Silicon Meta-Shell X-ray Optics for Astronomy: High Resolution, Light Weight, and Low Cost

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Next Generation X-ray Optics (NGXO) Team

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Developing X-ray optics technology of ever *higher* resolution, *lighter* weight, and *lower* cost.

Lynx Mirror Assembly in Context

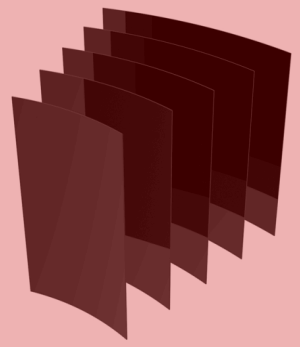
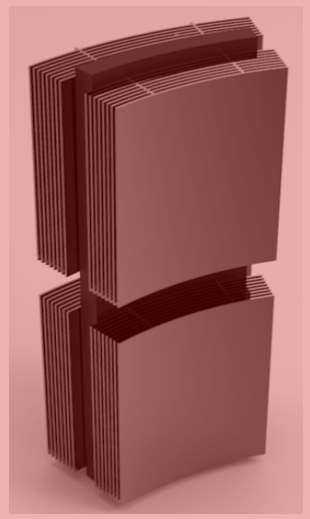
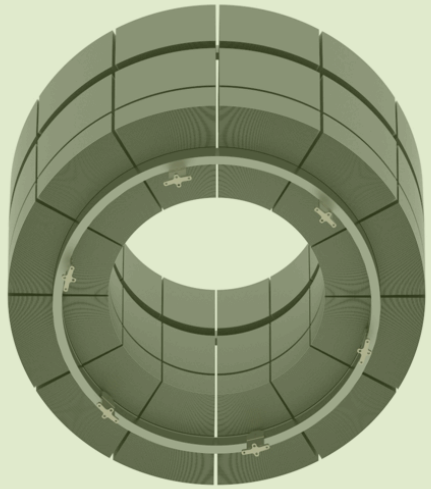
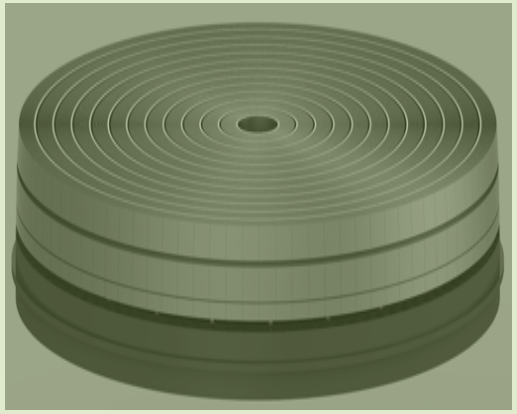
1.2m diameter	0.4m Diameter	3.0m diameter
0.5” PSF	58” PSF	0.5” PSF
19 m^2 mirror area	44 m^2 mirror area	372 m^2 mirror area
~1,200 kg mass	~40 kg mass	~1,200 kg mass

Chandra (1999)

NuSTAR (2012)

Lynx (~2036)

Major Steps to Build the *Lynx* Mirror Assembly

37,492 Segments	611 Modules	12 Meta-shells	1 Assembly
			
~0.01 kg ea.	~1.5 kg ea.	~80 kg ea.	~1,000 kg

Technology Development **Engineering Development**

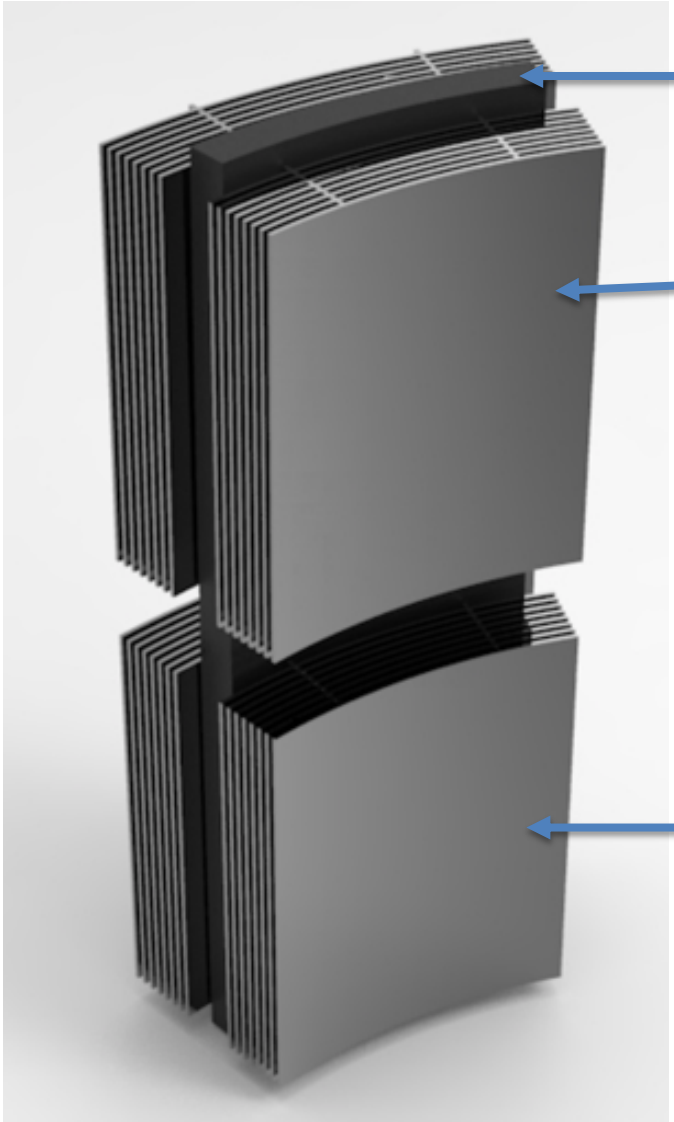
Mirror Module

Materials (relative proportions):

- Silicon: 10,000,000.
- Coatings (Cr, Ir, SiO_2): ~1.
- Epoxy: ~1.

Key Characteristics:

- Athermal:
  - Easy to test on ground.
  - Easy thermal control on orbit.
- Verifiable on ground:
  - Science performance.
  - Spaceflight environment.

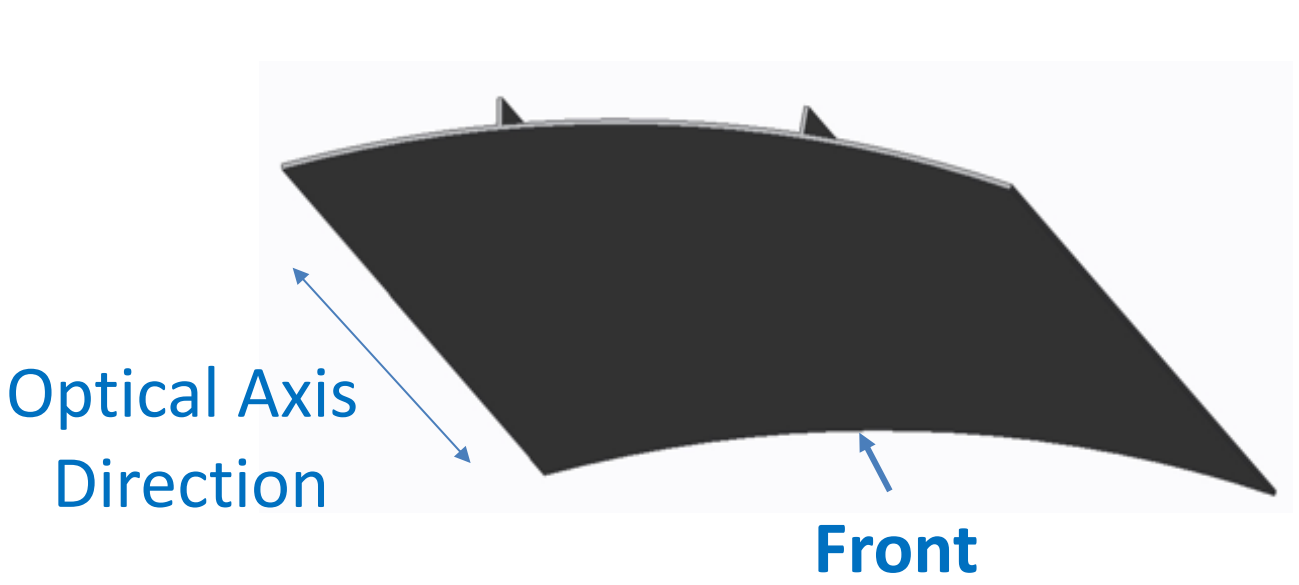


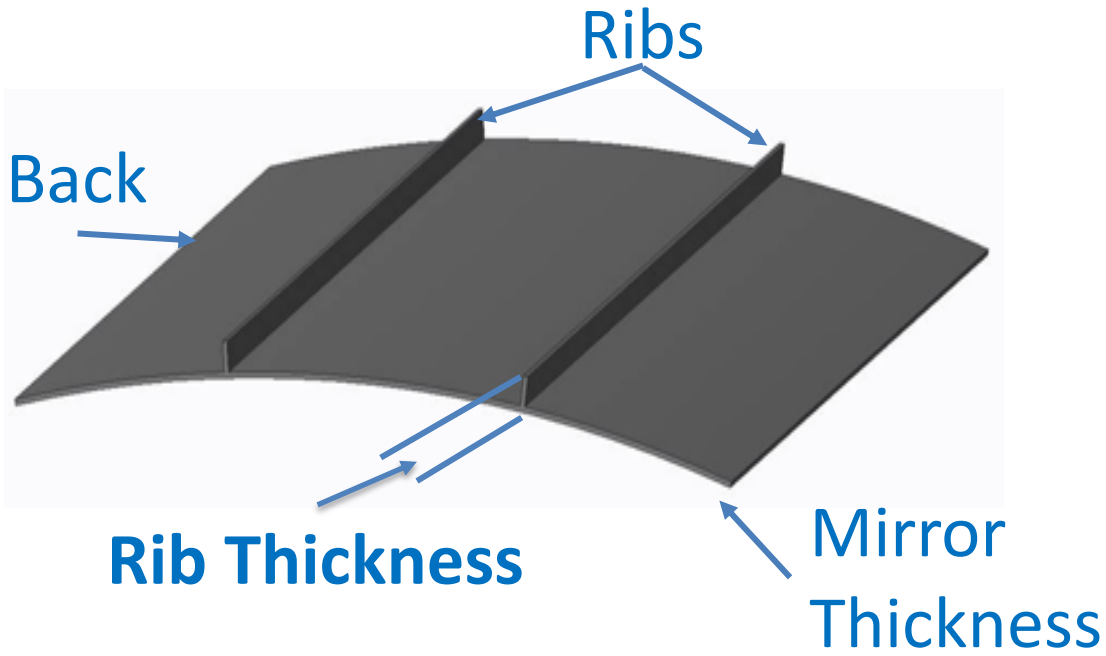
Central Plate:
200 mm by 90 mm by 10 mm

Primary Mirror Segment:
100 mm by 100 mm by 0.5 mm

Secondary Mirror Segment:
100 mm by 100 mm by 0.5 mm

Mirror Segment





Two Precision Parts of a Mirror Segment:

- **Front surface**: < 10 nm deviation from prescription.
- **Rib thickness**: < 20 nm deviation from prescription.

Process of Building a Module

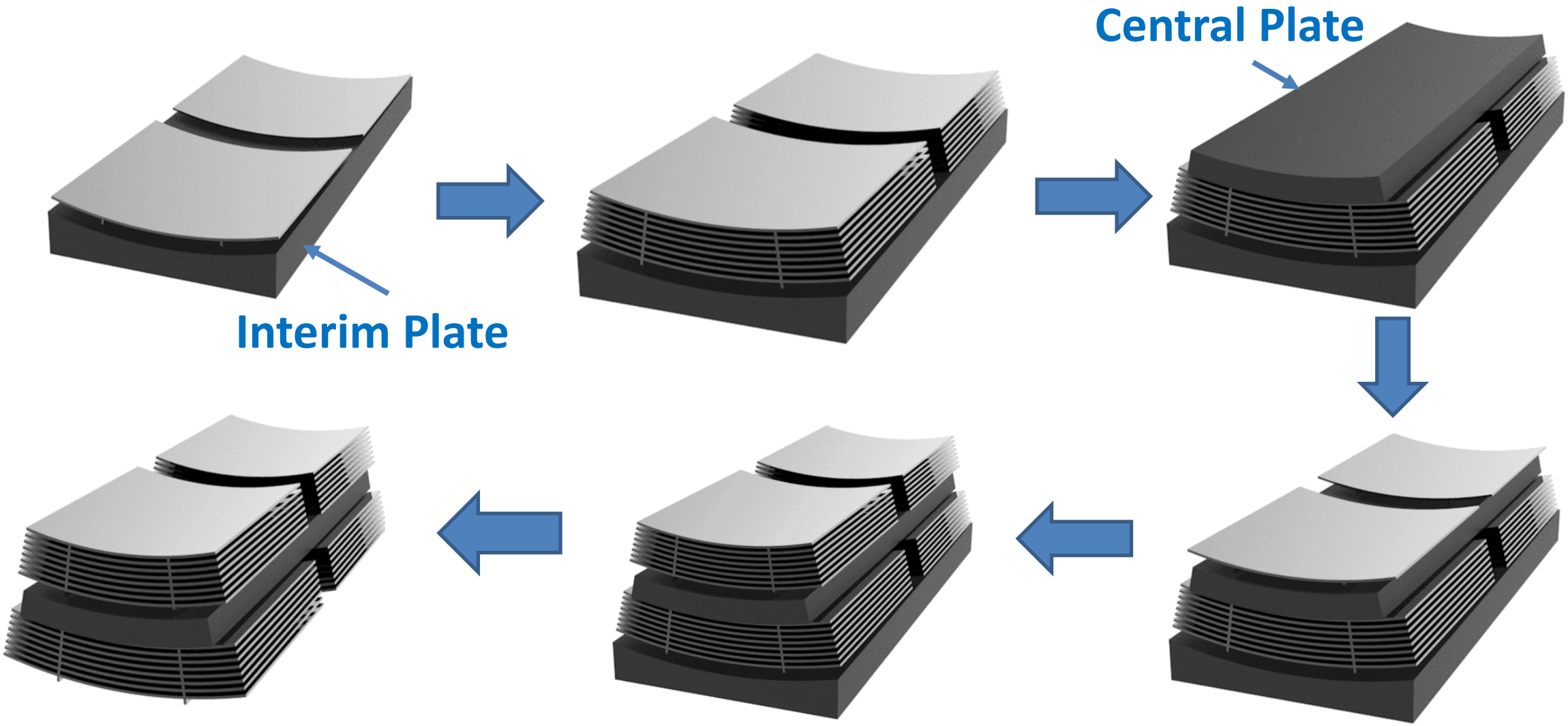
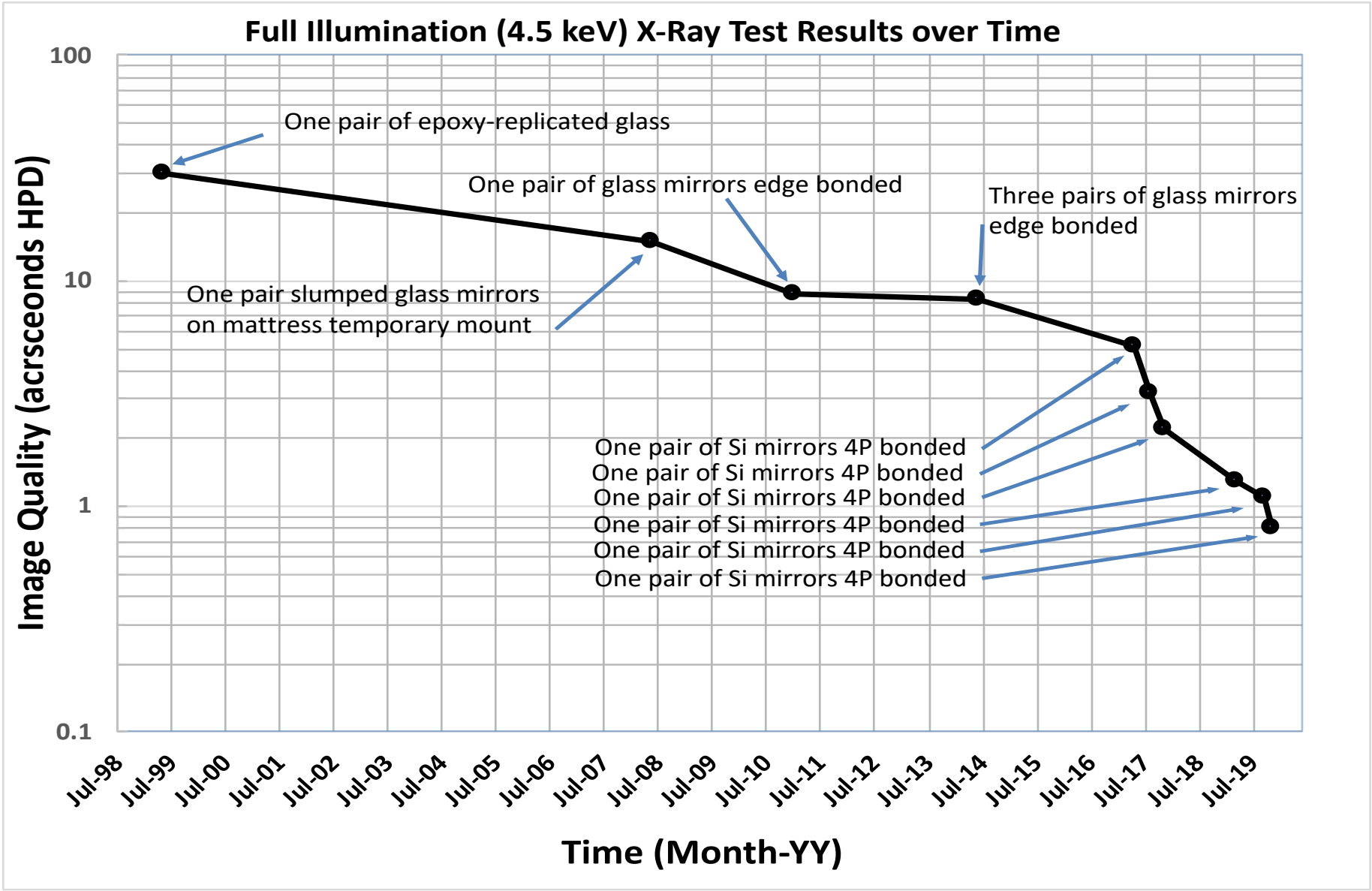
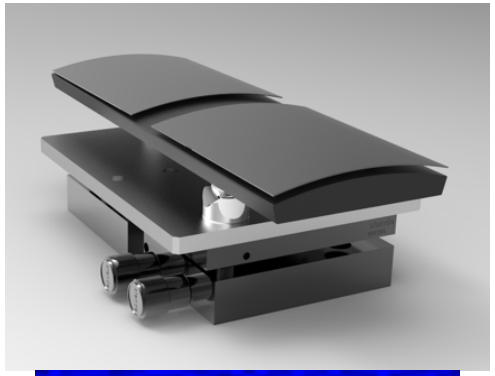
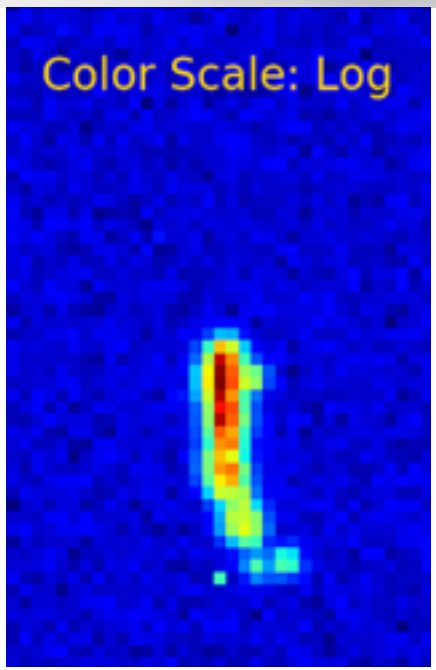


Image Quality Improvement Over Time







0.83” HPD
4.5 keV X-rays

Technology Status

- **We have devised and empirically validated an approach for building high-resolution, lightweight X-ray optics. This approach has four basic technical elements**
  - Substrate fabrication,
  - Coating,
  - Alignment, and
  - Bonding
- **We are in the process of building and testing mirror modules of ever higher level of integration to advance the technical readiness level.**
  - More mirror segments,
  - More stringent spaceflight environment requirements,
  - More efficient process, in terms of both production time and cost.

Major Milestones (COVID-19 may force change to this timeline)

- **TRL-3: Build and test *1-pair* modules continually.**
  - Reach and go beyond *Lynx*'s 0.5" HPD requirement, and
  - Achieve structural robustness for spaceflight.
- **TRL-4: Build and test *3-pair* modules by March 2021.**
  - Achieve images better than 0.5" HPD & structural robustness.
- **TRL-5: Build and test *many-pair* modules by September 2023.**
  - Meet 0.5" HPD image requirement, and
  - Pass environmental tests: vibration, acoustic, thermal-vacuum, and shock.
- **TRL-6: Build and test several *Lynx* modules by September 2027.**
  - Ensure that *Lynx* mirror can be built on schedule and budget, and
  - Meet all performance and spaceflight environment requirements.

Future Missions Requiring This Technology

- **Suborbital mission**
  - **OGRE** (Off-plane Gratings Rocket Experiment),
    PI: R. McEntaffer (PSU).
- **Explorer-class missions**
  - **STAR-X** (Survey and Time-domain Astrophysical Research Explorer),
    PI: W. Zhang (GSFC).
  - **FORCE** (Focusing on Relativistic universe and Cosmic Evolution),
    PI: K. Mori (Miyazawa Univ., Japan).
- **Probe-class missions**
  - **AXIS** (Advanced X-ray Imaging Satellite), **PI:** R. Mushotzky (Univ. of MD).
  - **TAP** (Transient Astrophysics Probe), **PI:** J. Camp (GSFC).
  - **HEX-P** (High Energy X-ray Probe), **PI:** F. Harrison (Caltech).
- **Flagship mission**
  - ***Lynx*** (formerly known as the X-ray Surveyor),
    Study Scientist: J. Gaskin (MSFC).

Acknowledgements

This work has been supported by NASA through
GSFC/IRAD, **ROSES/APRA**, and **ROSES/SAT**.