LYNX: OPTICS DEFINED

J. Gaskin. NASA MSFC

Presented on behalf of the Lvnx 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 leads in capability over Chandra and Athena:

- **Orders of magnitude gain in sensitivity** over Chandra and Athena, via high throughout 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 m² 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.
Science Driven Requirements

Lynx Optical Assembly
Angular resolution (on-axis) 0.5 arcsec HPD (or better)
Effective area @ 1 keV 2 m² (met with 3-m OD)
Off-axis PSF (grasp), A*(FOV for HPD < 1 arcsec) 600 m² arcmin²

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 than 0.5” HPD requirement.

Must mount and coat these thin optics without deforming the optic, or must be able to correct deformations.

Chandra did it! And so can Lynx!
OPTICS ASSEMBLY OVERVIEW

Optics Assembly
Pre-Collimator (Composite, passive)
Spider (Aluminum, active)
Optics (segments/modules or full-shell)
Post-Collimator (Aluminum, active)

PCAD Assembly
Optics Structural Tube
Aft Contamination Door
Gratings Array

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)

**CORRECTION**

- Piezo stress (SAO/PSU)
- Deposition (MSFC, XRO)
- Magnetic & deposition stress (NU)
- Ion implant stress (MIT)
- Ion beam figuring (OAB)

**INTEGRATION**

- Full shells Assembly
- Segmented Wedge Assembly
- Meta-Shell Assembly

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

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.
W. Zhang & NGXO Team (NASA GSFC)

Direct polished mono-crystalline silicon

### SILICON META-SHELL OPTICS

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

12-05-2018, APRA PI Forum by W. Zhang (NASA GSFC)
A good indication that mirrors can be made to meet Lynx (0.5” HPD) requirements.

Quality comparable to or slightly better than Chandra’s mirror.
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 \( \sim 1 \text{mm} \).

• 2018: Made sub-arcsec mirror with thickness \( \sim 0.5 \text{mm} \).

• 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).
Direct Polished Fused Silica or Similar

- Primary and secondary surfaces are realized detached.
- Distance between the primary and secondary surface is around 280 mm.
- Obscuration 9%.

Shell fixation side: $\varnothing_{\text{MIN}}$ for the primary surface and $\varnothing_{\text{MAX}}$ for the secondary surface by means of flexures.

Spherical distribution of intersection planes to correct plate scale.

Slumped glass with sputter deposited piezoelectric material.

- Deposited piezo actuator layer
- Glass mirror substrate
- Outer electrode segment
- Inner actuator electrode
- X-ray reflective coating (e.g., Ir)

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

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

164 Shells!

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12-06-2018, SPIE Austin by M. Civitani (INAF/Brera)
Lynx optics based on full monolithic shells: design and development
### 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

- **Initial fused silica cylindrical tube**
- **Final double conical shell shape**

### Fixation in a supporting system

- **Grinding**
- **Polishing**
- **Ion figuring**

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12-06-2018, SPIE Austin by M. Civitani (INAF/Brera)

Lynx optics based on full monolithic shells: design and development
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

Slumped glass with sputter deposited piezoelectric material

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

Deposited piezo actuator layer

Glass mirror substrate

Outer electrode segment

X-ray reflective coating (e.g., Ir)

Inner actuator electrode

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APRA PI Forum by P. Reid (SAO)
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.

<table>
<thead>
<tr>
<th>ID</th>
<th>Technology Gap</th>
<th>TRL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>High-Resolution ‘Lightweight’ Optics</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>Non-deforming X-ray Reflecting Coatings</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>Megapixel X-ray Imaging Detectors (HDXI)</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>X-ray Grating Arrays (XGS)</td>
<td>4</td>
</tr>
<tr>
<td>5</td>
<td>Large-Format, High Spectral Resolution X-ray Detectors (LXM)</td>
<td>3</td>
</tr>
</tbody>
</table>

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/

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- 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 than 0.5” HPD requirement.
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