Next Generation Astronomical X-ray Optics: High Resolution, Light Weight, & Low Cost

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Next Generation X-ray Optics (NGXO) Team

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Two Currently Operating X-ray Telescopes

Parameters	Chandra (Flagship)	NuSTAR (SMEX)
Year of Launch	1999	2012
Mirror elements	Full Shells (4 P & 4 S)	Segments (1200 P, 1200 S)
Mirror element thickness	16 mm (inner), 25 mm (outer)	0.21 mm
PSF	**0.5 arcseconds**	58 arcseconds
Surface area	19 m^2	45 m^2
Mass	1,500 kg (**79 kg/m^2**)	40 kg (**0.89 kg/m^2**)
Cost	$580M (**$30M/m^2**)	$10M (**$0.22M/m^2**)

Compared to that of NuSTAR, Chandra's mirror is

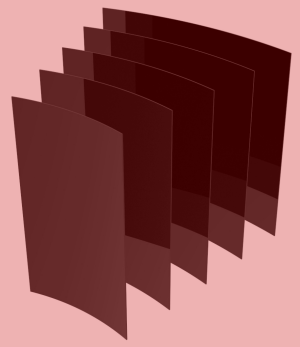
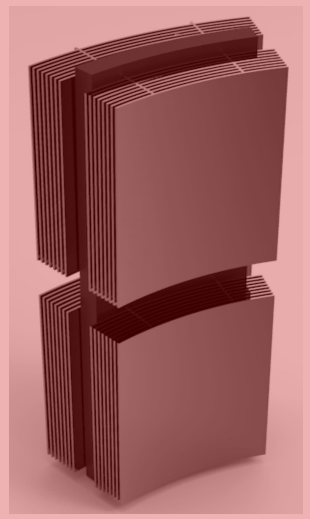
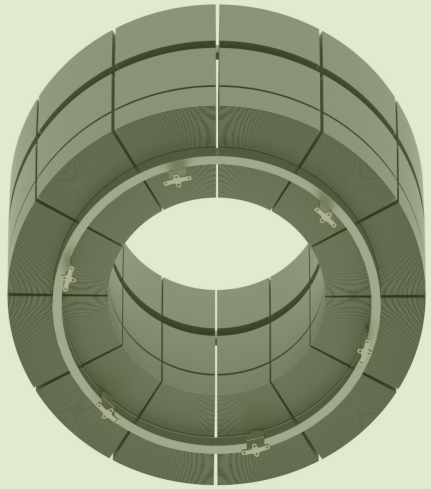
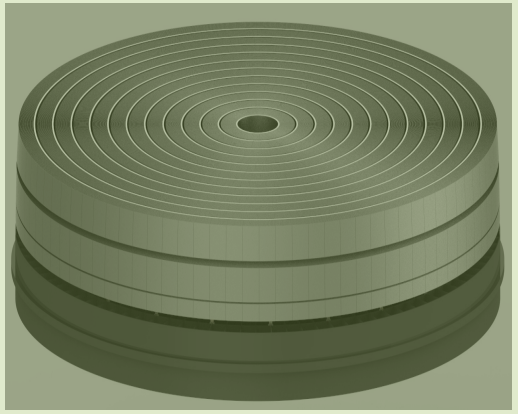
- **~100 times** better PSF;
- **~100 times** heavier; and
- **~100 times** more expensive.

Objective of Next Generation X-ray Optics

Develop and Perfect an X-ray mirror technology that is far superior to those of Chandra and NuSTAR.

- **Compared to Chandra's**
  - Comparable PSF: 0.5" by 2025.
    Much Better PSF: 0.1" by 2030.
  - At least 10 times lighter, and
  - At least 10 times cheaper.
- **Compared to NuSTAR's**
  - At least 100 times better PSF, and
  - Comparable mass, and
  - Comparable cost.

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**

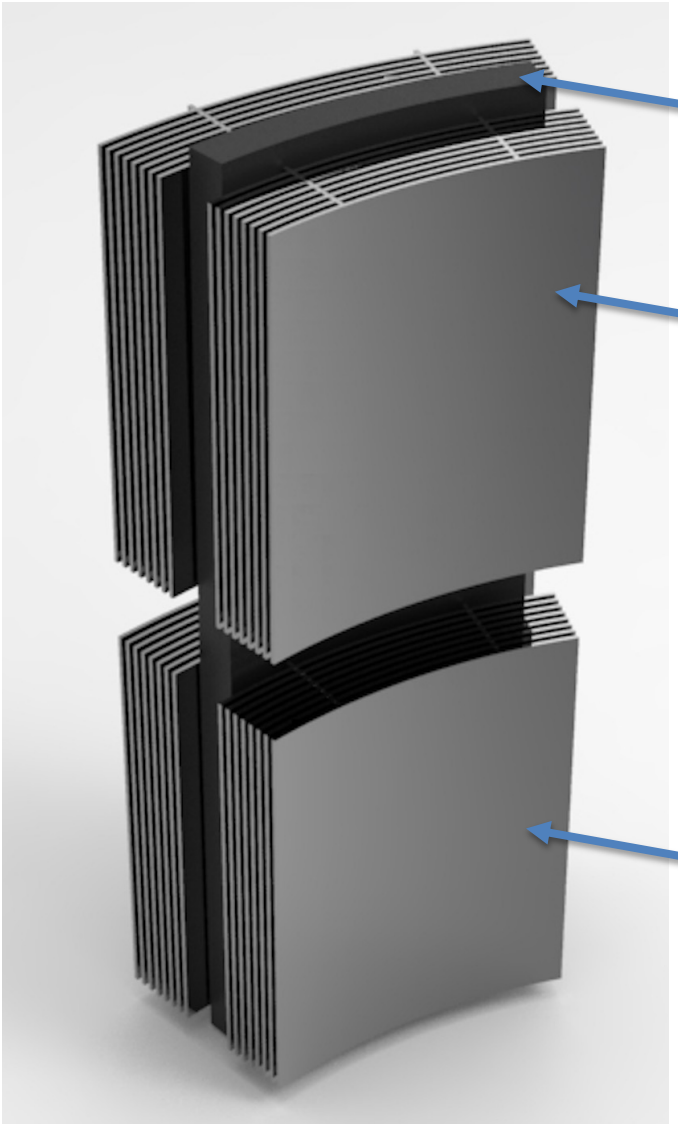
Mirror Module

Materials (relative mass):

- Silicon: 10,000.
- Coatings (Ir): ~5.
- Epoxy: ~1.

Key Characteristics:

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

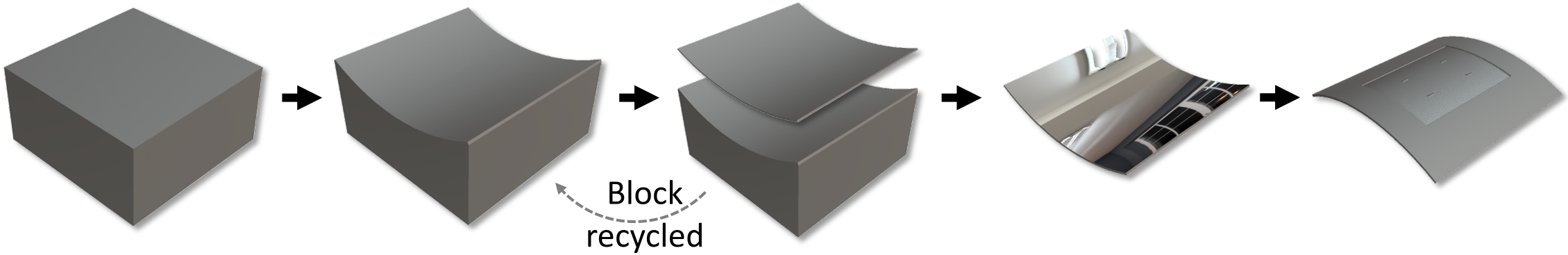


Central Plate:
200 mm by 90 mm by 10 mm

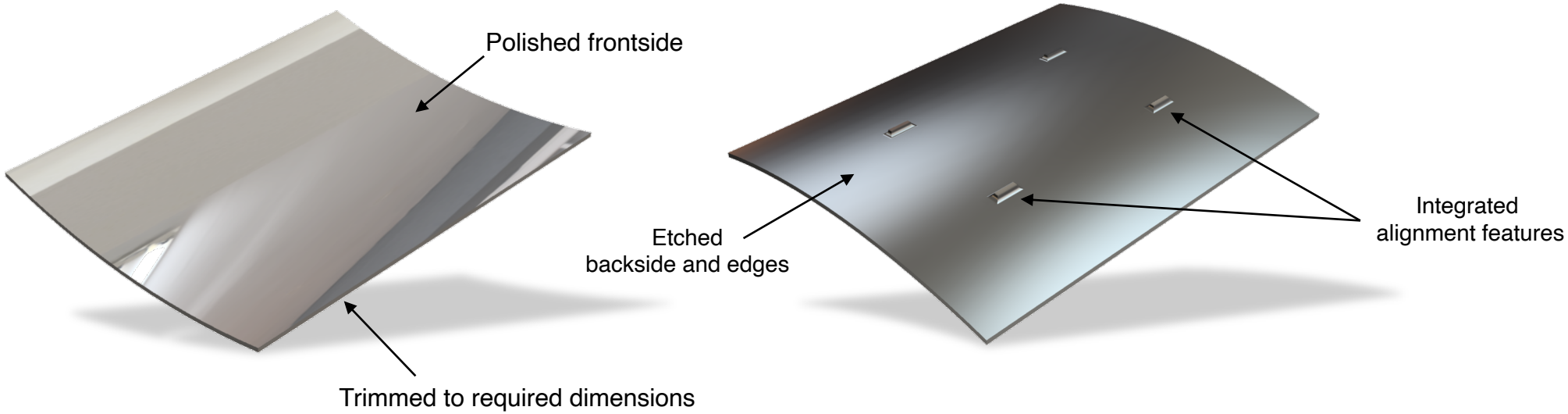
Primary Mirror Segment:
100 mm by 100 mm by 0.5 mm

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

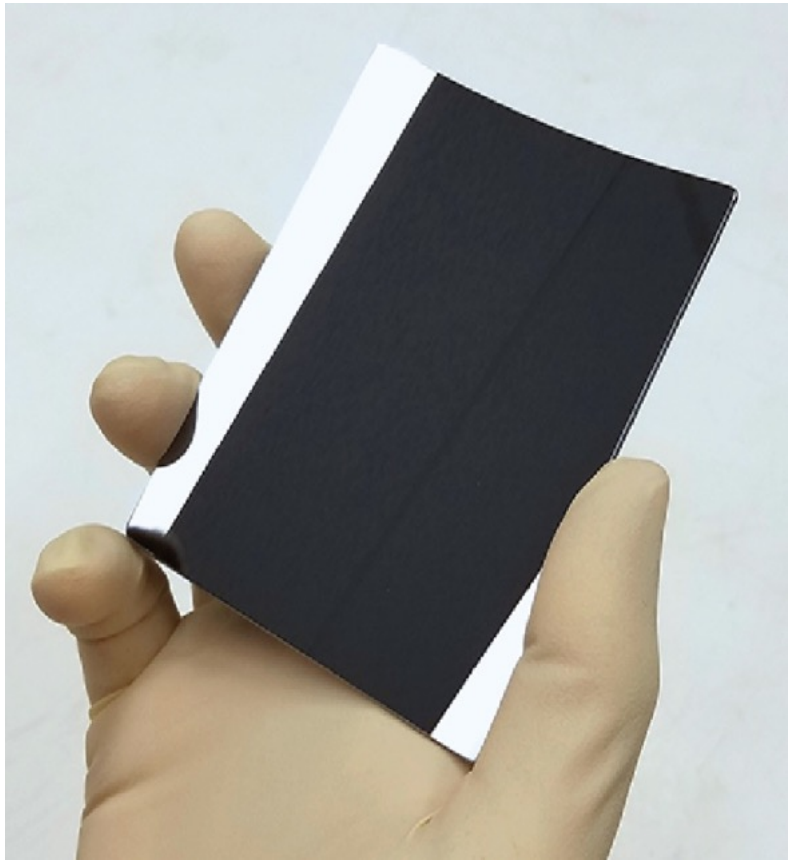
Mirror Fabrication Process

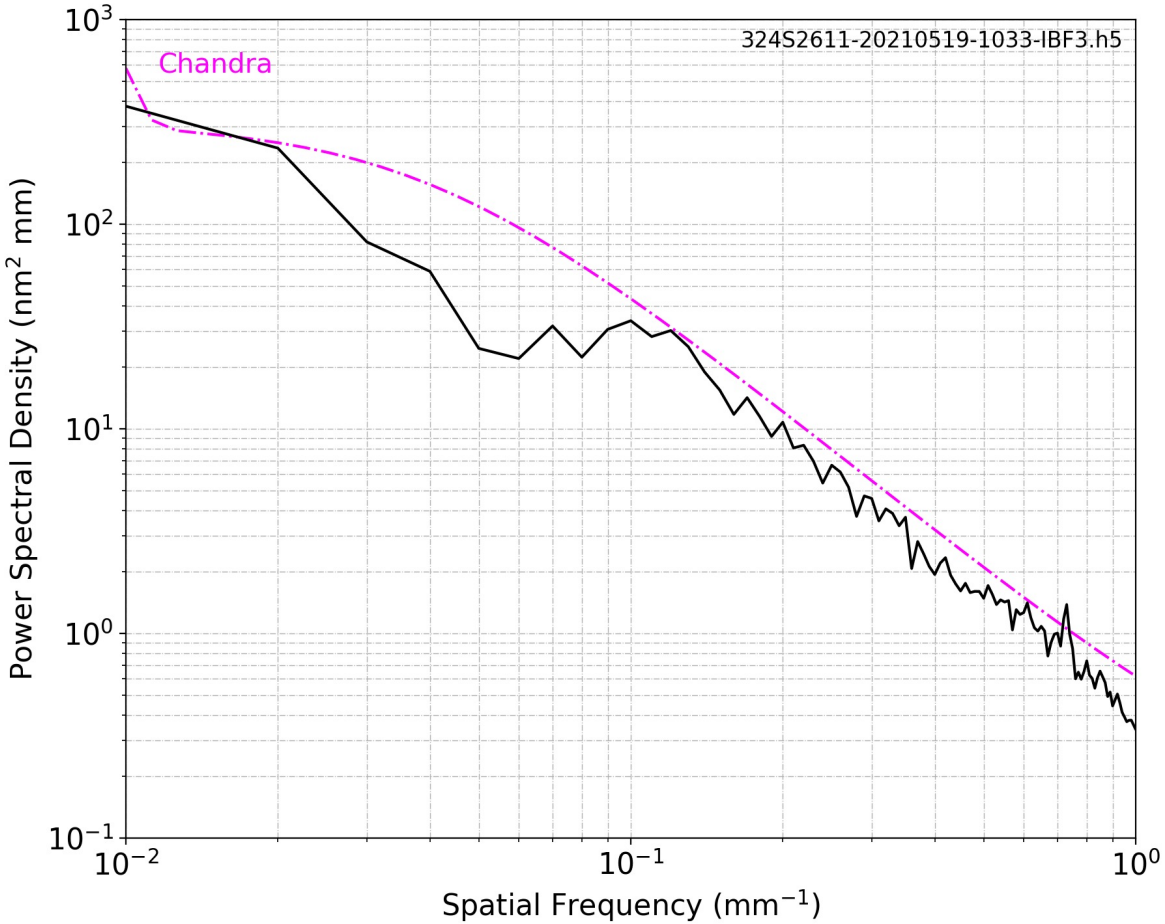


Finished mirror substrate



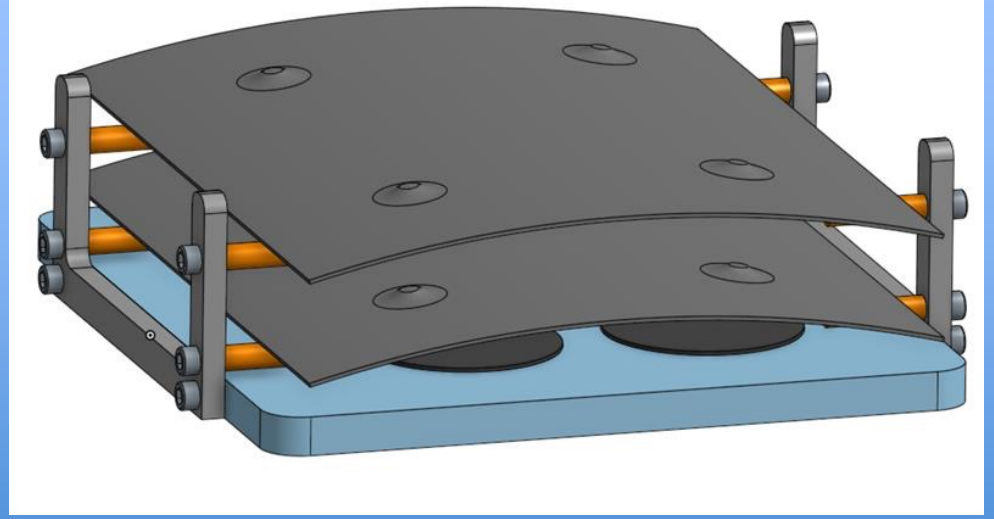
Mirror Segments are Better than Chandra's





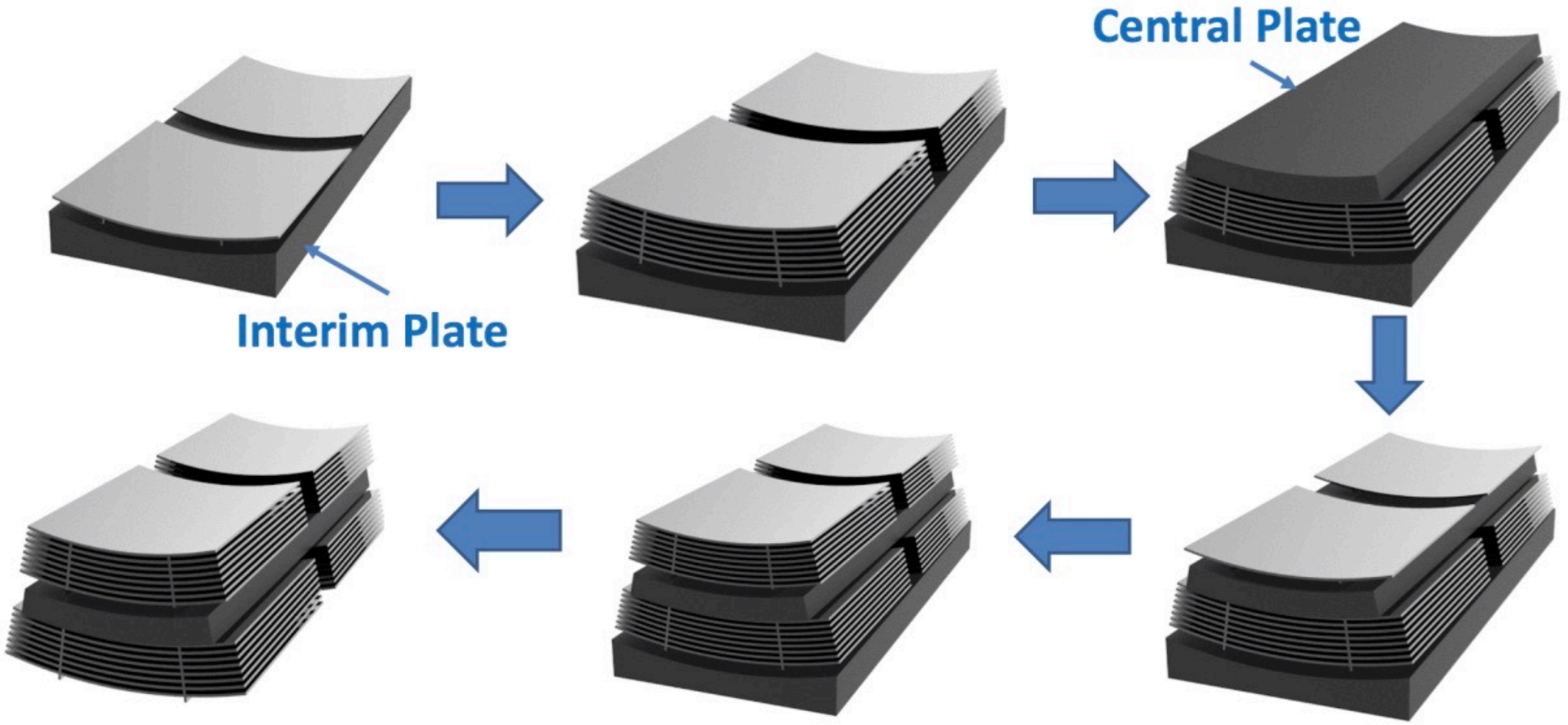
Iridium Coating to Enhance X-ray Reflectivity

ALD Chamber

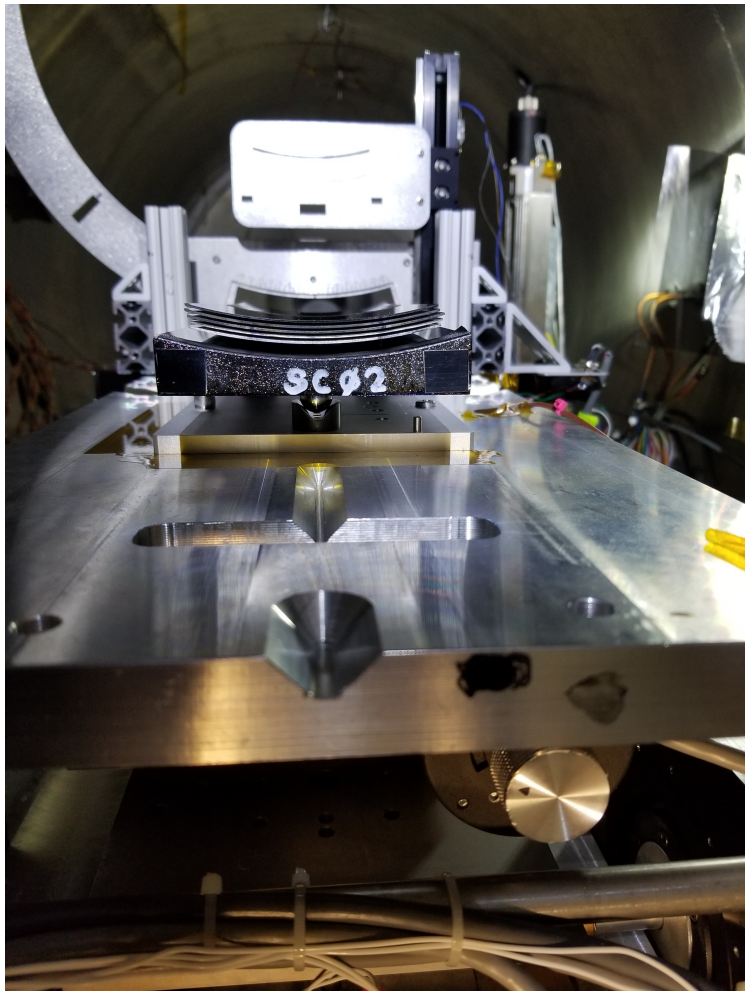


- **Atomic-Layer Deposition (ALD)**
  - Simultaneous and uniform coating,
  - Commercially available process,
  - Low cost and high throughput.

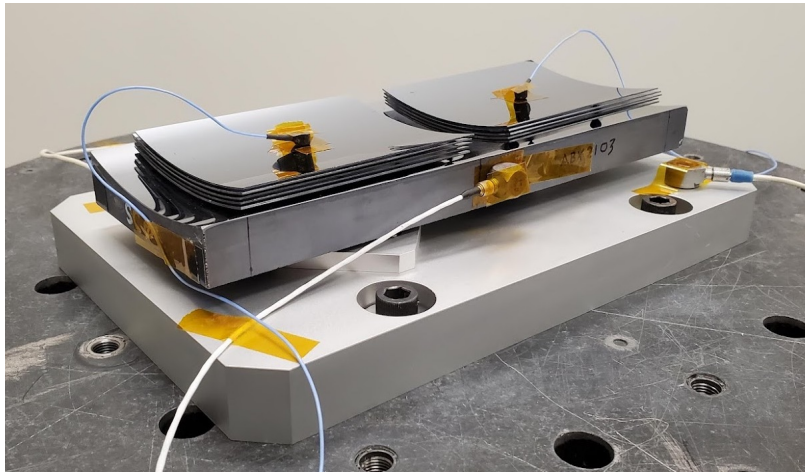
Mirror Integration Process



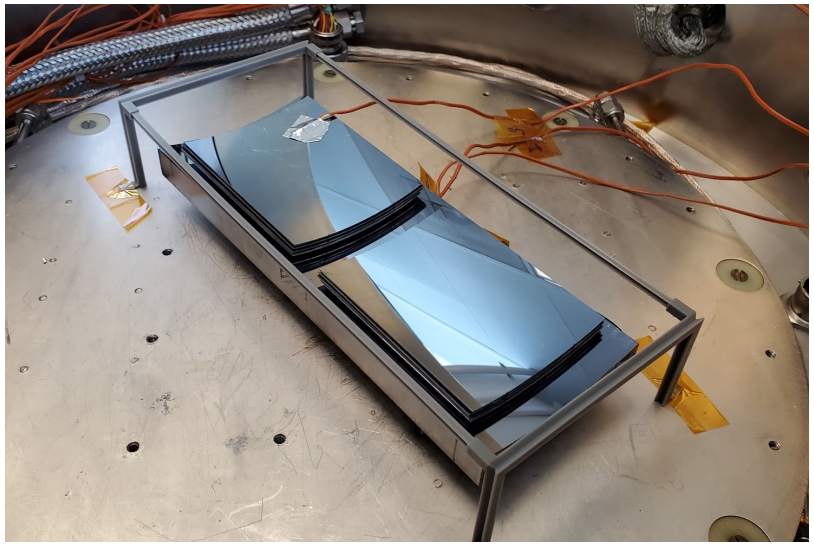
Performance and Spaceflight Environmental Testing



Mirror Module in an **X-ray Beam Line** in GSFC's Area 200



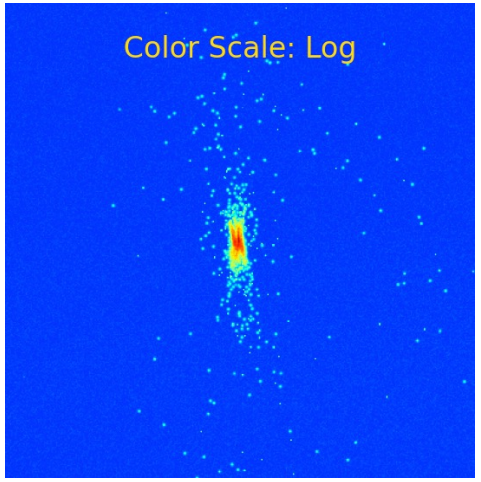
Mirror Module on a **Vibration Table** in Bldg 11 of GSFC



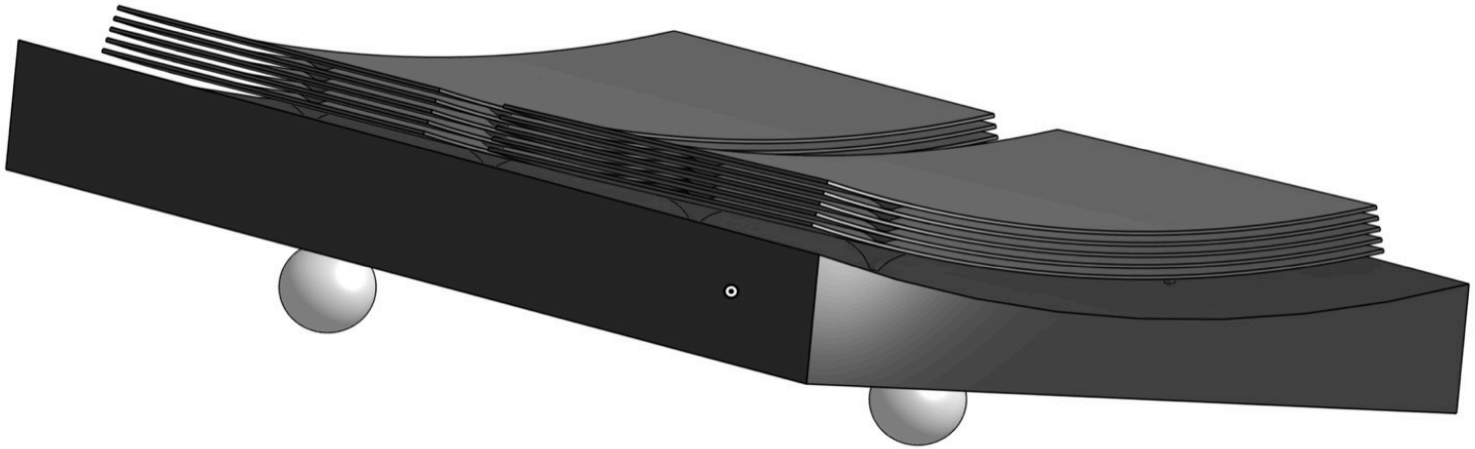
Mirror Module in a **Thermal Vacuum Chamber** in Bldg 11 of GSFC

Technology Status & Prospects

- **As of June 2021, Built and tested mirror modules**
  - Built two modules in recent weeks,
  - X-ray tested them, and
  - Thermal-vacuum tested one of them.
  - Vibration tested one of them.
- **Prospects**
  - Better than 2.0” PSF by December 2021,
  - Better than 1.0” PSF by December 2022,
  - Better than 0.5” PSF by December 2023



Full Illumination with 4.5 keV X-rays: 2.8” HPD.



Summary

- We have demonstrated the basic elements of a technology to make high-resolution, light-weight, and low-cost X-ray optics.
- We continue to advance this technology to meet all requirements of *Lynx:* performance and programmatic.
- This technology uses only commercially available equipment and materials. It piggybacks on the semiconductor industry, avoiding obsolescence and ensuring continual advance.
- This technology can be used for missions of all sizes: sub-orbital, SmallSats, Pioneers, SMEX, MIDEX, Probes, and Flagships (Lynx).