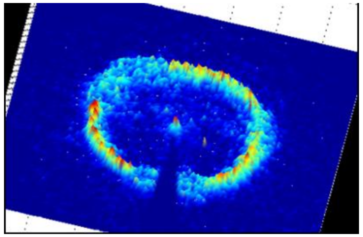
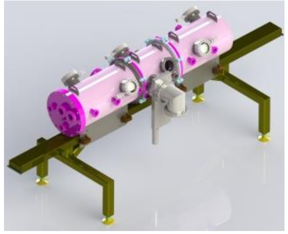
Mikhail Gubarev

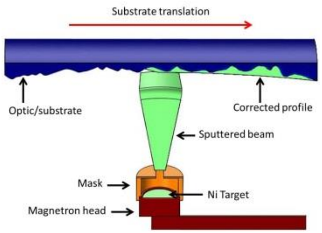
Overview of Differential Deposition at NASA MSFC

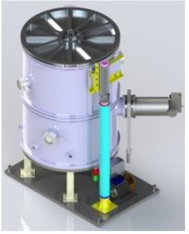
Presentation outline

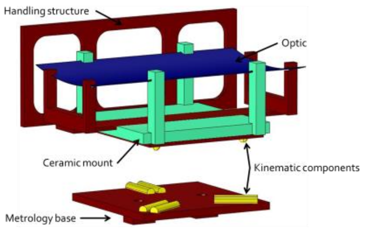
- Introduction
- Horizontal chamber
- Vertical chamber
- Summary, conclusion and future work











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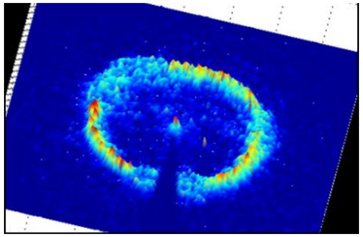
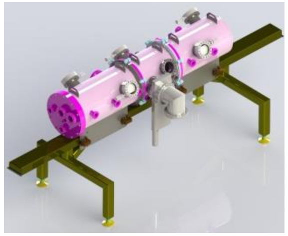
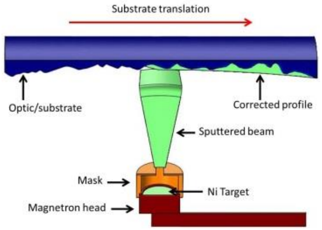
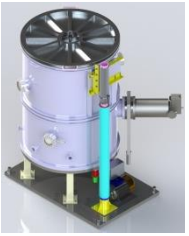
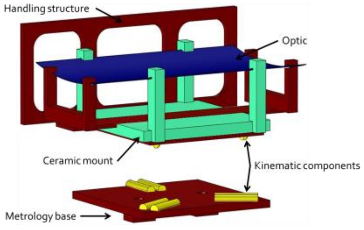


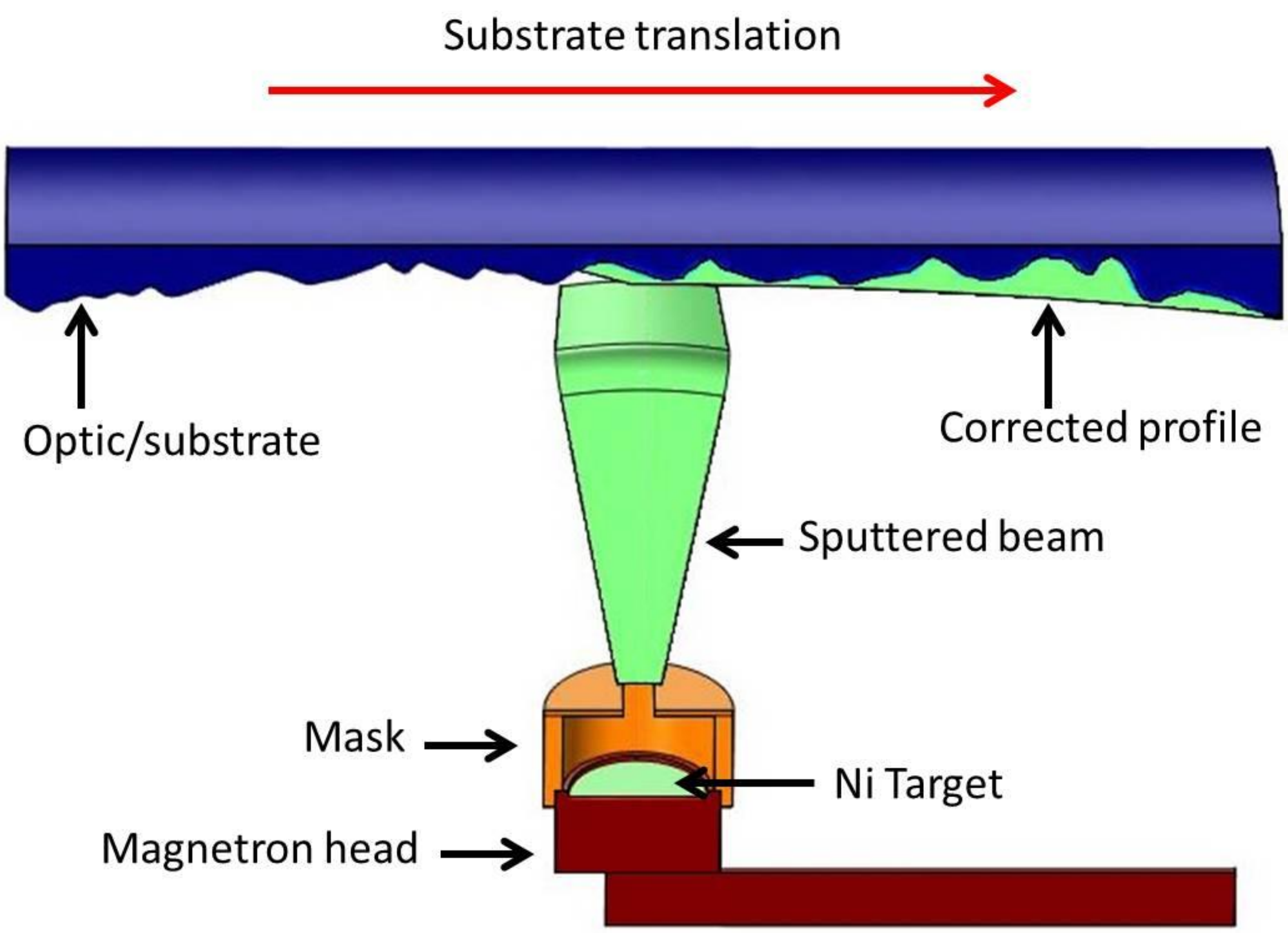






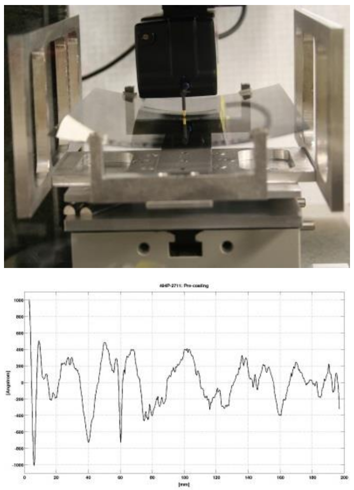


Introduction to Differential Deposition

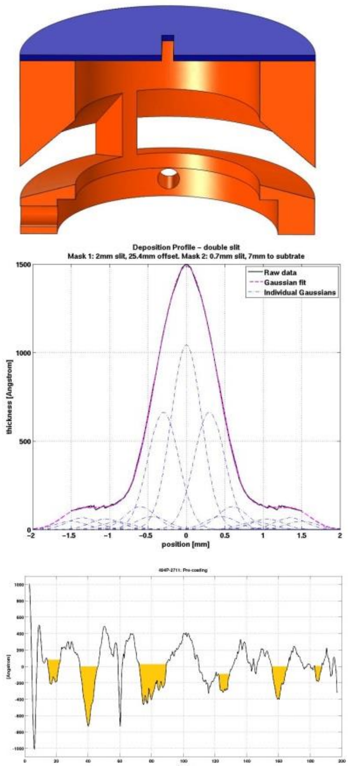


Differential Deposition process loop

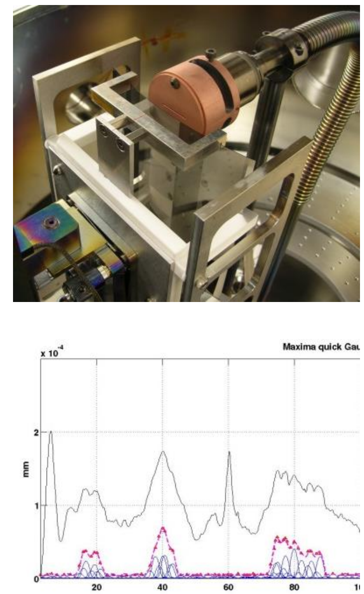
THE UNIVERSITY OF ALABAMA IN HUNTSVILLE



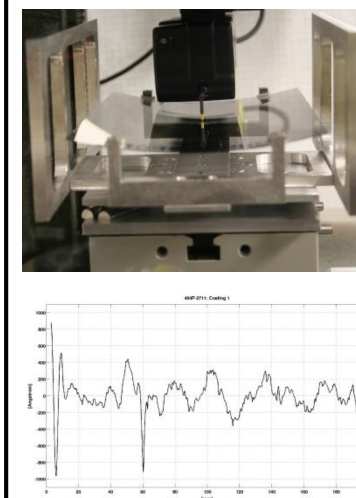
1. Metrology



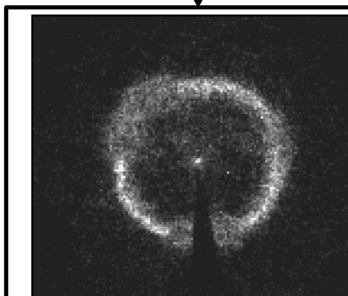
2. Correction profile and simulations



3. Perform correction



4. Metrology



5. X-ray testing

Proof of concept

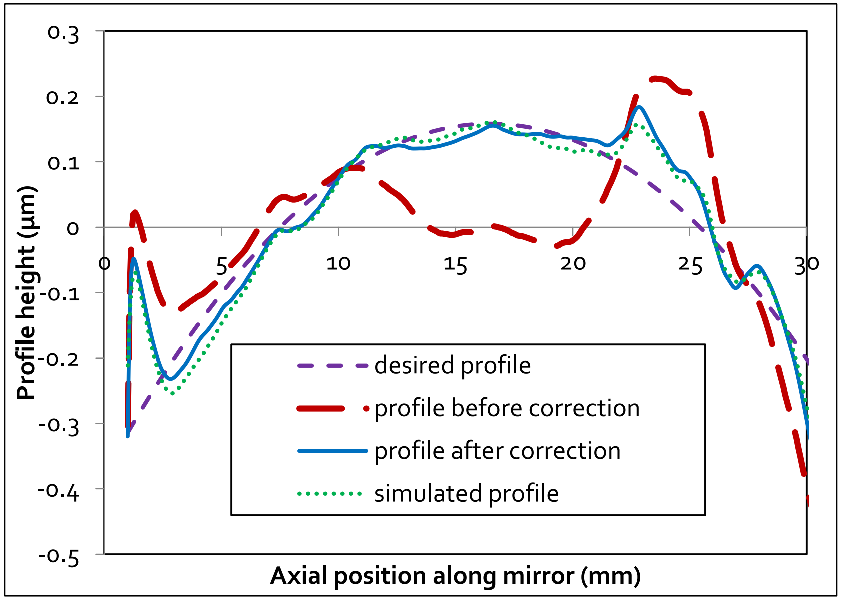
Initial proof of concept was performed upon miniature optics intended for radio-nuclide imaging using an existing RF sputtering system.

Form Talysurf data demonstrated an improvement in slope from 12 to 7 arc-sec.

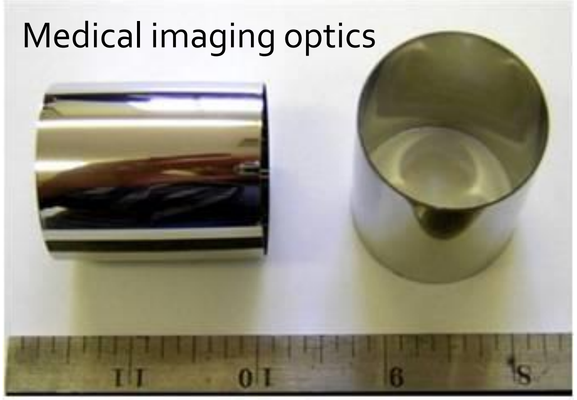
Accurate metrology was the limiting factor in this investigation.

K.Kilaru et al, Optical Engineering 50(10), 106501 (October 2011)

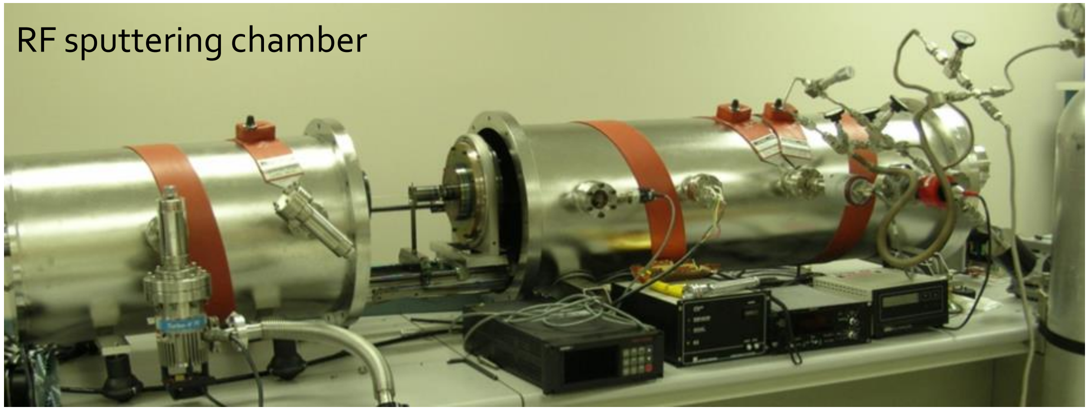
Slope improvement from 12 to 7 arcsec RMS



Medical imaging optics



RF sputtering chamber

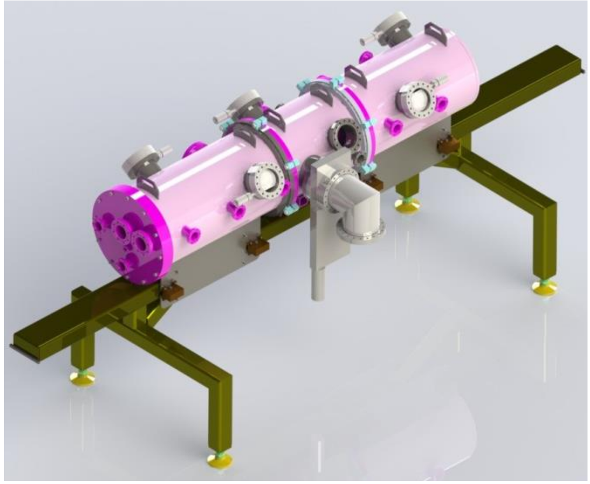


Concept development

Following on from the proof of concept investigation a grant was awarded to further the research to astronomical X-ray optics.

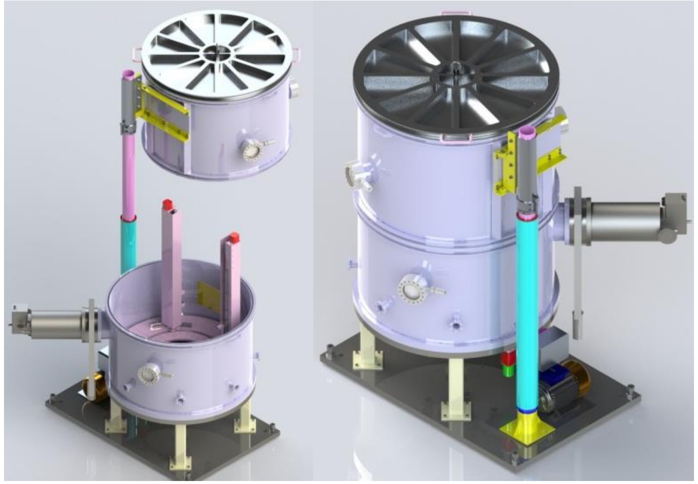
Horizontal Chamber

- DC magnetron sputtering source
- Designed for full shell electroformed optics



Vertical Chamber

- DC magnetron sputtering source
- Designed for segmented glass optics and large diameter full shell optics.



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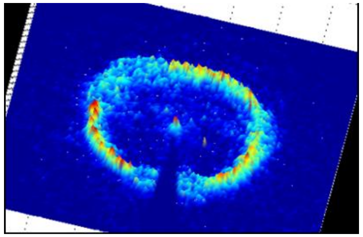
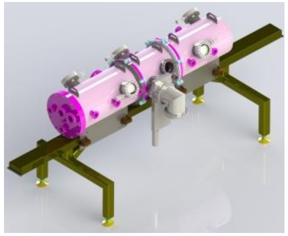
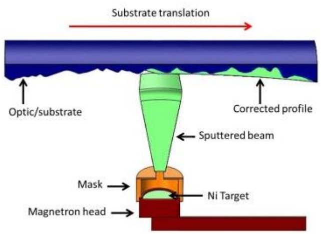
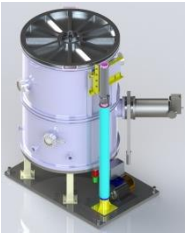
- Introduction
- Horizontal chamber

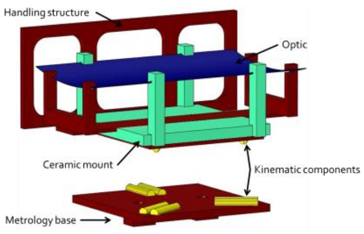
  - research conducted by Dr. Kiranmayee Kilaru
- Vertical chamber
- Summary and conclusion







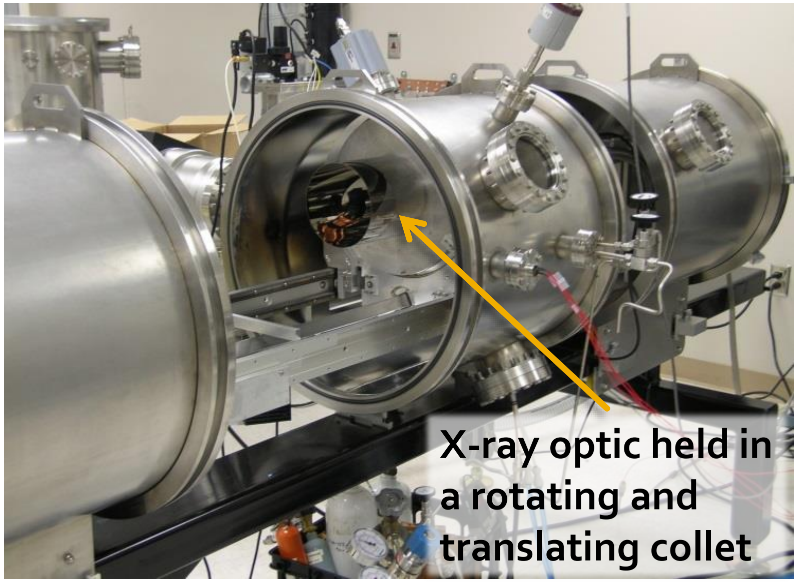




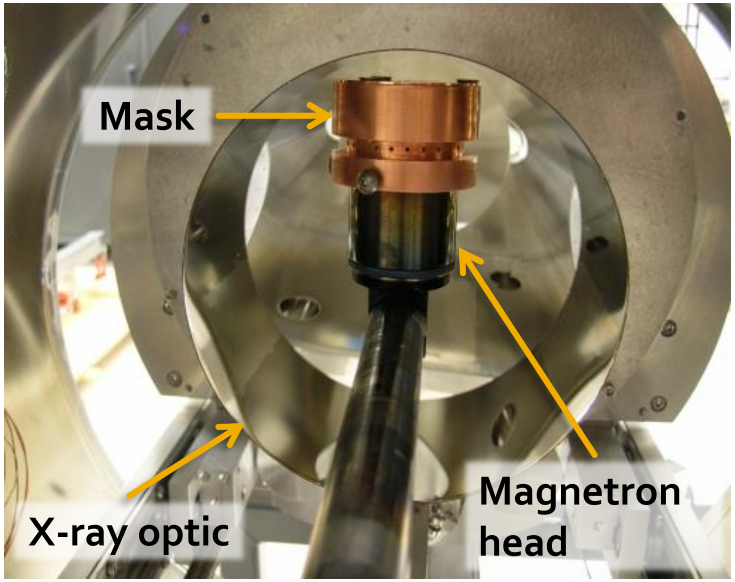
Horizontal Chamber

Work performed by **Dr Kiranmayee Kilaru**

Horizontal differential deposition chamber



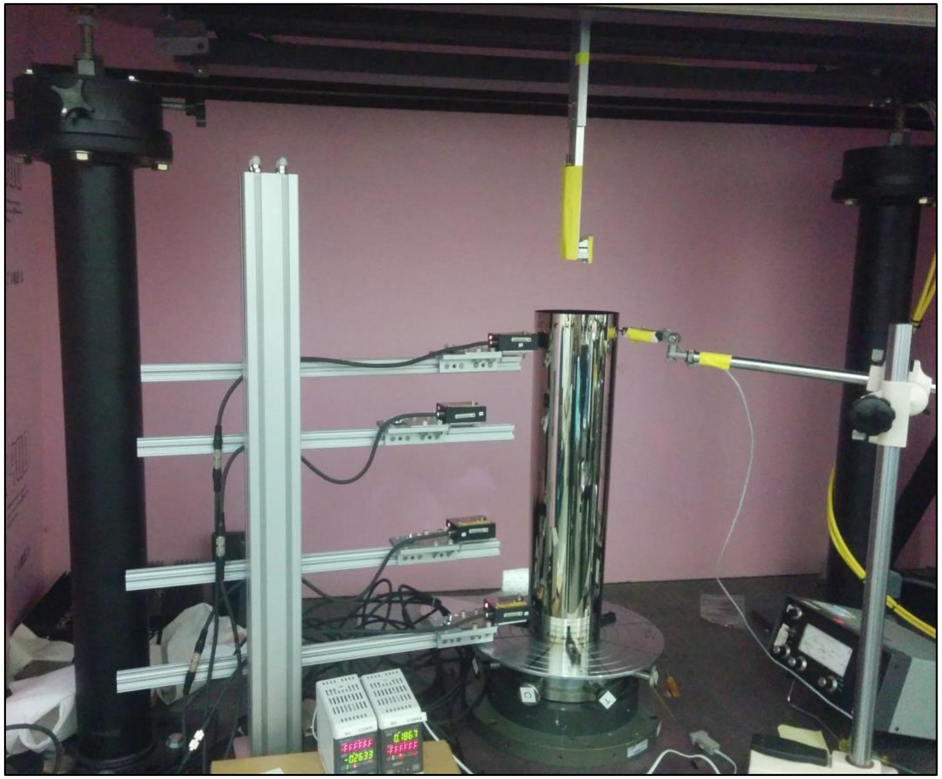
Magnetron head within the optic



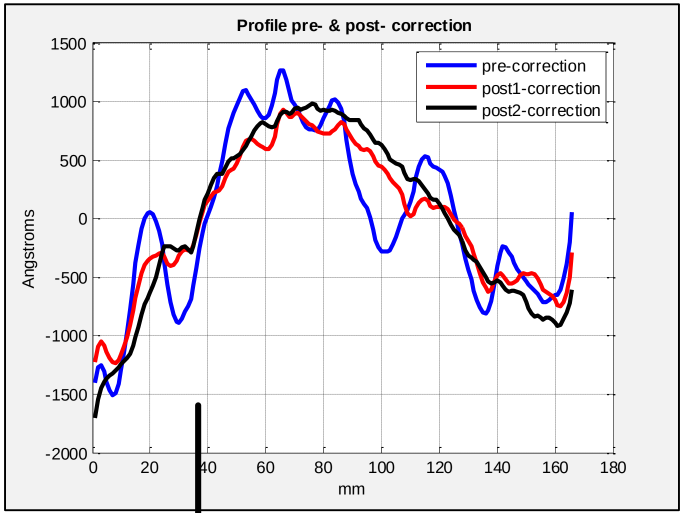
- Developed for full shell electroformed optics.
- The optic translates and rotates relative to a stationary sputtering/magnetron head.
- The rotation and translation are encoder to ensure accurate positioning.
- Maximum shell diameter and length: 0.25m and 0.6m respectively.
- 1 inch (25.4mm) diameter sputtering/magnetron head

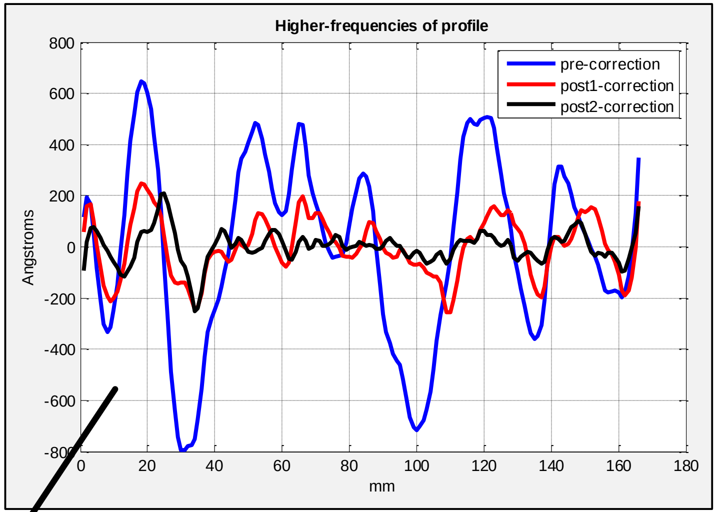
Metrology - VLTP

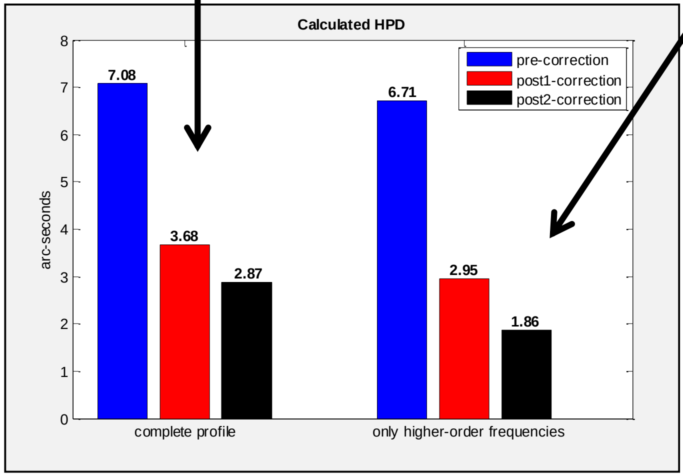
- Vertical Long Trace Profiler
- 1 mm spatial interval
- New 2D camera and modified software
- Established procedures to obtain repeatability of <100 Angstroms
- Multiple measurements - 4 scans per meridian with 4 realignment scans



Initial experimentation: single meridian correction







Initial experimentation was performed on single meridians from Con-X replicas.

These results demonstrate the successful application of Differential Deposition upon astronomical X-ray optics.

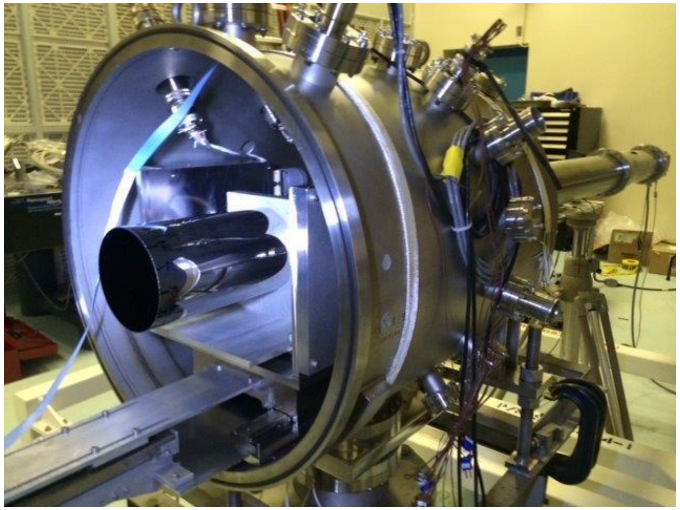
The HPD values are calculated solely from VLTP metrology data.

Correction of optics for X-ray testing

- Optical prescription: parabola-hyperbola, nominal 140mm diameter, 580mm in length.
- Correction applied to both the parabolic and hyperbolic sections of the shell.
- Correction was performed in 3 sections comprising of 3 meridians each. Each meridian was separated by 24°.

- The optic was measured at MSFC's 100m long Stray Light Facility.
- The optic can be tip-tilted and translated to obtain the optimum focus.

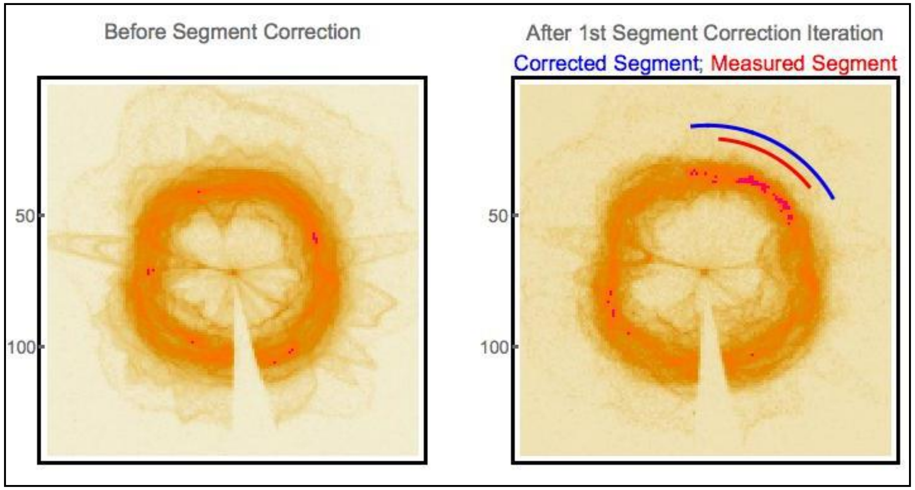
- Before and after correction measurements were performed using both the Stray Light Facility and the VLTP.

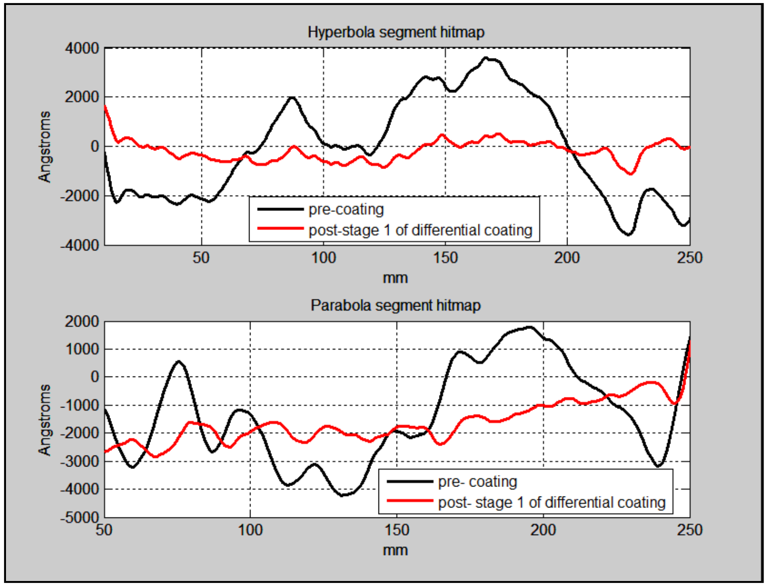


Correction 1 – X-ray testing and metrology

- VLTP metrology pre and post coating estimated an improvement from 15.7arc-sec to 9.2arc-sec.

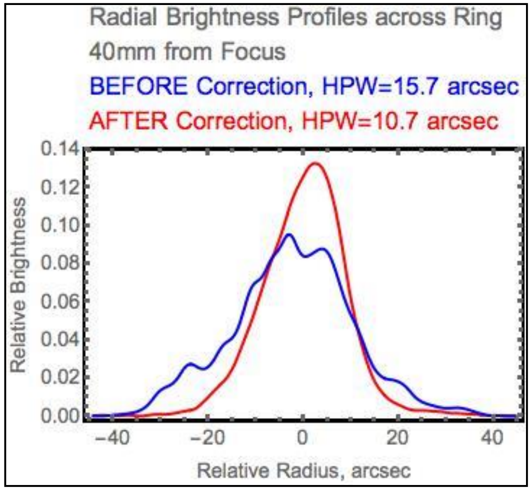
- A 5mm slit was used to perform this correction, which targeted all spatial frequencies and customised for each meridian.





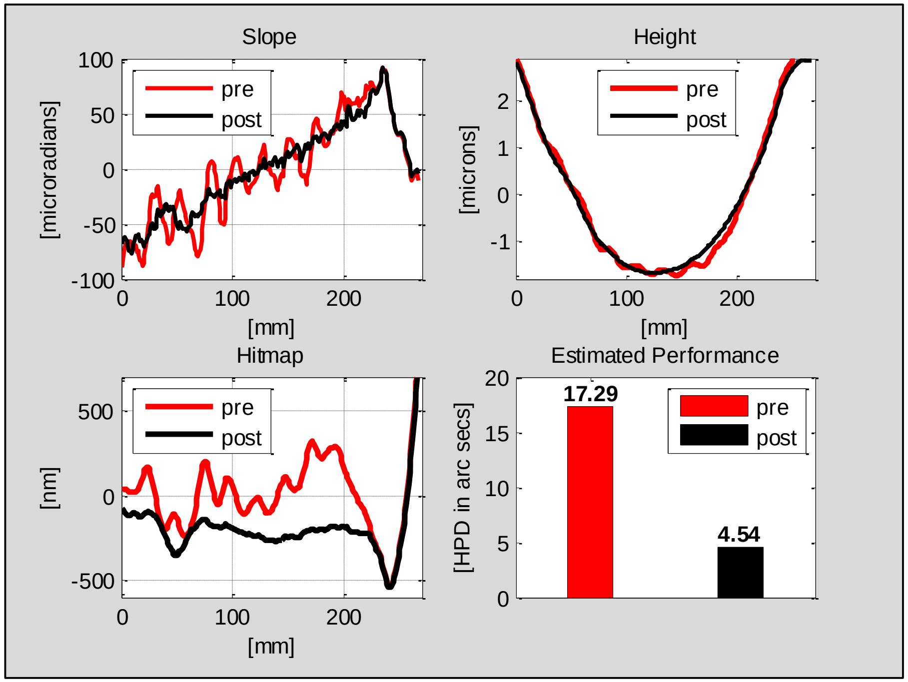
- X-ray testing highlighted an improvement from 15.7arc-sec HPW to 10.7 arc-sec HPW.

- Upon analysis the discrepancy between the expected and actual values was caused by the overlap region



Correction 2 – metrology

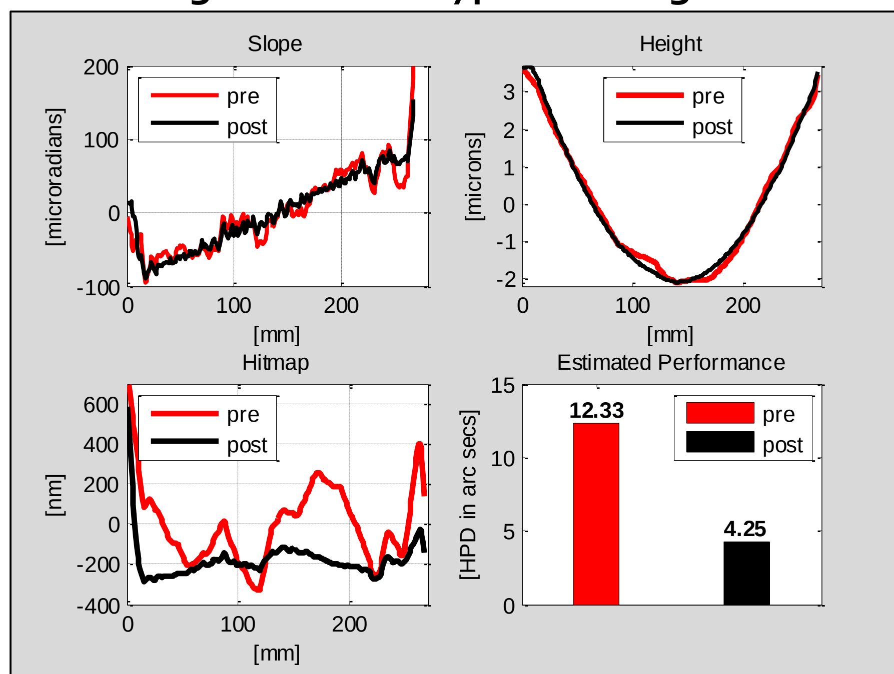
Single meridian parabolic segment



- When considering the overlap regions between meridians, an improvement of **7.9 arc-sec** was estimated post correction.

- Second correction used the same ART shell from correction 1, but on a different azimuthal region.
- 3 meridians at 24° separation were corrected.
- Corrections customised for each meridian were used.

Single meridian hyperbolic segment



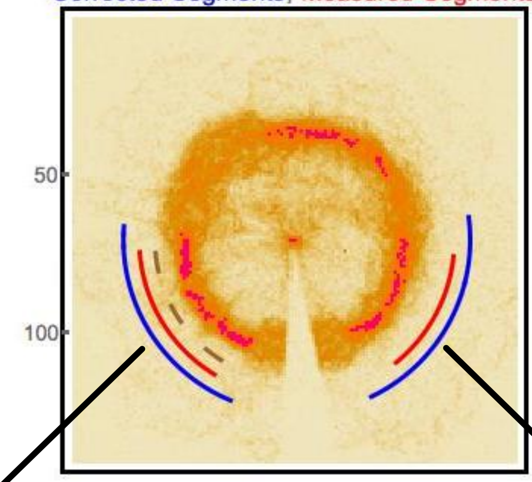
Correction 2 – X-ray testing

Key point

A factor of **>2** improvement has been observed in X-rays from a single stage of correction.

After 1st Segment Correction Iteration

Corrected Segments; Measured Segments



Further results and information can be found in the paper:

Kilaru, K. et al., "Progress in differential deposition for improving the figures of full-shell astronomical grazing incidence x-ray optics", *Proc. of SPIE 9603, 96031F, 2015*

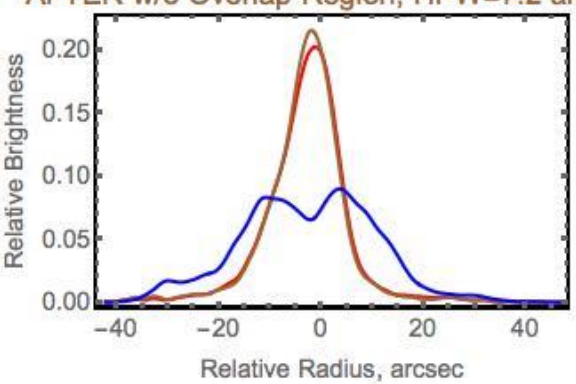
Radial Brightness Profiles across Ring

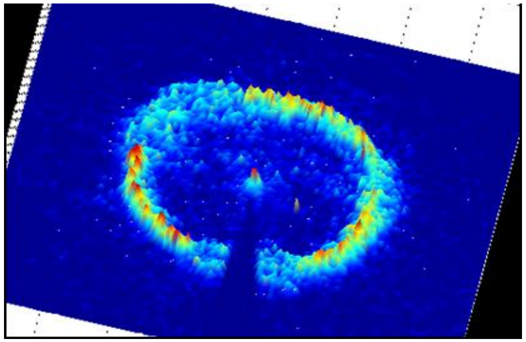
40mm from Focus

BEFORE Correction, HPW=17.7 arcsec

AFTER Correction, HPW=7.8 arcsec

AFTER w/o Overlap Region, HPW=7.2 arcsec





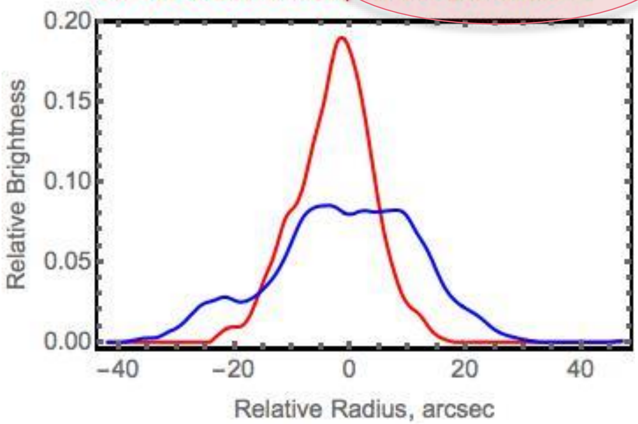
Higher frequency- correction

Radial Brightness Profiles across Ring

40mm from Focus

BEFORE Correction, HPW=16.3 arcsec

AFTER Correction, HPW=8.5 arcsec



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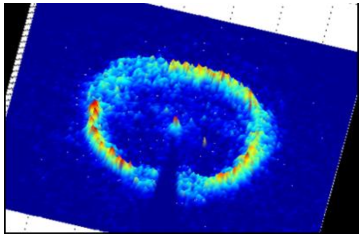
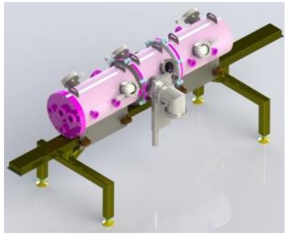
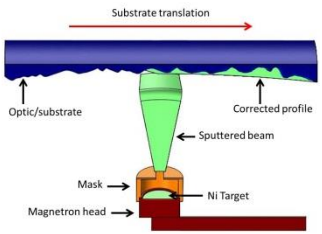
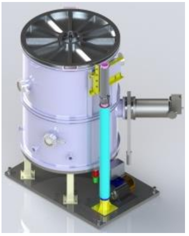
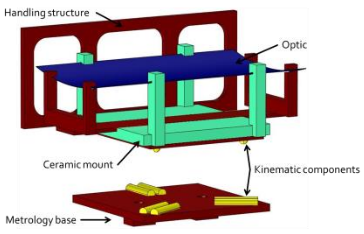




Challenges for segmented glass correction

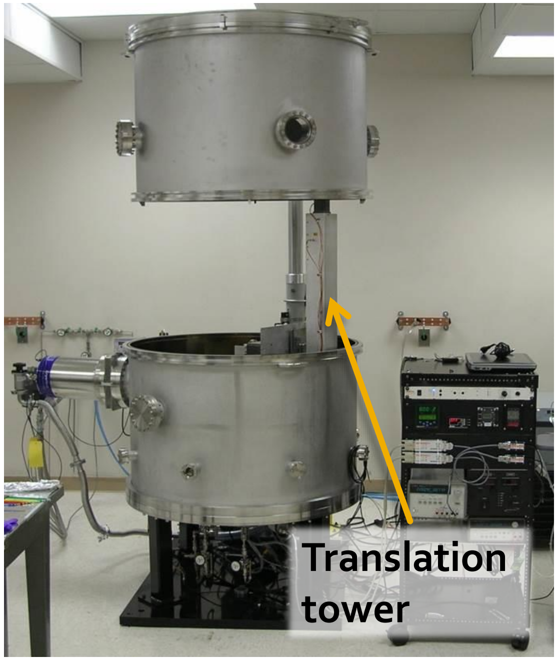
SEGMENTED GLASS OPTICS

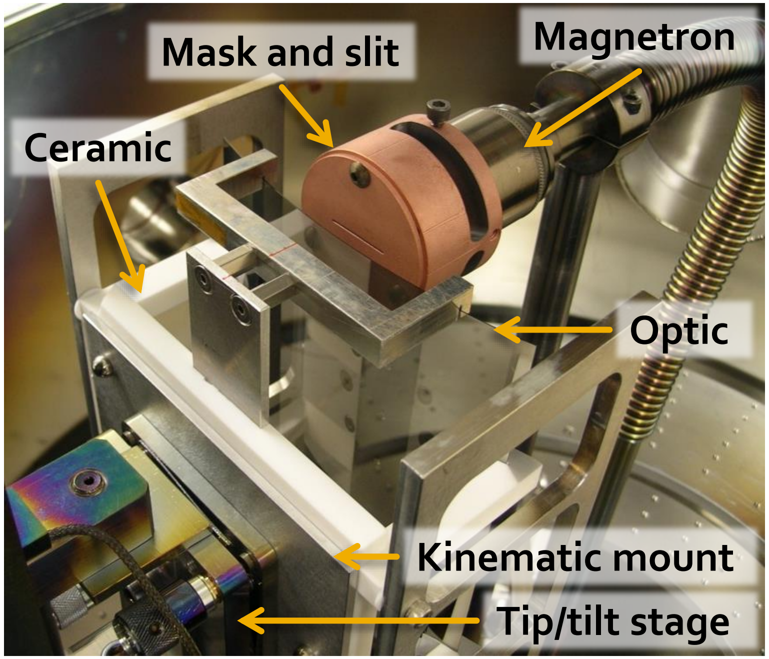
- Shape – segmented, leading to a less rigid structure.
- Material – borosilicate, lightweight, but easily deformed.
- Mounting – point fixture, where the optics are held at discreet points.

NI-CO REPLICATED OPTICS

- Shape – full shell, rigid structure.
- Material – Ni-Co alloy, heavier but less prone to deformation.
- Mounting – collet fixture, where the optic is held uniformly around its circumference.

Vertical chamber hardware

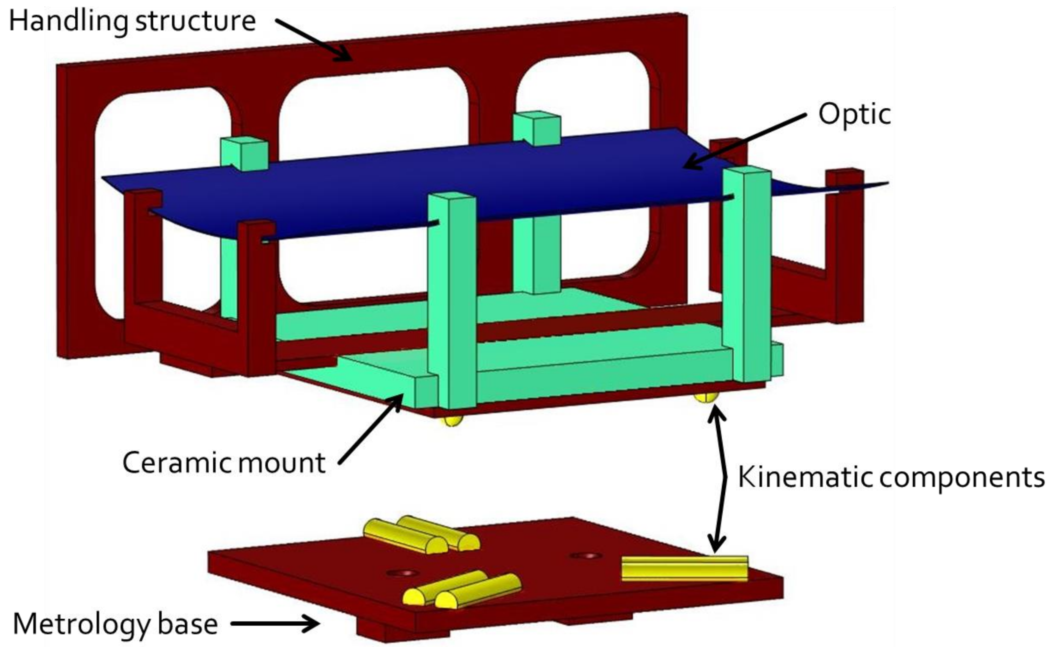




The slumped glass optics presented have been developed by NASA GSFC.

- 1m in diameter, 1.3m in height.
- Vertical translation provided by a portable tower which has a travel of ~680mm in the vertical direction.
- The 360° rotation is provided by an annular platform.
- Optical encoders are used on both the translation and rotation to ensure accurate positioning and feedback.
- A 1 inch DC magnetron is to sputter the material for the differential deposition process.

Metrology – Form Talysurf



Due to the requirement for accurate alignment and repeatability a kinematic mount has been developed to ensure accurate positioning of the optic relative to the profiler's stylus between coatings.

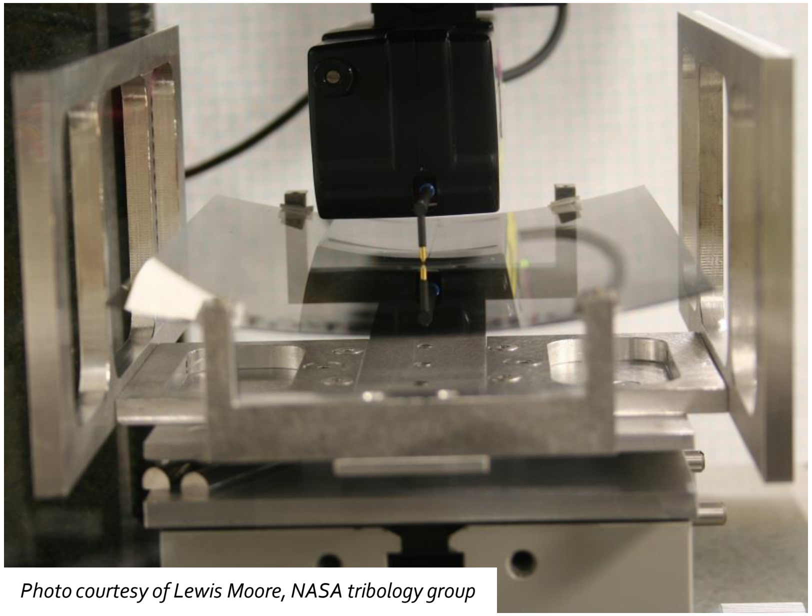
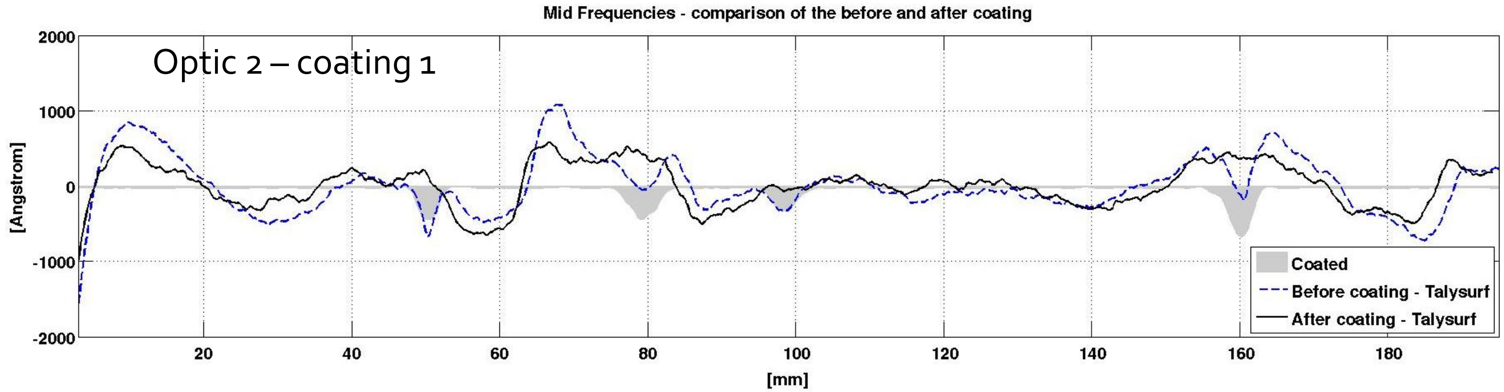


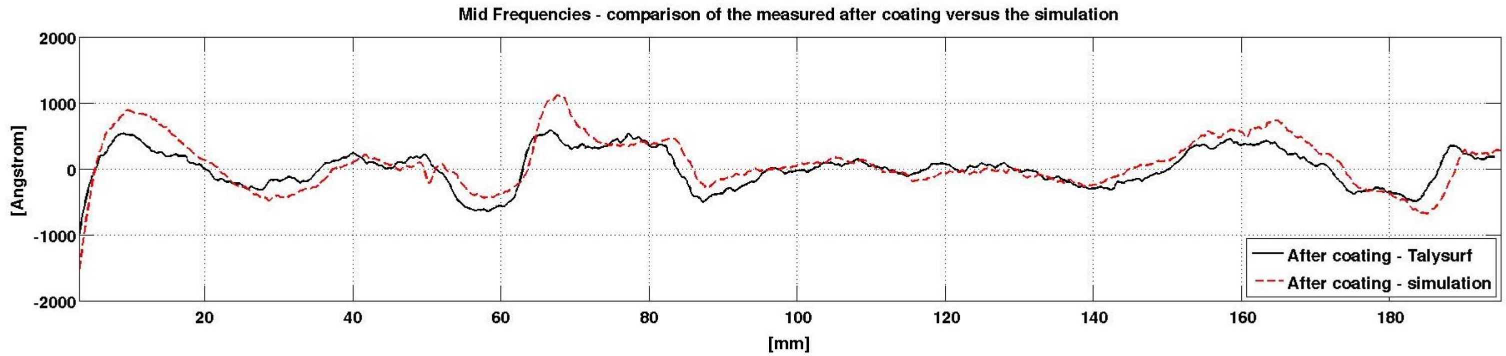
Photo courtesy of Lewis Moore, NASA tribology group

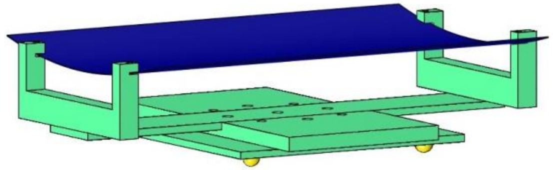
The final profile, which is used to define the required correction, is composed of 2 sets of 5 repeat measurements with the optic being repositioned between each set.

Typically the accuracy of alignment between placements is within 10/20 microns.

Initial experimentation: Optic 2, coating 1



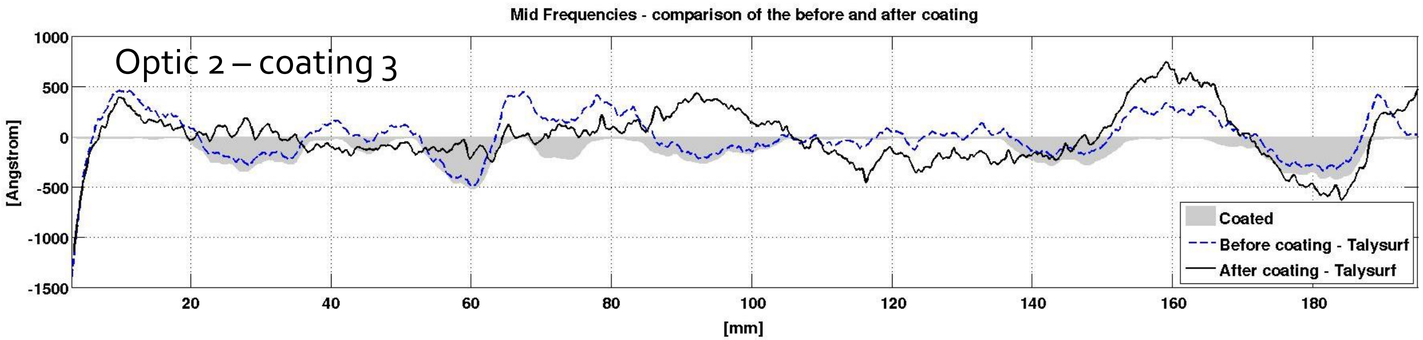


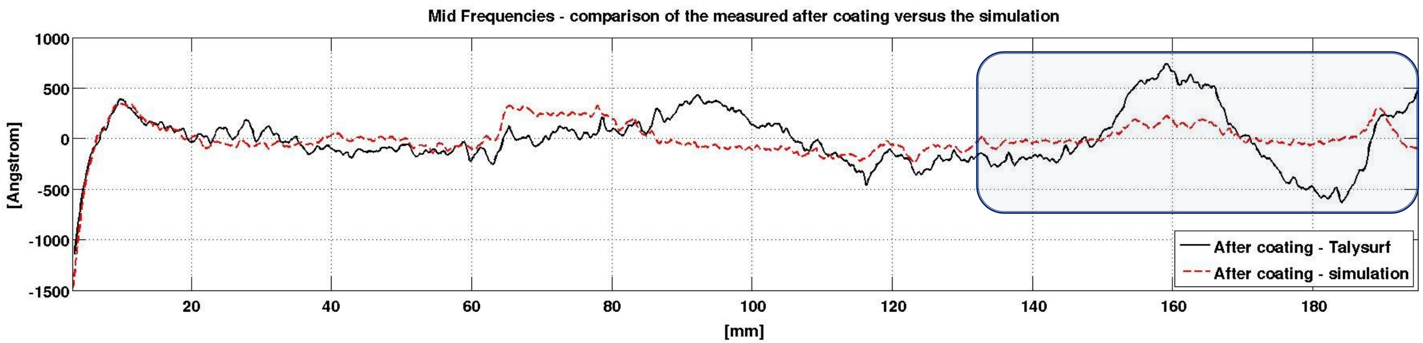


Initial experimentation used an aluminium fixture which held the optic along its azimuthal length.

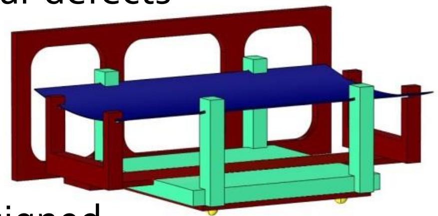
Successful corrections were obtained from targeting small localised regions.

Initial experimentation: Optic 2, coating 3





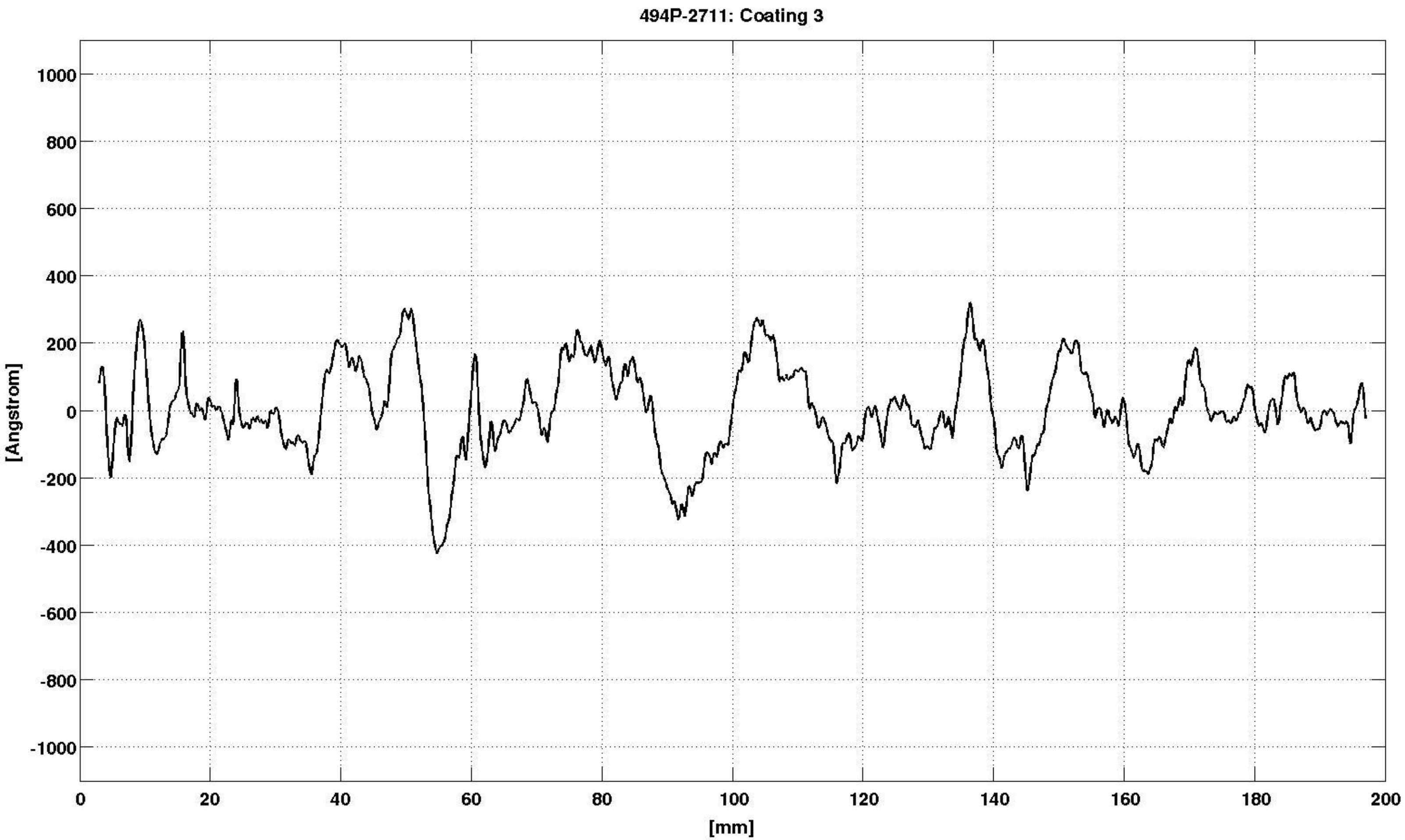
The third coating was successful in correcting the first half of the optic; however the latter half exhibited an artefact. Furthermore subsequent optics all demonstrated similar defects after 1-3 coatings.



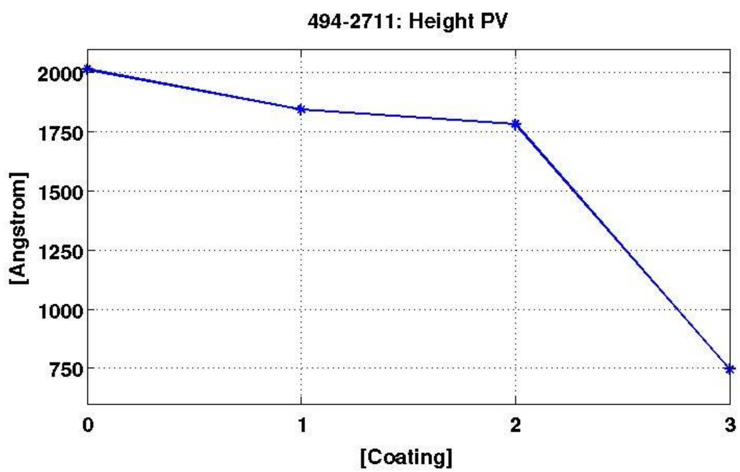
The following were investigated: **stress**, **mounting** and **thermal** effects.

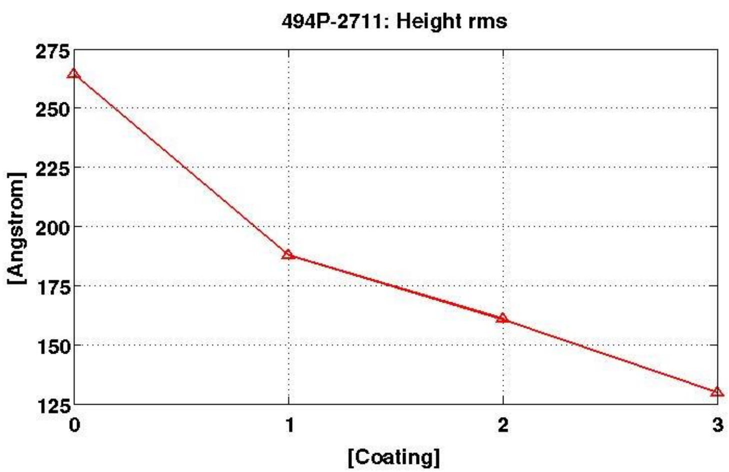
Results indicated that **all three** could be factors and as such the mount was redesigned with ceramic components (to match the optic's cte) in addition to different fixture points.

Ceramic mount results



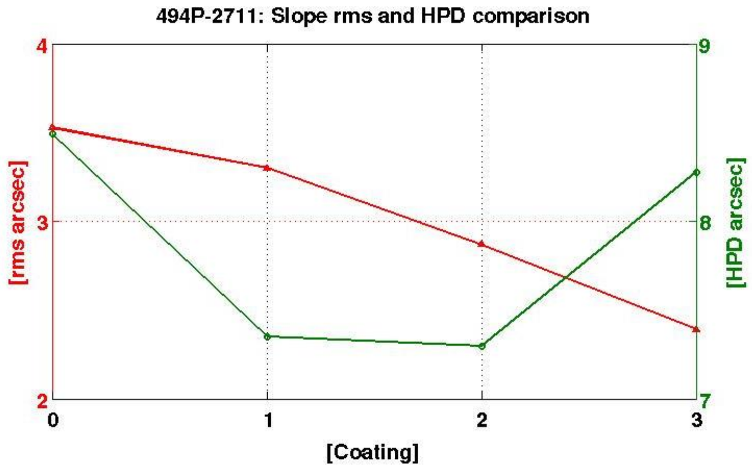
Ceramic mount results





These initial results from the ceramic mount demonstrate the gradual improvement of the slumped glass optic after each coating.

Further coatings upon this optic were abandoned due to loss of positioning accuracy, this has been rectified for future optics and coatings.



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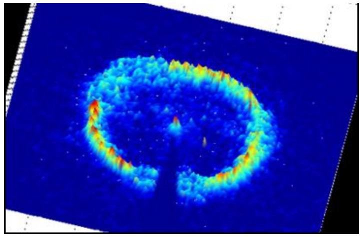
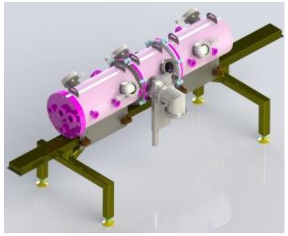
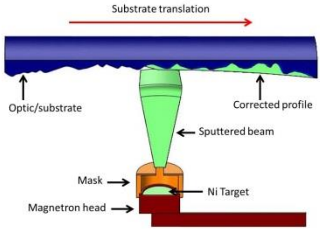
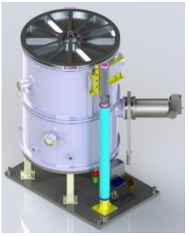
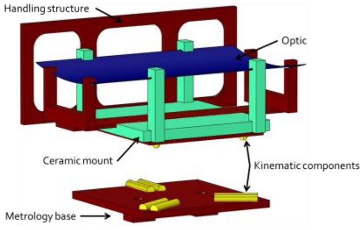
- Horizontal chamber
- Vertical chamber
- Summary, conclusion and future work

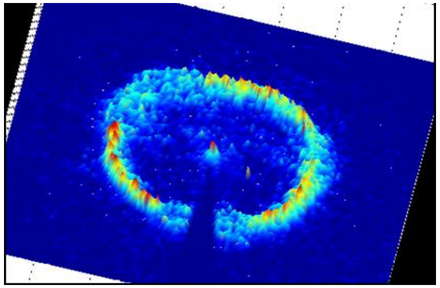




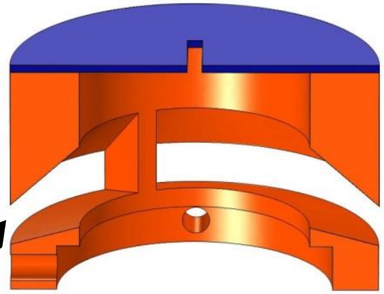
Summary, conclusion and future work: Horizontal

Summary and conclusion

- An improvement of a factor **>2** has been measured in X-rays from a NiCo full shell astronomical optic.
- Improvements by a factor of **3** are observed in VLTP metrology data.

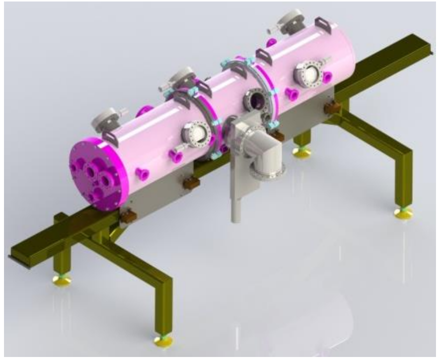


- Results indicate that **overlap regions** between meridians and undesired **scatter** from the gas inlets of the magnetron mask are currently limiting the full scope for the correction.

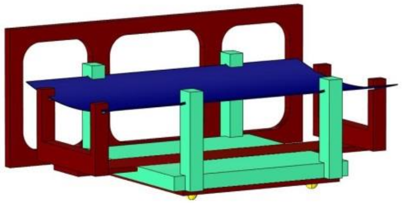


Future work

- To perform a full 360° correction of a NiCo full shell astronomical optic.
- To use different width slits to target different spatial frequencies to further improve the resolution.
- To improve the efficiency of the Differential Deposition process through incorporating *in-situ* metrology.



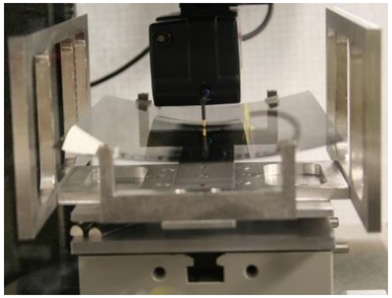
Summary, conclusion and future work: Vertical



Summary and conclusion

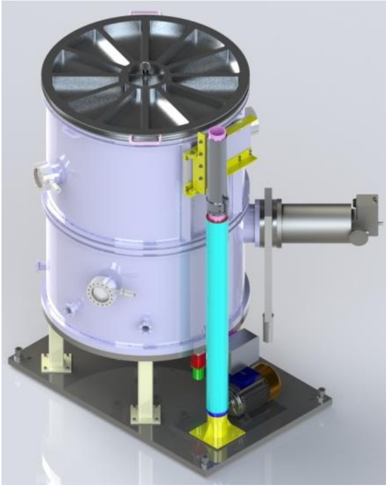
- The differences and challenges of the slumped glass optics versus the NiCo optics have been identified.
- Early results were presented which indicated sensitivity of the glass optics to: stress, mounting and thermal effects.
- The redesigned ceramic mount demonstrated successful corrections after several coatings.

- Slumped glass optics can be corrected via the Differential Deposition method.



Future work

- To ensure consistent correction after several coating using the ceramic mount.
- To implement the single meridian correction into a global full optic correction.



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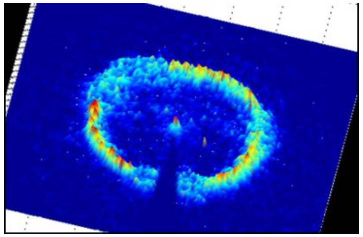
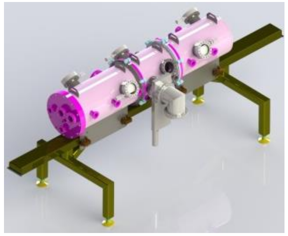
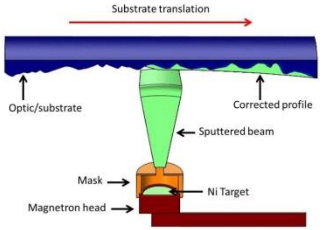
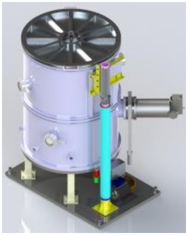
- All those who helped in the construction of the vacuum chambers.
- and the X-ray astronomy group at NASA's MSFC

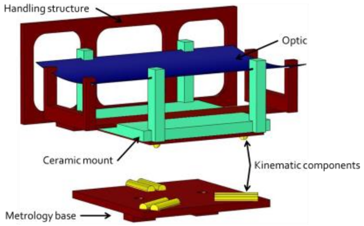
Thank you for your attention!











Initial Results – Stress?

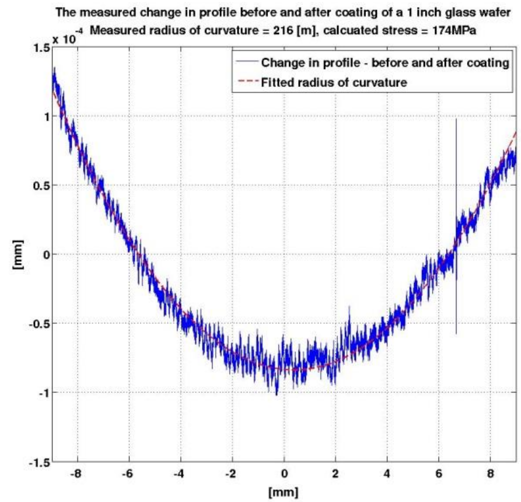
Stress in a thin film can be estimated using Stoney's equation,

$$\sigma_f = \frac{E * h^2}{(6 * (1 - \nu) * roc * t_f)}$$

σ_f = film stress
E = Young's modulus of the substrate
ν = Poisson's ratio of the substrate
roc = measured change in radius of curvature
t_f = film thickness

Borosilicate Glass wafer	Measured stress [MPa]
Wafer 1	119
Wafer 2	175
Wafer 3	172
Wafer 4	248

Average measured stress = 179MPa (Tensile)

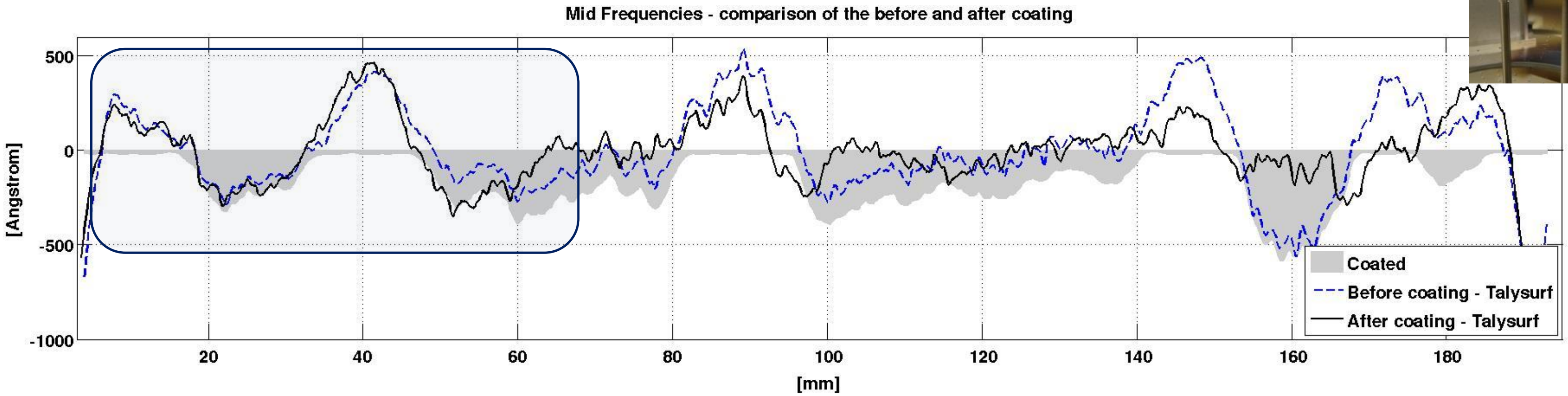


This is an active area of investigation with several options: -

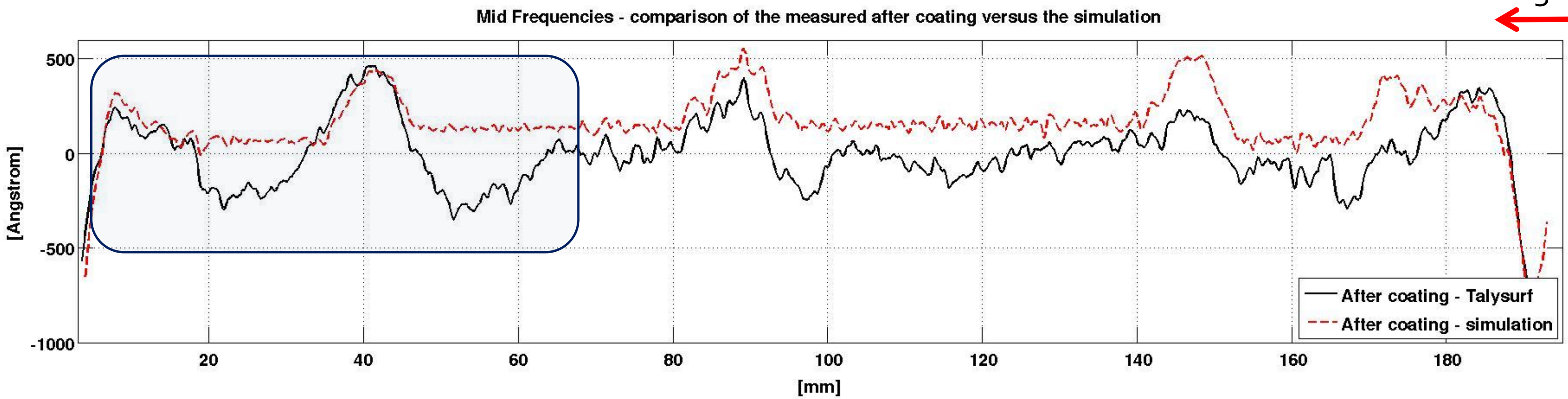
1. Reduce the stress through changing the coating parameters (gas pressure, power etc.)
2. Create an FEA model of the stress to predict its effects.
3. Use the stress to correct the low order spatial frequencies within the surface.

Initial Results – Mounting

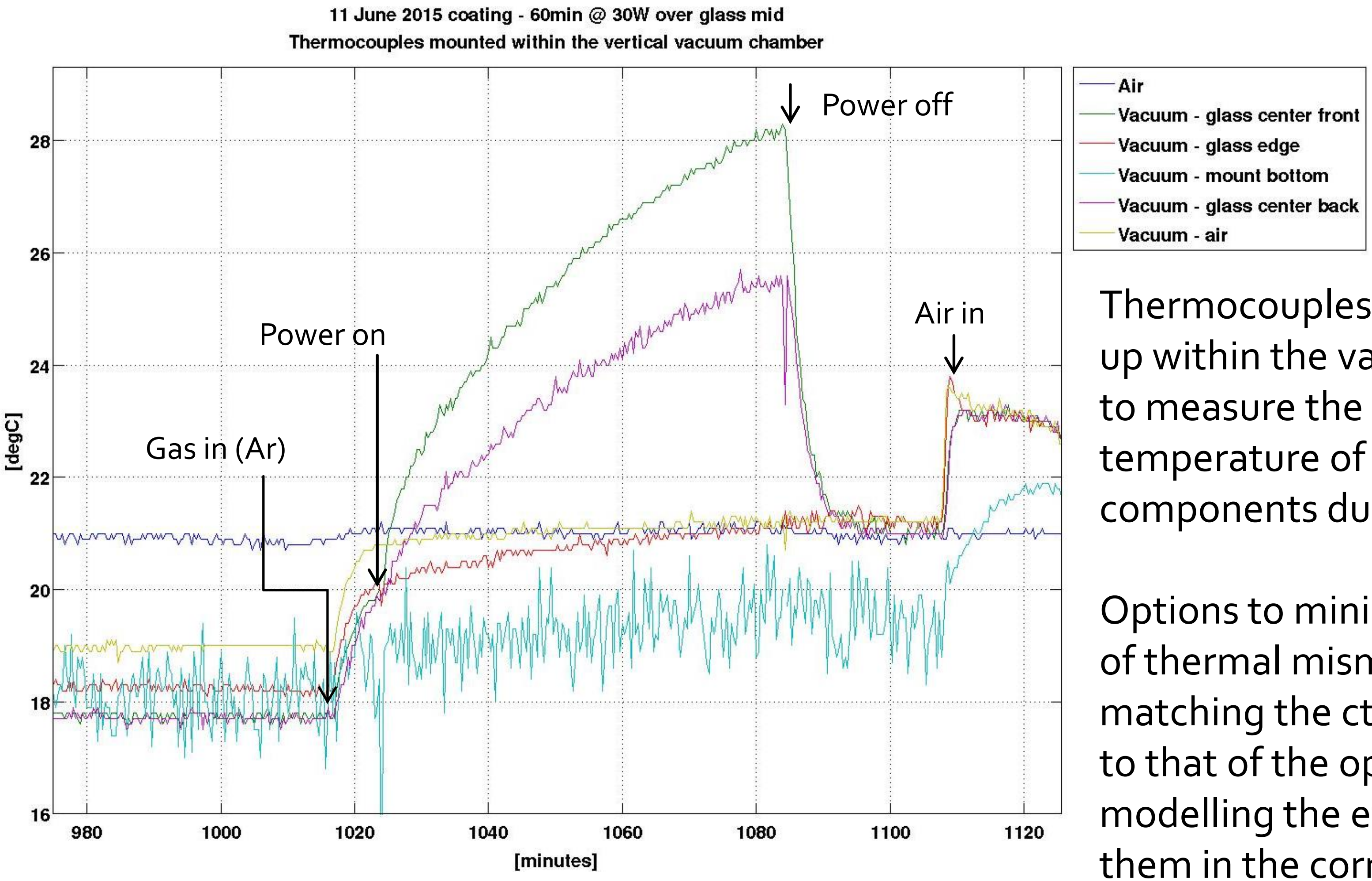
Second, the mount was flipped to reverse the direction of coating to see if there was a mechanical influence. The results indicate that there could be a mechanical effect and this warrants further investigation.



Coating direction



Initial Results - Temperature



Thermocouples have been set up within the vacuum chamber to measure the surface temperature of different components during coating.

Options to minimise the effects of thermal mismatch include: matching the cte of the mount to that of the optic; and modelling the effects to offset them in the correction