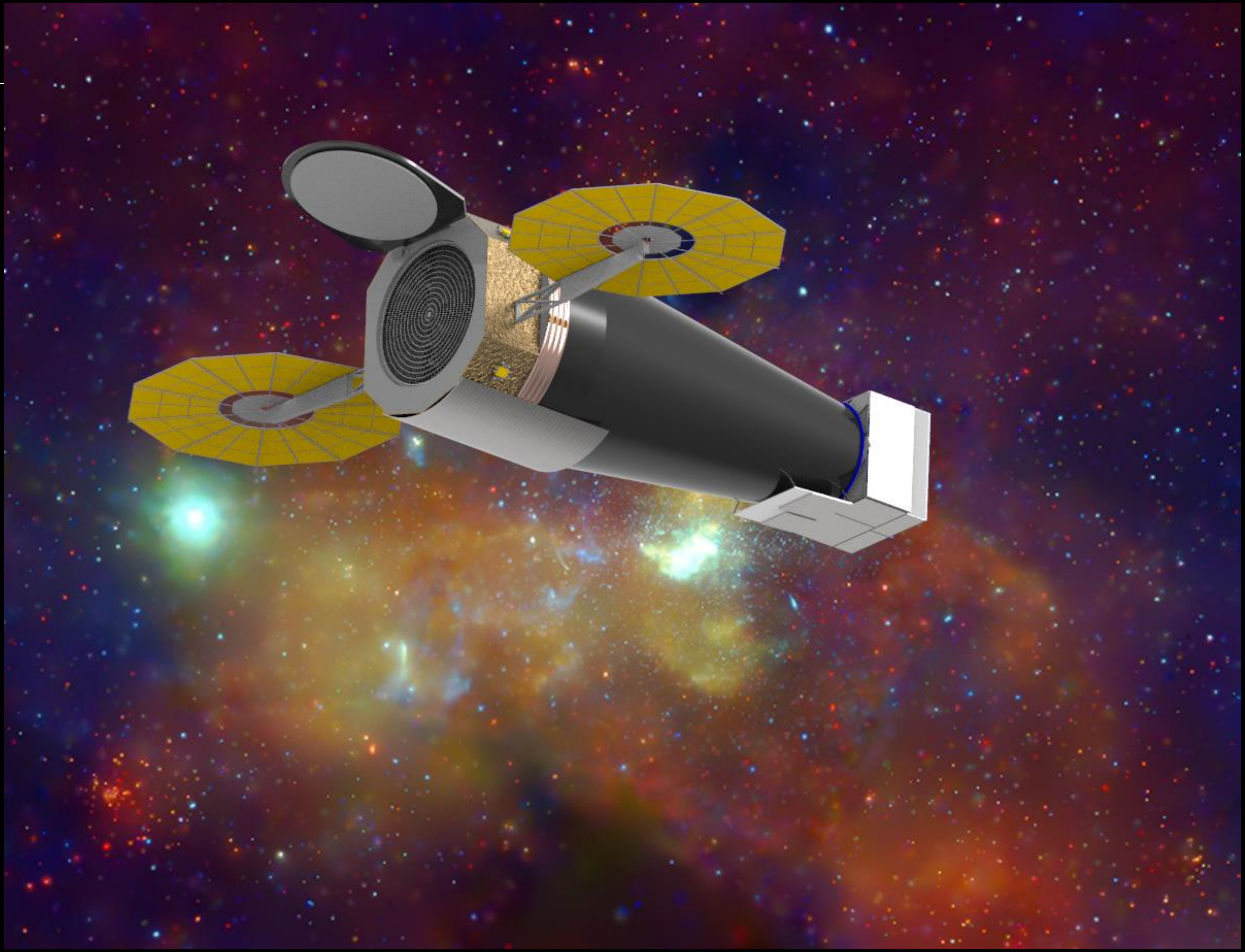
LYNX: OPTICS DEFINED

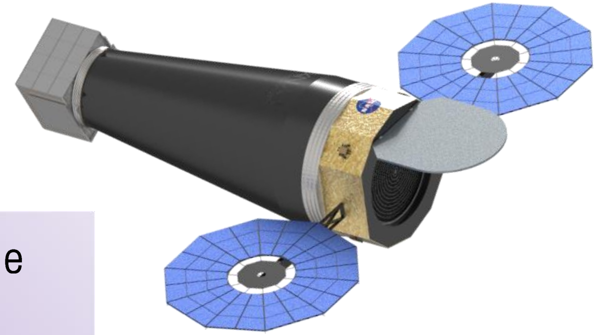
J. Gaskin. NASA MSFC

Presented on behalf of the Lynx Optics Team



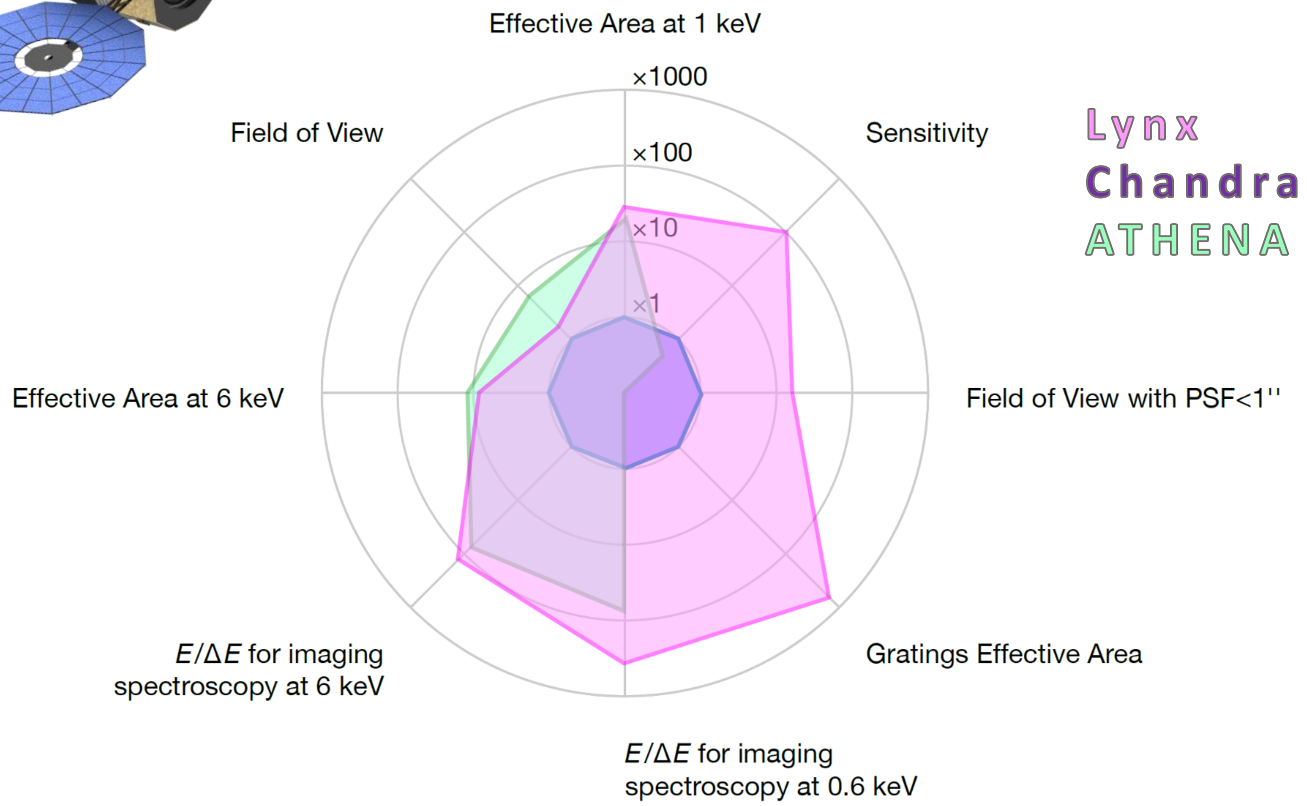
MEET LYNX!

Of the 4 large missions under study for the 2020 Astrophysics Decadal, Lynx is the only observatory that will be capable of directly observing the high-energy events that drive the formation and evolution of our Universe.



Lynx will provide unprecedented vision into the X-Ray Universe with leaps in capability over Chandra and ATHENA:

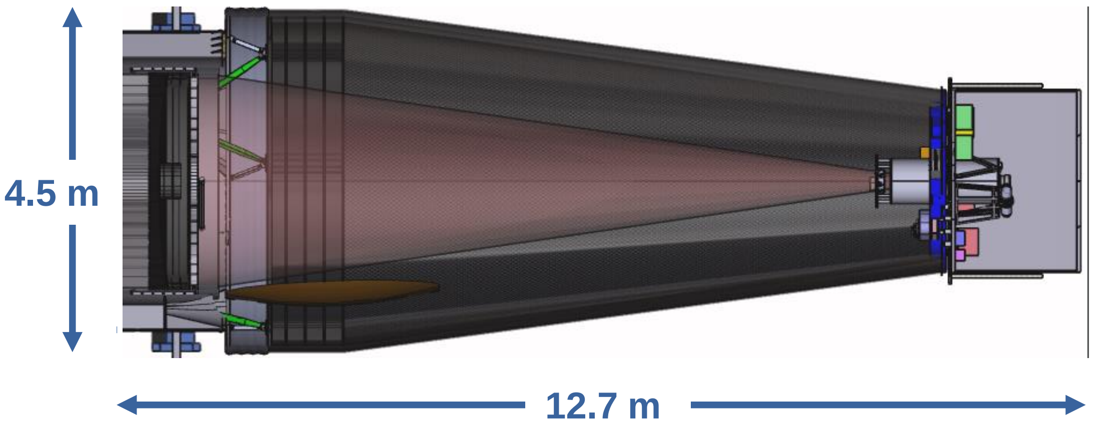
- **Orders of magnitude gain in sensitivity** over Chandra and Athena, via high throughput with high angular resolution
- **Increased field of view** for arcsecond or better imaging
- **Significantly higher spectral resolution** for point-like and extended sources

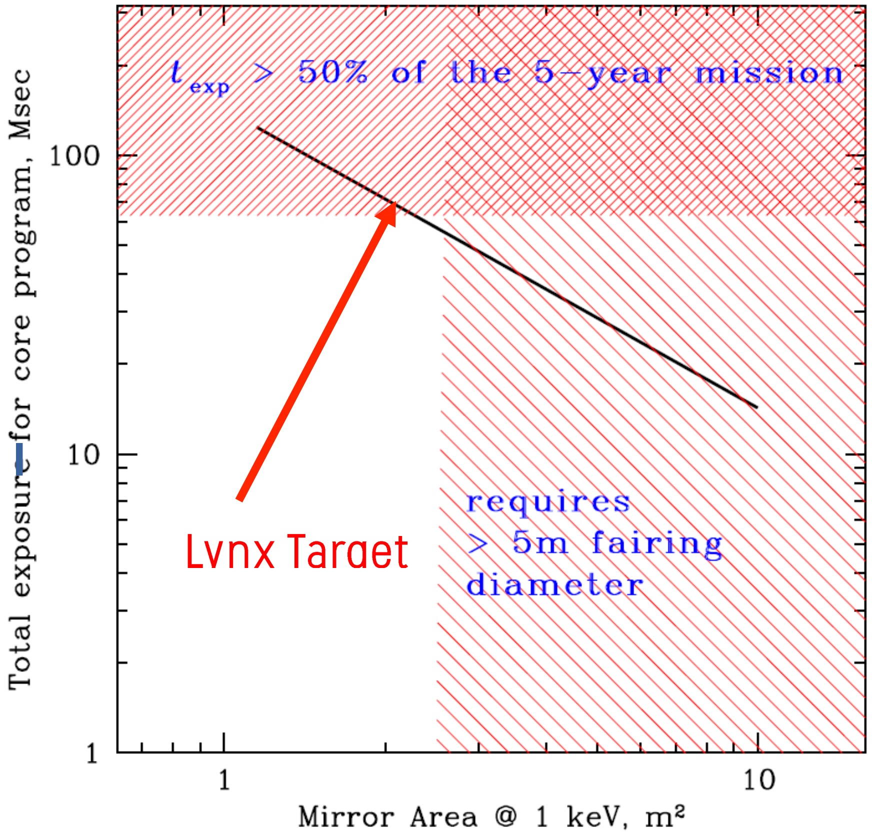


SCIENCE DRIVEN TELESCOPE CONFIGURATION

- 2 m^2 of effective area at E = 1 keV is required to execute the three science pillars in ~50% of the 5-yr mission baseline lifetime. **A goal of Lynx is to maximize discovery!**

- This is achieved with an outer diameter of 3-m with a focal length of 10-m.





LYNX MIRROR ASSEMBLY IN CONTEXT

1.2m Diameter

Chandra
(1999)

0.4m Diameter

NuSTAR
(2012)

3.0m Diameter

Lynx
(2036?)

Slide provided by W. Zhang (GSFC)

MIRROR REQUIREMENTS

- **<u>Large effective area</u>** is achieved by nesting a few hundred to many thousands of co-aligned, co-axial mirror pairs.

- Must fabricate **<u>thinner mirrors</u>** to allow for greater nesting of mirror pairs and larger effective area while reducing mass.

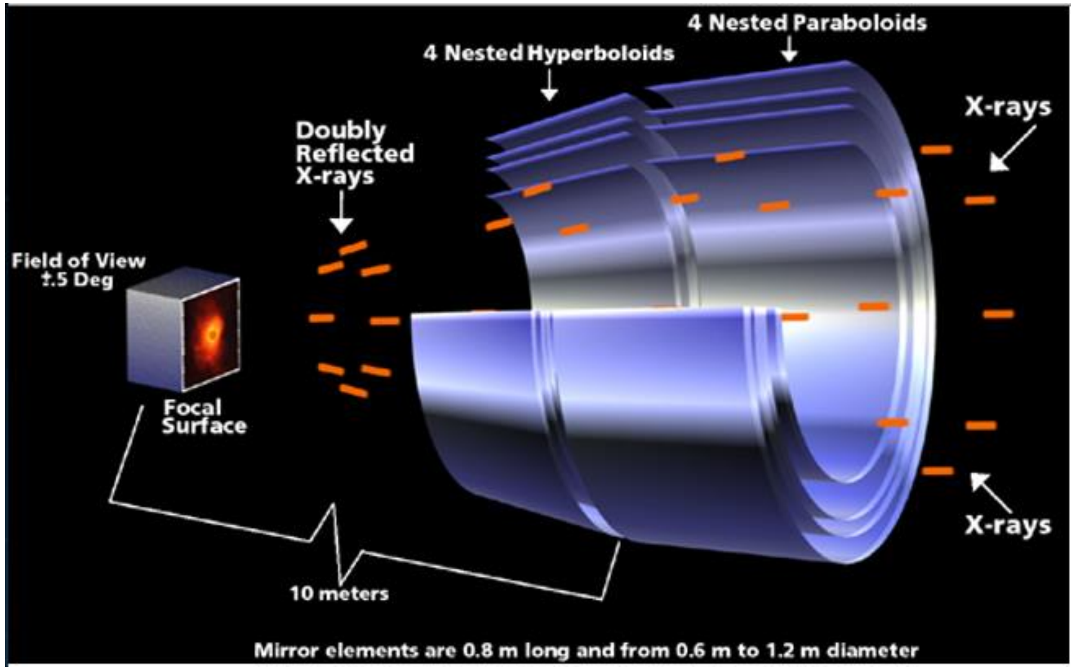
- These thin mirrors must be better that **<u>0.5” HPD</u>** requirement.

- Must **<u>mount and coat</u>** these thin optics **<u>without deforming the optic</u>**, or must be able to correct deformations.

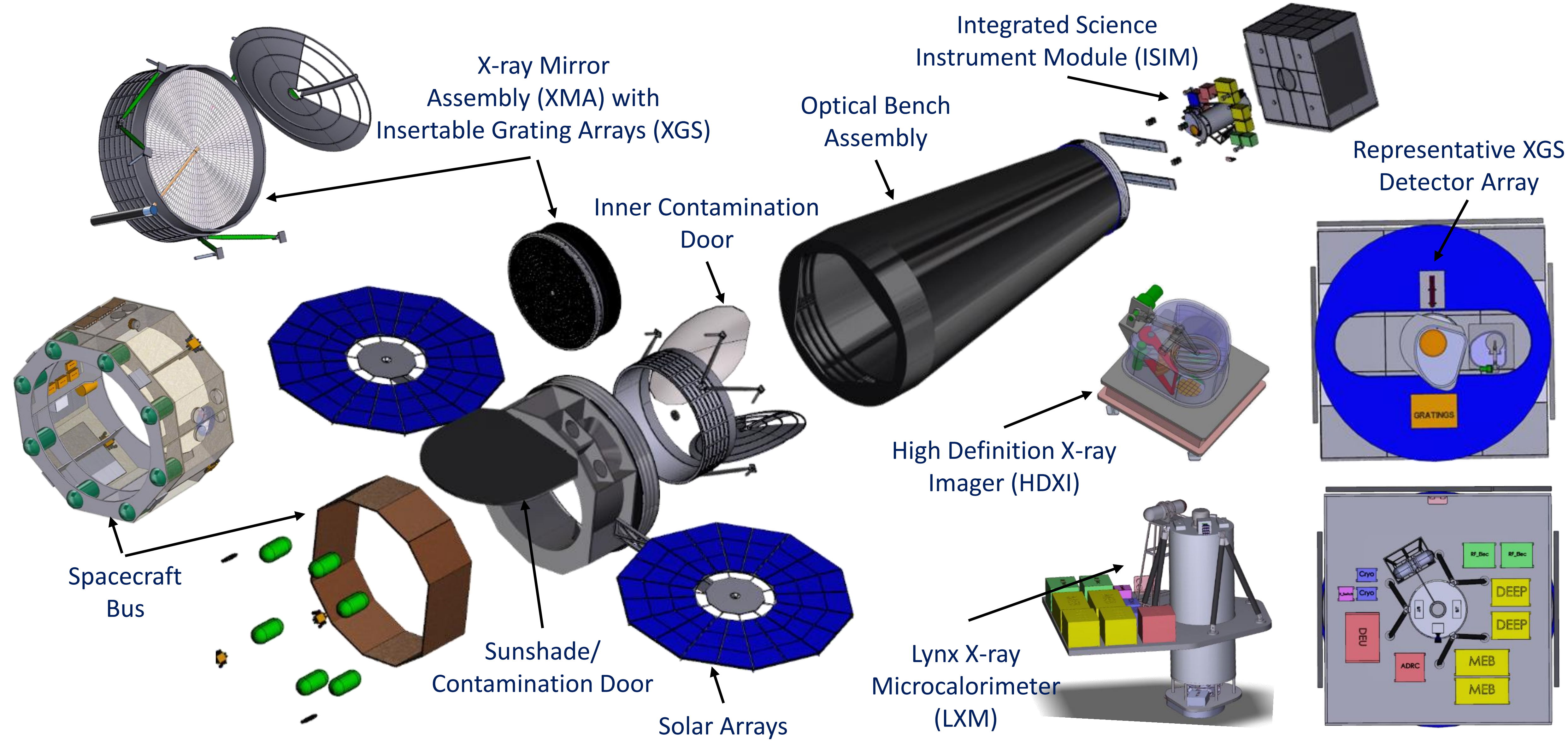
Science Driven Requirements

Lynx Optical Assembly	
Angular resolution (on-axis)	0.5 arcsec HPD (or better)
Effective area @ 1 keV	2 m^2 (met with 3-m OD)
Off-axis PSF (grasp), A*(FOV for HPD < 1 arcsec)	600 m^2 $arcmin^2$

Chandra did it! And so can Lynx!

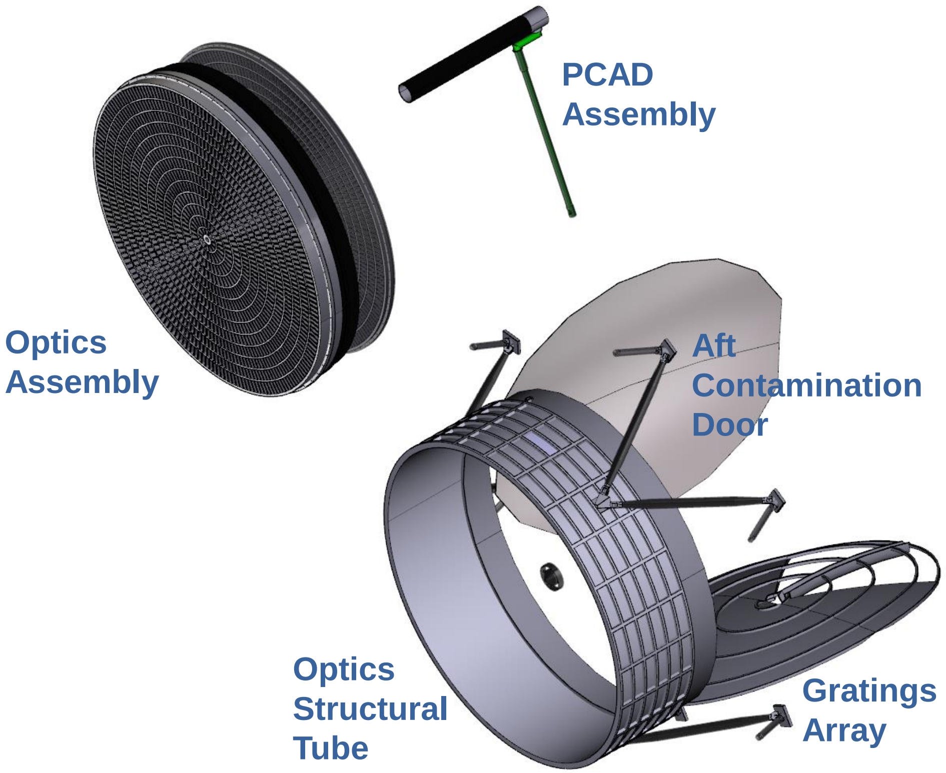


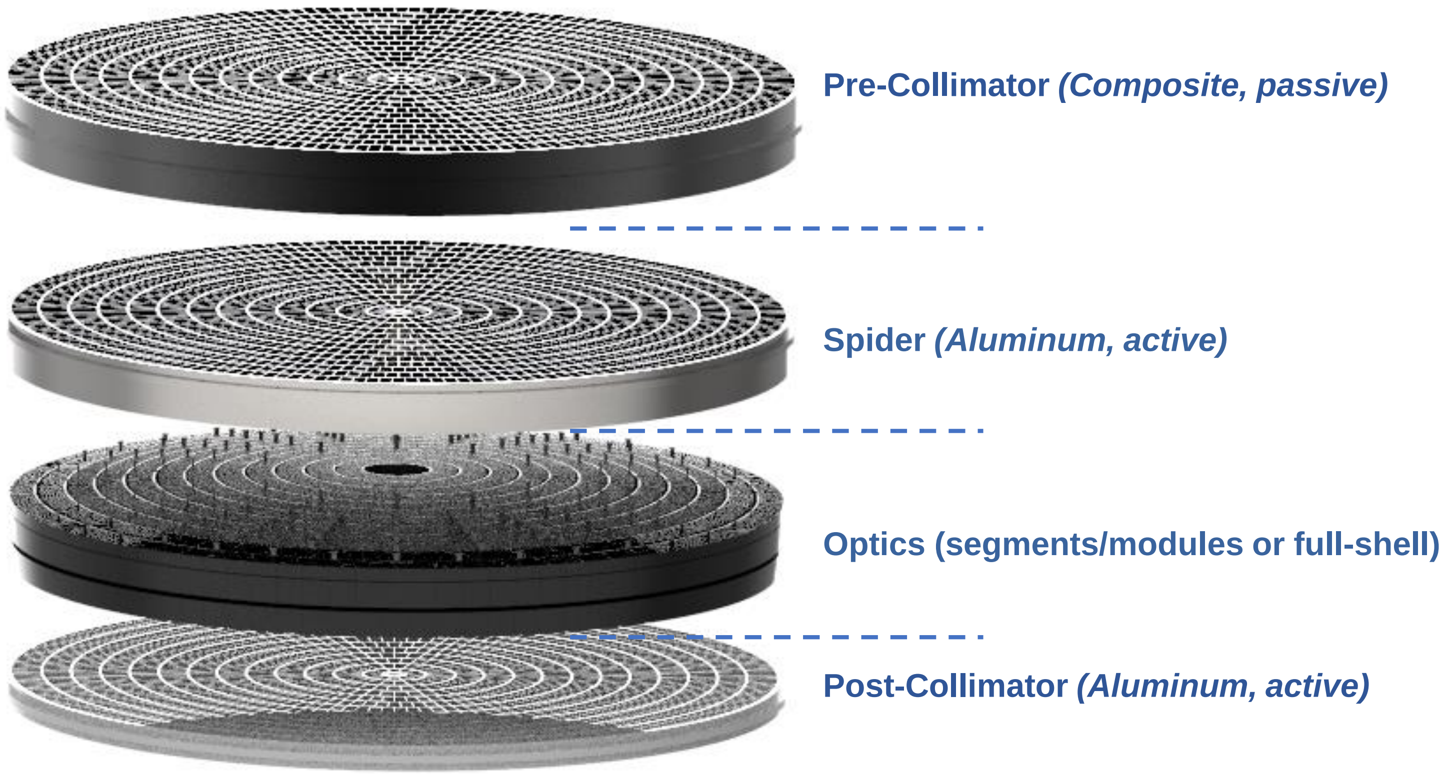
LYNX OBSERVATORY CONFIGURATION



Credit: NASA MSFC Advanced Concept Office

OPTICS ASSEMBLY OVERVIEW





Credit: NASA MSFC Advanced Concept Office

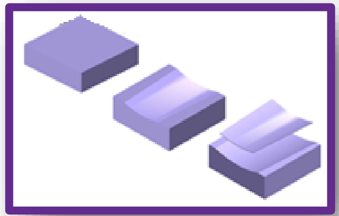
LYNX MIRROR ASSEMBLY

FABRICATION

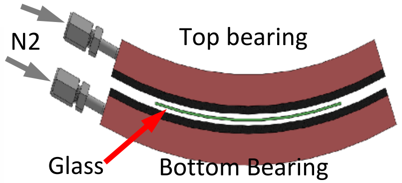
Thermal Forming (GSFC, SAO)

Full Shell (INAF-Brera, MSFC, SAO)

Si Optics (GSFC)



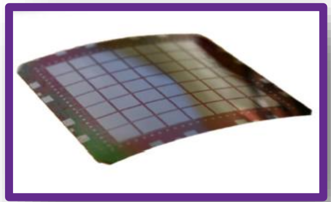
Air Bearing Slumping (MIT)



Testing/Simulation/Modeling

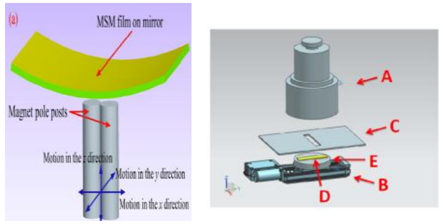
CORRECTION

Piezo stress (SAO/PSU)

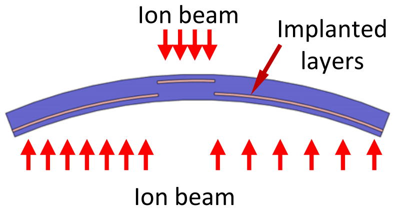


Deposition (MSFC, XRO)

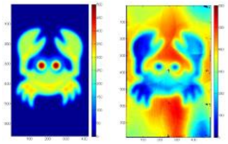
Magnetic & deposition stress (NU)



Ion implant stress (MIT)



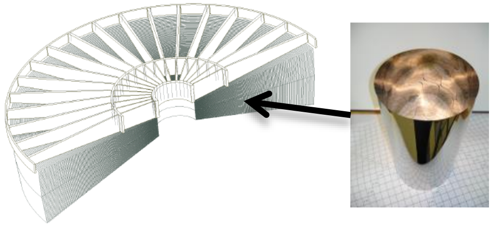
Ion beam figuring (OAB)



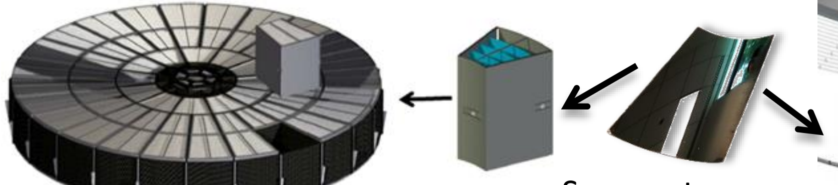
Testing/Simulation/Modeling

INTEGRATION

Full shells Assembly

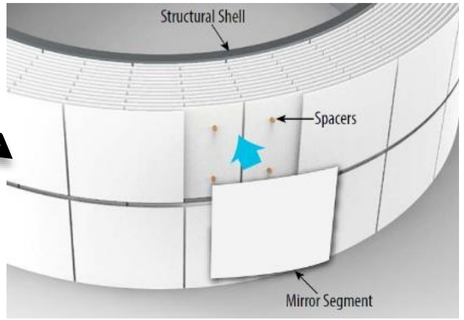


Segmented Wedge Assembly



Segments

Meta-Shell Assembly

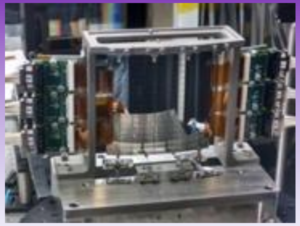


Testing/Simulation/Modeling

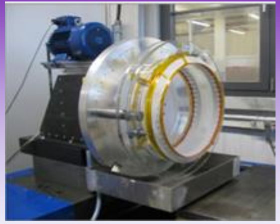
Schattenburg talk to NASA PCOS SIG, 04/2016 - Modified

LYNX OPTICS TRADE STUDY – DRM SELECTION

- 3 actively funded Optics Technologies
- Kepner-Tregoe Trade Study chartered by Lynx STDT
- Facilitated by G. Blackwood (NASA JPL)
- Recommendation was made to STDT on 8/8/18



Adjustable Segmented (SAO)



Full Shell (INAF-Brera/MSFC)

Silicon Meta-Shell (GSFC)

Executive Summary: Community working group conducted an open, science, technical, and programmatic evaluation using public evaluation criteria in a series of telecons and F2F meetings that took place over 6 months (2018).

A broad consensus was reached on the recommendation and on the basis for the recommendation

- **Large and diverse team from industry, universities, and multiple NASA Centers**
- **~ 5,000 person-hours over 6 months**
- **~100 documents produced (~650 pages of material)**

All 3 Optics Technologies are currently being funded by NASA, Institutional, Other funding!

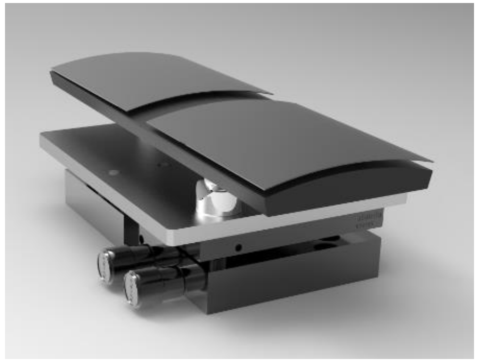
Recommendation

The LMAT recommends the Silicon Meta-Shell as the DRM concept Mirror Optical Assembly Architecture to focus the design for the Final Report. Full-Shell and Adjustable Optics are determined to be feasible alternates.

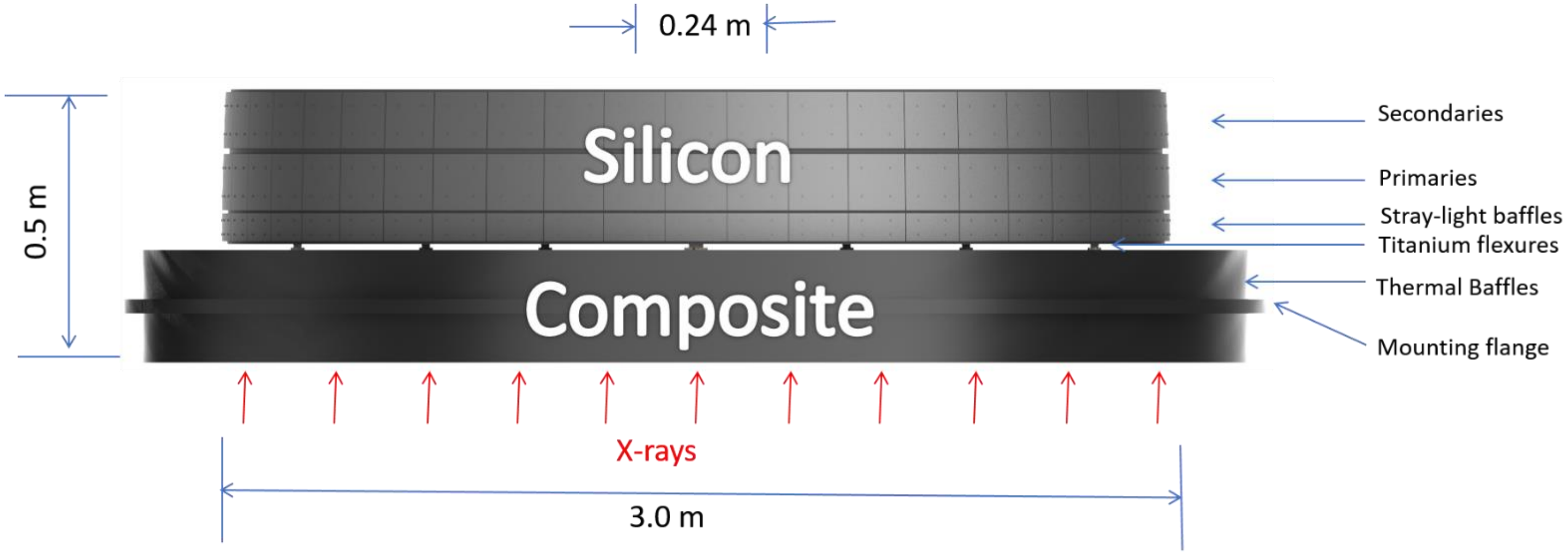
SILICON META-SHELL OPTICS

- W. Zhang & NGXO Team (NASA GSFC)

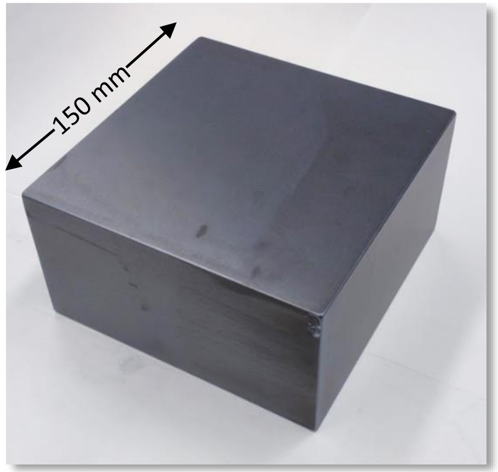
Direct polished mono-crystalline silicon



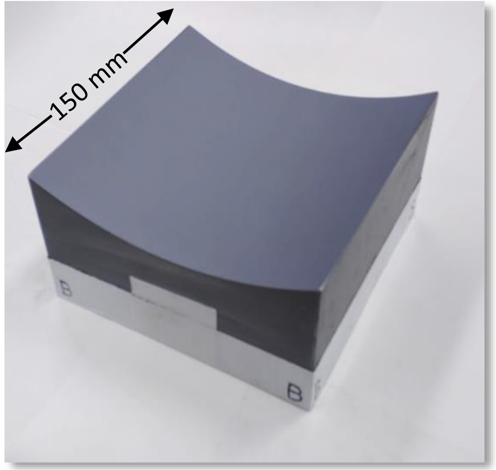
Parameters	Values
Total Number of Segments	37,492
Total Number of Meta-Shells	12
Radius (mm)	120 (Inner) – 1500 (Outer)
Segment Size (L x H) (mm)	100 x 100
Thickness Inner/Outer (mm)	0.5
Total mirror assembly mass (kg)	1,185 (including straylight & thermal baffles + structures)



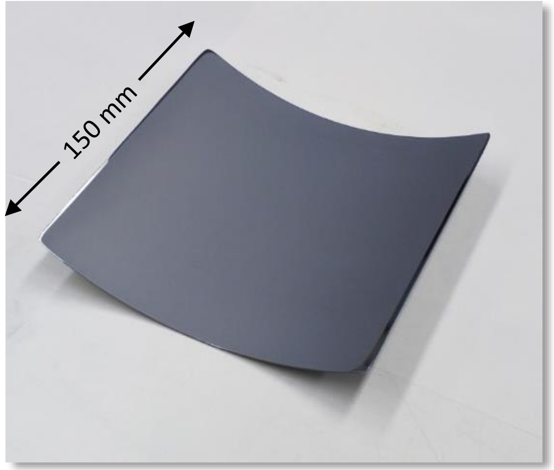
MAJOR STEPS OF SUBSTRATE FABRICATION



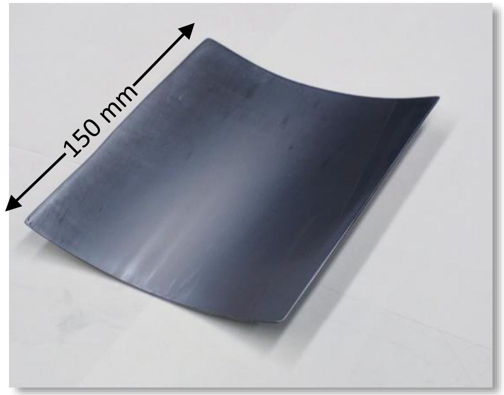
1. Mono-crystalline silicon block



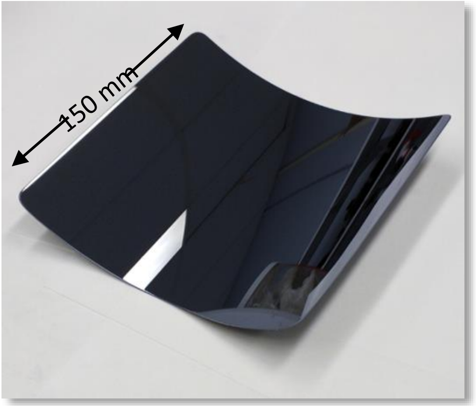
2. Conical form generated



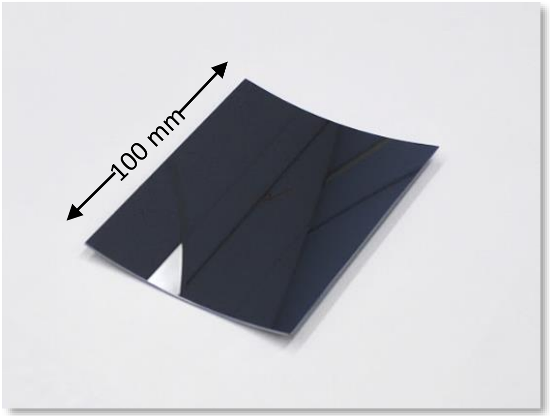
3. Light-weighted substrate



4. Etched substrate



5. Polished mirror substrate



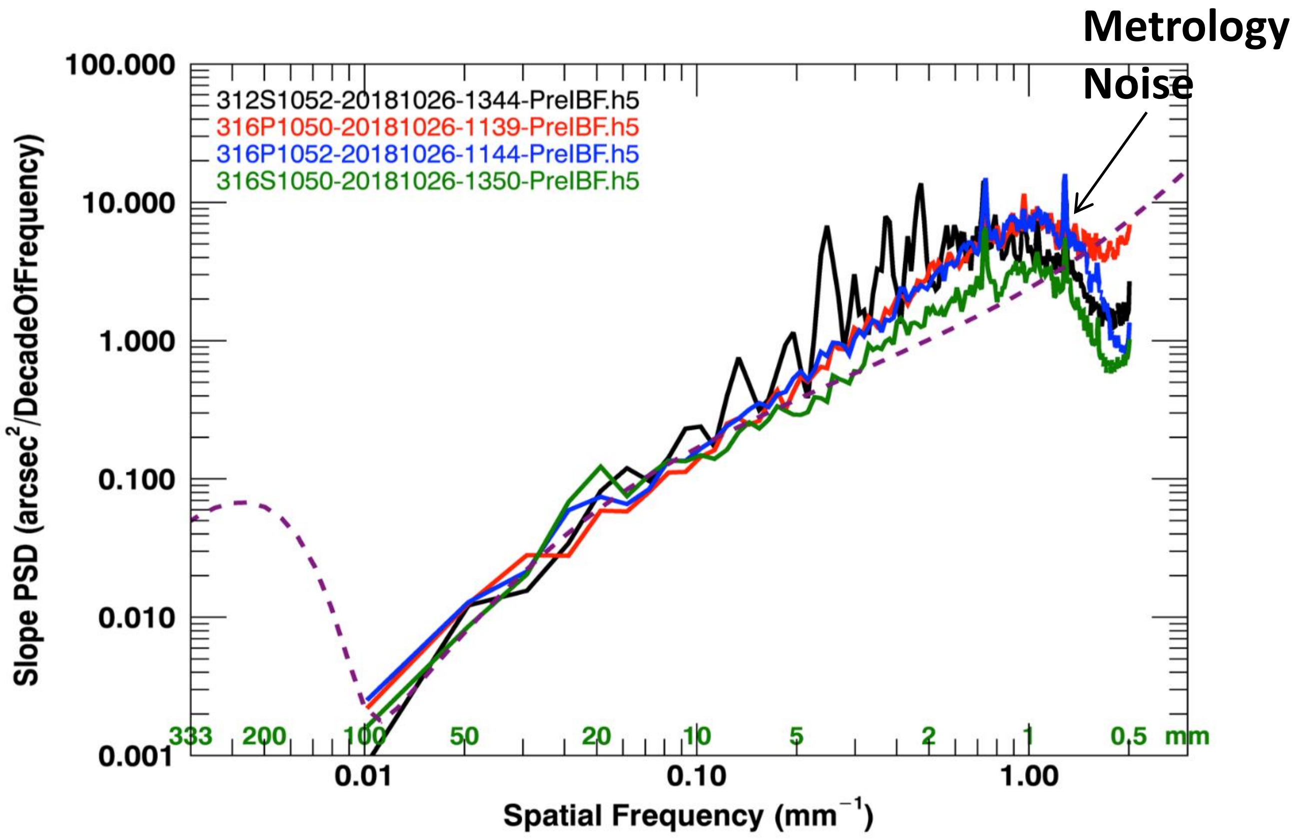
6. Trimmed mirror substrate

Key Features:

1. Use only commercially available equipment & materials.
2. Highly amenable to automation and parallel production.
3. Calendar Time: 5 days.
4. Labor Time: ~15 hours.

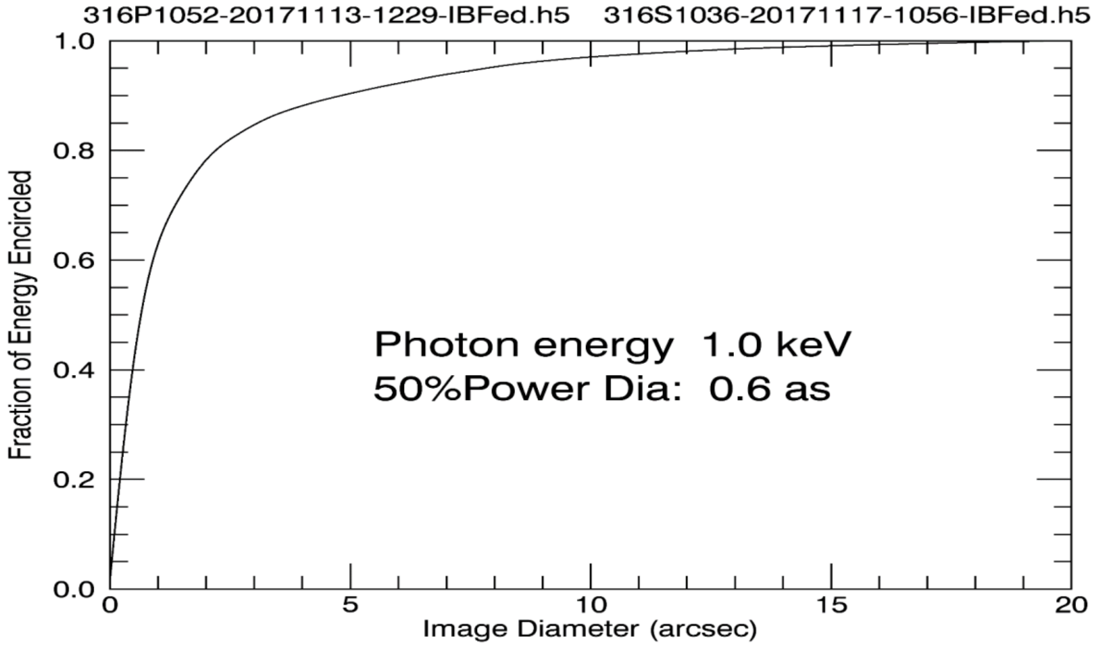
MANY MIRRORS MADE IN 2018 – METROLOGY LIMITED!

Measured Performance



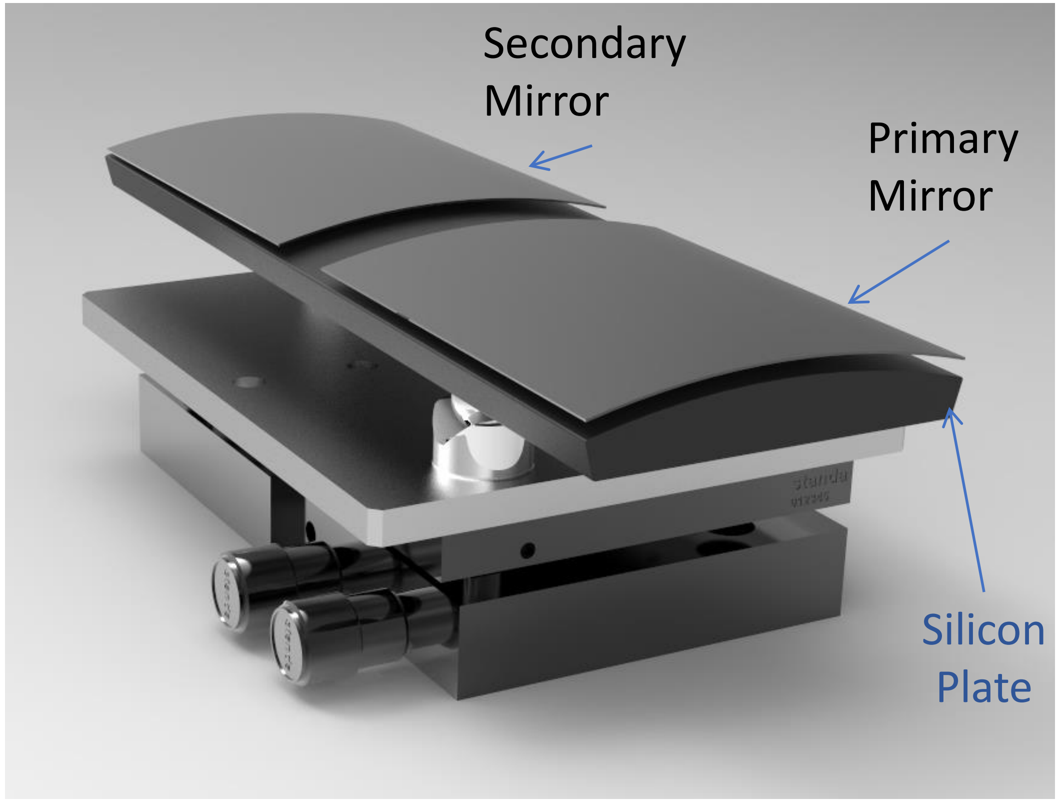
Quality comparable to or slightly better than Chandra's mirror.

Predicted Performance

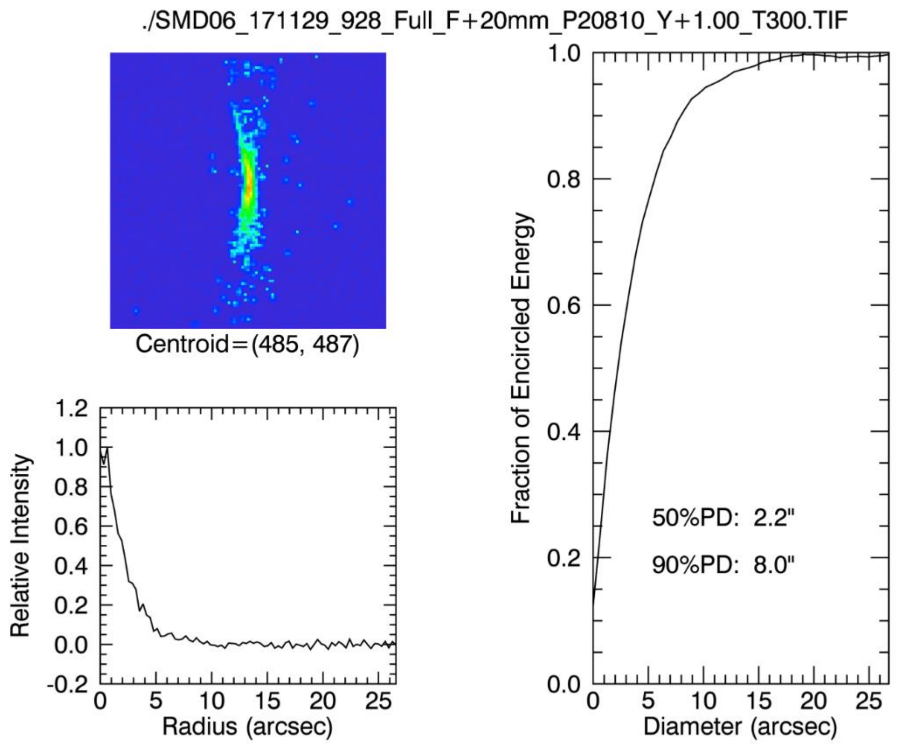


A good indication that mirrors can be made to meet Lynx (0.5" HPD) requirements.

X-RAY TESTING OF A PAIR OF MIRRORS



Two uncoated mono-crystalline silicon mirrors aligned and bonded on a silicon platform



Full illumination with Ti-K X-rays (**4.5 keV**)

SUMMARY AND *GOALS*

- 2012-2016: from a blue-sky idea to a practical process
  - Proof of principle, validating the approach based on precision-polishing of mono-crystalline silicon.

- 2017: Made sub-arcsec mirrors with thickness about *~1mm*.

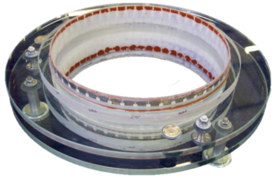
- 2018: Made sub-arcsec mirror with thickness ~0.5mm.

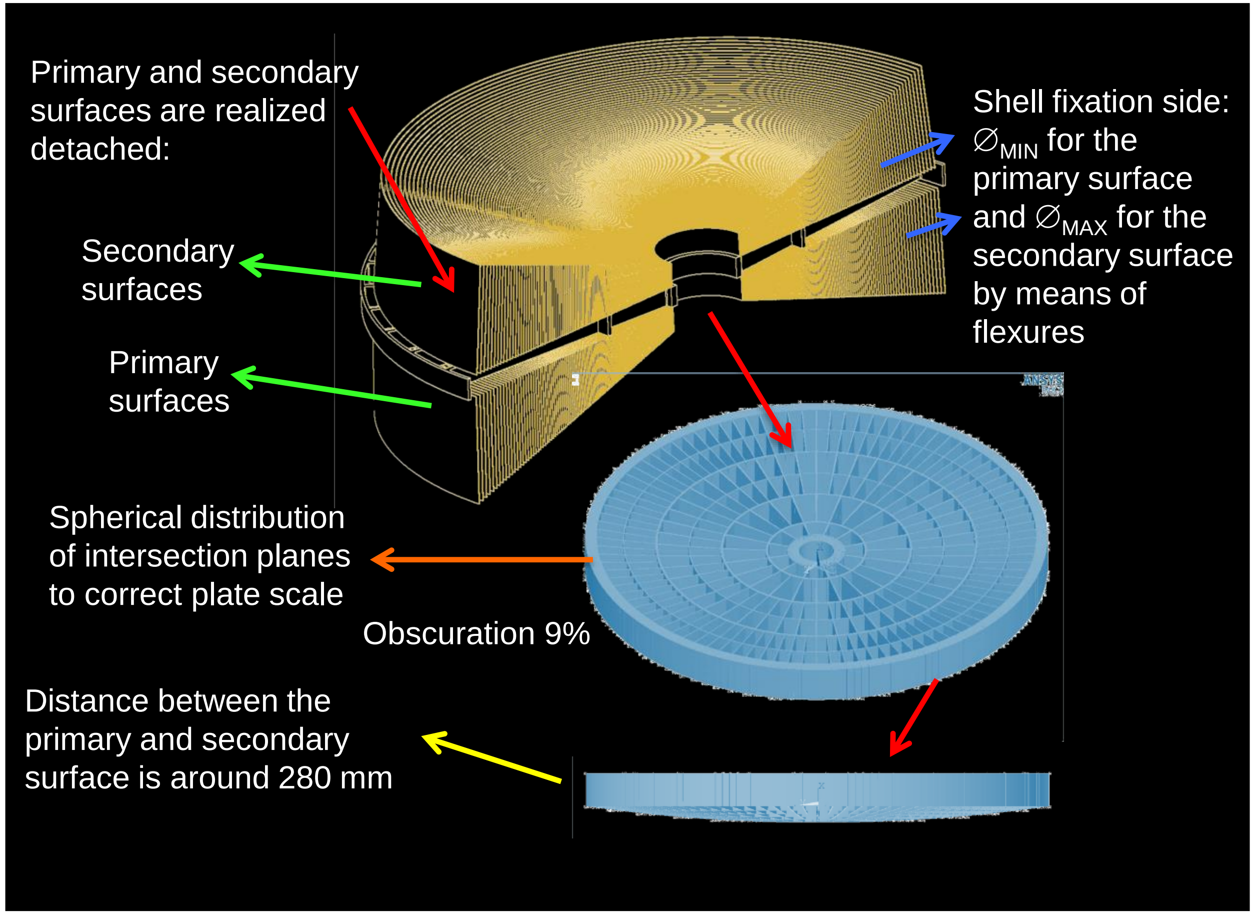
- 2019-2023(?): from sub-arc-second to diffraction-limited mirrors (~0.1 arc-seconds)
  - Continue to refine *fabrication* process and to understand and improve *measurement* process to make ever better mirrors: 0.3” (2019), 0.2” (2021), and 0.1” (2023).

MULTIPLE FUNDED ON-GOING EFFORTS- FULL SHELL & ADJUSTABLE OPTICS

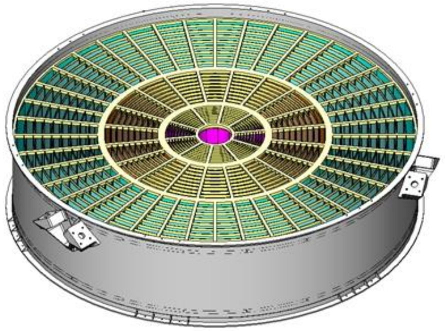
- G.Pareschi, M.Civitani, S.Basso & INAF Team (INAF-OAB)
- K. Kiranmayee , J. Davis, R. Elsner D. Swartz & MSFC Team (MSFC/USRA)

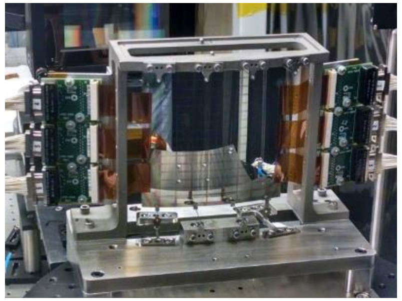
Direct Polished Fused Silica or Similar



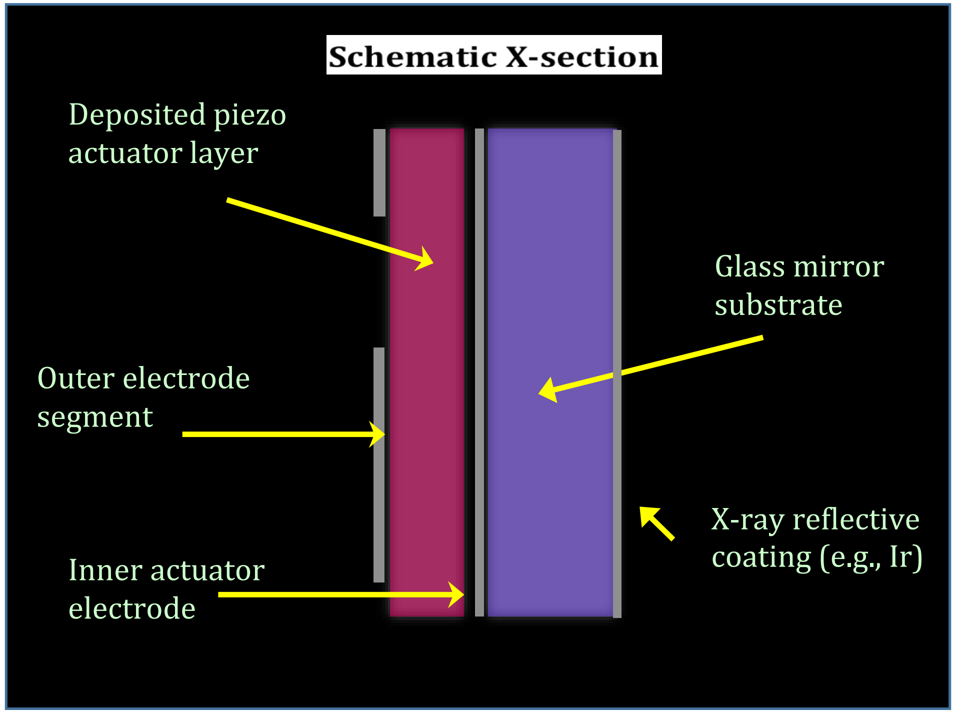


- P. Reid
- SAO Adjustable Optics Team
- PSU Adjustable Optics Team



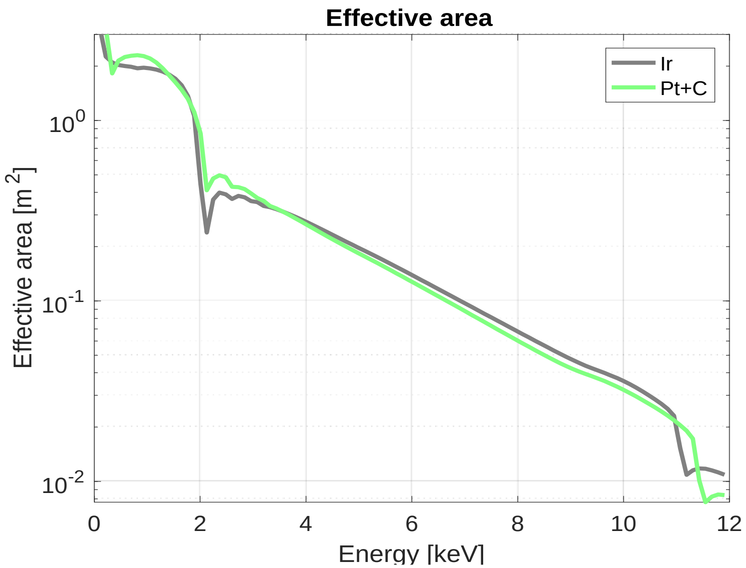


Slumped glass with sputter deposited piezoelectric material



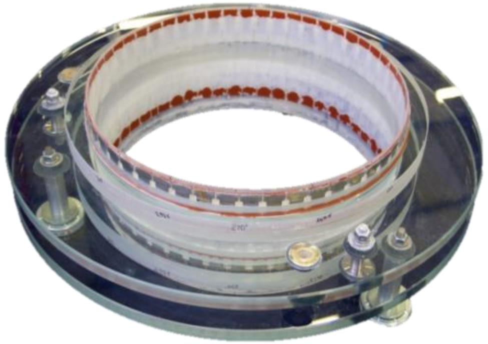
FULL SHELL OPTICS

- M.Civitani, G. Vecchi, J. Holysko, S.Basso, M.Ghigo, G.Pareschi, (INAF-OAB)
- G.Parodi (BCV progetti), G.Toso (INAF-IASF)
- K. Kiranmayee , J. Davis, R. Elsner D. Swartz (MSFC/USRA)



Parameters	Values
Gap @ IP (mm)	280
Shift IP (*) (mm)	2.3 (Inner) – 124.7 (Outer)
Total Number of Shells	164 (x2 Primary + Secondary)
Radius (mm)	203.2 (Inner) – 1483.8 (Outer)
Semi-Shell height IP (mm)	157.9 (Inner) - 348.2 (Outer)
Thickness IP Inner/Outer (mm)	1.6 – 3.4
Total mirror assembly mass (kg)	1,890.7 986.3 Primary 904.4 Secondary
Mirror support structures & thermal control (*estimate*) (kg)	300 (TBC)

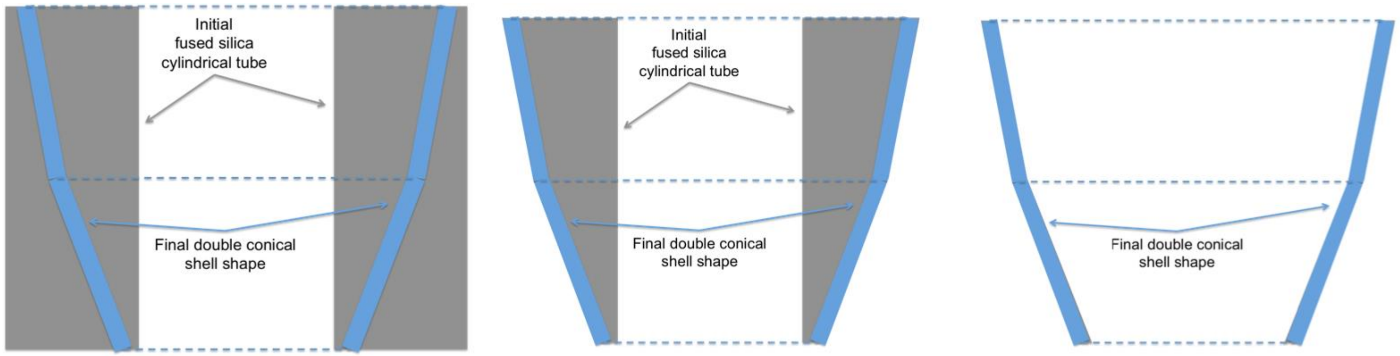
164 Shells!

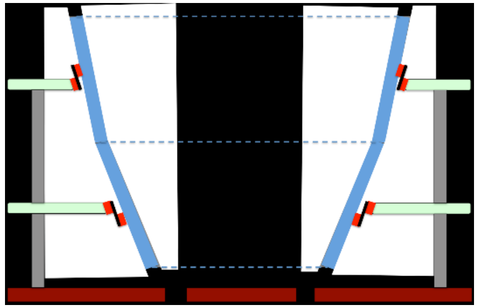


INAF-BRERA PROCESS OVERVIEW

Step	Status	< 2020
Procurement of the fused silica shell	Tested	X
Annealing		X
Chemical etching		X
Mounting the shell in a Shell Supporting System	Tested	
Fine grinding	Tested	
Bonnet polishing	Tested	
Pitch polishing	Tested	
Ion beam figuring		
Coating		
X-ray calibration	Tested	X

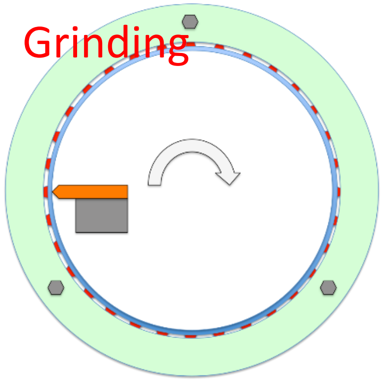
Raw shell production



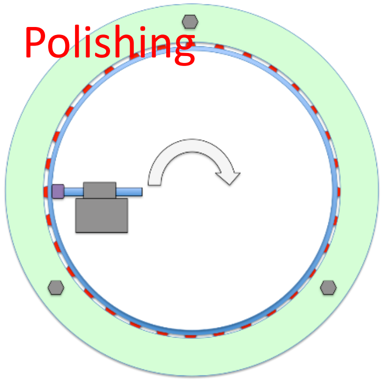


Fixation in a supporting system

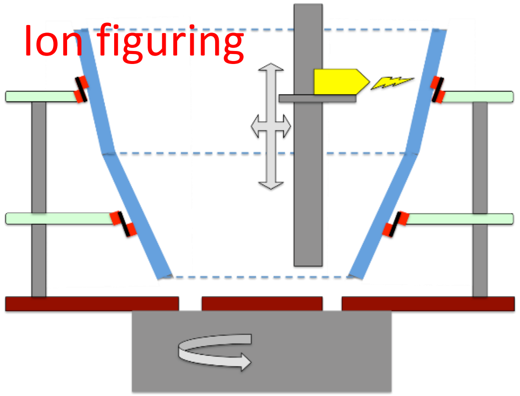
Grinding



Polishing

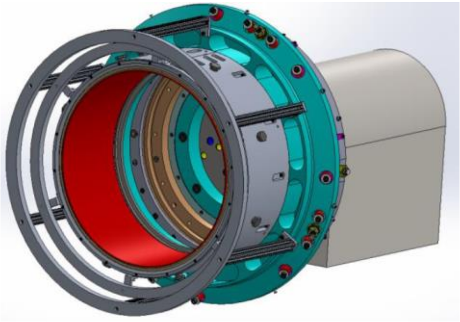


Ion figuring

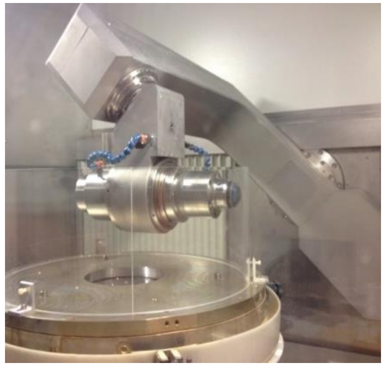


MSFC FULL SHELL OPTICS FABRICATION PROCESS

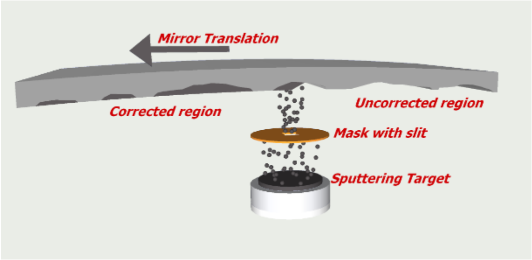
Machined mirror blanks



Diamond turning
TRL~2



Computer controlled polishing
TRL~3



Differential deposition
TRL~3

Low-stress reflective coatings
TRL~3

Alignment and module integration
TRL~3

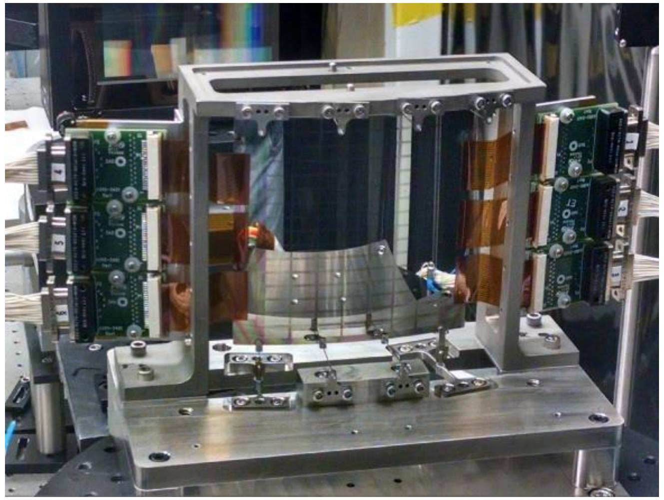
Slide provided by NASA MSFC X-Ray Group

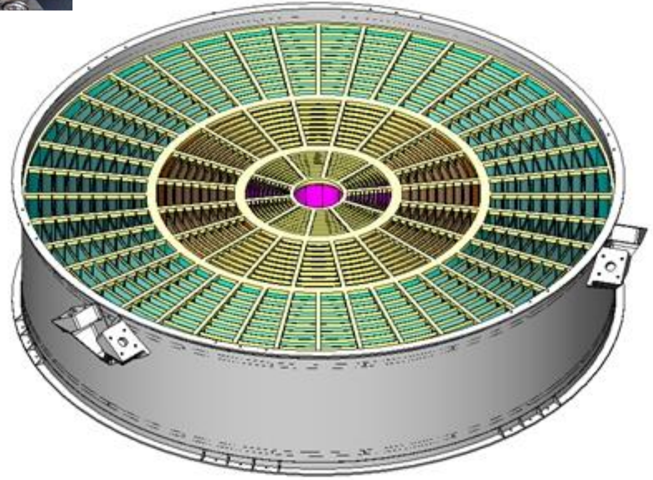
ADJUSTABLE OPTICS

- P. Reid
- SAO Adjustable Optics Team
- PSU Adjustable Optics Team

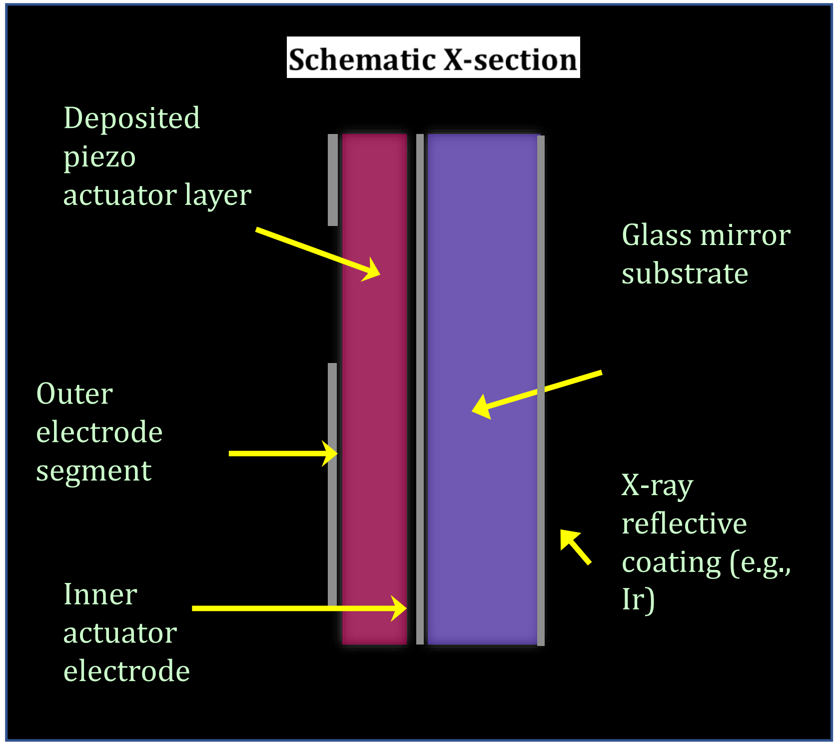
Parameters	Values
Total Number of Segments	12,720
Total Number of Shells	265
Number of Piezoelectric adjuster cells per mirror segment	~1500
Number of strain gauges per segment	~10
Radius (mm)	200 (Inner) – 1500 (Outer)
Segment Size (L x H) (mm)	200 x 220 – 200 x 120
Thickness Inner/Outer (mm)	0.4
Total mirror assembly mass (kg)	1,580 (includes pre- and post-thermal collimators)

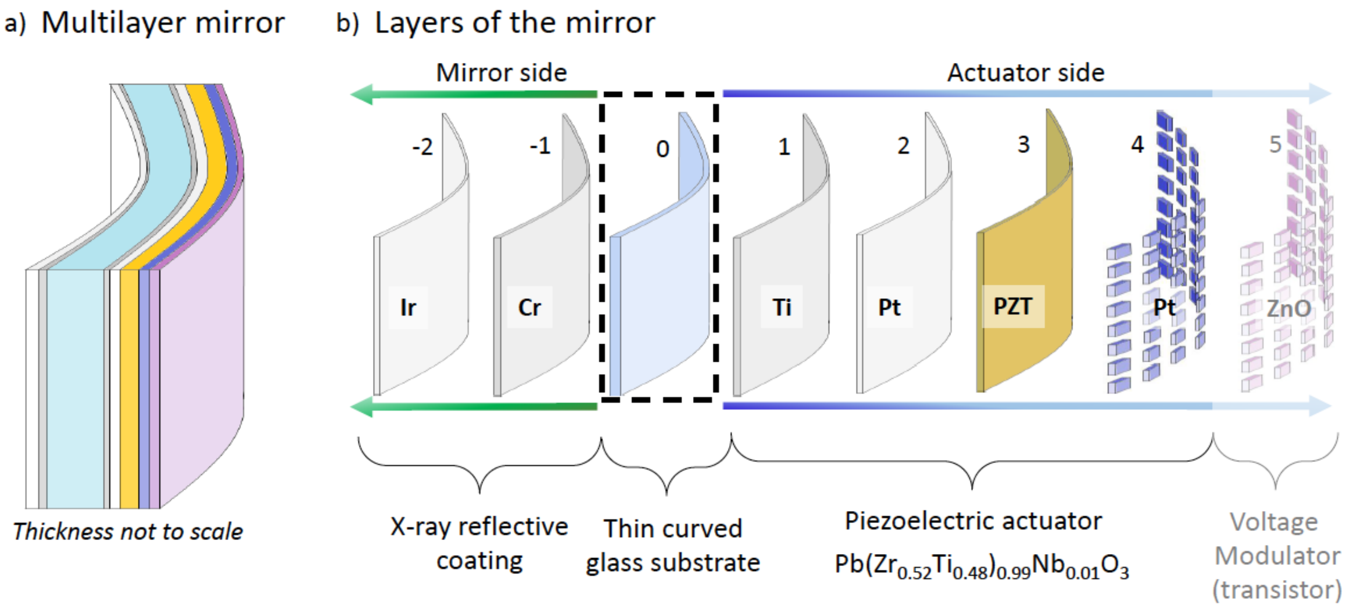
Slumped glass with sputter deposited piezoelectric material





ADJUSTABLE OPTICS PROCESS





Enabling Technologies TRL Assessment Summary

At Decadal Studies Management Team request, the ExEP, PCOS, and COR Program Offices and the Aerospace Corp assessed the TRL of tech gaps submitted by the teams as of Dec. 2016. Assessment was presented June 2017.

ID	Technology Gap	TRL
1	**High-Resolution 'Lightweight' Optics**	**~~2~~ 3**
2	**Non-deforming X-ray Reflecting Coatings**	**3**
3	Megapixel X-ray Imaging Detectors (HDXI)	3
4	X-ray Grating Arrays (XGS)	4
5	Large-Format, High Spectral Resolution X-ray Detectors (LXM)	3

Multiple Technologies 3-4+ by mid-2020

Multiple Technologies

Multiple Technologies

Subsystem Heritage

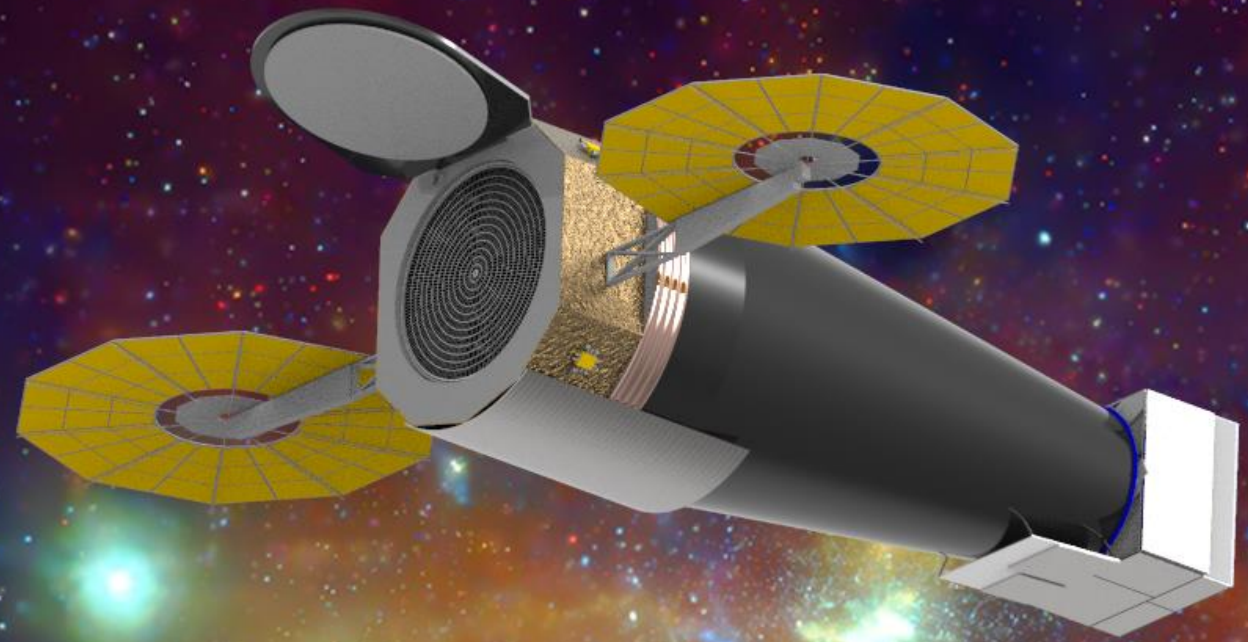
THANK YOU!

Jessica.Gaskin@nasa.gov

Lynx Websites:

https://wwwastro.msfc.nasa.gov/lynx/

https://www.lynxobservatory.com/



- **Large effective area** is achieved by nesting a few hundred to many thousands of co-aligned, co-axial mirror pairs.
- Must fabricate **thinner mirrors** to allow for greater nesting of mirror pairs and larger effective area while reducing mass
- These thin mirrors must be better that **0.5" HPD** requirement.
- Must **mount and coat** these thin optics **without deforming the optic**, or must be able to correct deformations.