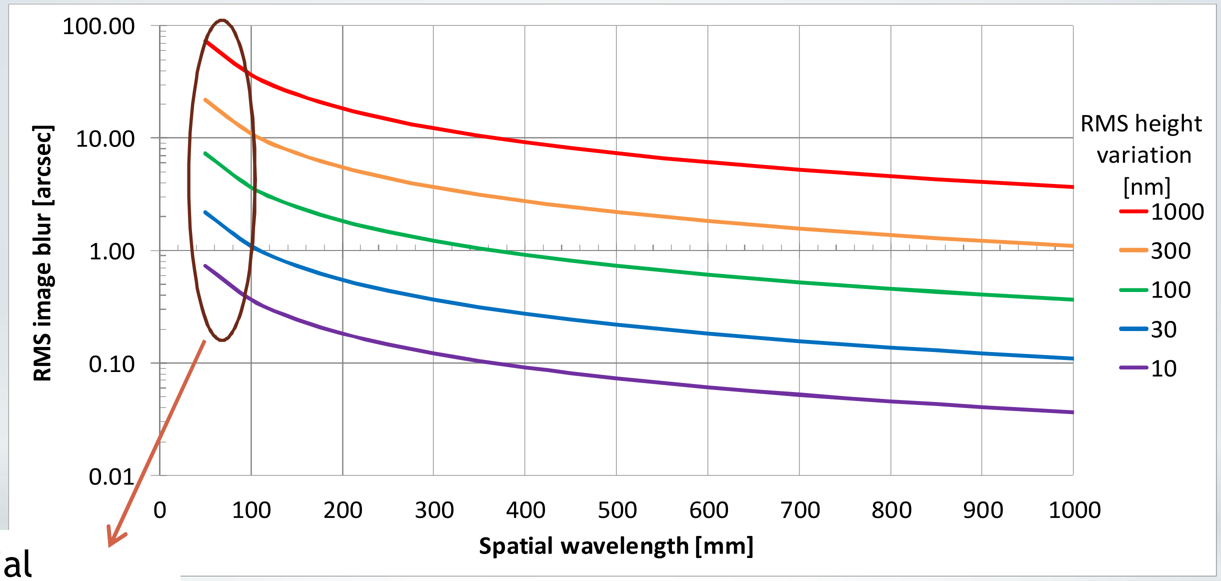
Progress in differential deposition for improving the figures of full-shell astronomical grazing incidence X-ray optics

* Kiranmayee Kilaru, USRA/NASA MSFC
* Carolyn Atkins, University of Alabama in Huntsville/NASA MSFC
* Brian D. Ramsey, NASA MSFC
* Jeffery Kolodziejczak, NASA MSFC
* Mikhail V. Gubarev, NASA MSFC
* Stephen L. O'Dell, NASA MSFC
* David M. Broadway, NASA MSFC

Why differential deposition?



Typical mid-spatial frequency range in X-ray mirrors

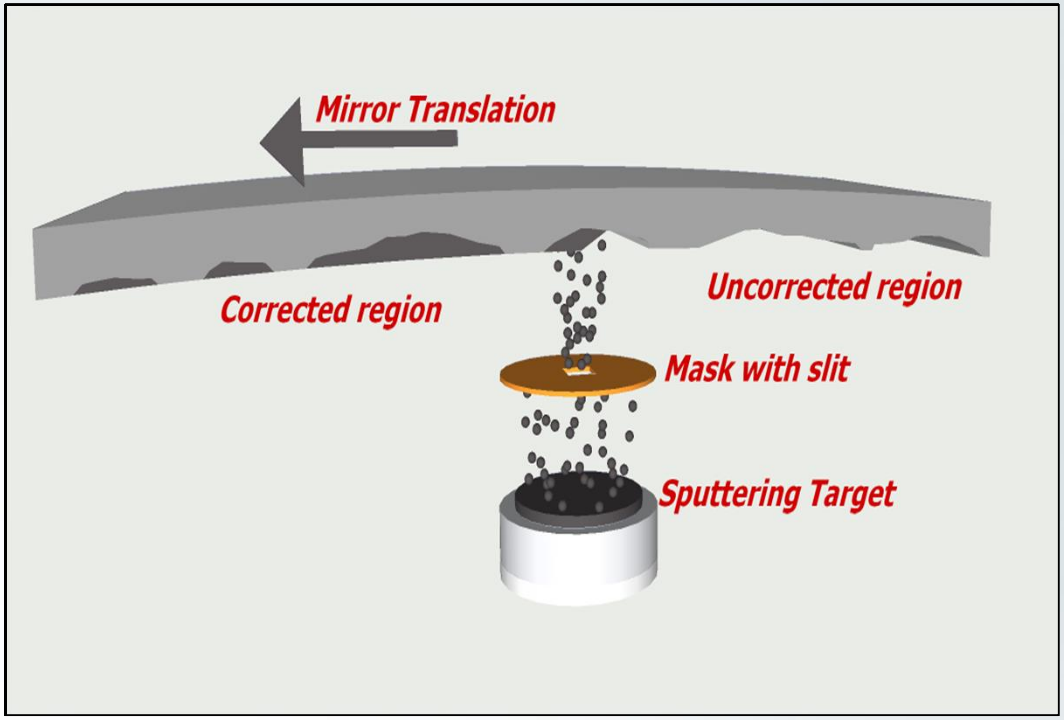
Plot Credits: Steve O'Dell, NASA MSFC

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

Concept of differential deposition

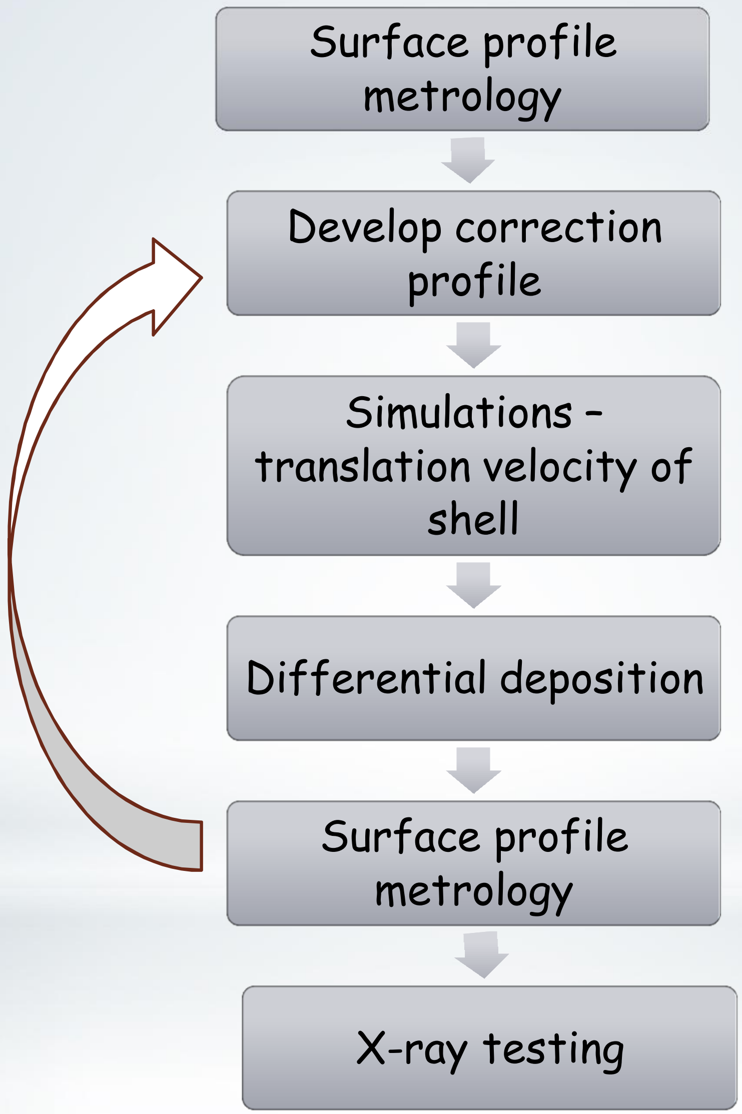
* Use of physical vapor deposition to selectively deposit material on the mirror surface to smooth out figure imperfections

* Various approaches –
* A) Constant mirror velocity- varying slit width
* B) Varying mirror translation velocity
* C) Varying power on target material
* D) Combination of above all



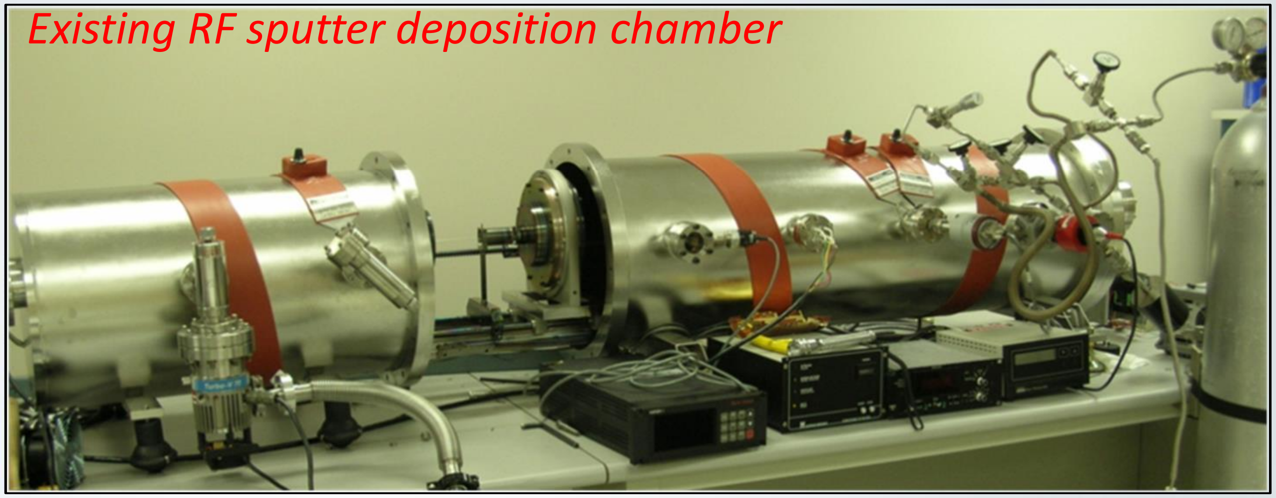
* Ice, G. E., Chung, J. S., Tischler, J. Z., Lunt, A., and Assoufid, L., "Elliptical x-ray microprobe mirrors by differential deposition", Rev. Sci. Instr., 71(7), 2635-2639 (2000).
* Handa Soichiro, Hidekazu Mimura, Hirokatsu Yumoto, Takashi Kimura, Satoshi Matsuyama, Yasuhisa Sano, Kazuto Yamauchi, "Highly accurate differential deposition for X-ray reflective optics", Surface and Interface Analysis, 40, 1019-1022 (2008).
* Alcock, S. G., and S. Cockerton. "A preferential coating technique for fabricating large, high quality optics." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 616, no. 2 (2010): 110-114.
* Two-dimensional differential deposition for figure correction of thin-shell mirror substrates for x-ray astronomy, David L. Windt…following talk

Process Sequence

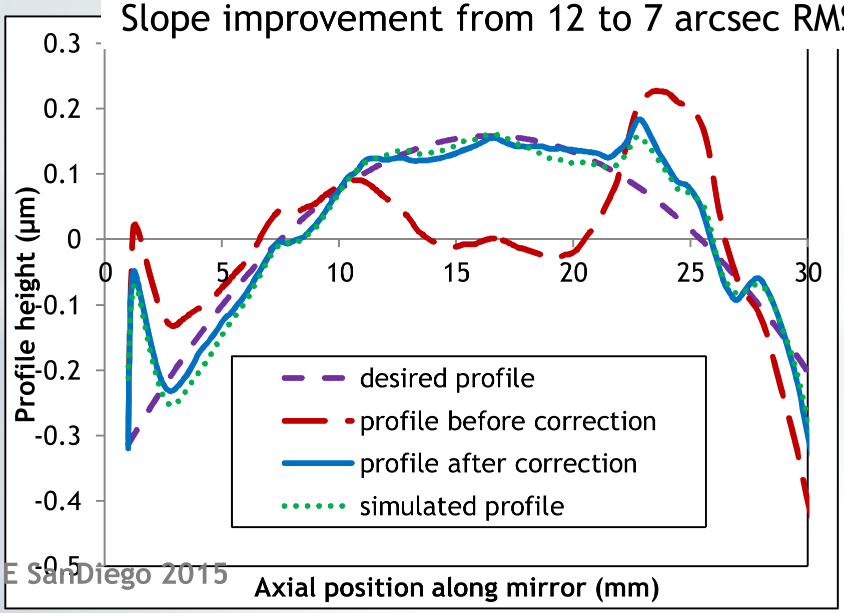


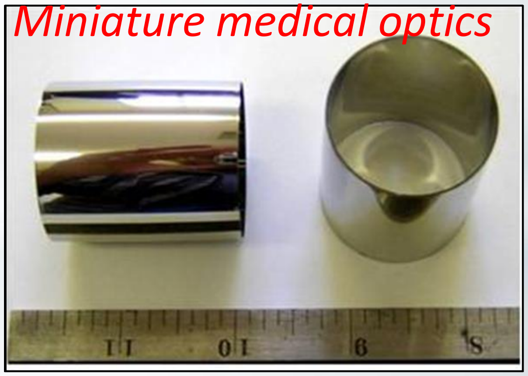
Proof of concept on miniature optics

- An existing vacuum chamber was modified for the proof of concept on the miniature optics developed for radio-nuclide imaging

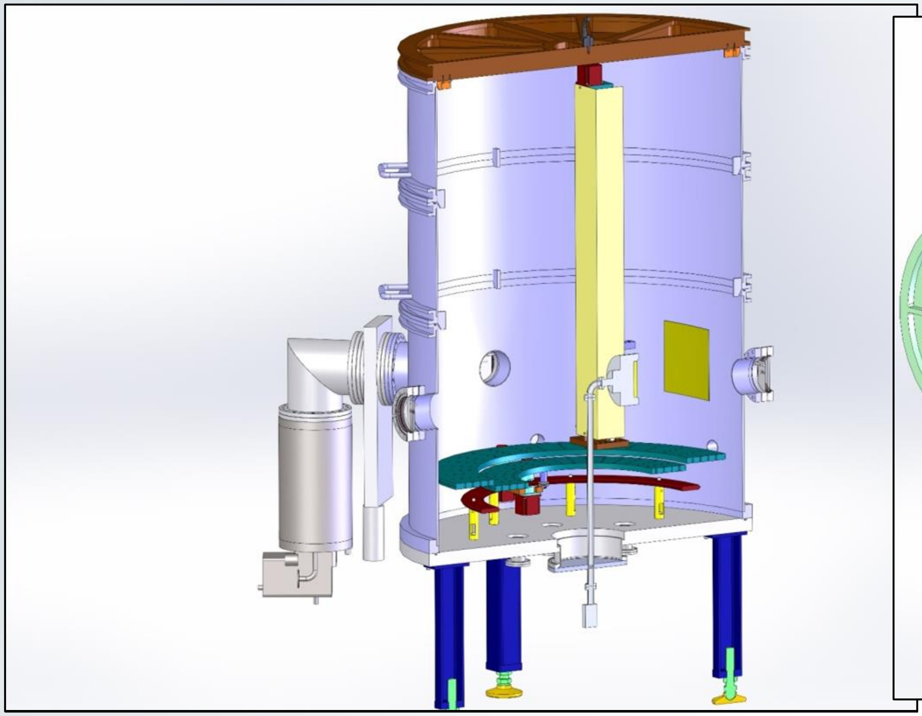


Slope improvement from 12 to 7 arcsec RMS

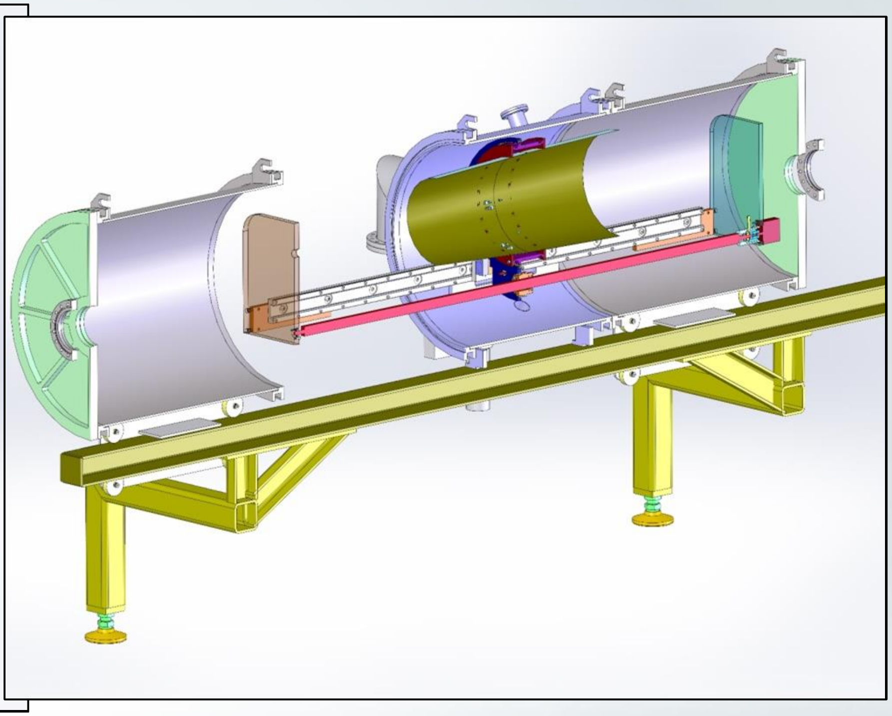




Coating Systems (DC magnetron)

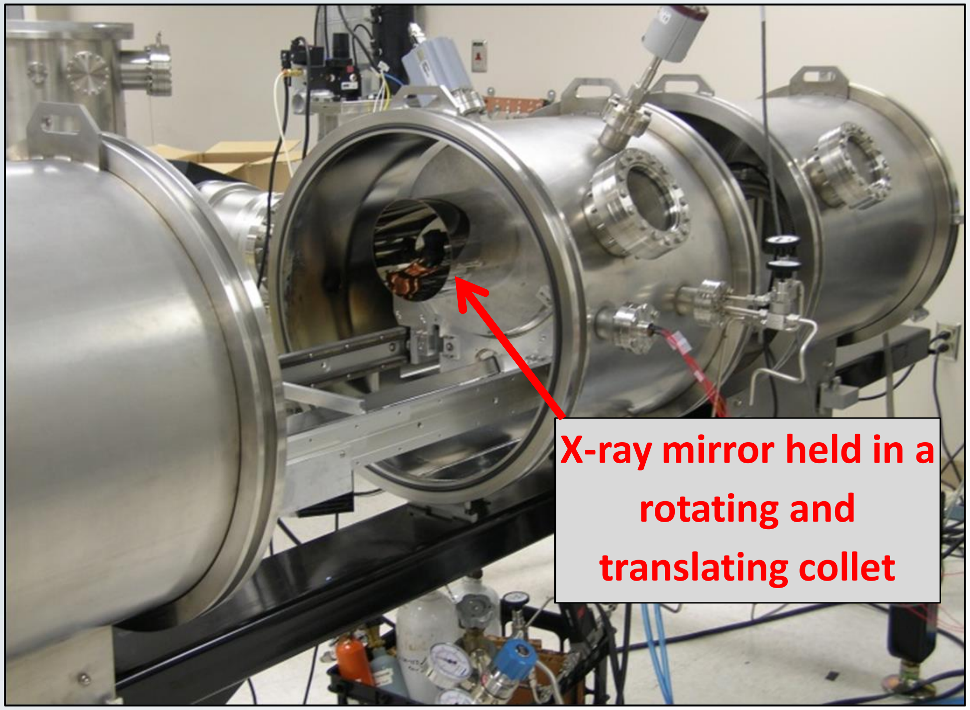


Vertical chamber for segmented optics and very large full shell optics (>0.5m diameter)

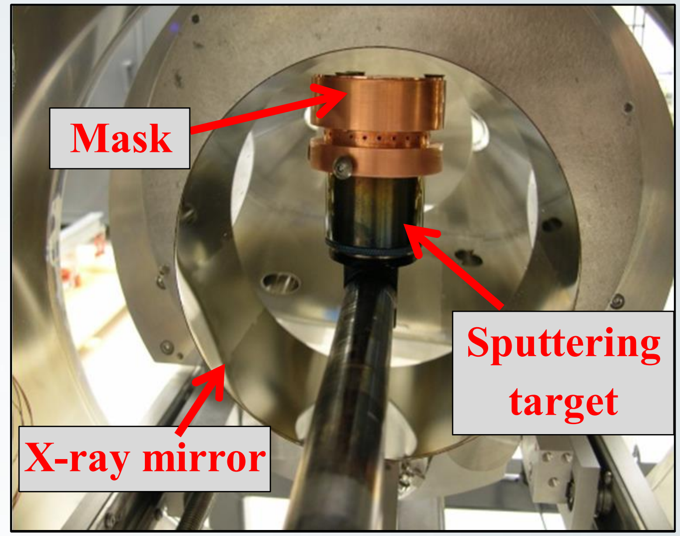


Horizontal chamber for 0.25m diameter and up to 0.6m length - scale full shell optics

Coating Systems



Horizontal differential-deposition chamber

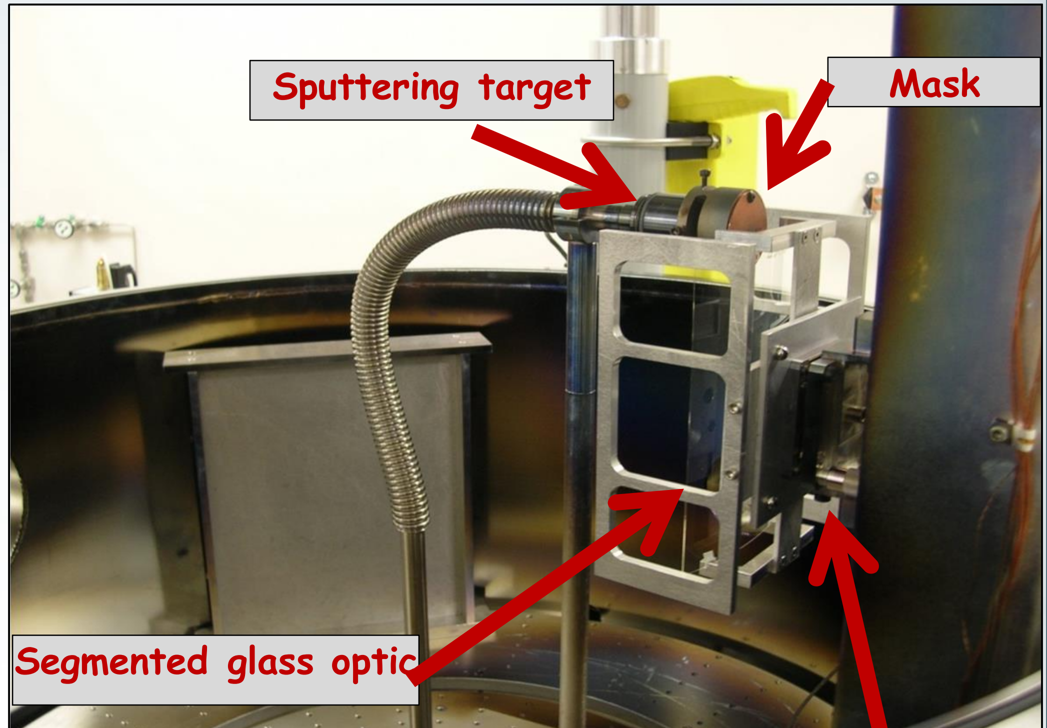


Sputtering head with copper mask positioned inside shell

* For full-shell cylindrical optics
* Oriented horizontally – mounted on rail system – splits into 3 section for easy access
* Computer controlled translation and rotation stages with encoders
* Matlab – GUI interface to control the stages

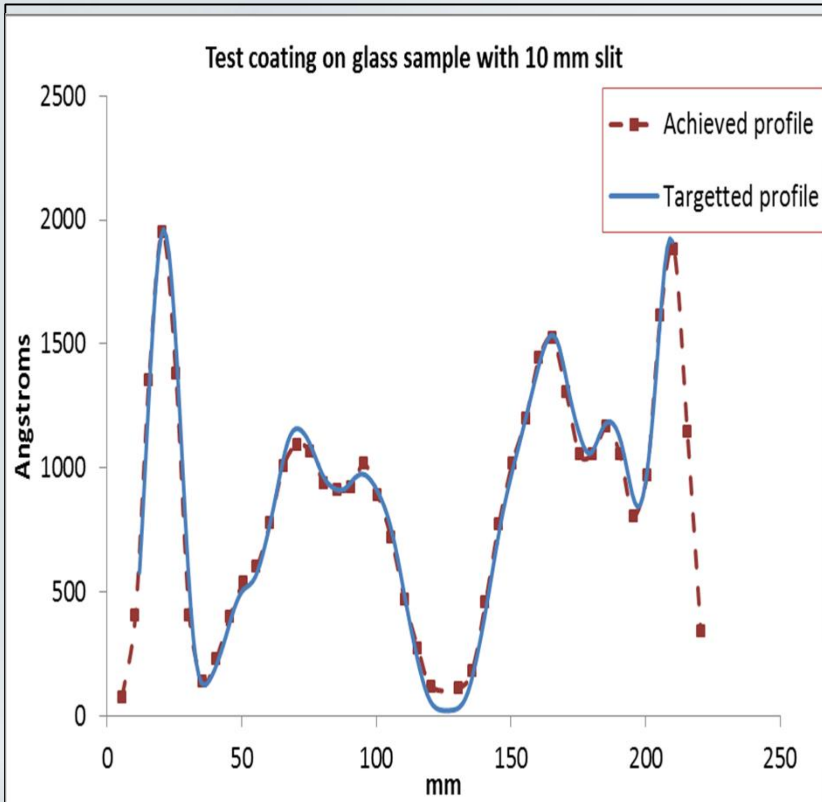
Coating Systems

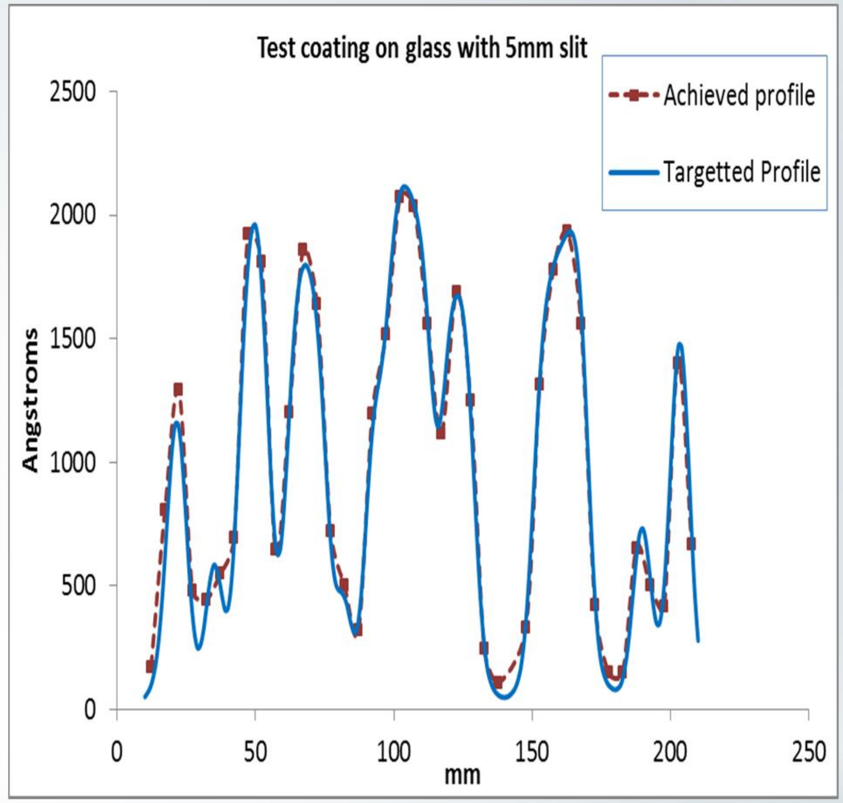
Vertical deposition chamber



- Details in the upcoming talk by Dr. Carolyn Atkins
- Optimization of coating parameters
- Good estimate of sputter beam profile for various slit-widths

Test Coatings



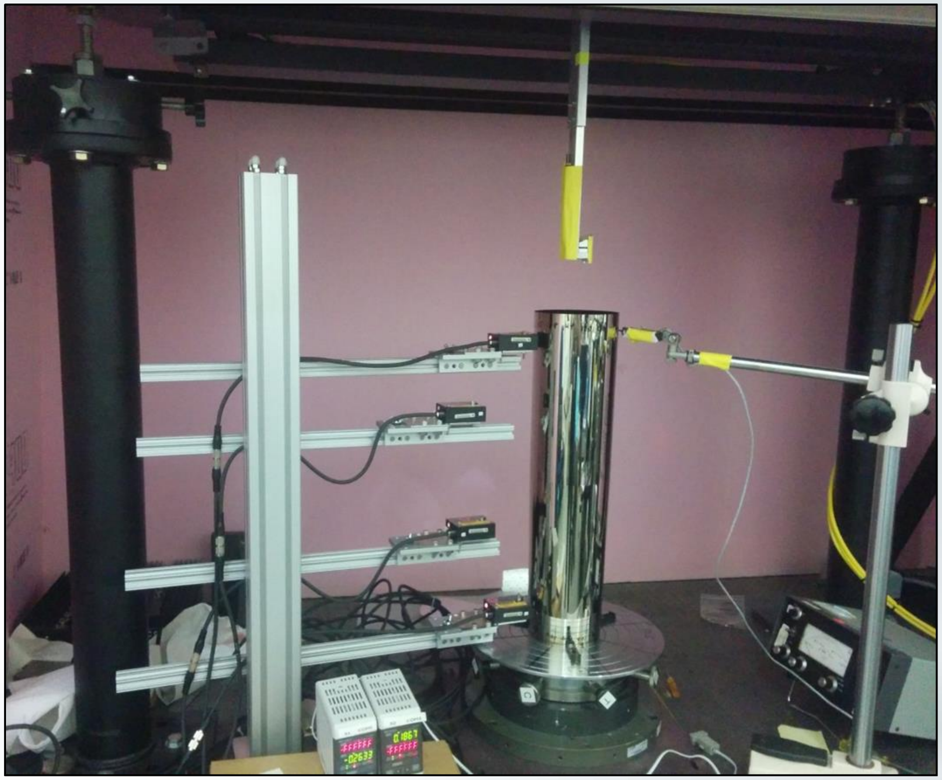


Test coatings on glass samples with 10mm and 5mm slits

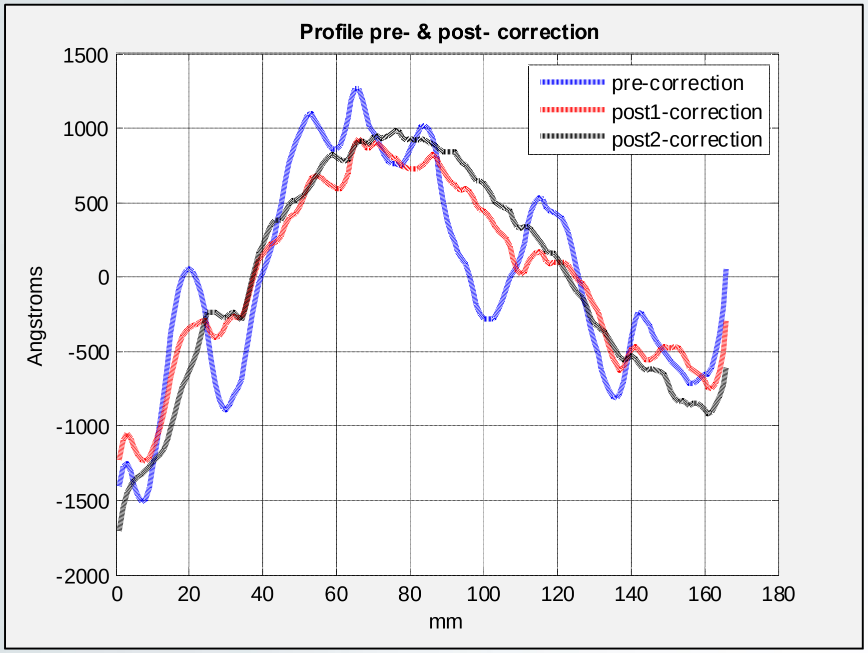
* KLA-Tencor step profiler is used to measure the coating thickness on glass samples
* Good agreement with simulations

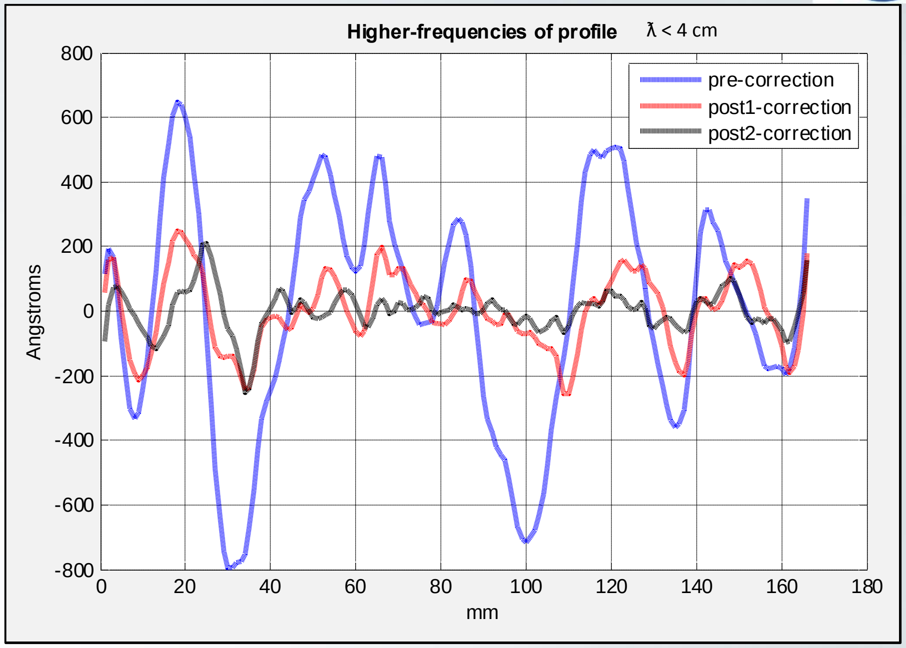
Metrology - VLTP

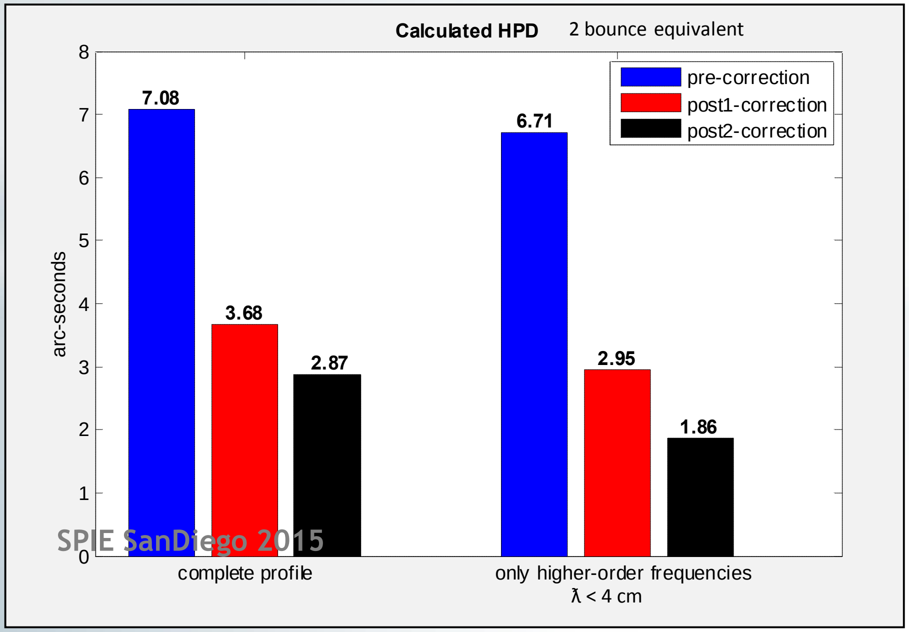
* Vertical Long Trace Profiler
* 1mm spatial interval
* New 2D camera and modified software
* Established procedures to obtain repeatability of <100 Angstroms



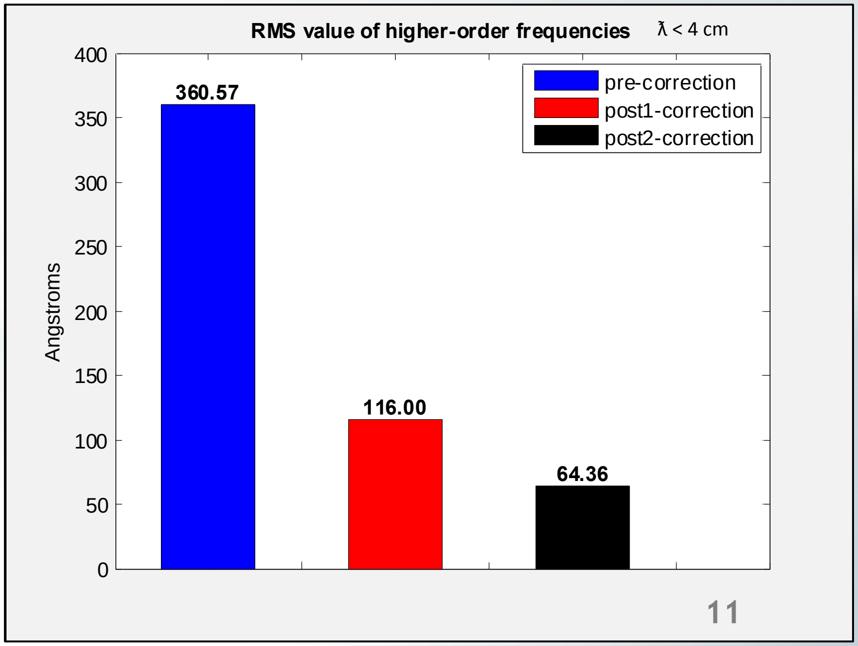
150 mm diameter shell – single meridian; pre- and post- two stages of correction - high frequencies only





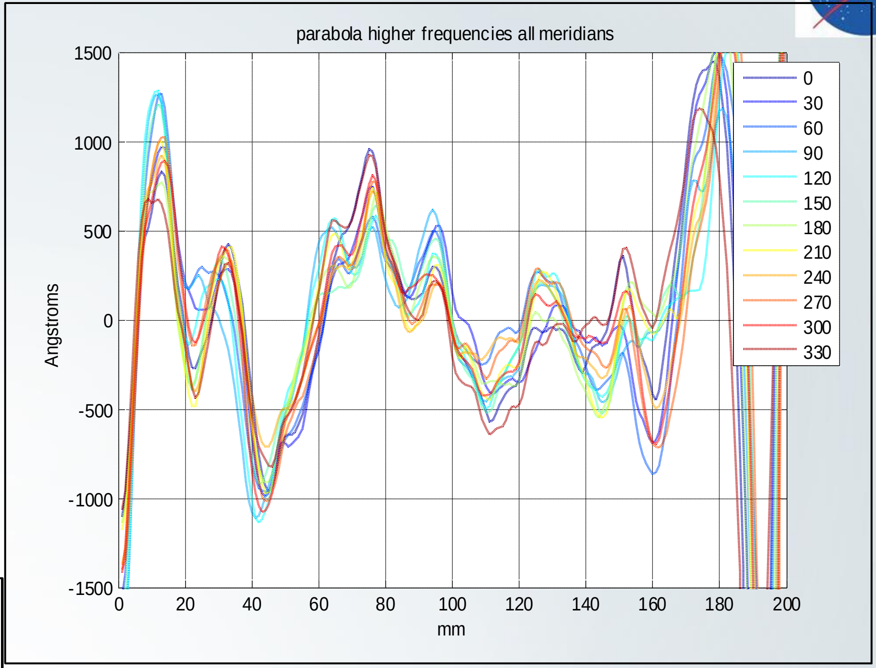


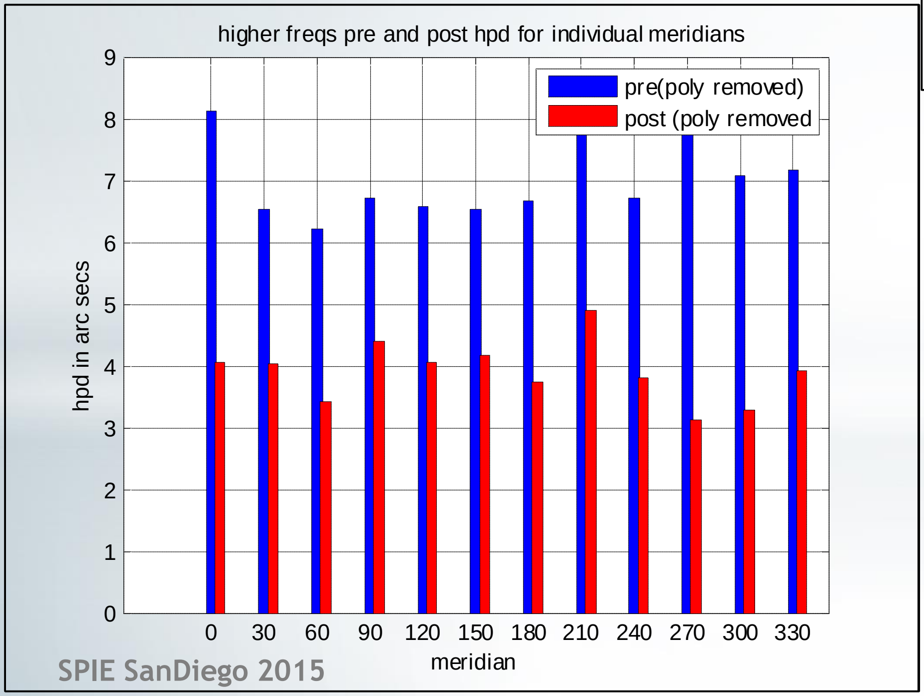
SPIE SanDiego 2015

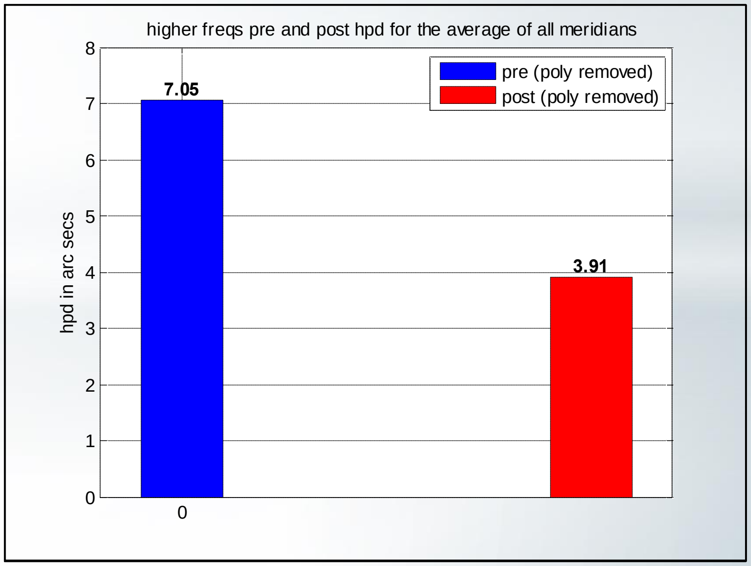


Higher–frequencies complete full-shell – average of all meridians

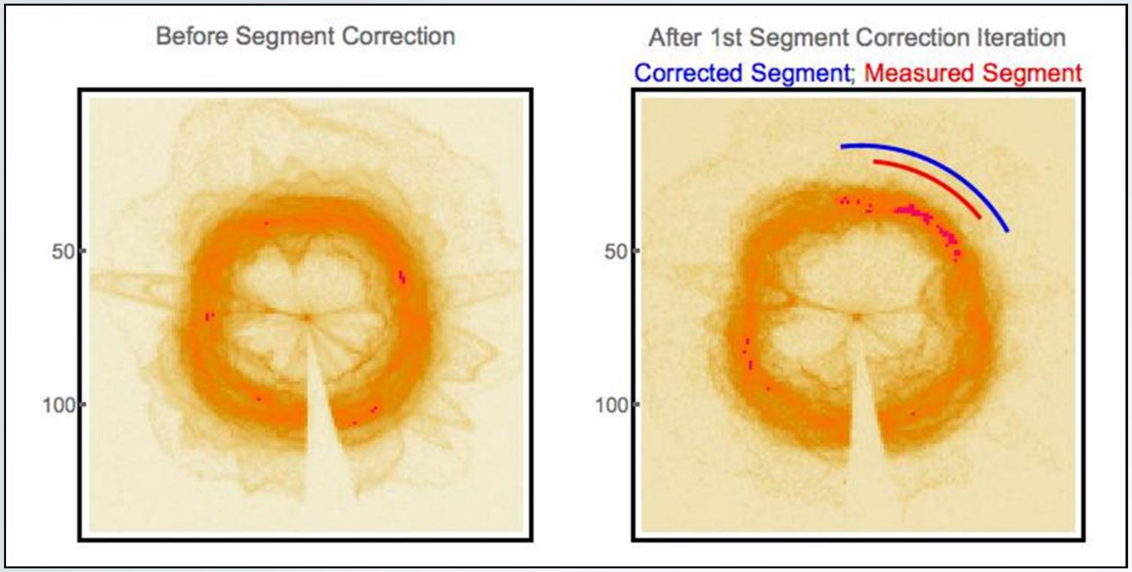
- Higher-frequencies of individual meridians are similar in deviations – replicate from the mandrel
- Average of all meridians –1st stage of correction
- 2nd stage of correction is better achieved with specialized correction at first stage

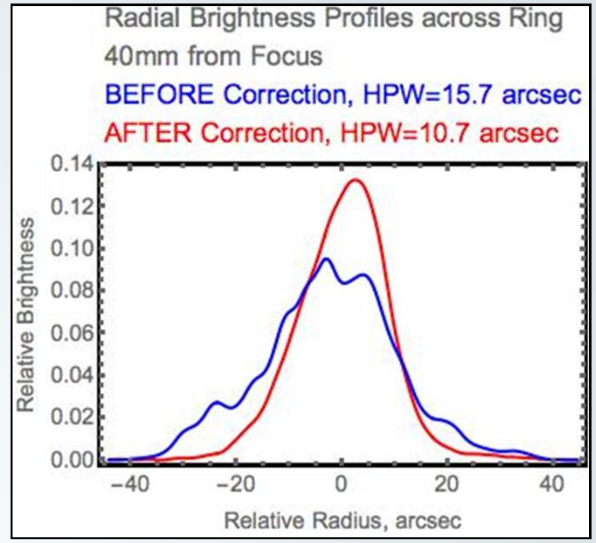


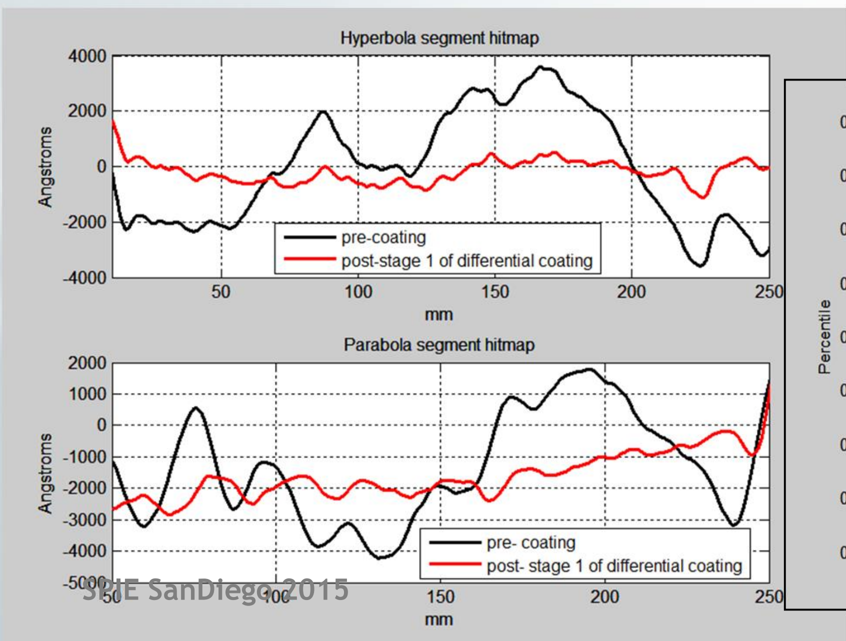


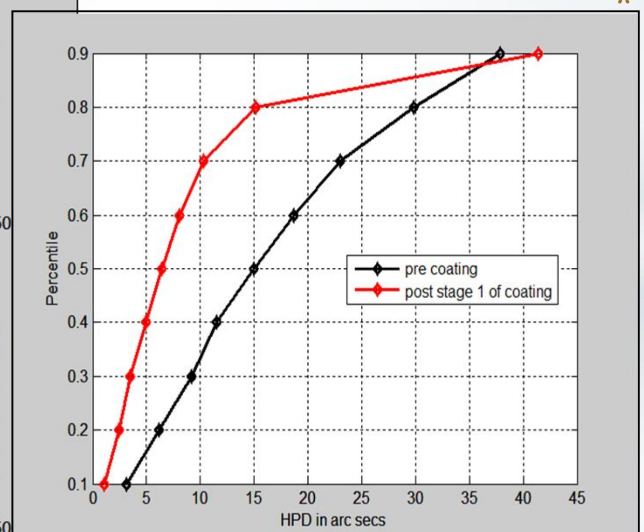


X-ray testing – pre-and post- differential coating

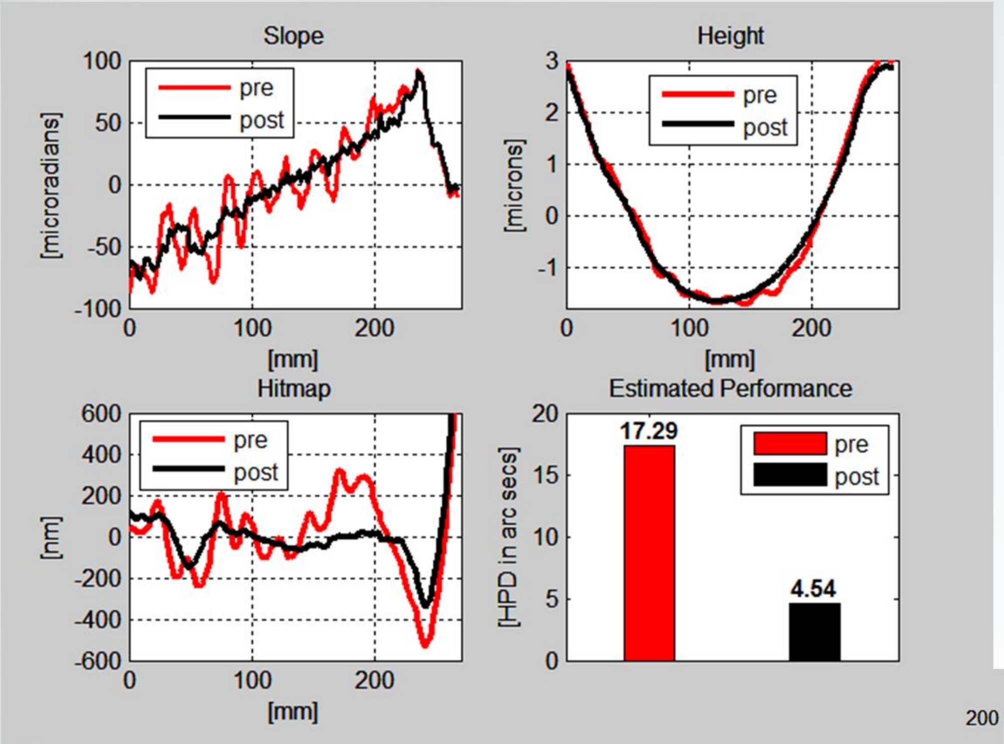


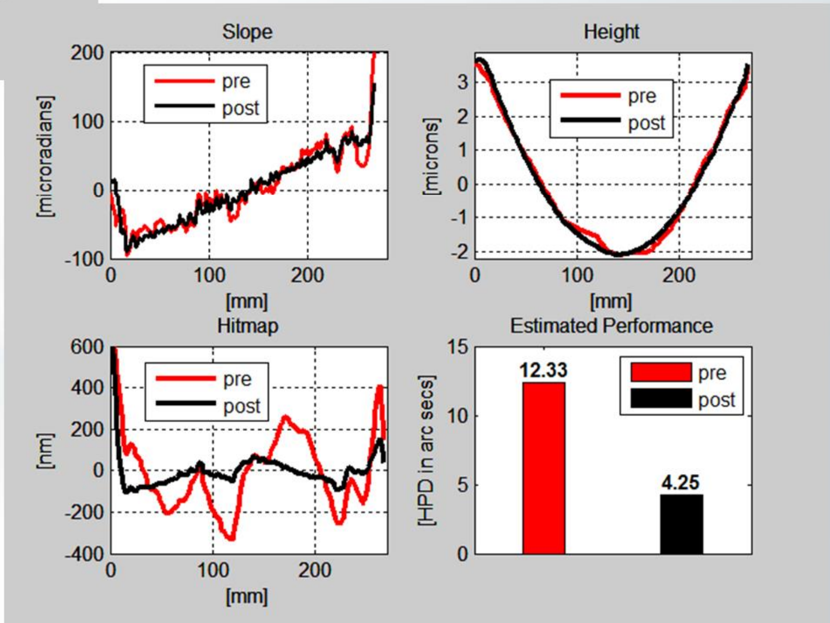






* Though initial metrology profiles show an estimated improvement from ~15 to ~ 6 arc secs, careful analysis of all the possible errors bring this number down to of 9.23 arc secs


Slope
[microradians]
[mm]
Height
[microns]
[mm]
Hitmap
[nm]
[mm]
Estimated Performance
[HPD in arc secs]
17.29
4.54
pre
post


Slope
[microradians]
[mm]
Height
[microns]
[mm]
Hitmap
[nm]
[mm]
Estimated Performance
[HPD in arc secs]
12.33
4.25
pre
post

Possible Sources of Errors - Improvements

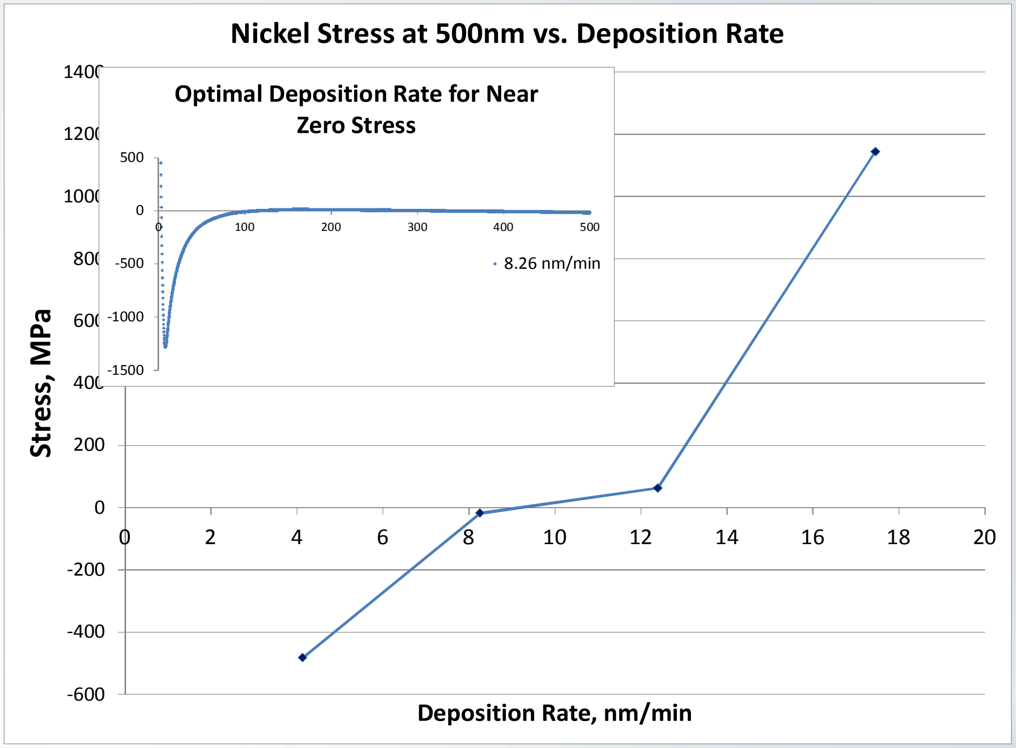
* Variation of sputtered beam profile along the length of mirror – particularly for short focal length mirrors – Improvements in mechanical set-up

* 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

Coating Stress Measurement System



* Simulations show that for full shell optic need < 10MPa stress to get < 1 arcsec optic (dominated by longer-wavelength corrections). Set up dedicated system to characterize coating stresses.

Conclusions

* Advantages –
  * Can be used on any type of optic, full-shell or segmented, mounted or unmounted
  * Can be used to correct a wide range of spatial errors
  * Could be used in conjunction with other techniques… e.g. active optics

* Efforts are in progress to achieve the best possible improvement with differential deposition and to quantify the improvement with X-ray testing