Lynx Mirror Assembly: Seeing Through the Details

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PCOS/Aerospace TRL Assessment
May 2017

<table>
<thead>
<tr>
<th>STDT</th>
<th>Total Gaps</th>
<th>TRL 2 Gaps</th>
<th>TRL 3 Gaps</th>
<th>TRL 4+ Gaps</th>
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<tbody>
<tr>
<td>HabEx</td>
<td>13</td>
<td>0</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>LUVOIR</td>
<td>10</td>
<td>1</td>
<td>3</td>
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</tr>
<tr>
<td>Lynx</td>
<td>5</td>
<td>X</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>OST</td>
<td>11</td>
<td>3</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
Challenges

- 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 thin optic, or must be able to correct deformations.

### Science Driven Requirements

<table>
<thead>
<tr>
<th>Lynx Optical Assembly</th>
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<tbody>
<tr>
<td>Angular resolution (on-axis)</td>
<td>0.5 arcsec HPD (or better)</td>
</tr>
<tr>
<td>Effective area @ 1 keV</td>
<td>2 m² (met with 3-m OD)</td>
</tr>
<tr>
<td>Off-axis PSF (grasp), A*(FOV for HPD &lt; 1 arcsec)</td>
<td>600 m² arcmin²</td>
</tr>
</tbody>
</table>

**Chandra did it! Why can’t Lynx?**
Challenges

- Systems engineering
  - Error budgets
  - Defining local and global structures and allocating requirements to each
- Understanding and mitigating coating stresses
- Structures and mounting
  - Epoxy creep
  - Alternative pinning techniques
  - Different challenges for sub-assemblies and aggregation
- Thermal control of the assembled telescope
- Community mirror metrology (and calibration) assets
  - Gravity distortion (for example) during mirror metrology is much worse than Chandra

M. Pivovaroff (SPIE 2016)

Example Working Error Budget

All values are RMS diameter in arc-sec unless noted

L. Cohen (OWG Talk 2016)
Overcoming Challenges

3 Viable Lynx Mirror Architectures Studied

- Full Shell (K. Kilaru/USRA/MSFC, G. Pareschi/OAB)
- Adjustable Optics (P. Reid/SAO)
- Meta-Shell Si Optics (W. Zhang/GSFC)

One of these will be selected for the Design Reference Mission Concept. Additional feasible concepts will be included in the Final Report to the Decadal.

Must Develop Technology Maturation Plan:

- Define State-of-the-art
- Maturation (and development) Milestones
- Schedule & Cost
Lynx Mirror Assembly

**FABRICATION**

- Thermal Forming (GSFC, SAO)
- Full Shell (Brera, MSFC, SAO)
- Si Optics (GSFC)
- Air Bearing Slumping (MIT)
- Ion beam figuring (OAB)
- Ion beam implanted layers
- Ion implant stress (MIT)
- Magnetic & deposition stress (NU)
- Deposition (MSFC, XRO)
- Piezo stress (SAO/PSU)

**CORRECTION**

- Full shells Assembly
- Segmented Wedge Assembly
- Meta-Shell Assembly
- Top bearing
- Bottom Bearing
- Glass

**INTEGRATION**

- Testing/Simulation/Modeling
- Segments
- Schattenburg talk to NASA PCOS SIG, 04/2016 - Modified
Some issues to be investigated
- Large shells need to be thicker: thickness drives the mass of the assembly
- Large shells are not easy to sustain during manufacturing
- The surface correction and coating process may be more difficult

Integration into the Shell Supporting System

After the grinding, the use of spinning bonnet tool has been successfully implemented on the precision lathe to obtain the profile

Fine grinding to correct the out of roundness and longitudinal profiles

Same approach used for Chandra, but mirrors (shells) need to be thinner
- Limited (<200) number of shells (produced/assembled)
- Azimuthal symmetry of the shells (measure/correct)
- Coating effects are mitigated by the symmetry
- Primary and secondary surface can be joined or detached
The superpolishing made more effective using 3M Trizact abrasive tapes.

Trade-off study on mounting configuration successfully completed.

Reduced Superpolishing Time

Superpolishing time much improved: mean PTV and RMS (MFT 10x) In blue are reported the data of the last tests on shells#4 compared to the typical time needed for simple pitch tool (in black).

- Continue to optimize the configuration
- The entire polishing process (including the ion-figuring correction) is being tested on dummy shells
- Waiting for (expected!) funds from ASI for the development of a representative breadboard based on 2 shells to be X-ray tested based on the mounting configuration.
Correcting slumping errors
Control mirror figure to ~ 0.5 arcsec HPD

• Mounted adjustable mirror 0.4 mm thick, 112 piezo cells

• ACF bonded electrical connections

Relative Correction

Left – slumped mirror figure = figure to be corrected (~ 7 arcsec HPD @ 1keV, 1 surface); Right – measured (using metrology) difference between imparted figure correction and desired figure correction (~ 0.5 arcsec HPD)

Critical proof-of-concept aspect met for adjustable X-ray mirrors. Still lots to do before 0.5” HPD optics can be realized.
Adjustable Optics Status

- Slumping to high precision Wolter-I mandrel
- Implement side mirror mount
  - Modeled and designed, parts being ordered
- Incorporation of next level of back surface electronics integration
  - Insulating layer with conductive vias and narrower gap between piezo cells
    - 0.2mm vs 1.0mm
    - Mirrors in fabrication now, ~288 piezo cells (5mm x 5mm)
- Repeat optical mounted mirror test describe on previous slide with higher fidelity mirror
- Single mirror X-ray test
- Extend single mirror mount to mirror pair
- Incorporate row-column addressing via ZnO thin film transistors printed directly on mirror
- Mount, correct, align, and test mirror pair at MSFC SLF with target 1 arcsec HPD 1 keV performance.
Silicon Meta-Shell Status (W. Zhang & Team - GSFC)

Three-Level Hierarchy

1. 40,000 Mirrors
2. 12 Meta-shells
3. 1 Assembly

Four Technical Elements

1. Precision-polishing of Mono-crystalline silicon.
2. Coating to maximize reflectivity w/o distortion.
3. Alignment using four precision-machined spacers.
4. Permanent bonding w/o frozen-in distortion.

Two Foundational Principles

1. Mono-crystalline silicon can be processed deterministically because it has no internal stress.
2. An X-ray (curved) mirror’s location and orientation are kinematically determined by four points.
• The meta-shell optics have been shown by STOP (structural, thermal, and optical performance) analysis to meet
  • Mass, effective area, FOV, and stray-light requirements,
  • Structural requirements to survive launch, and
  • Thermal and gravity release requirements to preserve PSF on-orbit.
• The four technical elements have been validated by building and X-ray-testing mirror modules,
  achieving 2.2” HPD as of Dec 2017.
• Further refinement for all four elements is needed to meet PSF requirements.

![Diagram of Lynx Observatory components]

2.2” HPD image,
Full illumination with Ti-K X-rays (4.5 keV)

**Status and Expectations**

<table>
<thead>
<tr>
<th>Status</th>
<th>TRL-4 (Single-pair)</th>
<th>TRL-5 (Multi-Pair)</th>
<th>TRL-6 (Meta-shell)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lynx reqmnt</td>
<td>On-going</td>
<td>Done</td>
<td></td>
</tr>
<tr>
<td>Dec-16</td>
<td>Dec-17</td>
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<tr>
<td>Dec-24</td>
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[Graph showing progress and status over time]
• Charter from STDT chairs calls for a recommendation for “one Primary Mirror Optical Assembly architecture to focus the design for the final report and identify any feasible alternates.”

• The Lynx Mirror Architecture Trade (LMAT) Working Group represents scientific and technical leadership across academia, NASA, and industry

• Full signed charter: Lynx Optics Trade Study
• Using JPL-facilitated Kepner-Tregoe process (*JPL contributed effort*)
• Each optics technology will be evaluated against the decision criteria by programmatic, technical and science teams
• Trade criteria is chosen by the full LMAT team and requires consensus from the ‘Consensus Members’

LMAT Process:
• Kickoff Telecon with Steering Group
• Kickoff Telecon with the LMAT Working Group
• Establish consensus criteria for a successful trade outcome
• Description of options for evaluation
• Evaluation of Science, Technical, and Programmatic criteria
• Reach consensus by LMAT Consensus Members on evaluation criteria, risks, and opportunities
• Reach consensus via Consensus Member recommendation
• LMAT delivery recommendation to the STDT by 7/13/18
### Facilitator

Gary Blackwood  
NASA ExEP / JPL

### Consensus Members

**Members at Large**  
Mark Schattenburg  
MIT

**Advocates**  
Kiran Kilaru  
USRA / MSFC Full Shell
Giovanni Pareschi  
INAF / OAB Full Shell
William Zhang  
NASA GSFC Silicon Meta-shell
Peter Solly  
NASA GSFC Silicon Meta-shell
Paul Reid  
Harvard SAO Adjustable Segmented
Eric Schwartz  
Harvard SAO Adjustable Segmented

**Science Evaluation Team (SET)**  
Daniel Stern  
NASA JPL
Frits Paerels  
Columbia University
Ryan Hickox  
Dartmouth

**Technical Evaluation Team (TET)**  
Gabe Karpati  
NASA GSFC TET Lead
Ryan McClelland  
NASA GSFC structural/thermal
Lester Cohen  
Harvard SAO structural
Gary Mathews  
Harvard SAO Kodak systems engineering
Mark Freeman  
Harvard SAO thermal / SE
David Broadway  
NASA MSFC coatings
Dave Windt  
Company coatings
Marta Civitani  
OAB optical design, test
Paul Glenn  
Company metrology
Ted Mooney  
Harris polishing
Chip Barnes  
Ball systems engineering

### Programmatic Evaluation Team (PET)

Jaya Bajpayee  
NASA ARC PET Lead
John Nousek  
Penn State
Karen Gelmis  
NASA MSFC
Steve Jordan  
Ball
Charlie Atkinson  
NGAS

### Subject Matter Experts, Observers and Guests (not inclusive):

Denise Podolski  
NASA STMD
Rita Sambruna/Dan Evans  
NASA HQ
Terri Brandt/Bernard Kelly  
NASA PCOS
Vadim Burwitz  
MPE
Susan Trolier-Mkinstry  
Penn State
Casey DeRoo  
U. Iowa
Kurt Ponsor  
Mindrum
TBD  
Optics Working Group
TBD  
Optics Working Group

### Steering Group

Feryal Ozel  
University of Arizona
Alexey Vikhlinin  
Harvard SAO
Jessica Gaskin  
NASA MSFC
Robert Petre  
NASA GSFC
Doug Swartz  
NASA MSFC
Jon Arenberg (Bill Purcell/Lynn Allen)  
NGAS (Ball/Harris)
Jaya Bajpayee  
NASA ARC consensus member
Gabe Karpati  
NASA GSFC consensus member
Mark Schattenburg  
MIT consensus member

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**Lynx Mirror Assembly Trade Team**
AGENDA

• Day 1: Develop consensus on trade criteria

• Day 2:
  • Reach consensus on trade criteria;
  • Introduction of mirror architecture option that will be evaluated in the trade
  • Slides should address:
    • Description of flight architecture
    • Current state of the technology (recent manufacturing, test and/or analysis results)
    • Plans between now and early 2020 (prior to Decadal)
    • Anything else the advocate considers important for LMAT to know

Face-to-Face Trade Criteria Meeting

• Date: March 21 (1pm-5pm – or later as needed) – 22 (8am-2pm)

• Location: Hilton Chicago O'Hare Airport, 10000 W O'Hare Ave, Chicago, IL 60666

• Dublin/London Room
Thank You!

https://www.astro.msfc.nasa.gov/lynx/
Mechanical Design

Integrated Science Instrument Module

X-ray Microcalorimeter Designs

Internal strut design:

~100 cm OD

Chandra Heritage Considered

Mono-prop tanks

Internal contamination door & gratings mechanisms

Filter wheel

X-rays in from telescope

Optical Assembly

Mono-prop supports

Grating Array

Mono-prop supports

70 cm OD

Focal Plane Assembly

Calibration sources

Compressor on separate tower (vibration isolation)

Deck: to be attached to movable table and focusing mechanisms

N. Bandler, NASA GSFC

S. Bandler, NASA GSFC

Bipod cryostat supports

X-ray calibration source electronics (high voltage)