power
- Mechanical
- Costing

NOT NECESSARILY THE FINAL CONFIGURATION

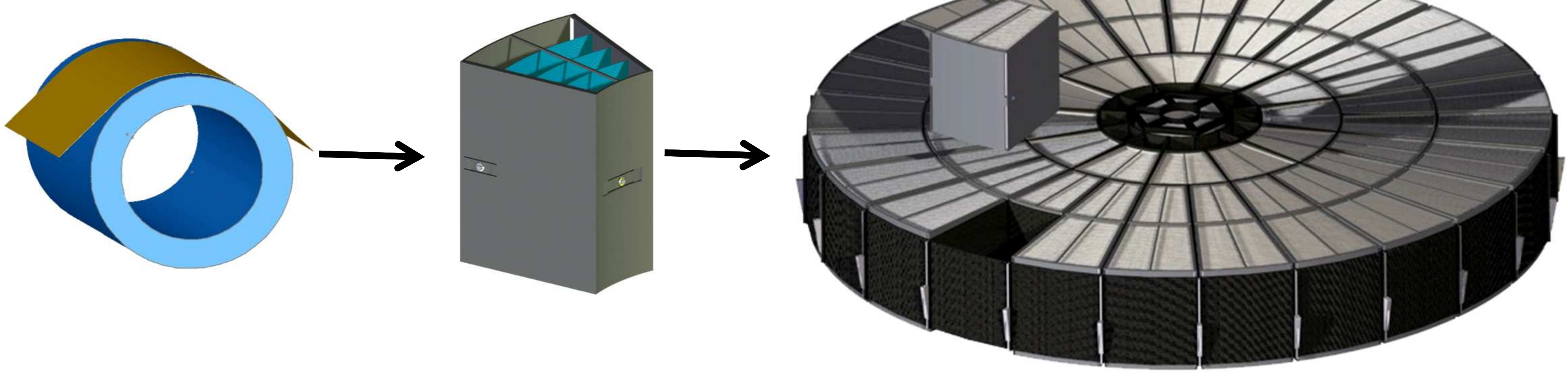
	Chandra	X-Ray Surveyor
Relative effective area (0.5 – 2 keV)	1 (HRMA) 1 (HRMA + ACIS)	30 50
Angular resolution (50% power diam.)	0.5”	0.5”
4 Ms point source sensitivity (erg/s/cm^2)	5x10^{-18}	3x10^{-19}
Field of View with < 1” HPD (arcmin^2)	20	315
Spectral resolving power, R, for point sources	1000 (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

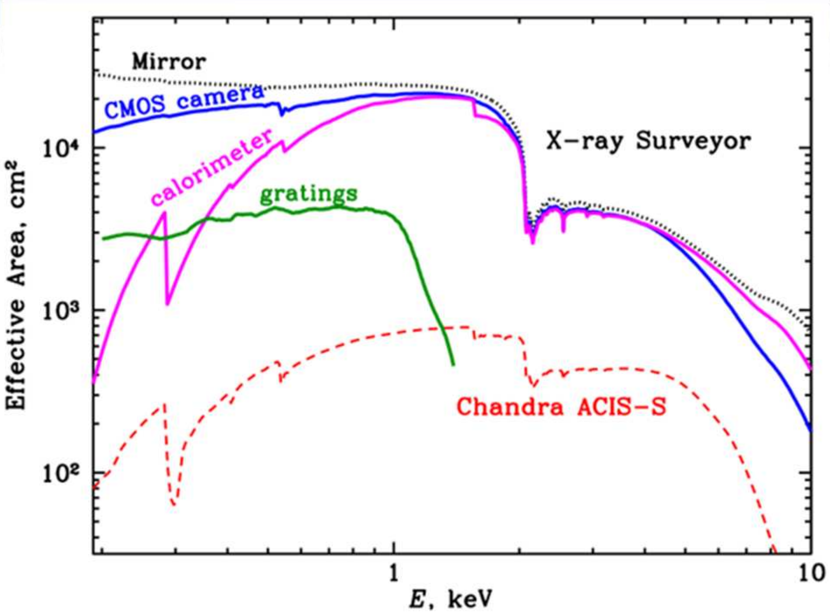
- Build upon segmented optics approaches considered for Con-X, IXO, AXSIO
  - -The segmented optics approach for IXO was progressing and a ~10″ angular resolution was demonstrated

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

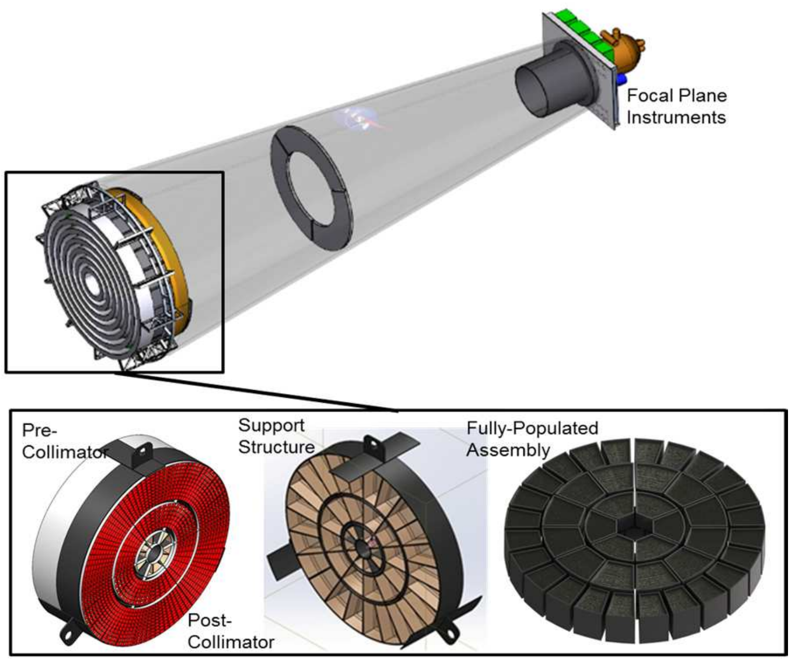
Fabrication → Alignment & Mounting → Integration

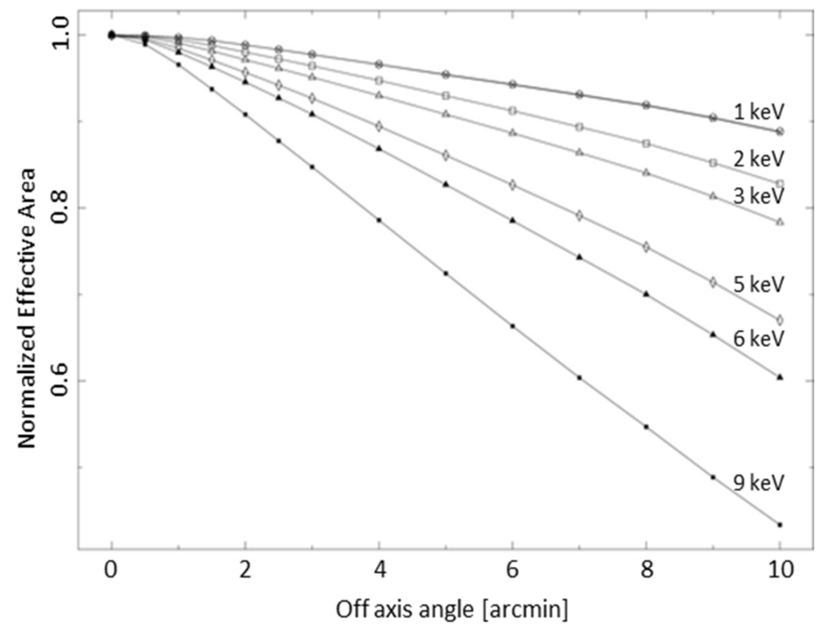


Optics – Specifications & Performance



- Wolter-Schwarzschild optical scheme
- 16x larger solid angle for sub- arcsecond imaging
- 292 nested shells, segmented design
- 3m outer diameter
- 50x more effective area than Chandra HRMA + ACIS
  - -(2.3 m^2 @ 1 keV)
- 800x higher survey speed at the CDFS limit





Obtaining Sub-Arcsecond Elements

APPROACHES

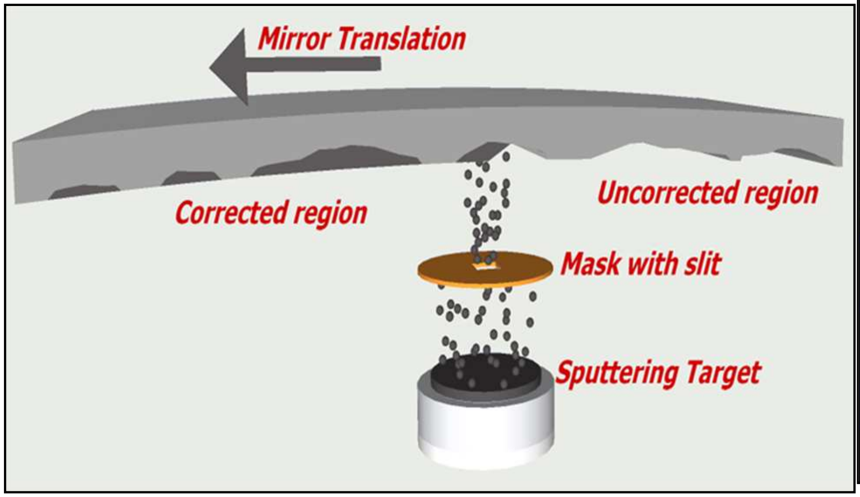
- Differential deposition
  - Fill in the valleys to improve figure profile (MSFC/RXO)
- Adjustable optics
  - Piezoelectric film on the back surface to control figure (SAO/PSU)
- Figuring, polishing, and slicing silicon into thin mirrors (GSFC)
- Ion Implantation (MIT)

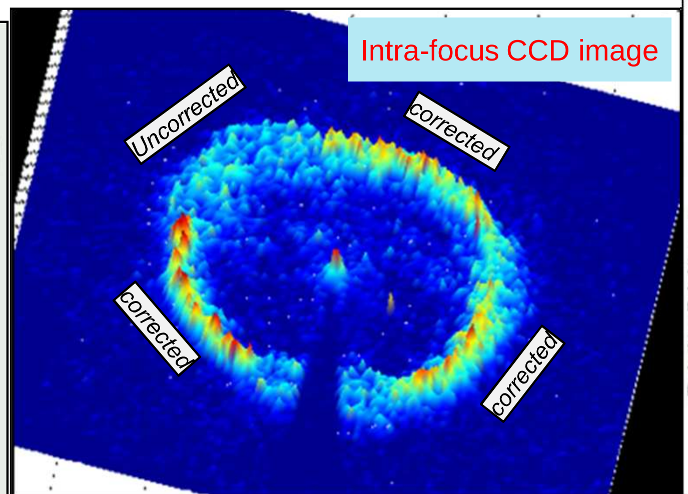
ALSO WATCH

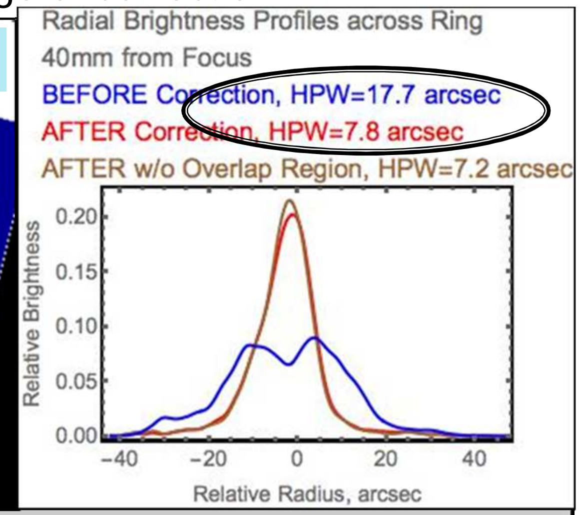
- Magnetostrictive film on the back surface (Northwestern)
- Direct polishing of a variety of thin substrates (MSFC/Brera)

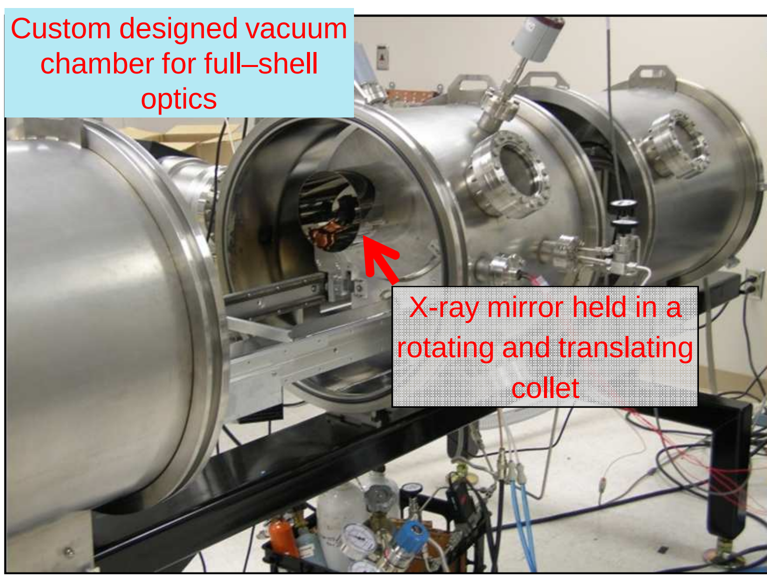
Differential Deposition (MSFC, RXO)

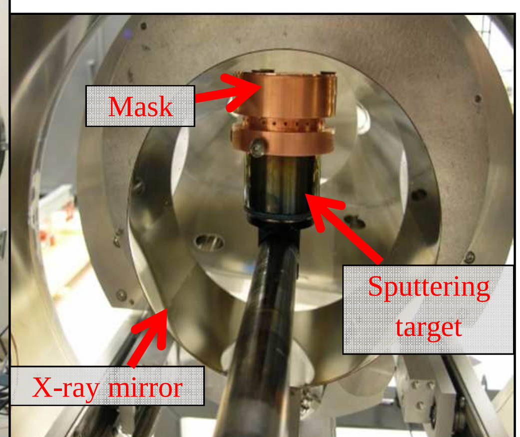
- Custom vacuum chambers have been developed at MSFC for the implementation of differential deposition on full-shell and segmented optics
- Preliminary X-ray test results on quadrants of a full shell show a factor of 2 improvement in Half Power Width after a single stage of correction.

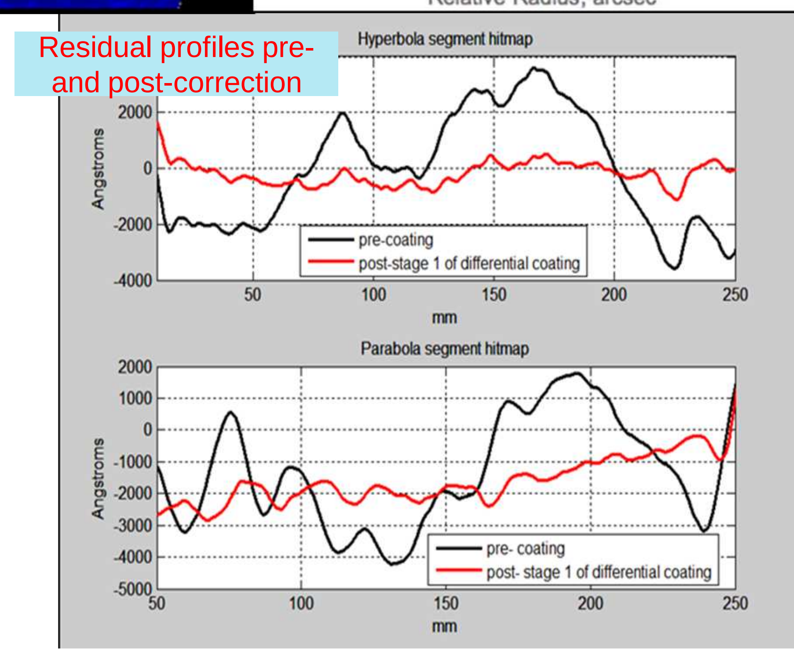




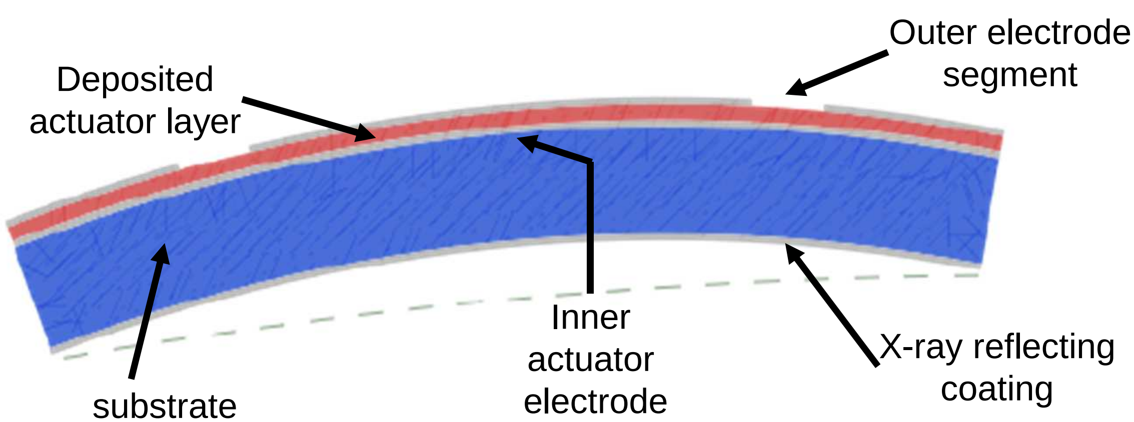


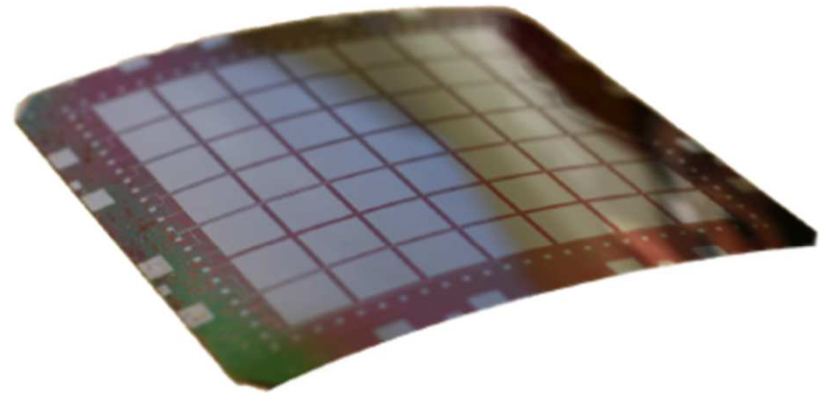






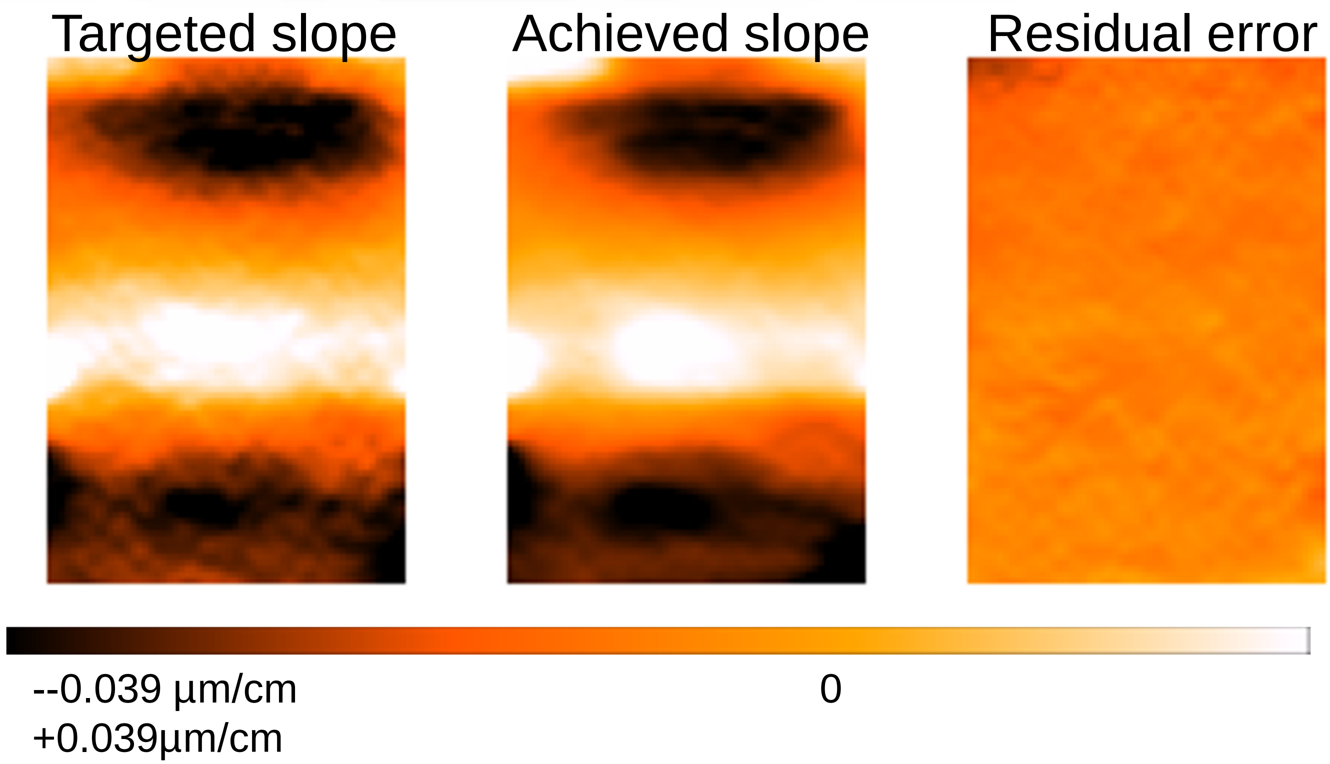
Adjustable Optics – Piezoelectric (SAO/PSU)





- 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

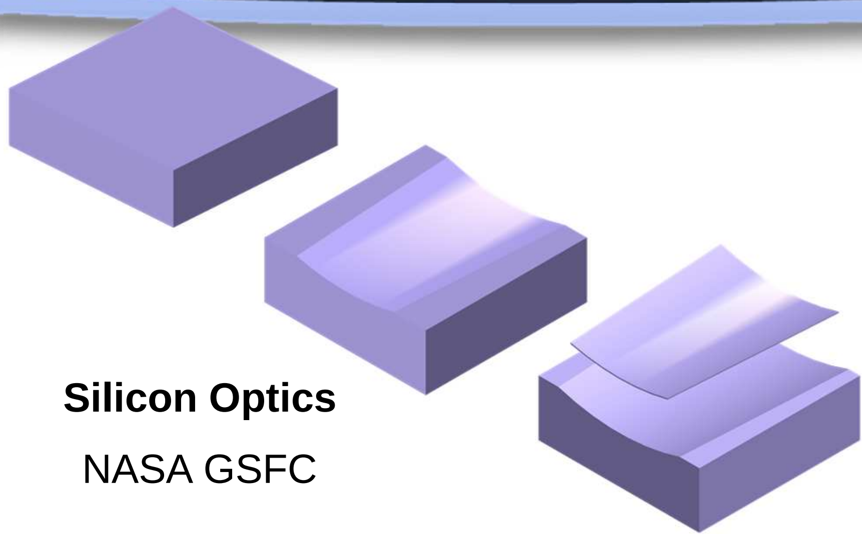
Adjustable Optics – Piezoelectric (SAO/PSU)



***Demonstrates that corrections can be applied with an accuracy of 15% by operating nearly 86 piezo cells together.**

- 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

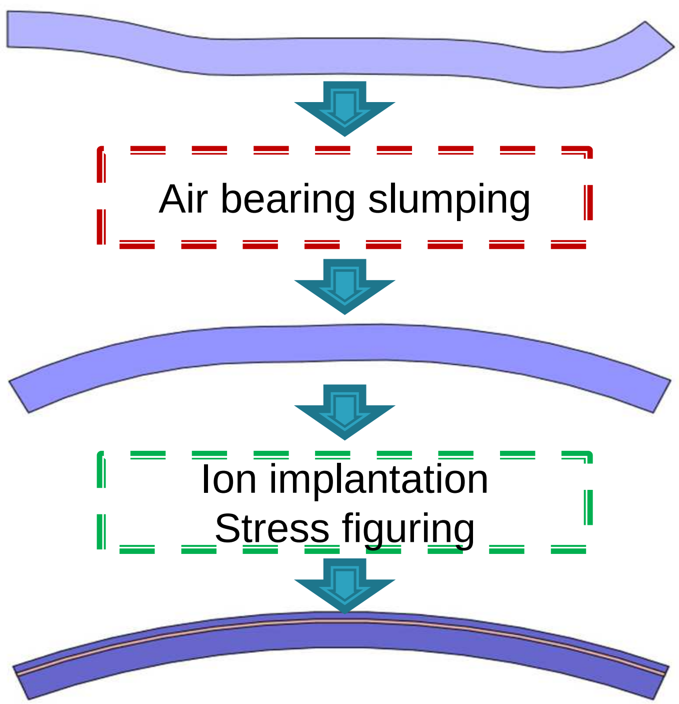
Silicon Optics & Ion Implantation



Silicon Optics

NASA GSFC

- Uses the grinding and polishing technology.
- Uses monocrystalline silicon, which has no internal stress and enables a mirror to be light-weighted post-fabrication with minimal figure degradation.
- Concept has been proven (0.6” RMS slope error, which corresponds to about 2.3” HPD)



Ion Implantation

MIT, Space Nanotech Lab

Flat glass

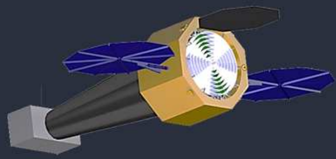
- Low roughness

Air bearing slumped glass

- Low roughness
- No mid spatial-frequency ripples
- Good figure, but not perfect

Figure-corrected glass

- Low roughness
- No mid spatial-frequency ripples
- Excellent figure



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

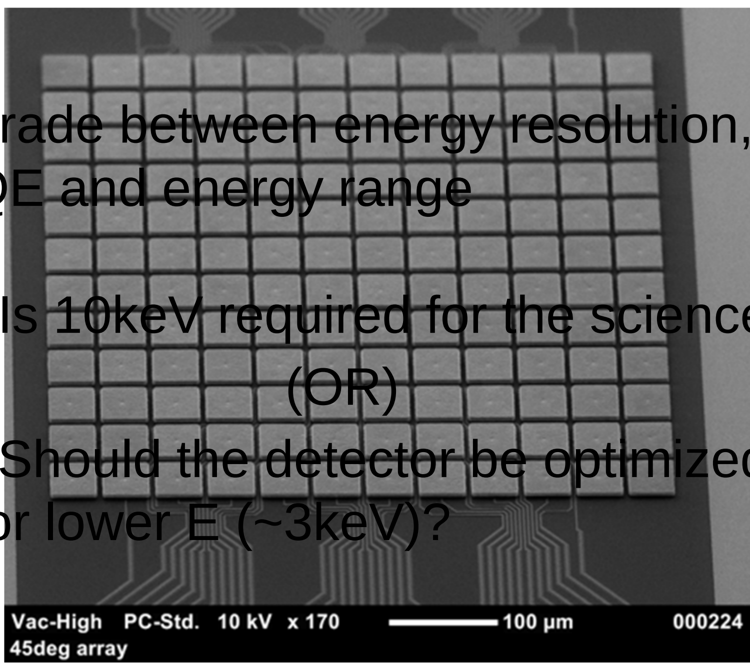
– Are 1” pixels required across 5’ FOV?

(OR)

– Larger FOV and larger pixels in outer part of the array?

(OR)

– Are Smaller pixels than 1” desired?

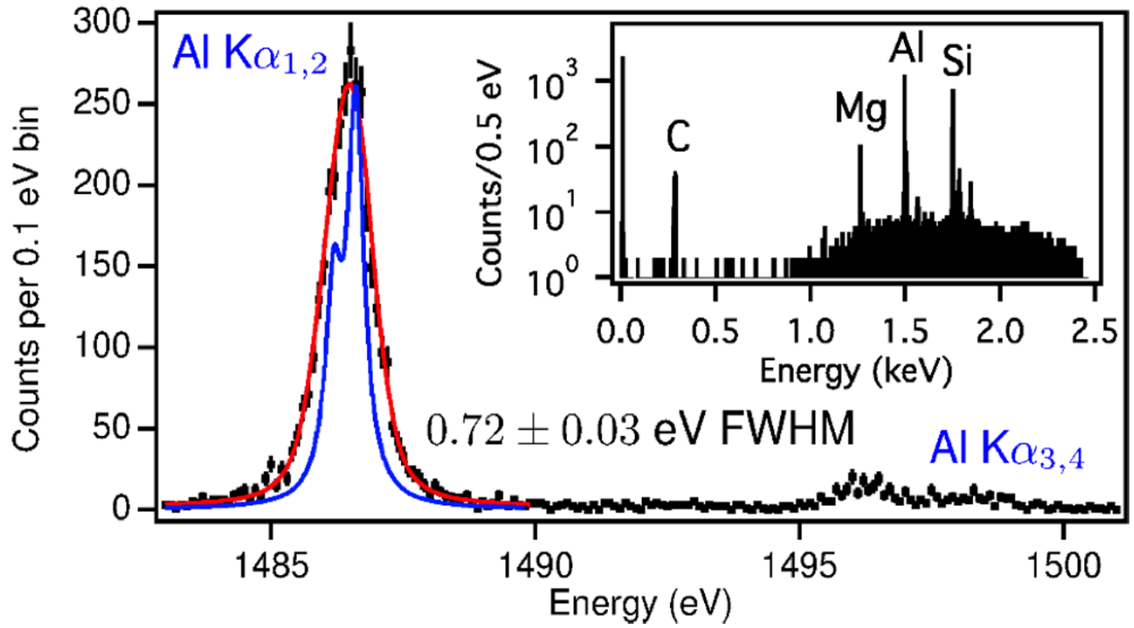


Trade between energy resolution, QE and energy range

–Is 10keV required for the science?

(OR)

–Should the detector be optimized for lower E (~3keV)?

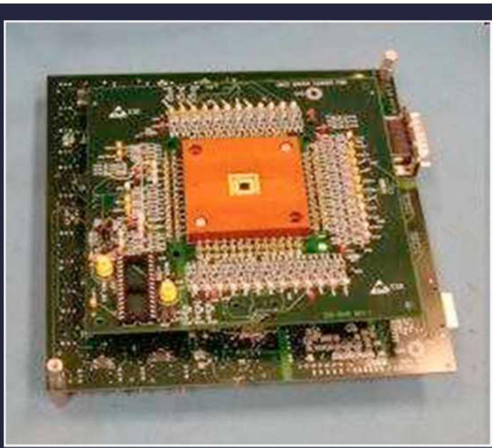


Challenge: Develop multiplexing approaches for achieving ~10^5 pixel arrays

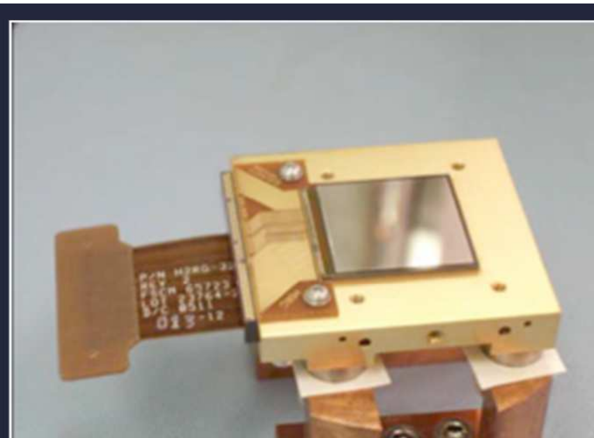
High Definition X-ray Imager

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

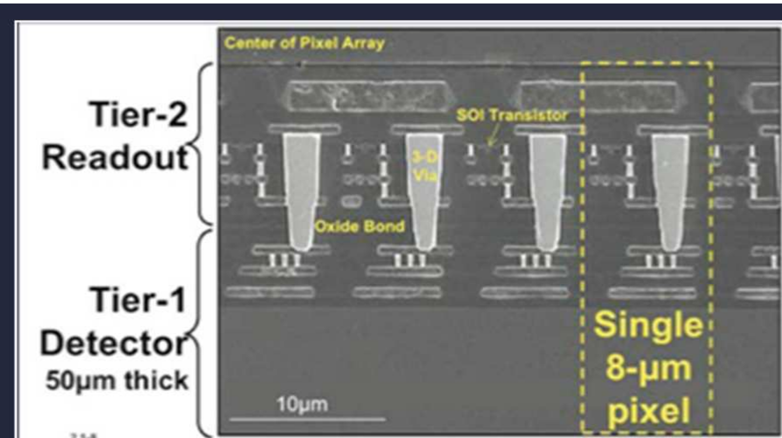
All have been demonstrated individually



SAO/Sarnoff



PSU/Teledyne



MIT/Lincoln Lab

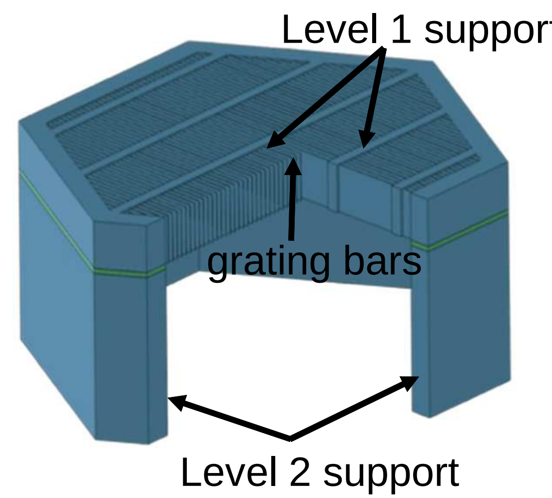
Challenges: Develop sensor that meets all requirements, and approximates the optimal focal surface

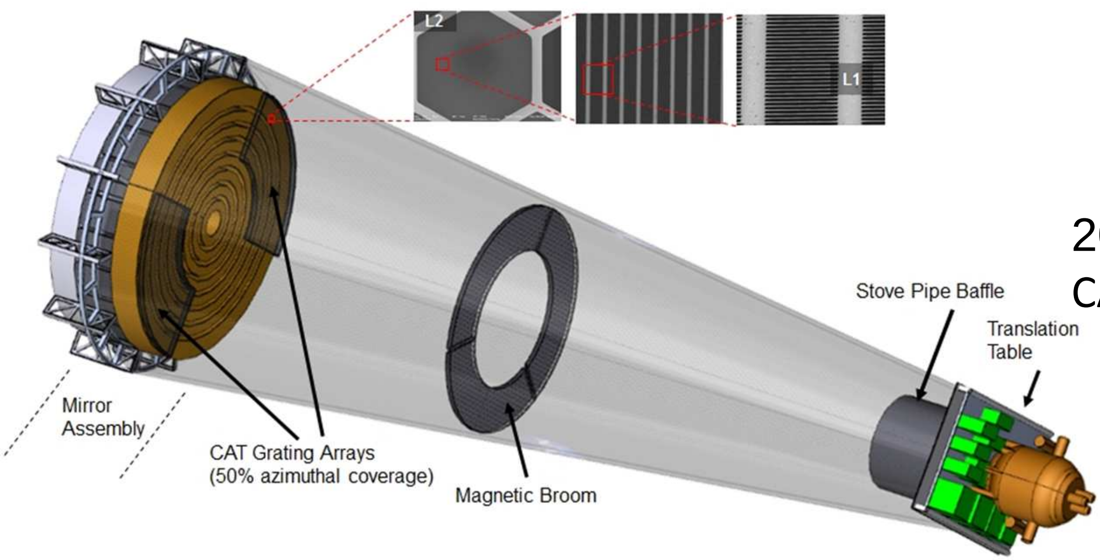
Critical Angle Transmission Gratings

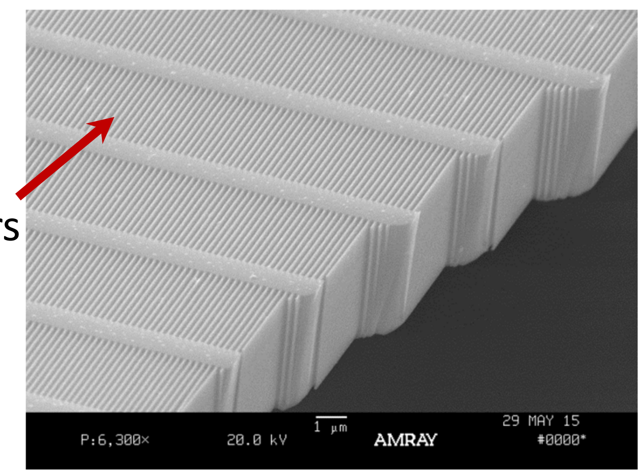
- Resolving power = 5000 & effective area = 4000 cm^2
- Energy range 0.2 – 2.0 keV

Advantages:

- High diffraction efficiency
- Up to 10X dispersion of Chandra HETGS
- Blazed gratings; only orders on one side are utilized
- Only fraction (<50%) of mirrors is covered: "sub-aperturing" boosts spectral resolution.

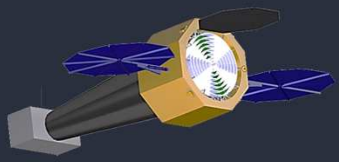






Schattenburg –XR-SIG meeting, Jan. 5, 2014

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



Costing: Surveyor's *Chandra* Heritage

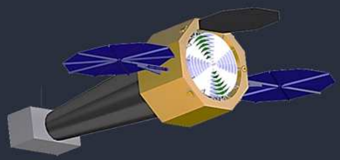
Identical requirements

- 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 Spacecraft technology challenges

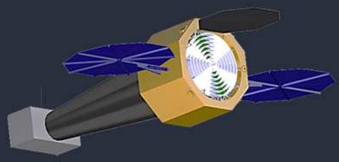


X-Ray Surveyor Cost Estimates

- 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)
- 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



X-Ray Surveyor Success

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

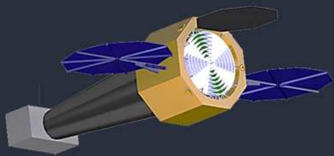
- Gather broad (domestic and international) Science Community Support beyond the X-Ray Astronomy Community
- Maintain steadfast science requirements throughout the lifetime of the Program

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*

- Allow for multiple technology paths to achieve the optics and Science Instruments
- Formulate a strong plan for achieving the optics and instrument goals
- Invest in technology development and proof-of-concept testing
  - Concept studies are great, but having working hardware is better

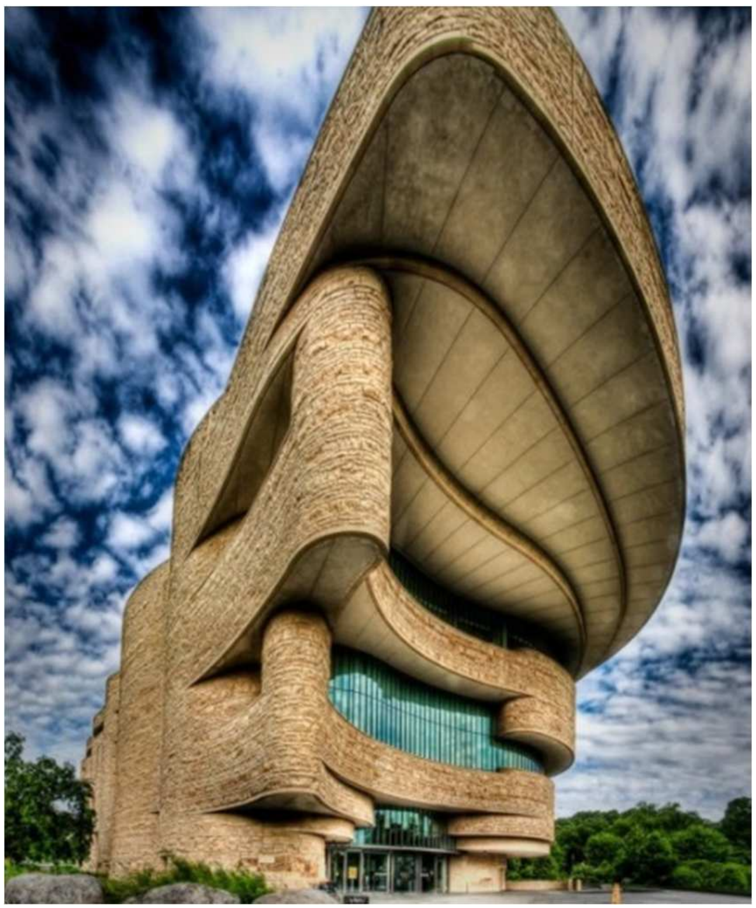
Feasible: *Chandra-like mission with regards to cost and complexity with the new technology for optics and instruments already at TRL3 and proceeding to TRL6 before Phase B*

- Embrace Chandra Heritage and lessons learned
- Utilize multiple previous studies (IXO, Con-X, AXSIO, etc…)
- **Fabricate an optics module that meets requirements prior to the Decadal**



THANK YOU!

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



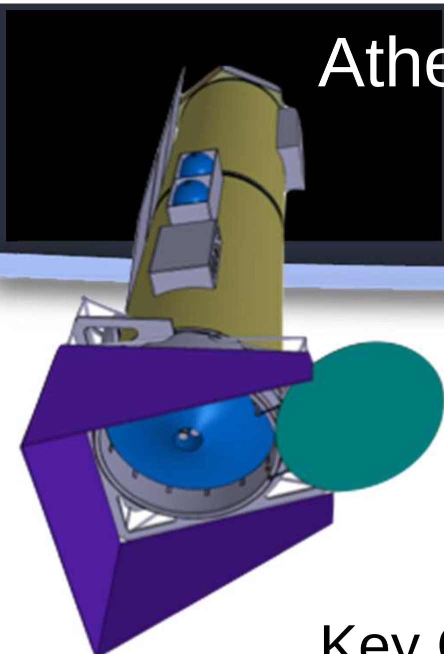
Science Organizing Committee:
Jessica A. Gaskin (MSFC), Martin C. Weisskopf (MSFC), Harvey Tananbaum (SAO), Alexey Vikhlinin (SAO), Fabbiano Giuseppina (SAO), Christine Jones (SAO), Eric Feigelson (PSU), Neil Brandt (PSU), Leisa Townsley (PSU), Dave Burrows (PSU), Priya Natarajan (Yale), Maxim Markevitch (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)

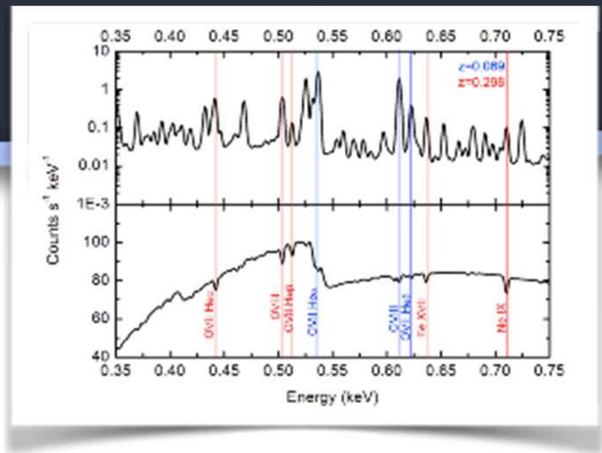
Indispensable Workshop Facilitators:

Katherine Wyman (SAO)	Website Lead
Jessy Jauw (SAO)	Registration
Joe DePasquale (SAO)	Logo Design
Michael Trischitta (SAO)	Resource Manager
Connie Andrews (MSFC)	Resource Analyst
Jenine Humber (SAO)	Event Coordinator
David Hood (NASA)	Event Support

Backup slides

Athena





Key Goals:

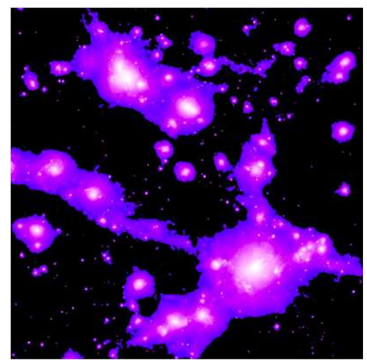
- Microcalorimeter spectroscopy ($R \approx 1000$)
- Wide, medium-sensitivity surveys

Area is built up at the expense of angular resolution (10 × worse) & sensitivity (5 × worse than *Chandra*)

X-ray Surveyor

Key Goals:

- Sensitivity (50 × better than *Chandra*)
- $R \approx 1000$ spectroscopy on 1″ scales, adding 3rd dimension to data
- $R \approx 5000$ spectroscopy for point sources

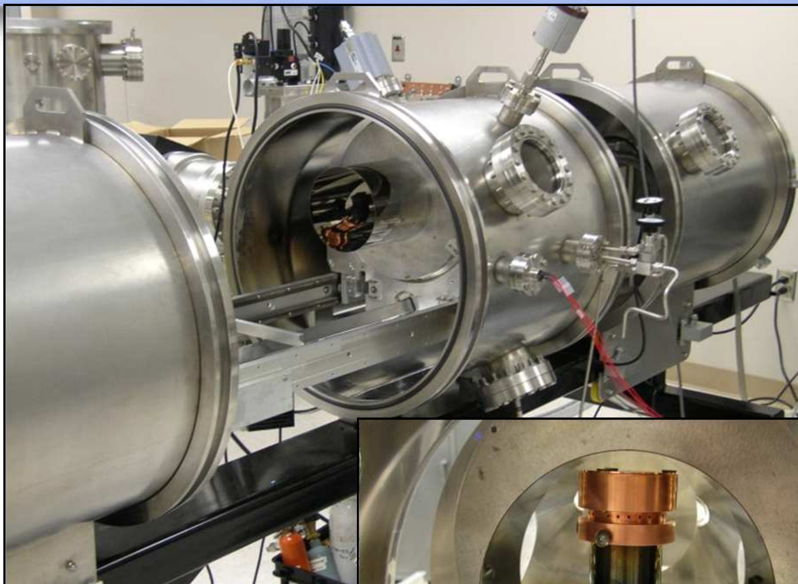


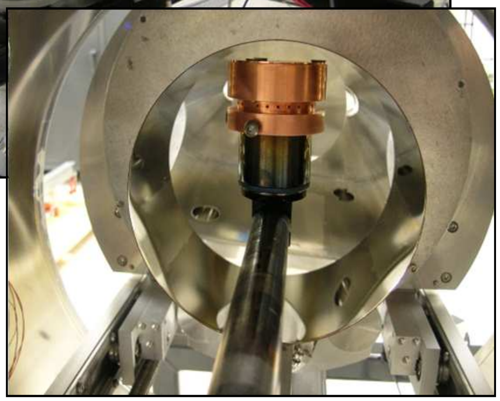
✓ Area is built up while preserving *Chandra* angular resolution (0.5″)

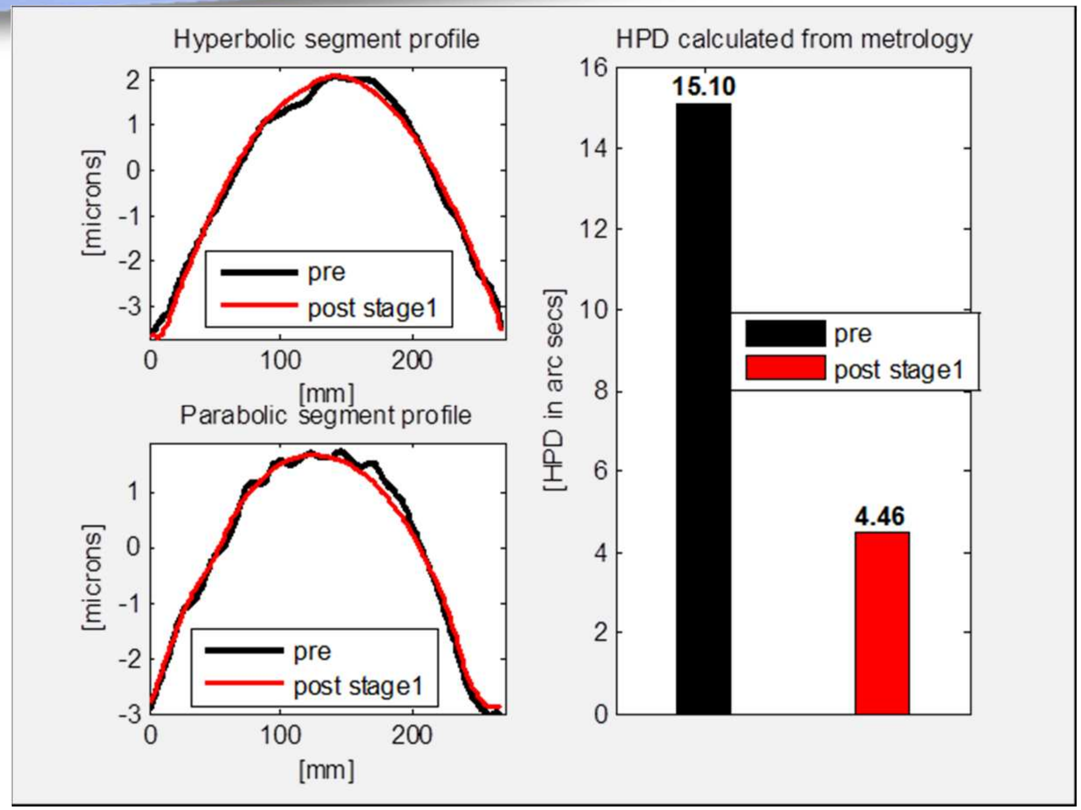
✓ 16 × field of view with sub-arcsec imaging

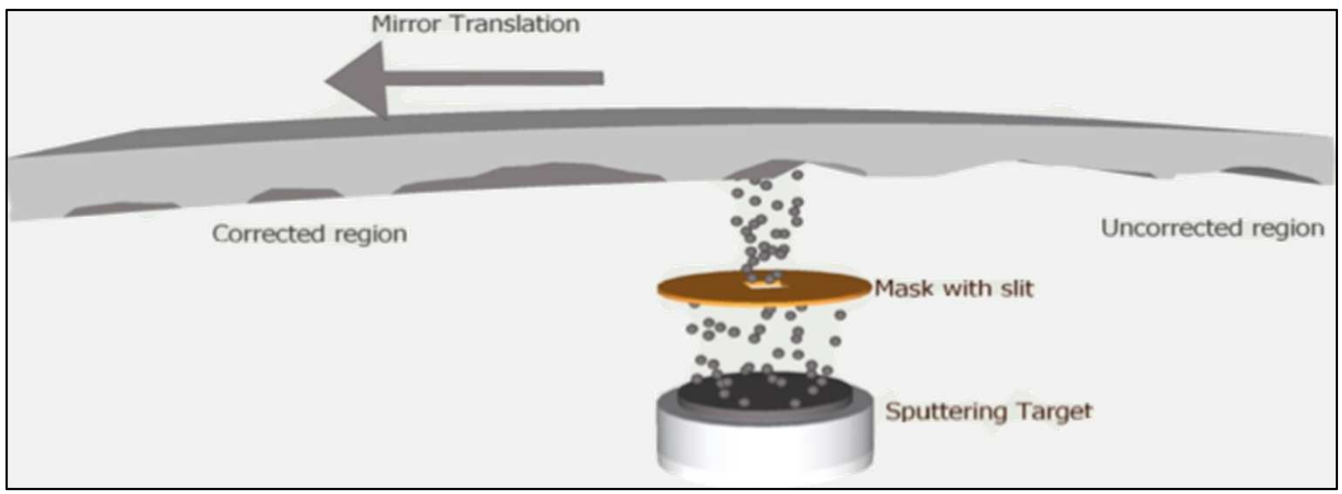
Chandra

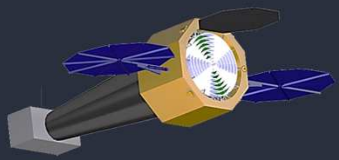
Differential Deposition (MSFC, RXO)











X-Ray Surveyor Success

Scientifically compelling

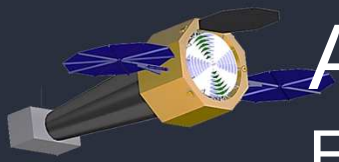
- Gather broad (domestic and international) Science Community Support beyond the X-Ray Astronomy Community
- Maintain steadfast science requirements throughout the lifetime of the Program

Leaps in Capability

- Allow for multiple technology paths to achieve the requirements for the optics and Science Instruments.
- Formulate a strong plan for achieving these requirements
- Invest in technology development and proof-of-concept testing
  - Concept studies are great, but having working hardware is better

Feasibility

- Embrace Chandra Heritage, and lessons learned
- Utilize multiple previous studies (IXO, Con-X, AXSIO, etc…)

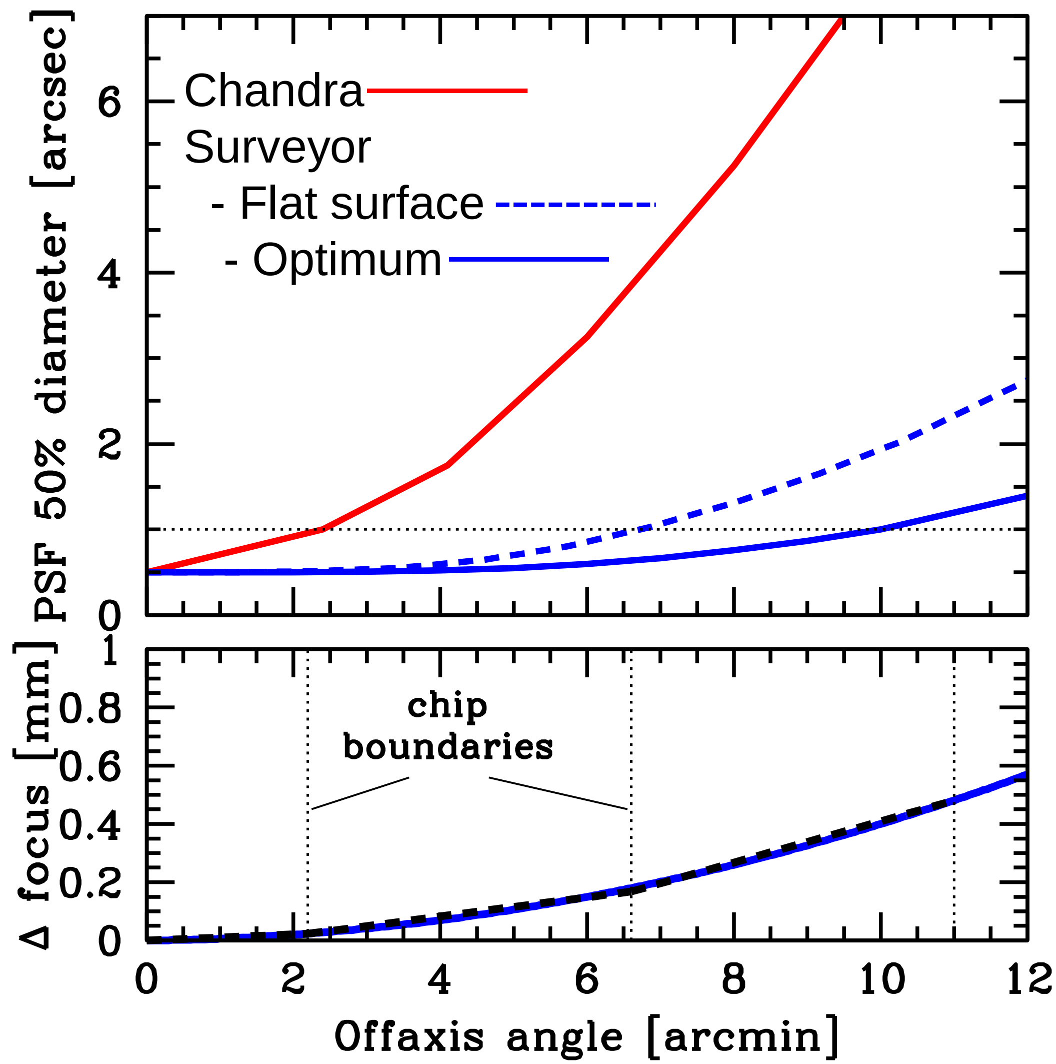


Angular Resolution Versus Off-axis Angle

E < 2 keV

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

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

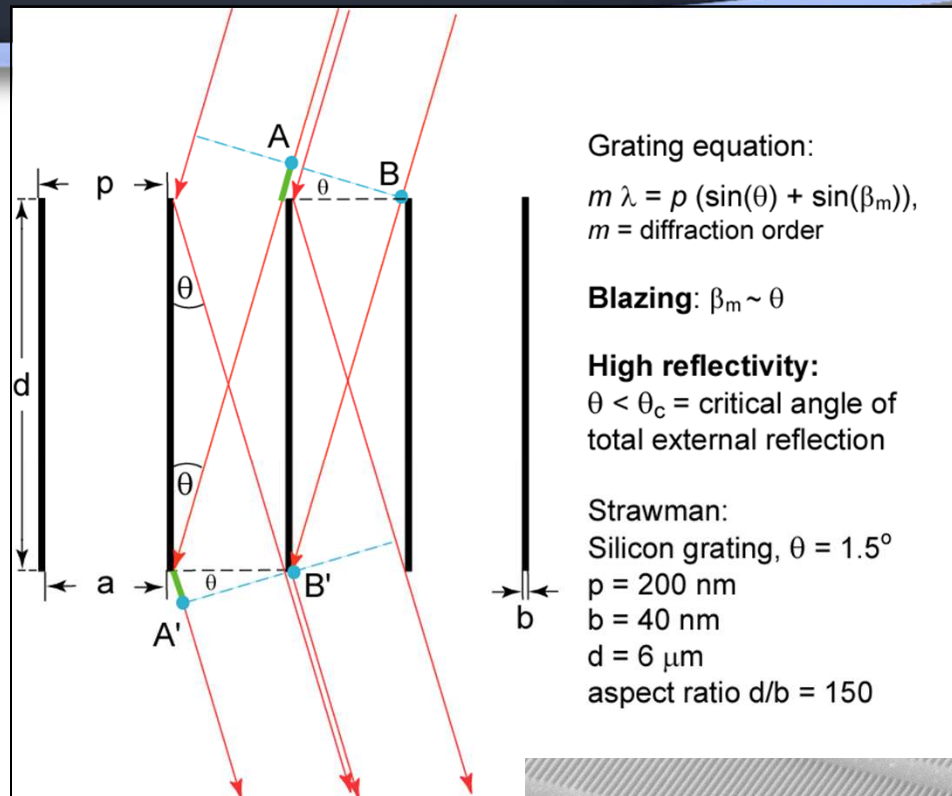


Critical Angle Transmission Gratings

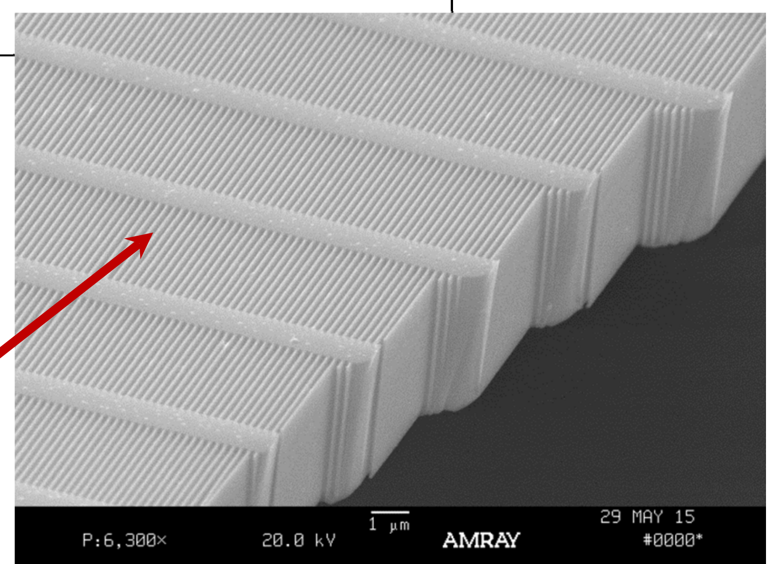
- CAT grating combines advantages of transmission gratings (relaxed alignment, low weight) with high efficiency of blazed reflection gratings.

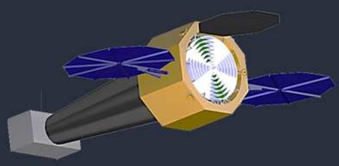
- Blazing achieved via reflection from grating bar sidewalls at graze angles below the critical angle for total external reflection.

- High energy x rays undergo minimal absorption and contribute to effective area at focus.



200 nm pitch
CAT grating bars

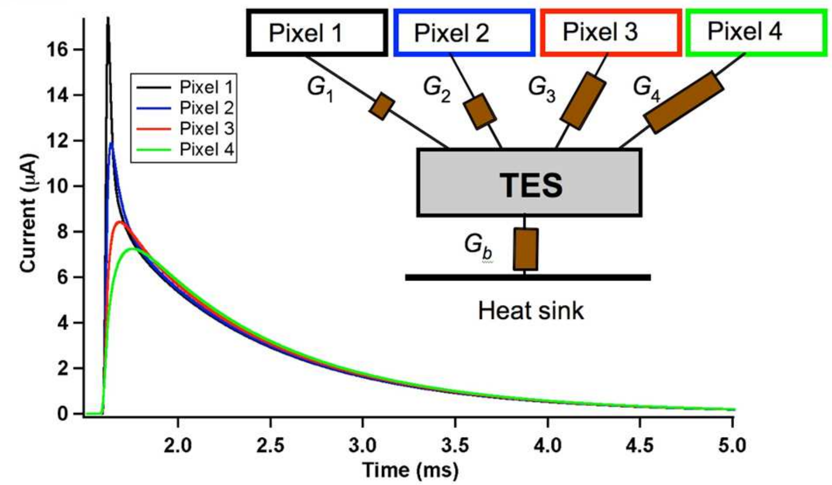


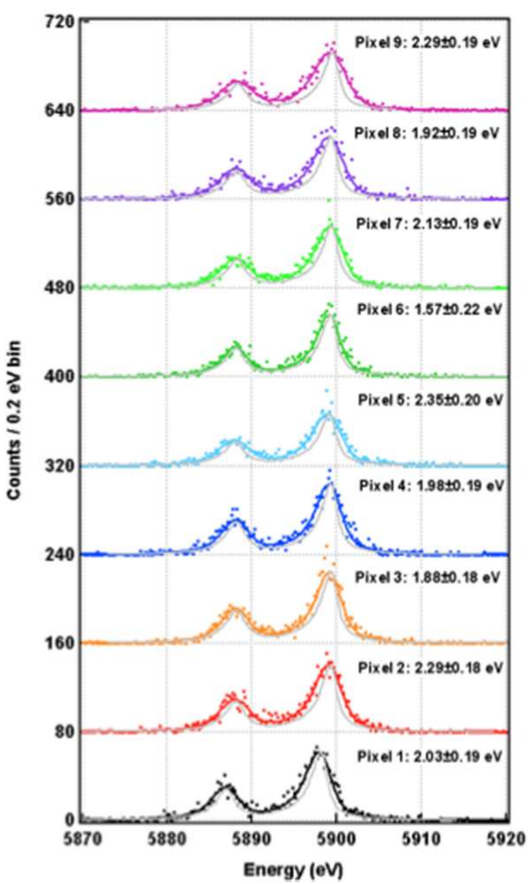


X-ray Microcalorimeter Imaging Spectrometer (XMIS)

Progress with respect to multiplexing:

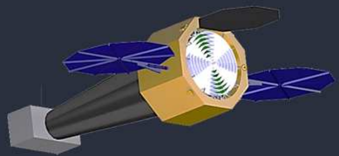
- Multiple absorbers per one TES ("Hydra" design). Multiple TES readout with one SQUID
- Hydra concept <u>minimizes</u> the number of TES *and* the number of SQUID readouts





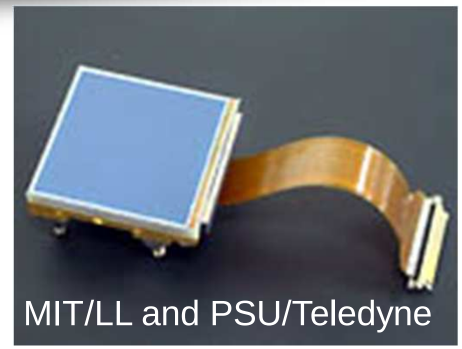
- Current lab results with 3 × 3 Hydra, 65μm pixels on 75 μm pitch shows 2.4 eV (FWHM) resolution at 6 keV
- More work needs to be done to determine the maximum number of absorbers

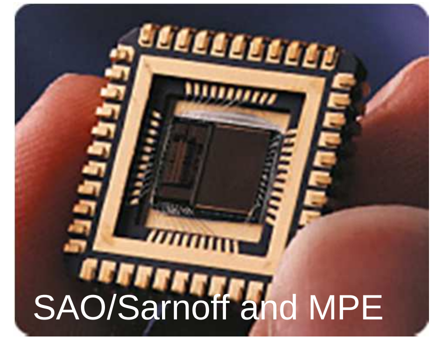
Smith, S.J., et al., IEEE Trans. on Appl. Superconductivity, 2009
Kilbourne, C., et al, A response to RFI : Concepts for the Next X-ray Astronomy Mission submission, 2011



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)
  - – Backside illuminated for improved QE over soft X-ray band
  - – Large formats (up to 4k × 4k abuttable devices)
  - – Pixel sizes from 8 μm to 100 μm

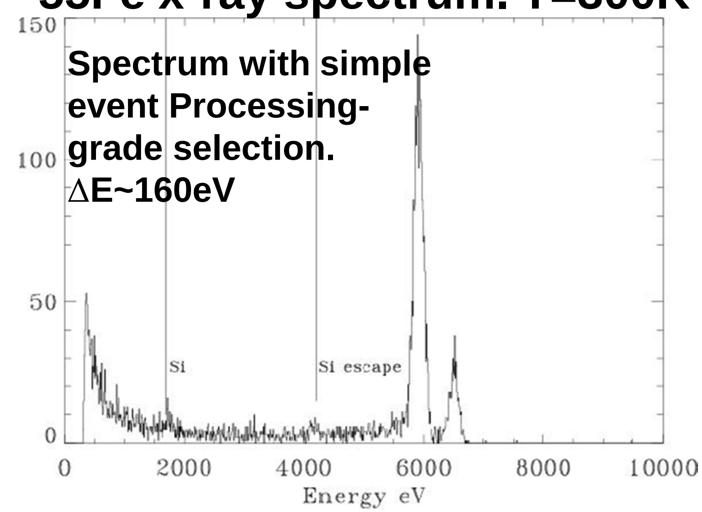




Hybrid
– Multiple bonded layers, with layers for photon detection and readout circuitry optimized independently

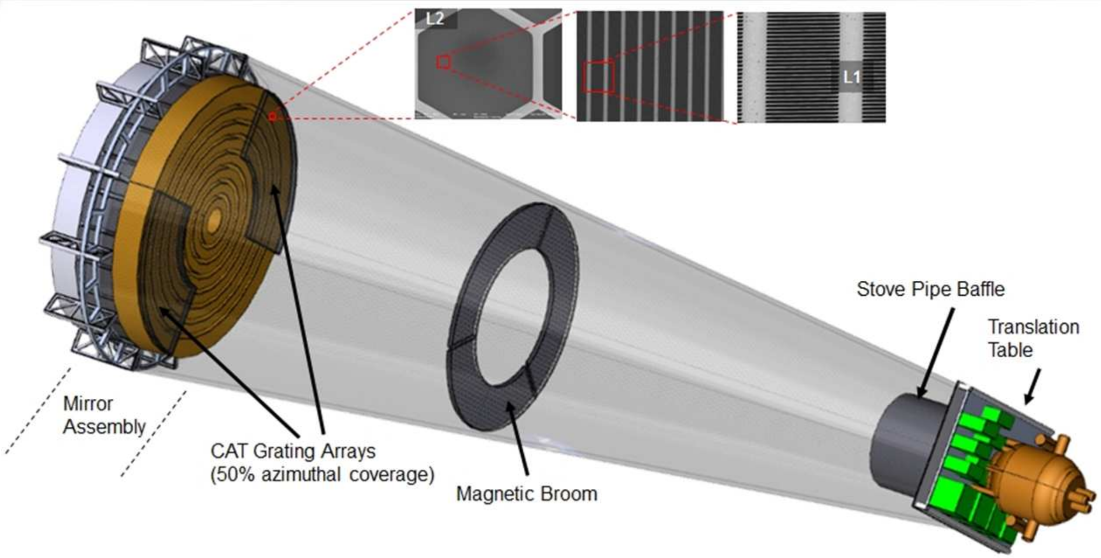
Monolithic
– Single Si wafer used for both photon detection and readout electronics

55Fe x-ray spectrum. T=300K



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

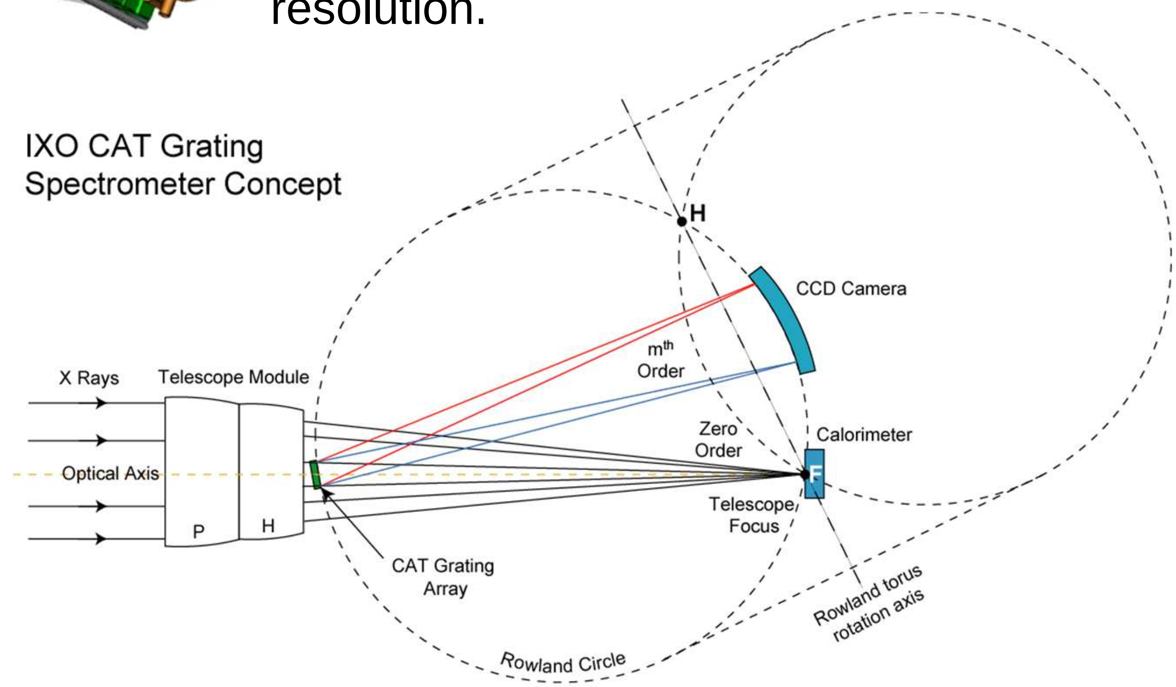
Critical Angle Transmission Gratings



Advantages:

- relaxed alignment & figure tolerances
- high diffraction efficiency
- up to 10X dispersion of Chandra HETGS
- Blazed gratings; only orders on one side are utilized

Only fraction (<50%) of mirrors is covered: “sub-aperturing” boosts spectral resolution.



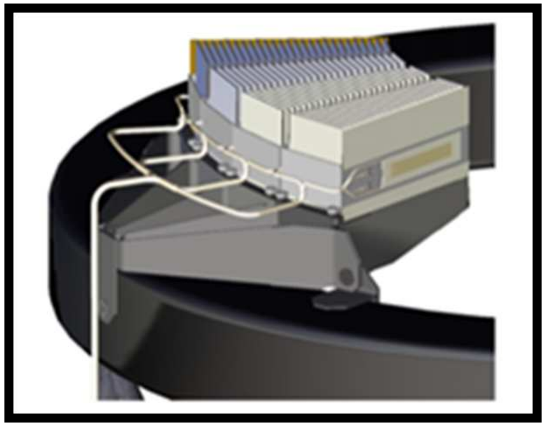
Schattenburg –XR-SIG meeting, Jan. 5, 2014

Grating Spectrometer

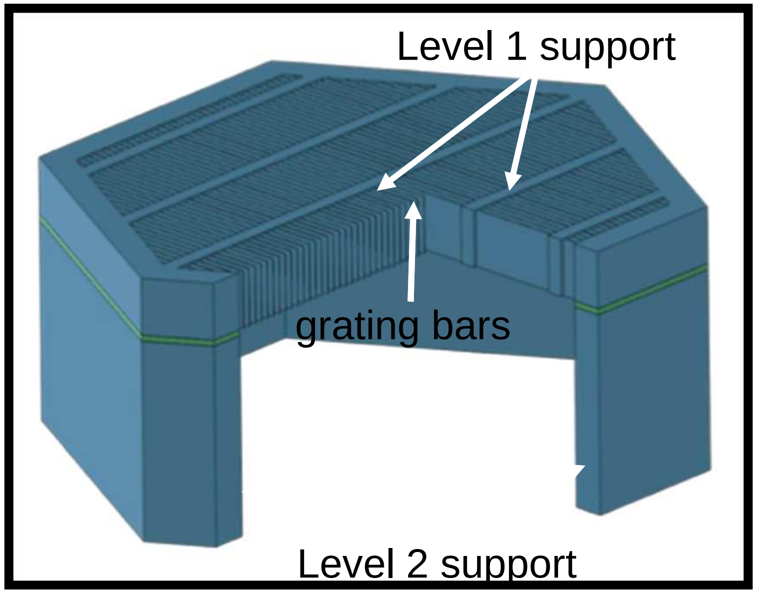
- Resolving power = 5000 & effective area = 4000 cm^2
- Energy range 0.2 – 2.0 keV

Blazed Off-Plane Reflection gratings

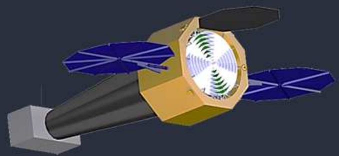
(Univ. of Iowa)



Critical Angle Transmission (CAT) gratings (MIT)

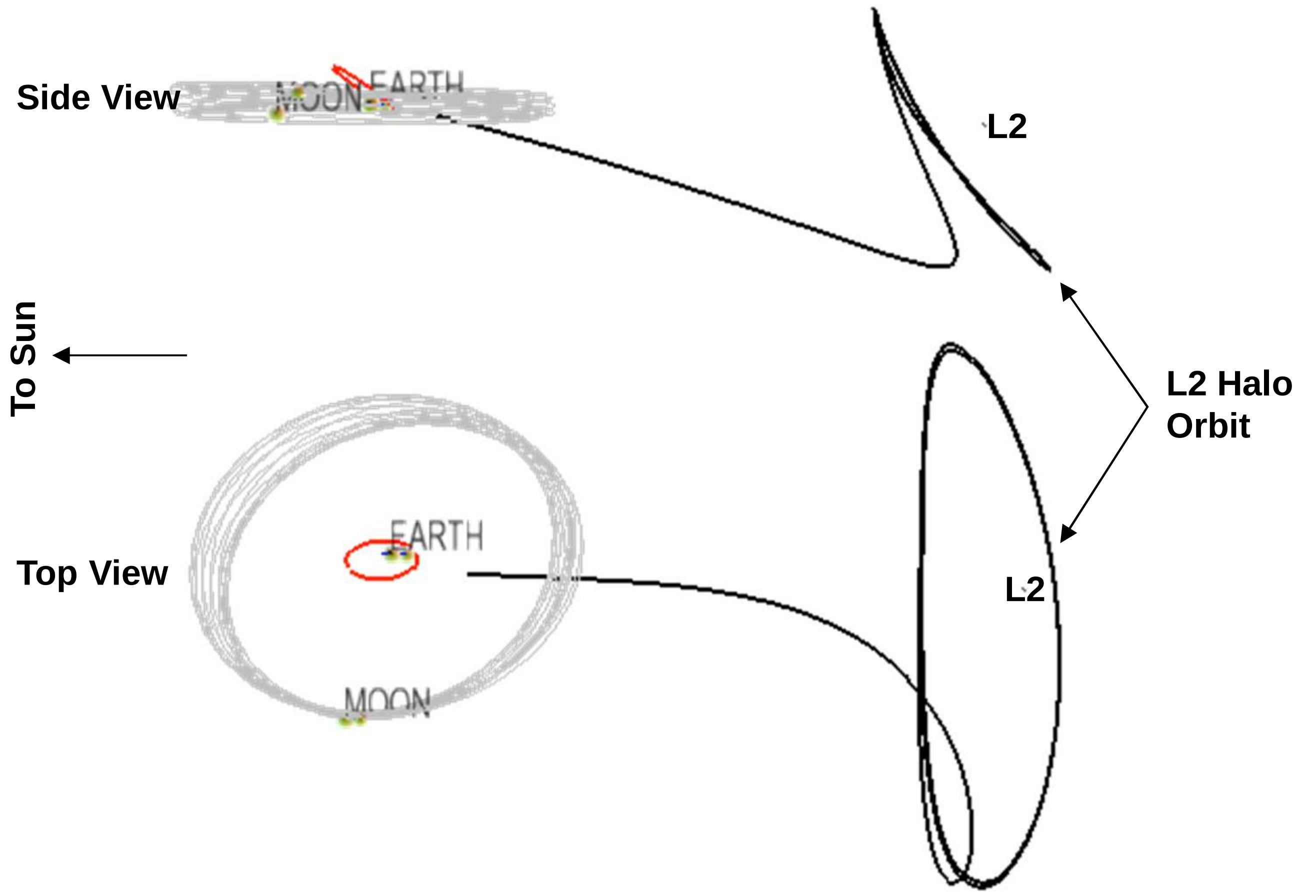


Challenges: improving yield, developing efficient assembly processes, and improving efficiency

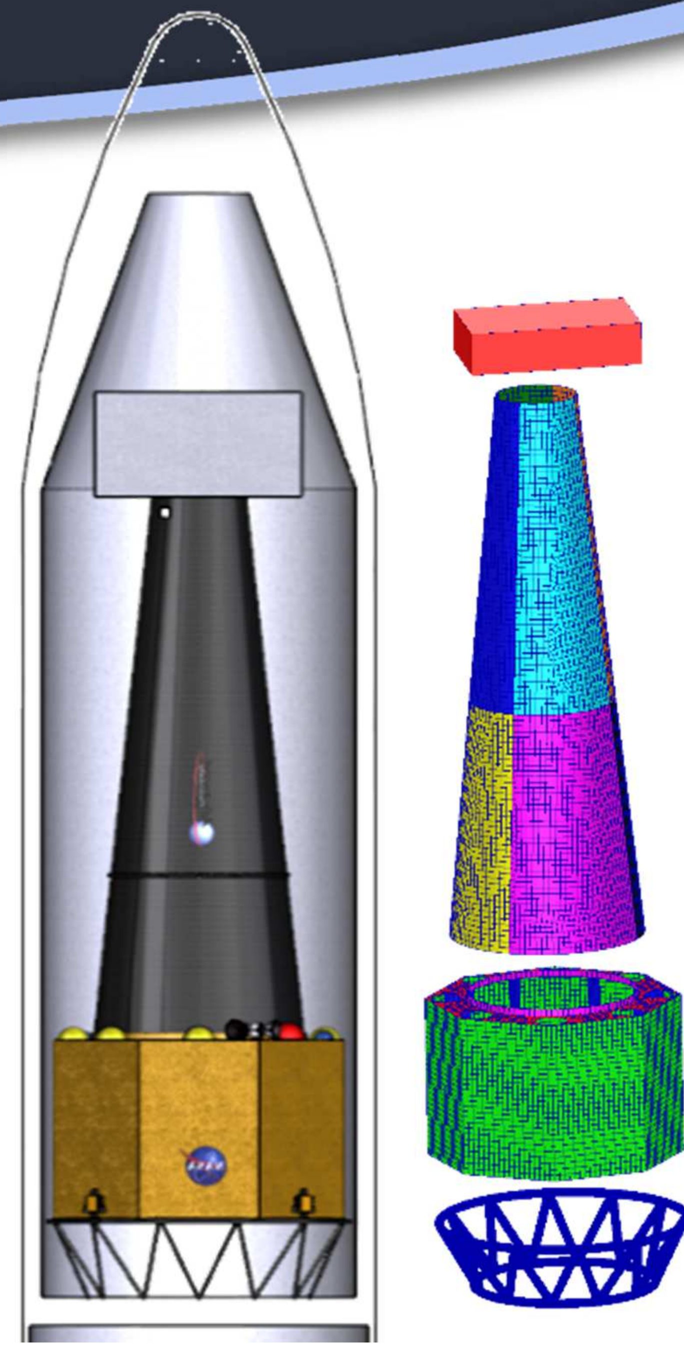


Orbit & Launch Vehicle

- L2 halo orbit & 5 year lifetime
- Expendables sized for 20 years



Halo orbit about Sun-Earth L2 provides stable thermal environment.



AtlasV 5m Long Shroud