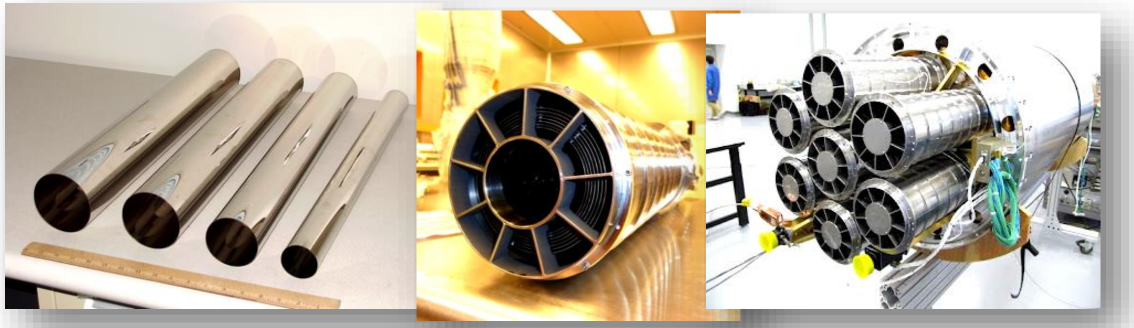
Differential deposition for the figure correction of X-ray optics

KIRANMAYEE KILARU, USRA
BRIAN D. RAMSEY
JEFFERY KOLODZIEJCZAK
NASA MSFC

Full-shell electroformed optics @MSFC

Optical design and analysis → Fabrication → Metrology → Coatings → Mounting and alignment → Assembly → X-ray testing



Past

HERO
FOXSI ROCKET
ART-XC

Spin-off
Sandia Z machine

Current

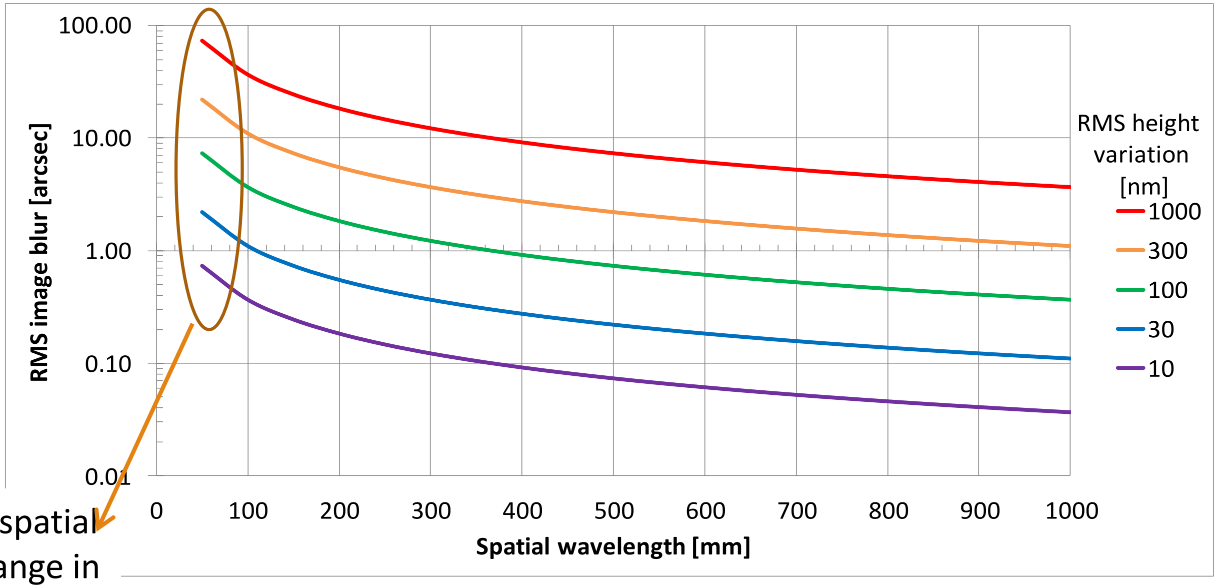
IXPE
MIXO
MICRO-X
FOXSI SMEX concept study

Spin-off
NIF
Neutron Microscope

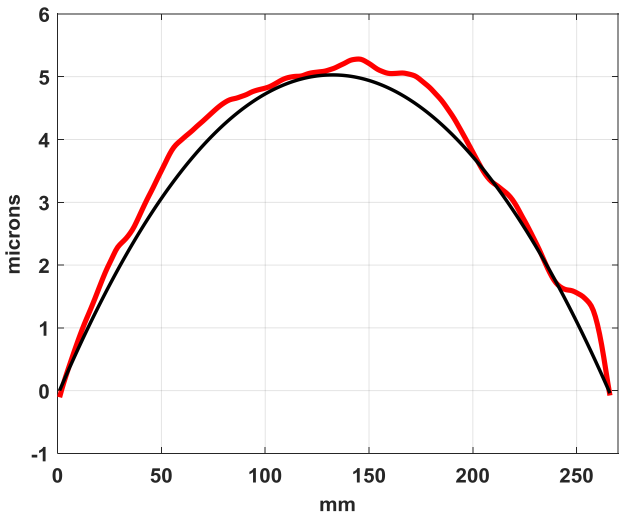
State of art - full-shell optics

X-ray Optics - State of art

- Full-shell: <5 arc sec FWHM; 10 to 15 arc sec HPD
- A key factor that limits the angular resolution is Axial Figure Imperfections

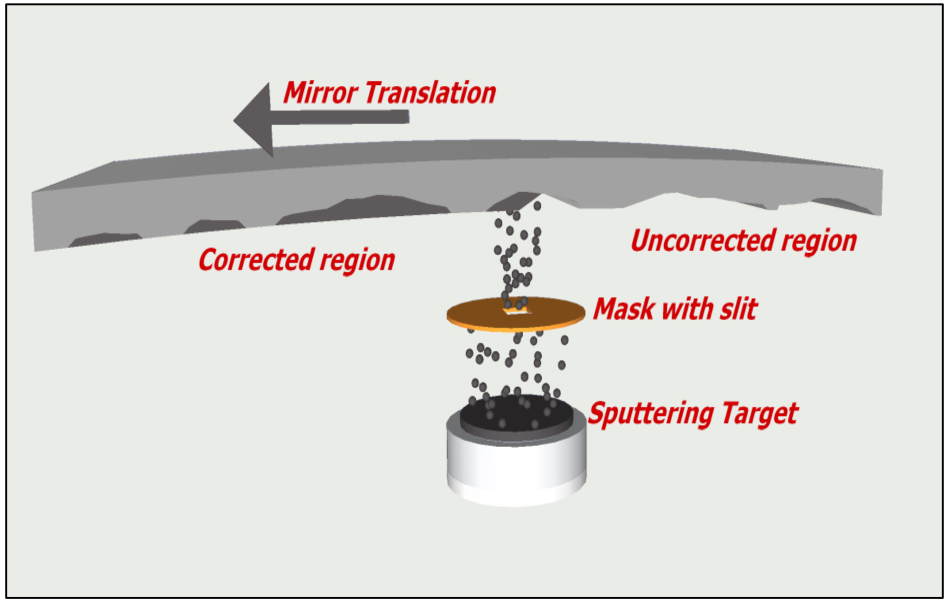


Typical mid-spatial frequency range in X-ray mirrors



Imaging quality of X-ray optics can be significantly improved if the RMS height variations can be reduced

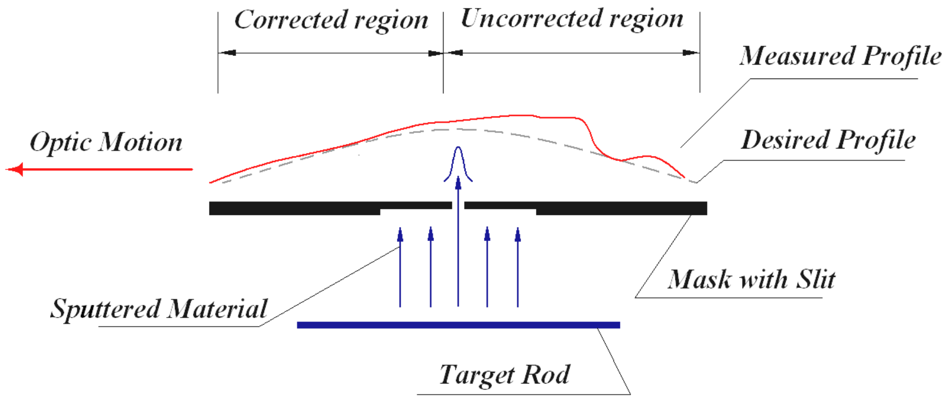
Concept of differential

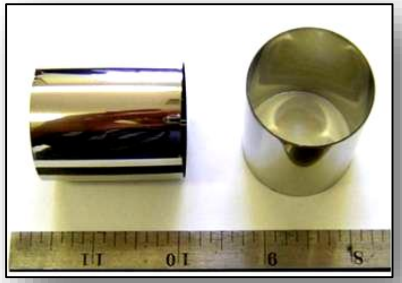


Use of physical vapor deposition to selectively deposit material on the mirror surface to smooth out figure imperfections

- Surface profile metrology
- Develop correction profile
- Simulations – translation velocity of shell
- Differential deposition
- Surface profile metrology
- X-ray testing

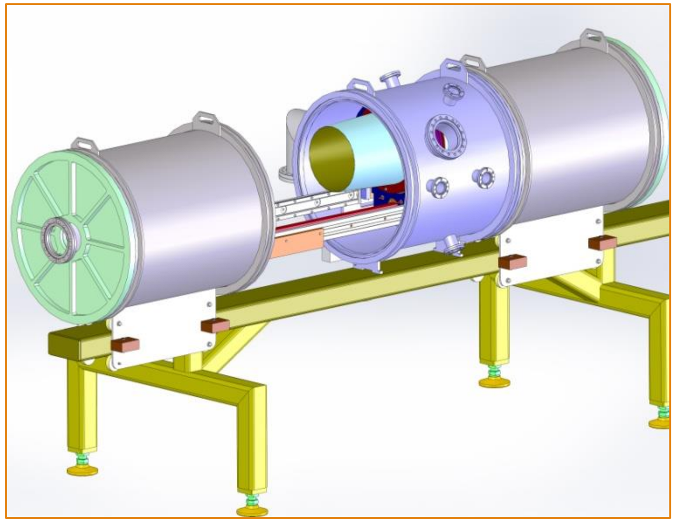
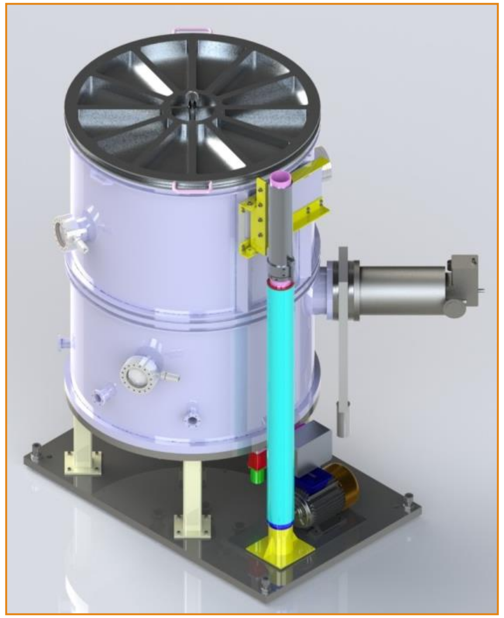
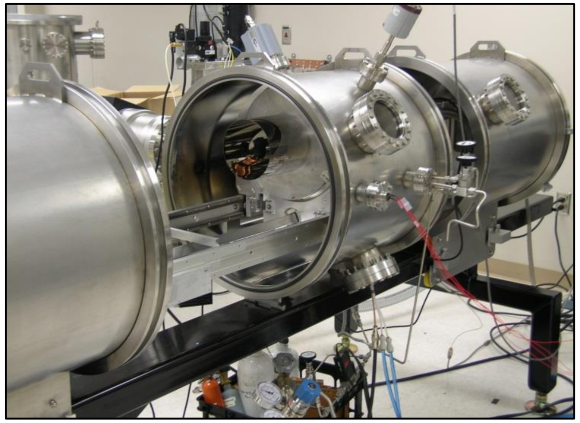
Differential Deposition – proof of concept





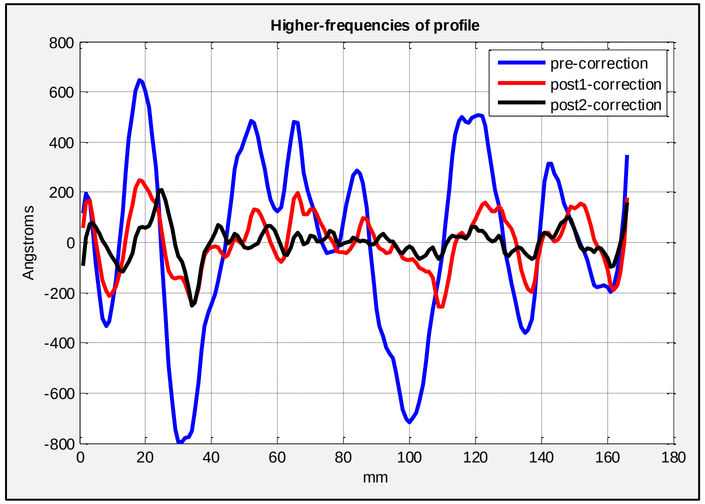
- Proof of concept on smaller scale NIH optics
- Use of existing sputter deposition chambers
- Demonstrated improvement through metrology data

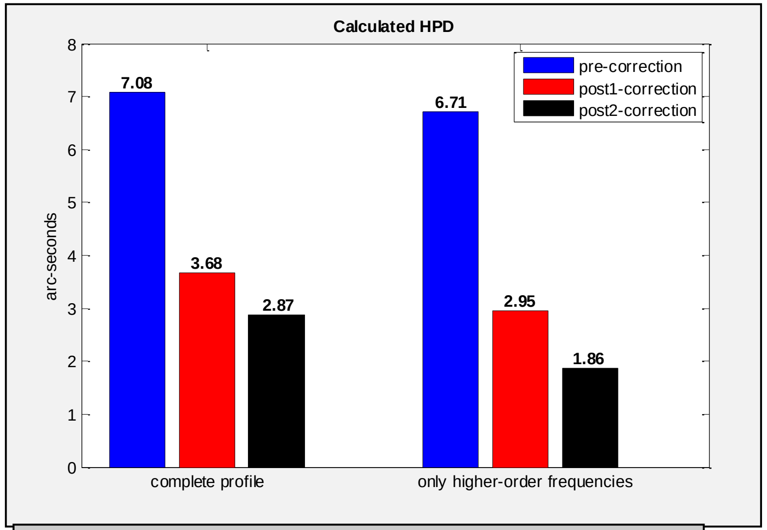
Custom built vacuum chambers

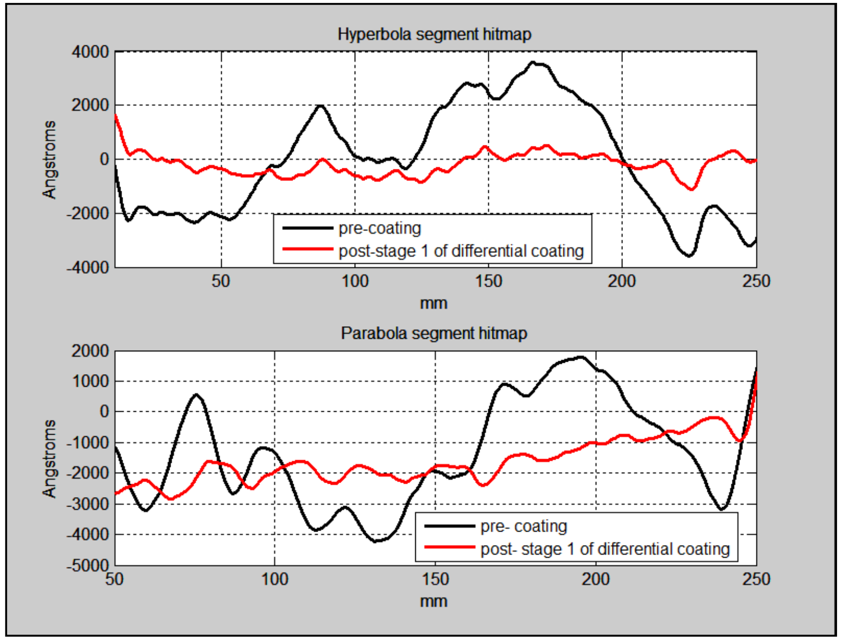




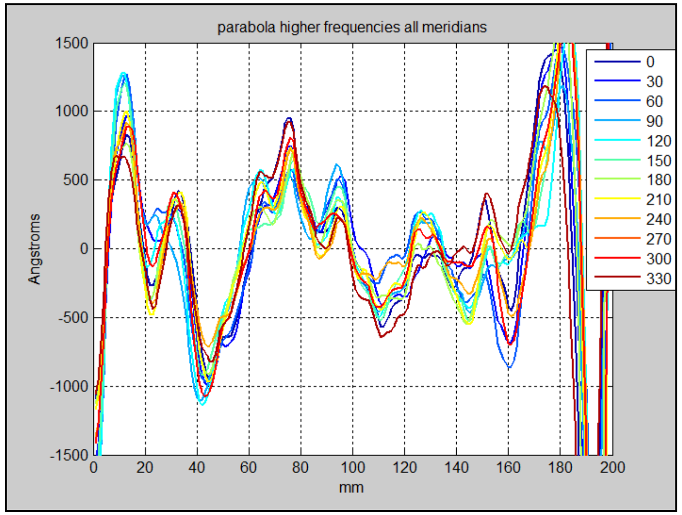

- Horizontal chamber for full shell optics – can accommodate upto 0.25m diameter, 0.6m length
- Vertical chamber for segmented and very large full-shell optics (0.5 m diameter)
- Computer controlled translation and rotation stages with encoders
- Matlab – GUI interface to control the stages

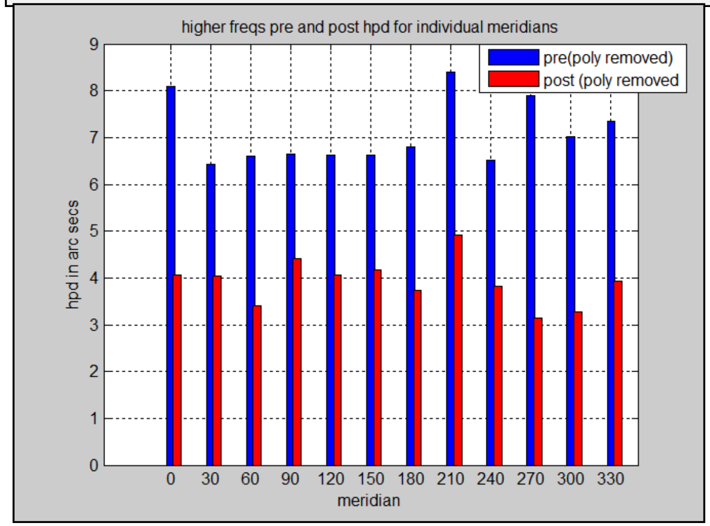
Metrology results





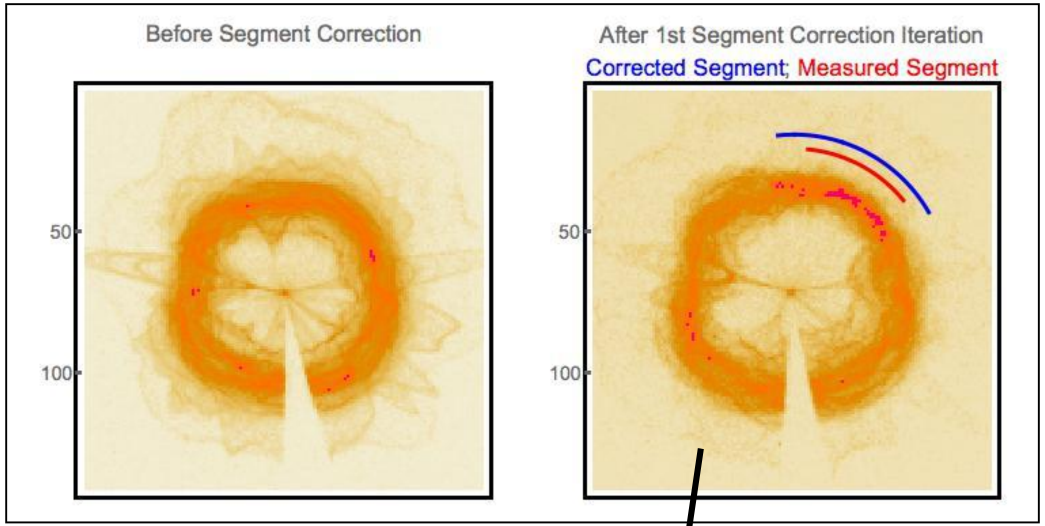


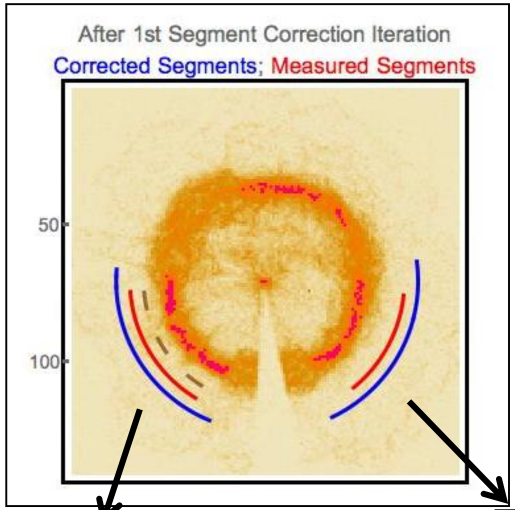


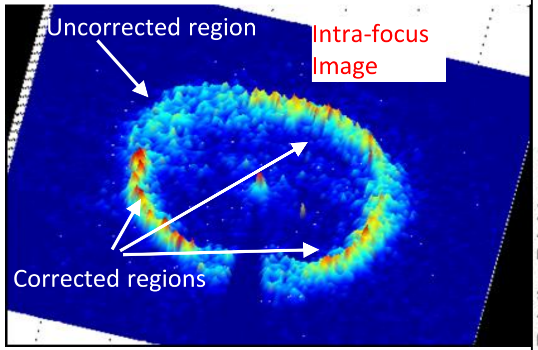


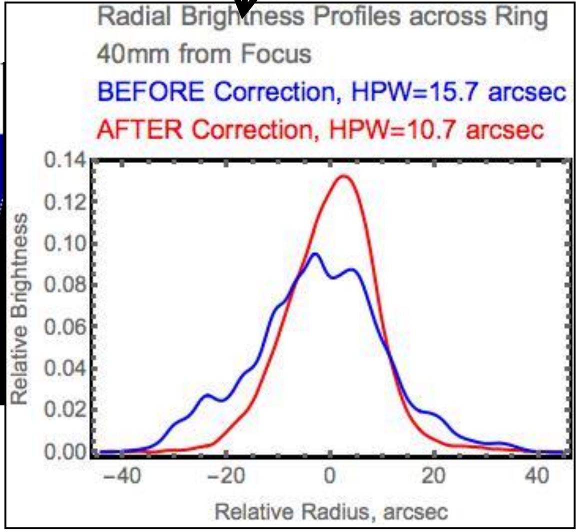
X-ray test results -1

- X-ray testing @stray light facility
- Off-focus CCD image – measure of profile across the ring
- 18 to 8 arc secs with one-stage differential correction

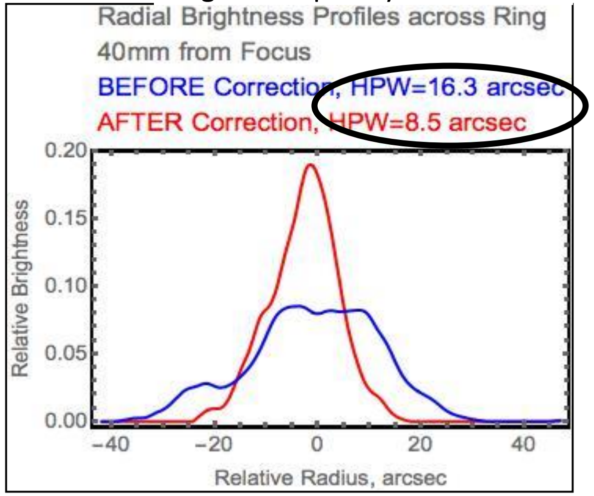


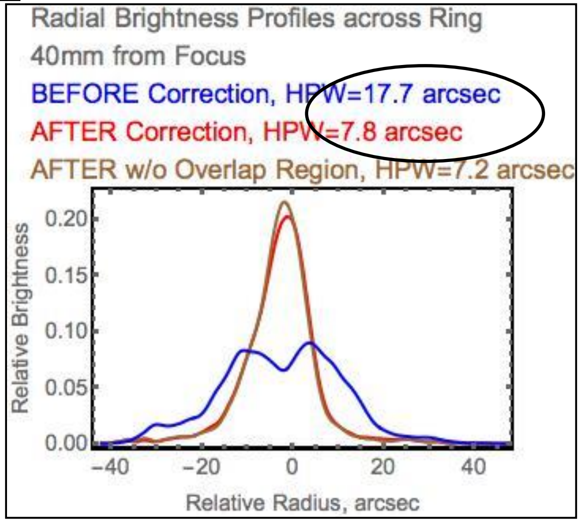




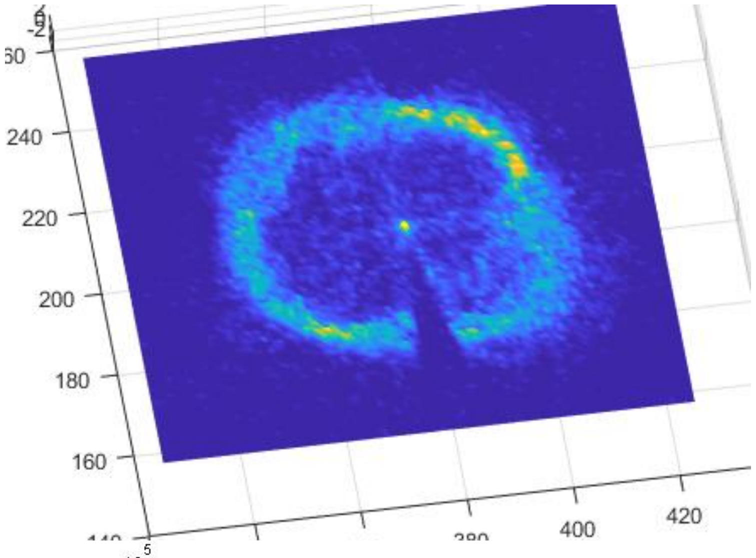


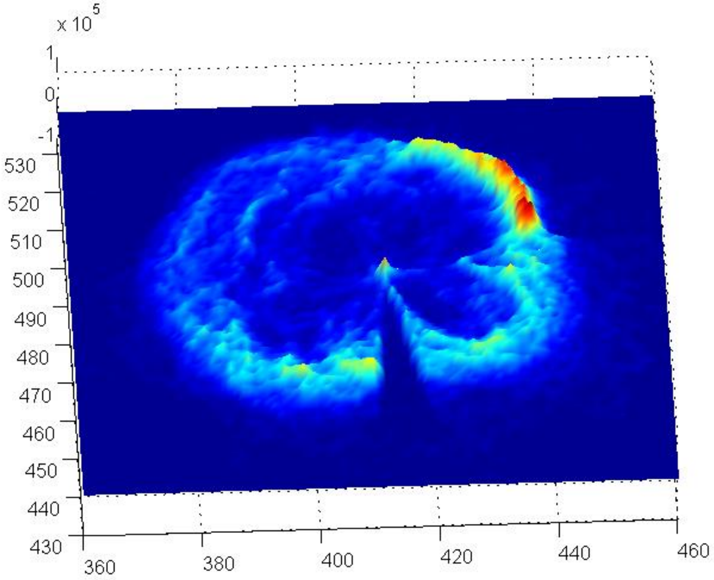
Higher frequency- correction

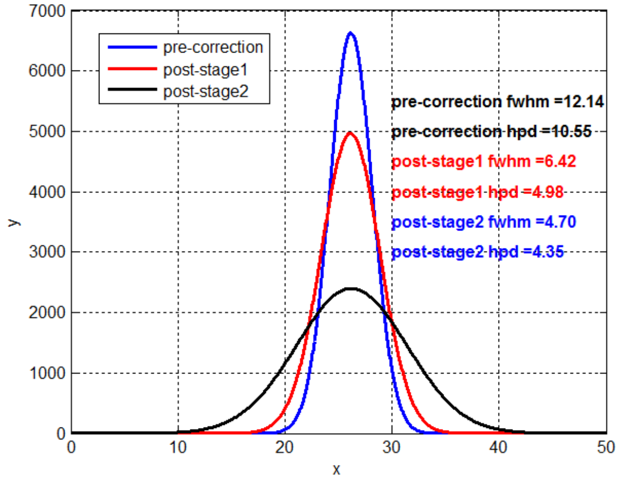


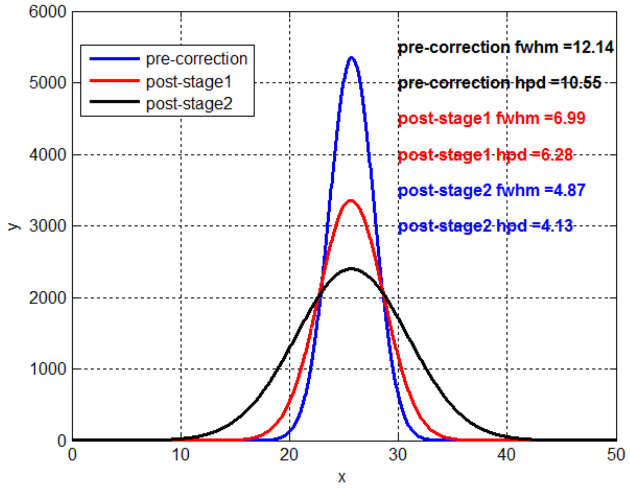


X-ray test results -2





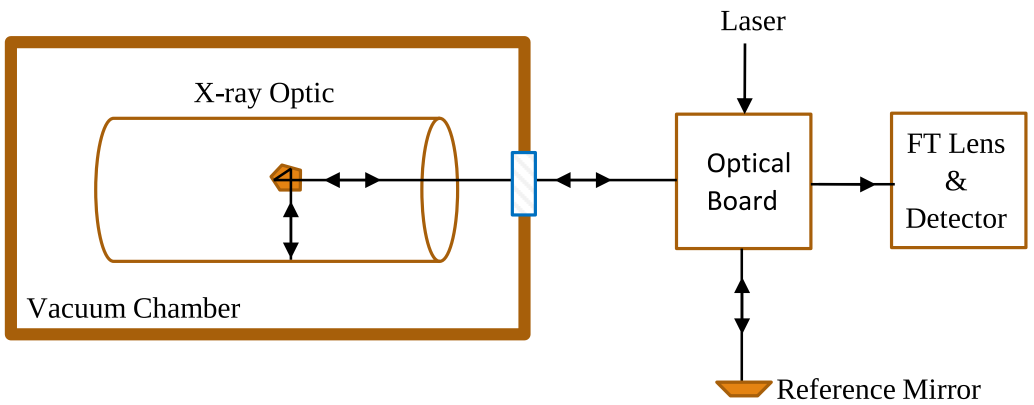




Working towards 2nd stage improvement

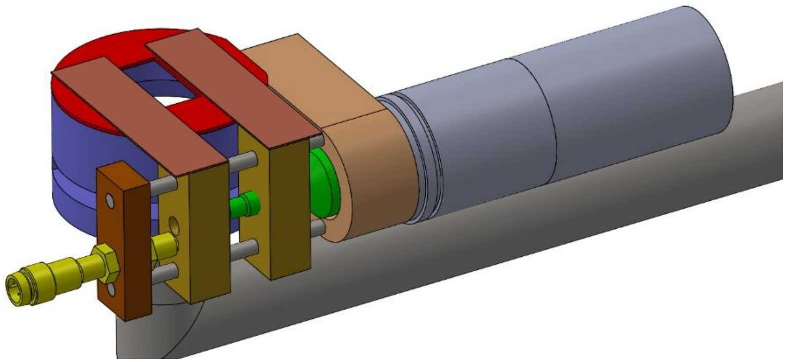
Future work

In-situ metrology - VLTP approach



Schematic of in-situ metrology. The path from the optical board to the test surface passes into the vacuum chamber through an optical feed-through flange to a penta-prism which directs the laser light to and from the test surface.

Active slit approach



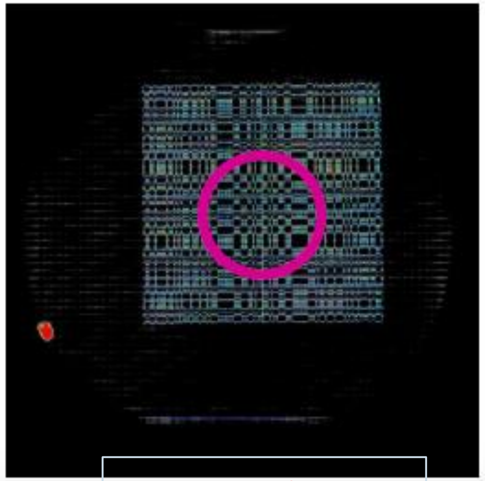
Design concept of active slit approach

- **Detailed stress analysis**

Spin-off applications

NIST – Neutron microscope

- Prototype optics demonstrated 70 microns spatial resolution
- Goal – 10 microns spatial resolution (~1 arc sec)

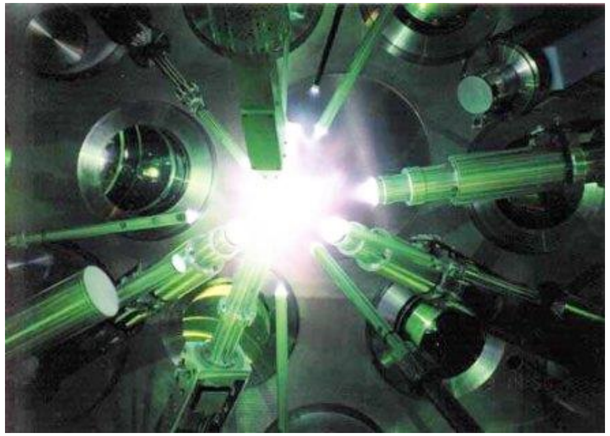


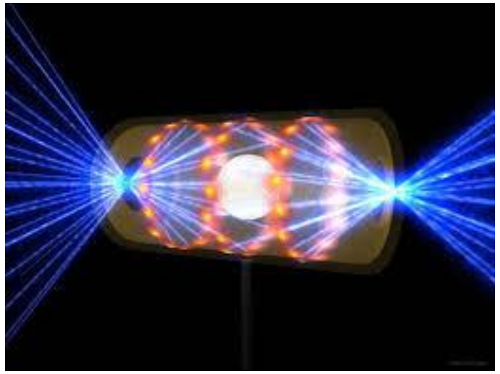
Contact image

Prototype microscope image

National Ignition Facility

- X-ray imaging is critical to the physical understanding of ICF implosions
- Need for high-resolution 5microns (FWHM) spatial resolution (few arc secs) imaging optics for hard 10-25 keV x-rays





(Newly-Funded) Direct fabrication of full-shell X-ray optics

Replication

Mandrel fabrication → Electrolytic plating → Shell Separation → Post replication correction

Direct Fabrication

Substrate fabrication → Electroless Plating Diamond Turning → Figuring, Superpolishing → Post fabrication correction

Metal substrate

Material	Density (g/cm^3)	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.

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.

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

Zeeko polishing machine

Wear function characterization:

Wear rate is proportional to

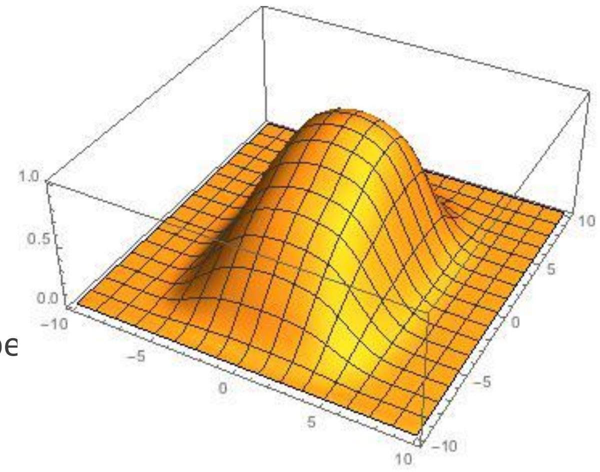
- Velocity of bonnet - depends on
  - Spindle rotation
  - Head attack angles
- Bonnet pressure - depends on
  - Internal pressure of bonnet
  - Bonnet structural and mechanical prope

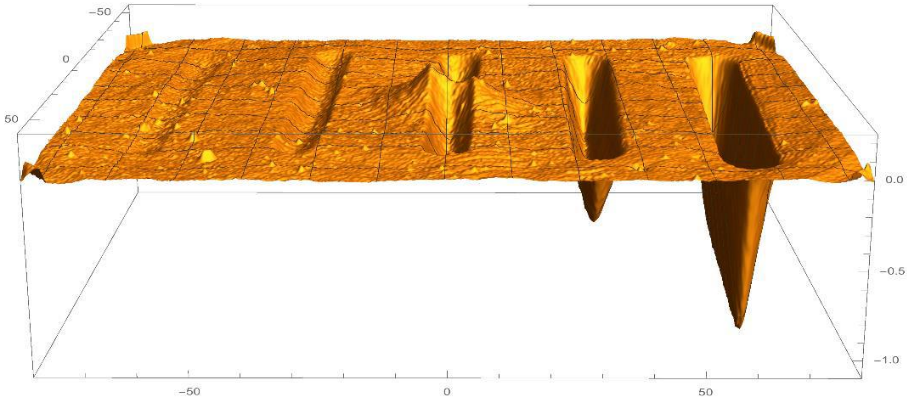
Parameter optimization

Bonnet pressure

Spindle speed

Tool Offset

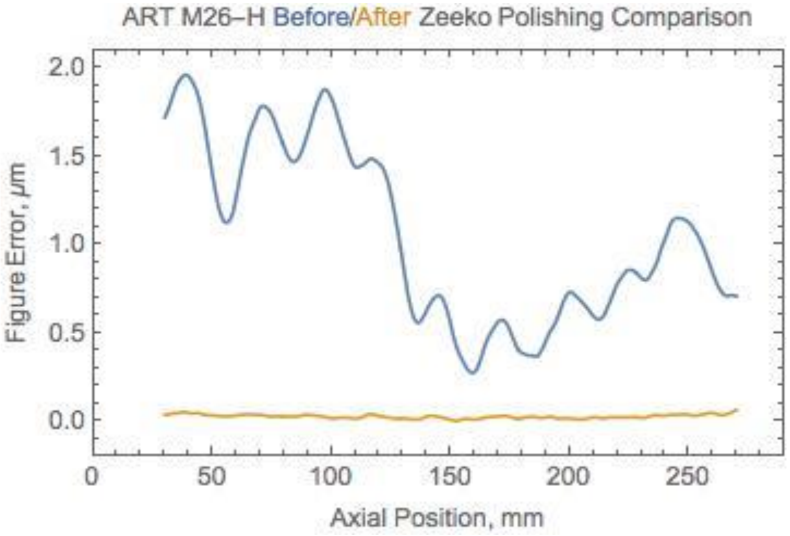


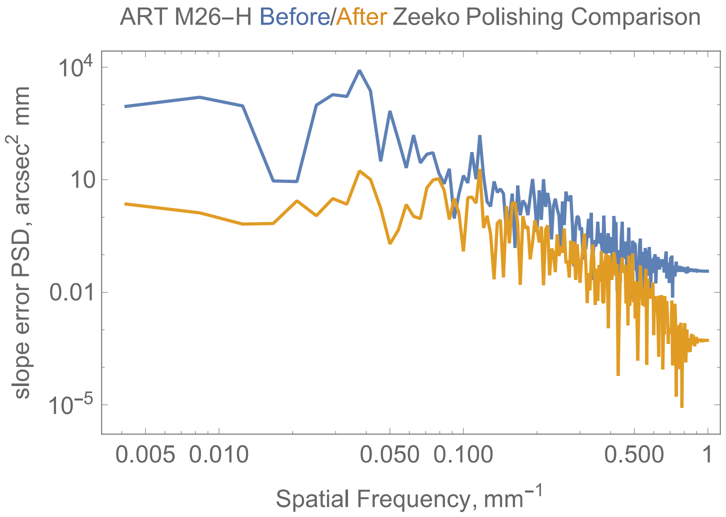


Test polishing runs

- 100mm dia NIP electroplated Al flat samples.
- Initially diamond turned and then polished over small linear regions – ''trenches''.
- The polishing parameters were varied from one trench to another and the wear function dependence on these parameters was determined.

ZEEKO polishing – demonstration on existing mandrel





Surface height error profile of the hyperbolic side of a NiP plated mandrel before (upper curve) and after (lower curve) polishing using a 40 mm bonnet.

Mandrel > 5x better than any made with conventional polishing

	before	after
Figure error (St. Dev.)	500 nm	10.7 nm
Slope error (> 2 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