Supporting Technologies for High Resolution Optics

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On behalf of the X-ray Astronomy Group

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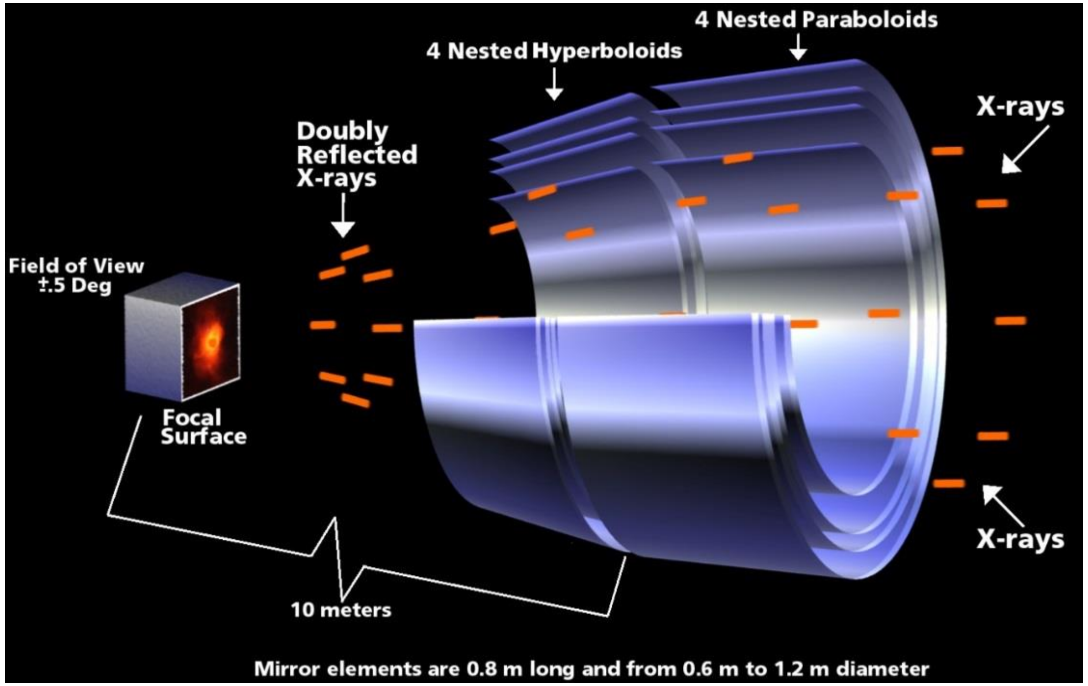
Introduction

- X-rays reflected at very shallow angles

- Typical configuration uses combination of parabola and hyperbola to reduce aberrations

X-ray optics permits detailed imaging and background reduction

- Typically many such mirrors are concentrically nested to increase effective area



Chandra – x-ray mirror system

The challenge is to develop the optical fabrication technology capable of producing x-ray optics but with an order of magnitude lighter mirrors and at an affordable price.

Direct Fabrication

Material	Density (g/cm³)	CTE (10^{-6} / K^{-1})	Elastic Modulus GPa	Yield Strength MPa
Fused Silica	2.2	0.5	72	48*
Beryllium	1.8	12	318	240
BeAL-162MET	2.1	24	69	276
AlSi	2.8	13.9	193	314
Duralcan F3S.30S AlSi+SiC(30% by vol)	2.8	14.6	120	210

Mechanical Properties of Potential Mirror Substrate Materials
*Maximal achievable value. The 'working' value is typically much less and depends on the surface/subsurface condition.

Companies are confident they can deliver the Be, BeAl and AlSi substrates fabricated with necessary tolerances

Additional Benefits of metal substrate:

- Less joints – less epoxy error
- Thermal design could be simplified, the support structure from the same material

Ideally, the mirror shell has low density, low coefficient of expansion (CTE), high modulus of elasticity and high yield strength. It should also be a material that is not too difficult to figure and polish.

Substrates can be plated with the nickel phosphorous alloy:

- Be + NiP (CATS-ISS telescope)
- BeAl +NiP
- AlSi + NiP

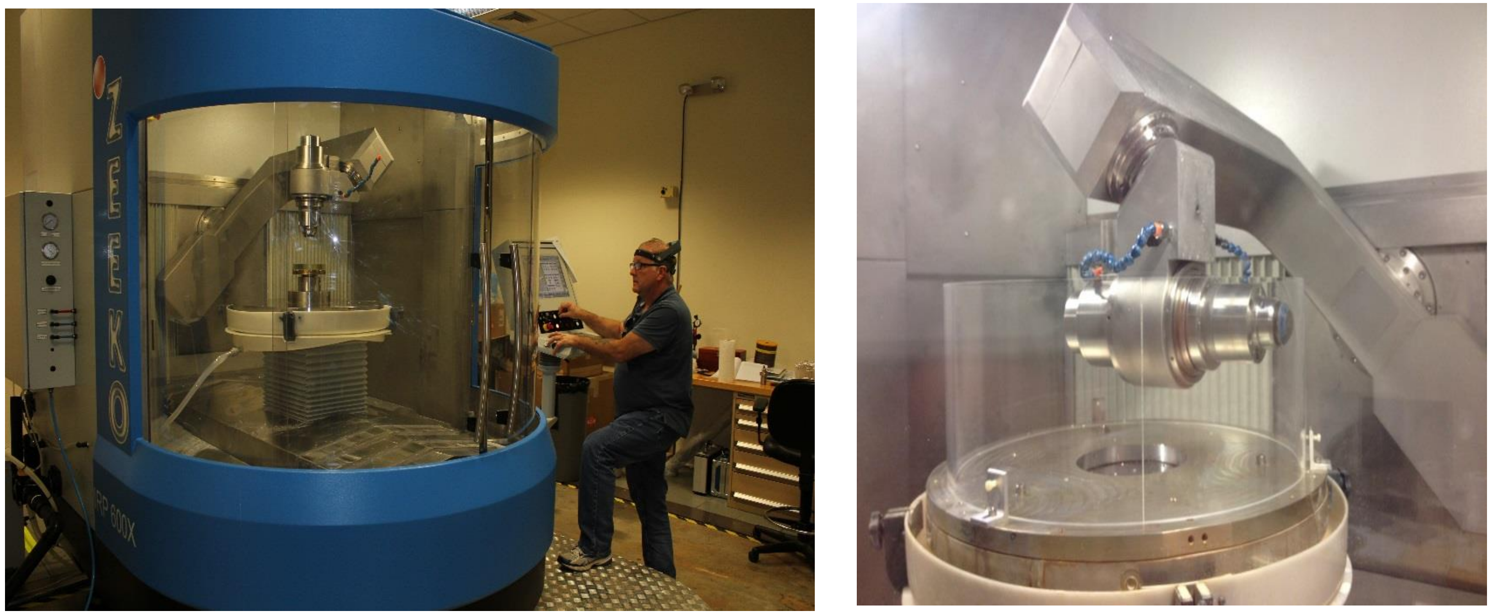
Correction of figure through deterministic material removal

- The machine utilizes a “bonnet” technique in which an inflated rubber hemispherical diaphragm supports the polishing medium.

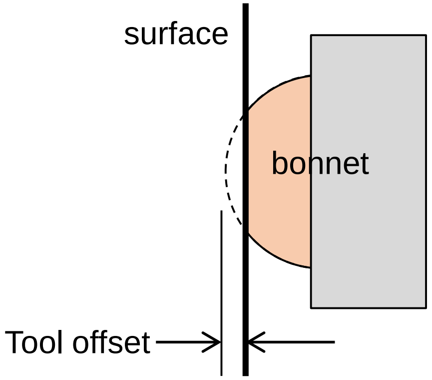
- there are different “bonnet” sizes (20 mm, 40 mm and 80 mm radii of curvature)

- This computer-controlled deterministic polishing processes leads to a high convergence rate.

- The control software had to be developed in order to figure x-ray optics

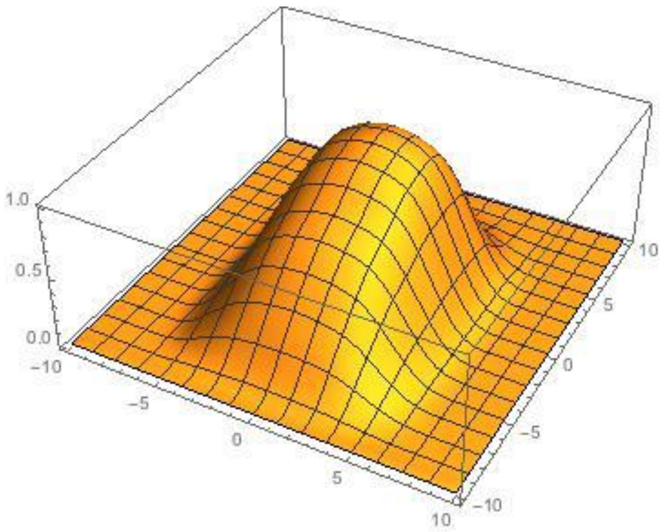


Zeeko machine

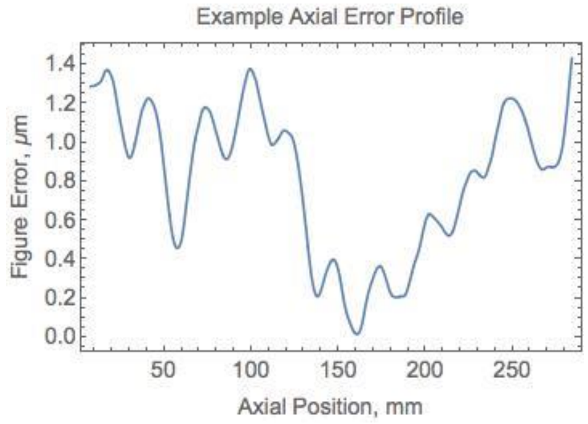


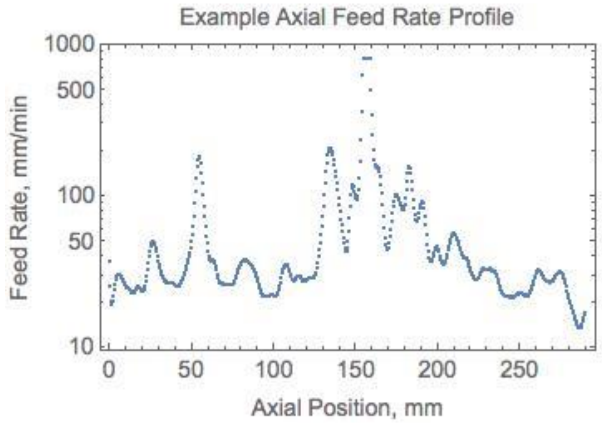
Process development

- ✓ Parametric model is created
- ✓ The process operational parameters are optimized
- ✓ Algorithm for optimal correction of the surface errors are verified

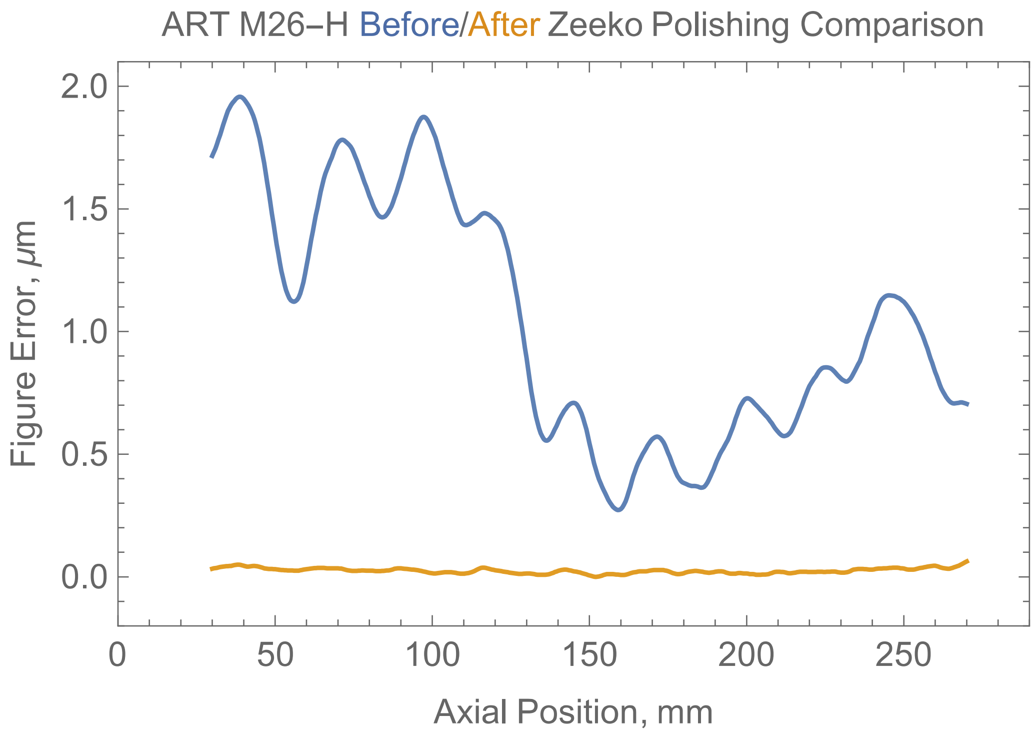


Example of measured wear function





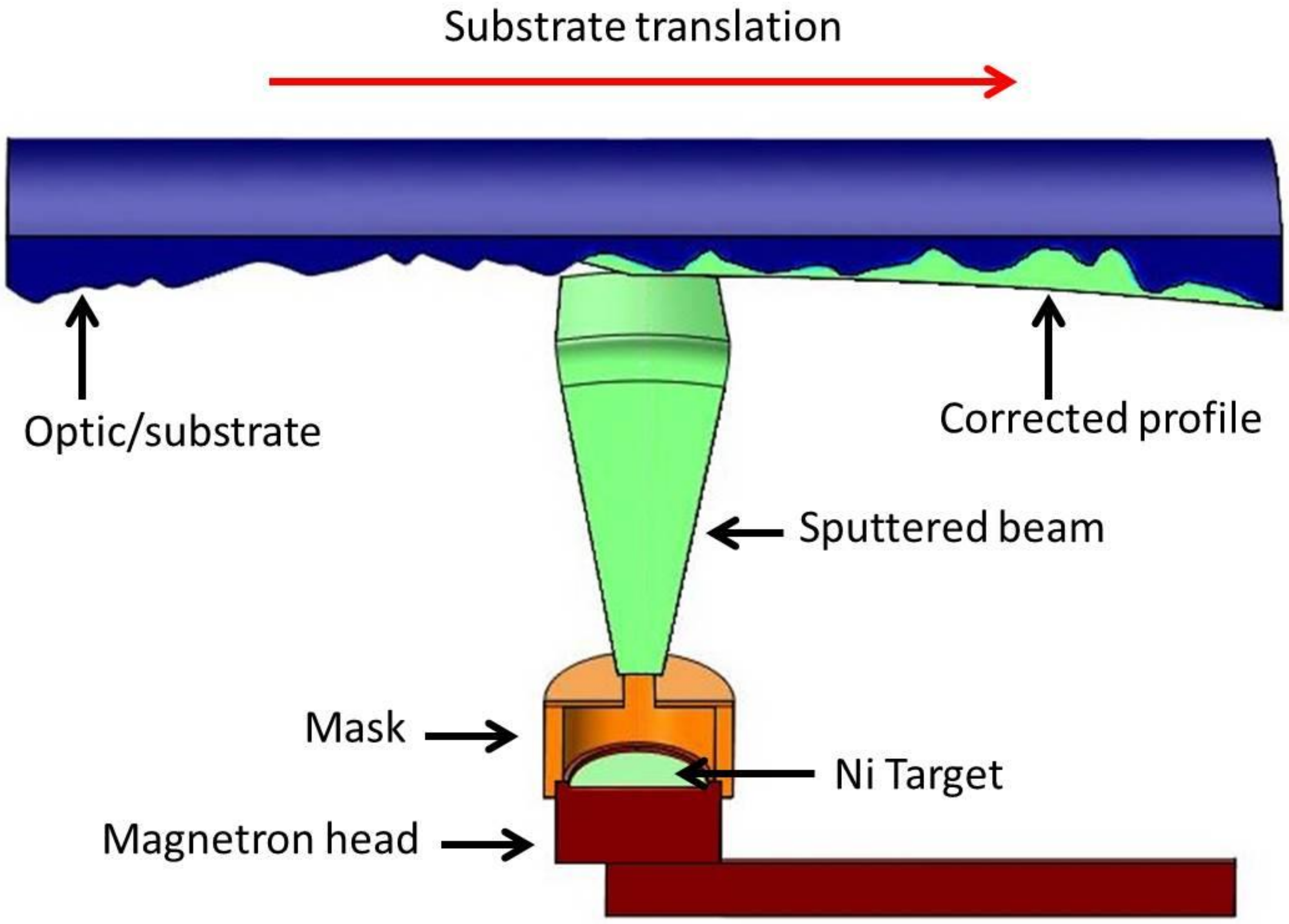
Mandrel Experiments- before and after



ART-XC mandrel installed on the Zeeko machine for figuring experiments

	before	after
Figure error (St. Dev.)	500 nm	10.7 nm
Slope error (> 2 cm) cm(RMS)	6.32 arcsec	0.30 arcsec
Low frequency (> 7 cm) slope error (RMS)	2.66 arcsec	0.09 arcsec
Mid frequency (2-7 cm) slope error (RMS)	5.73 arcsec	0.29 arcsec

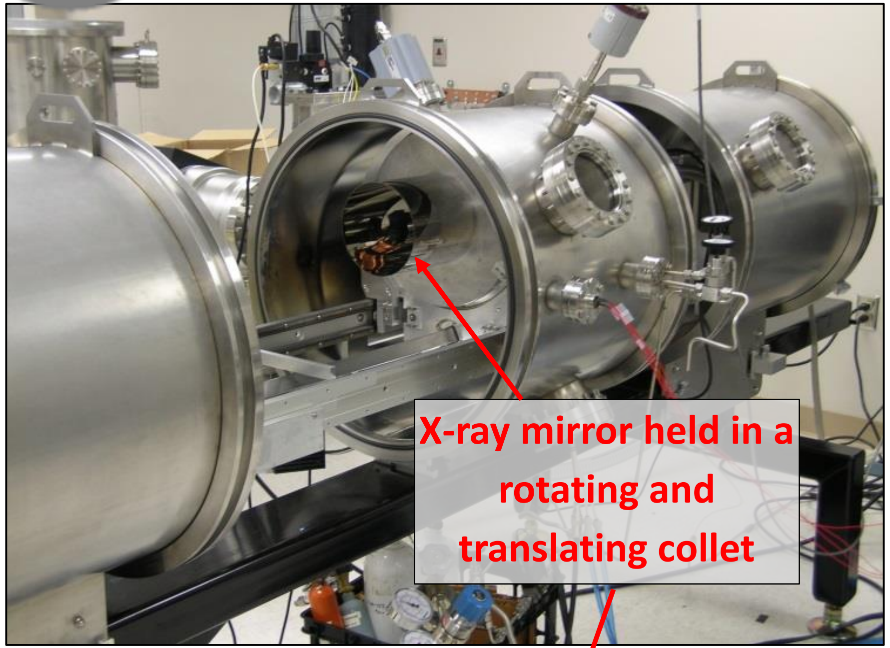
Correction of figure through Diferential Deposition

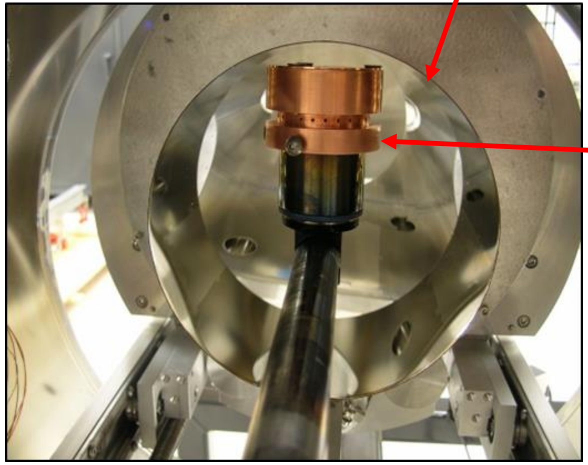


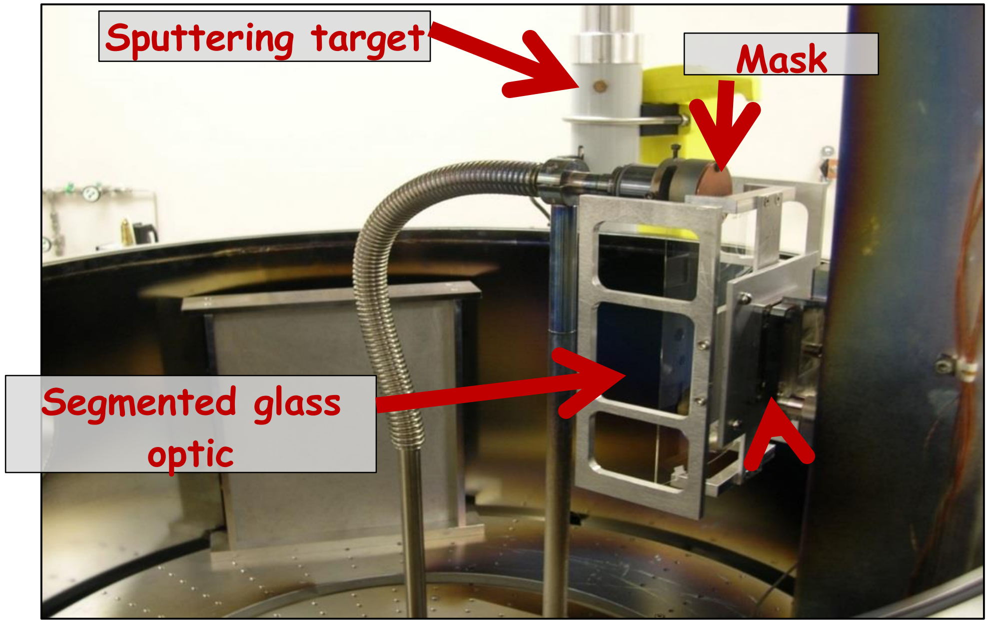
Principle of Differential Deposition

- Differential Deposition
- Kiranmayee Kilaru (USRA, MSFC)
- Carolyn Atkins (UAH)
- David Windt (Reflective X-ray Optics, LLC)

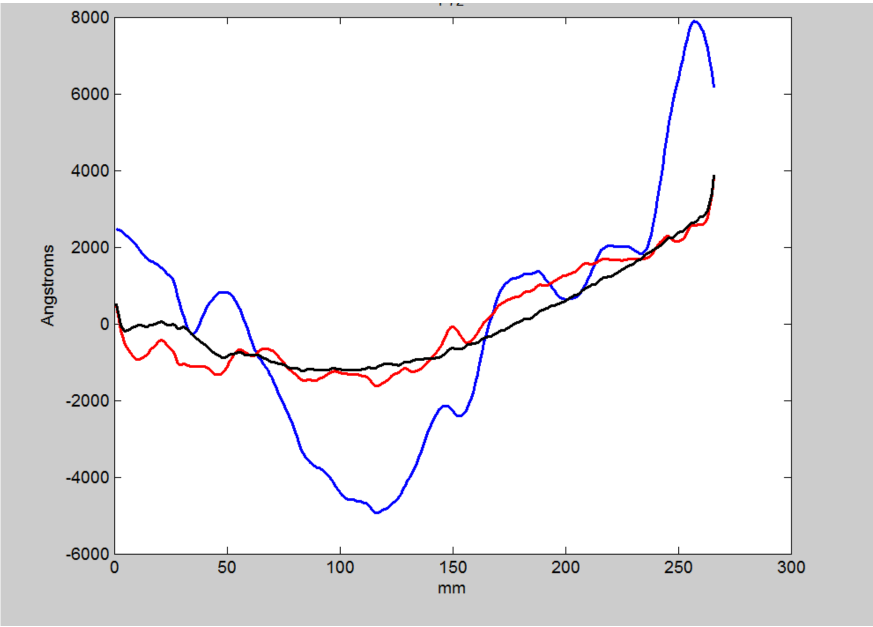
Horizontal and Vertical Coating systems at MSFC

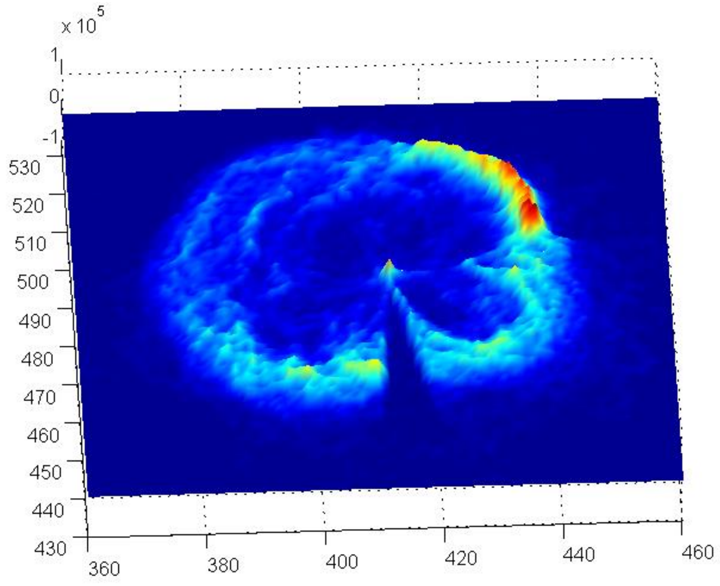


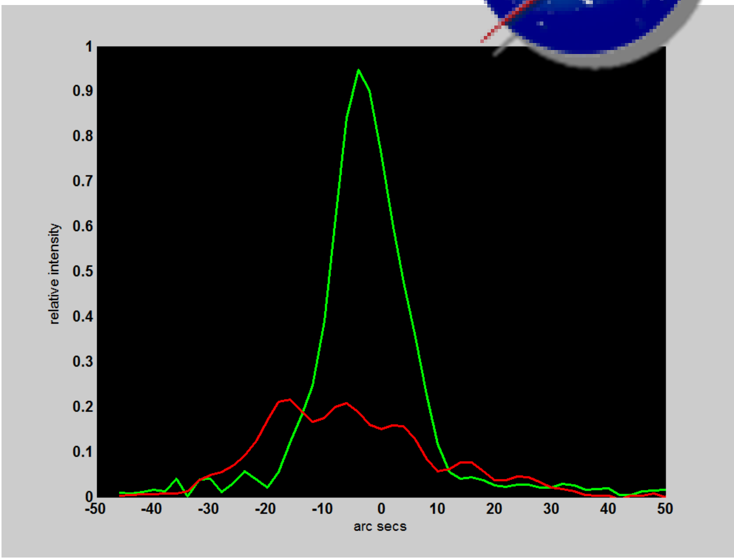




Recent X-ray test results: Angular resolution is improved from 17 to 20 arc secs to ~ 5 arc secs HPD.





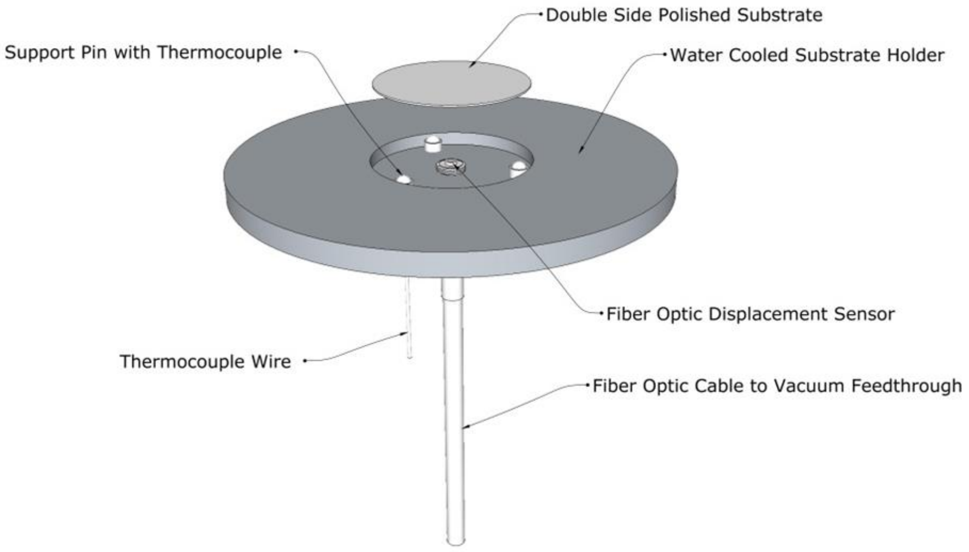


Sources of errors

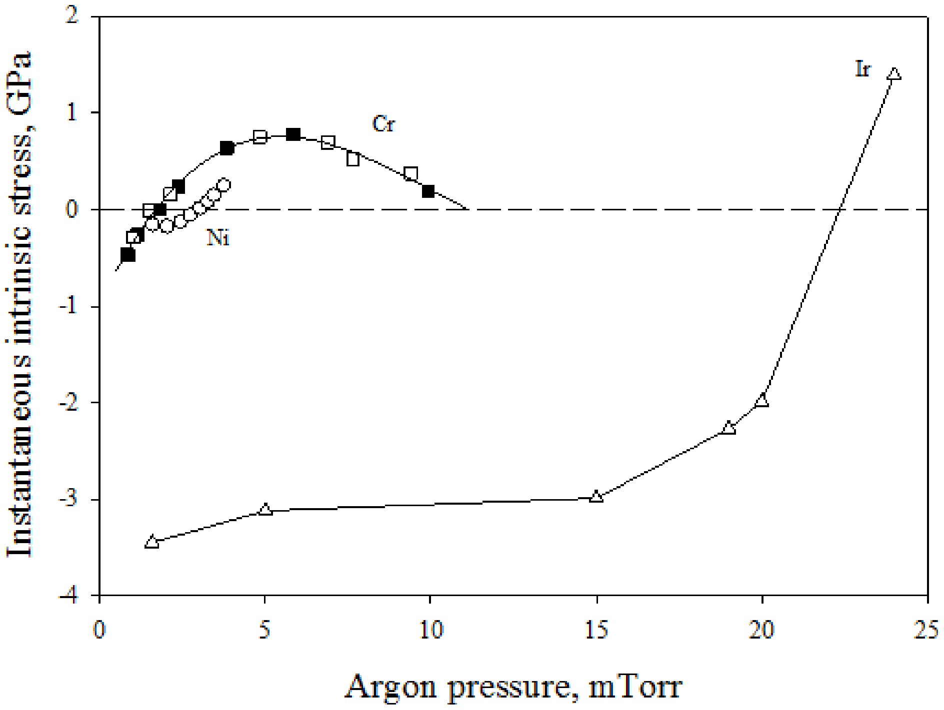
- Variation of sputtered beam profile along the length of mirror, particularly for short focal length mirrors – Improvements in mechanical set-up to maintain constant target-to-substrate distance for tapered-shells
- Thorough characterization of the overlap areas in the case of customized correction for each meridian
- Improvements in the mask to shell alignment system
- Stress effects – Quantify and control stress – so far simulations and metrology agree well and there is no evidence for stress induced distortion for these full-shell optics

Thin-film stress (In-situ stress measurement)

- Stress is a leading technological challenge in thin-film coatings regardless of their application.
- The intrinsic stress in the thin-film single and multilayer reflective coatings will deform the optic's figure and compromise their ability to render sharply-focused, high-resolution images.
- We have developed a method for the in-situ, high-resolution measurement of the stress during film growth
  In-situ measurement has helped identify a mechanism for reducing the stress in iridium by three orders of magnitude



United States Patent Application #14,645,994, (2015), D. Broadway



Future work

- Working on demonstration of x-ray optics fabricated directly.
- Working towards the in-situ metrology of X-ray mirrors inside the differential deposition vacuum chambers and during polishing
- Combine the direct fabrication with Differential Deposition Technique
- Incorporate the in-situ stress measuring system into coating chambers

Summary

- MSFC develops the direct fabrication technology for full shell x-ray optics made from metal substrates;
- Post-fabrication and post-assembly figure correction provides an additional venue to meet the requirements;
- Differential Deposition technique has potential for development of sub-arc-second x-ray optics;
- Use of in-situ stress measurement system could significantly reduce x-ray optics deformation when single or multi- layers are used to boost reflectivity.