Constellation-X Mirror Development: Achievements, Problems, and Prospects

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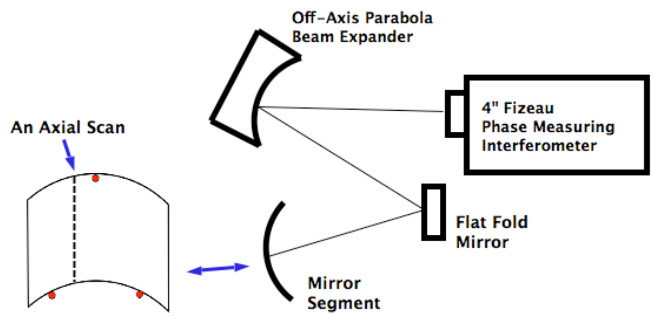
Fabrication

- Start with a sheet of commercially available borosilicate glass, 0.4mm thick
- Place it on a fused quartz mandrel whose surface has been treated to prevent sticking and provide other necessary properties for slumping
- Start a temperature cycle between between 20 and 600 degrees C

Metrology



- Mirror segment held at 3 points
- 25 axial scans for each mirror, one every 2 degrees
- Verification of the fabrication process
- Feedback to the fabrication process

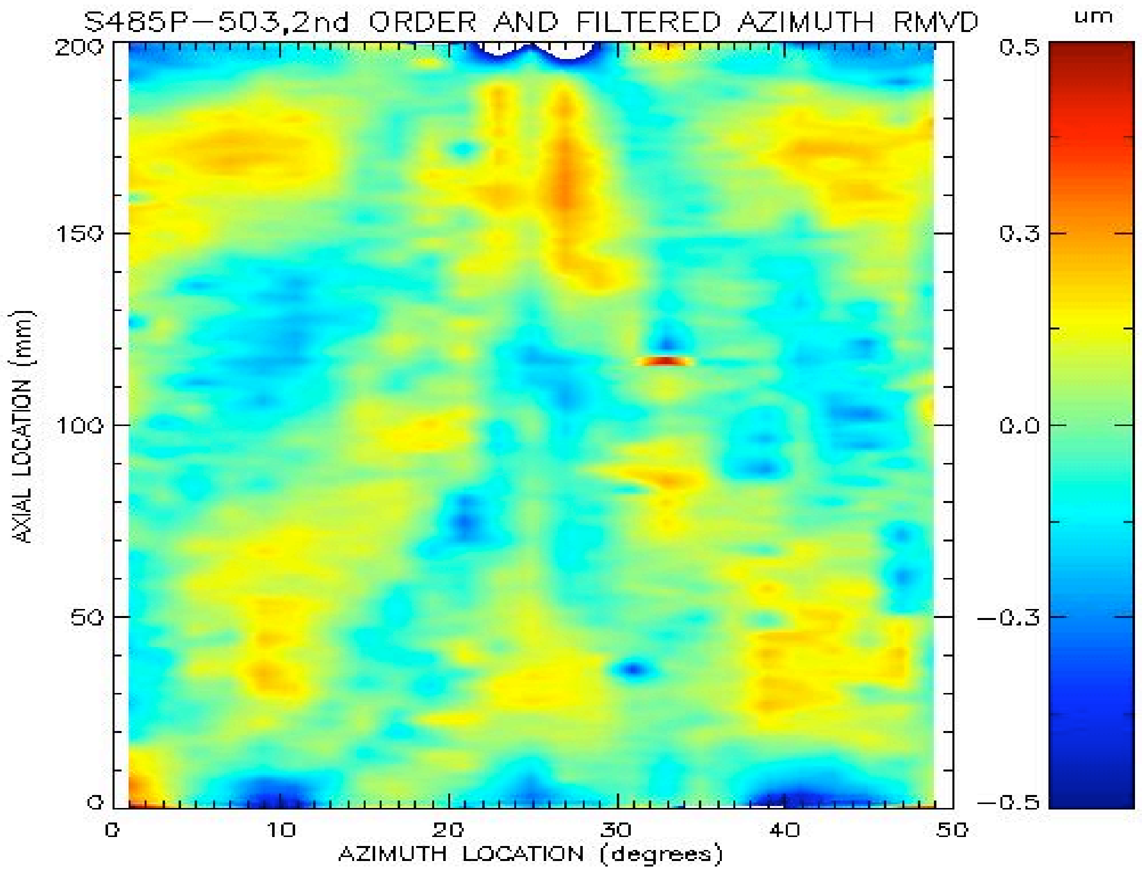
Goal: Make every mirror look exactly like the mandrel and prove it

Development Strategy

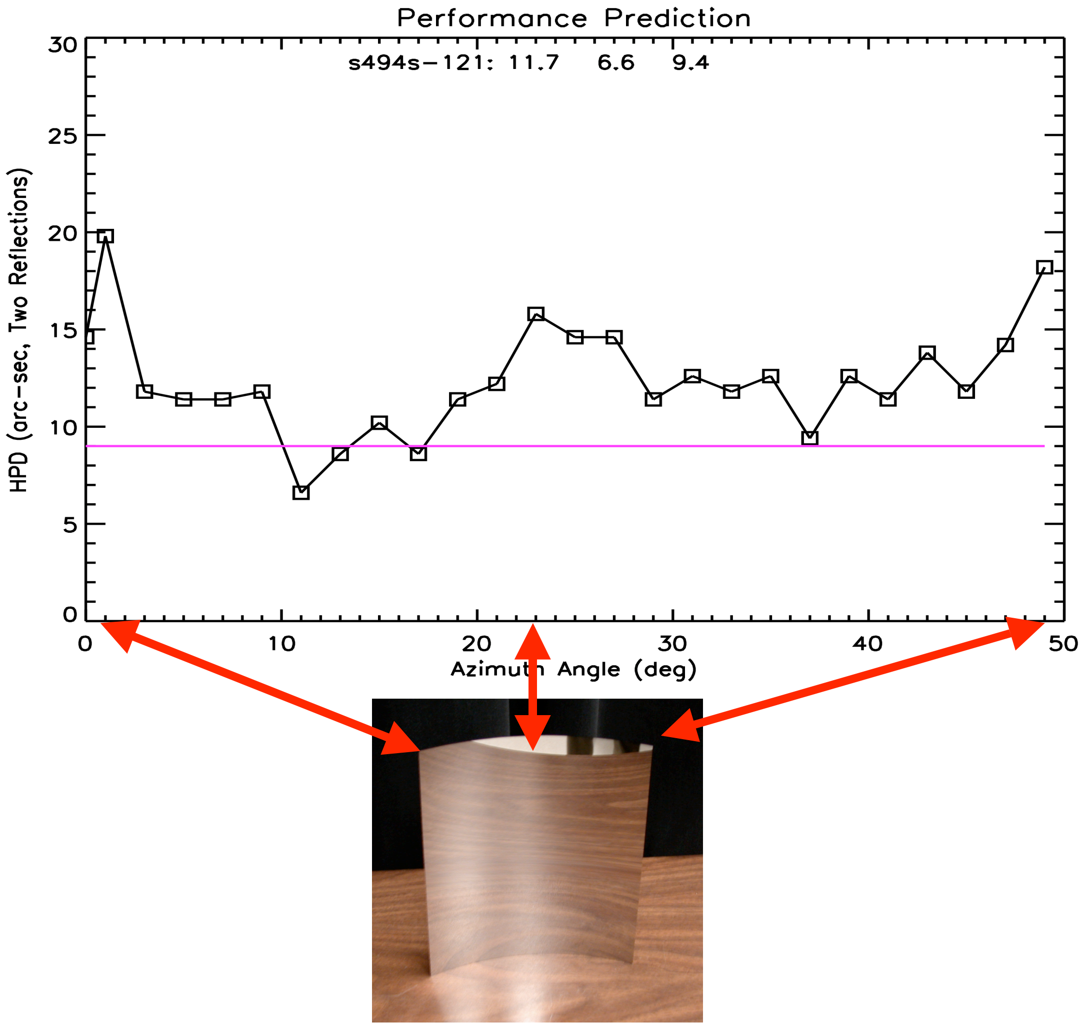
- Start with a technique that meets **three** (effective area, mass, and production cost) of the **four** requirements, work on the fourth one (**angular resolution**)
- Pursue **reproducibility**, or process determinism: making all the mirrors look alike
- Pursue **traceability**: making all the mirrors look like the mandrels

Apparent Surface Map

(including both fabrication error and gravity distortion)

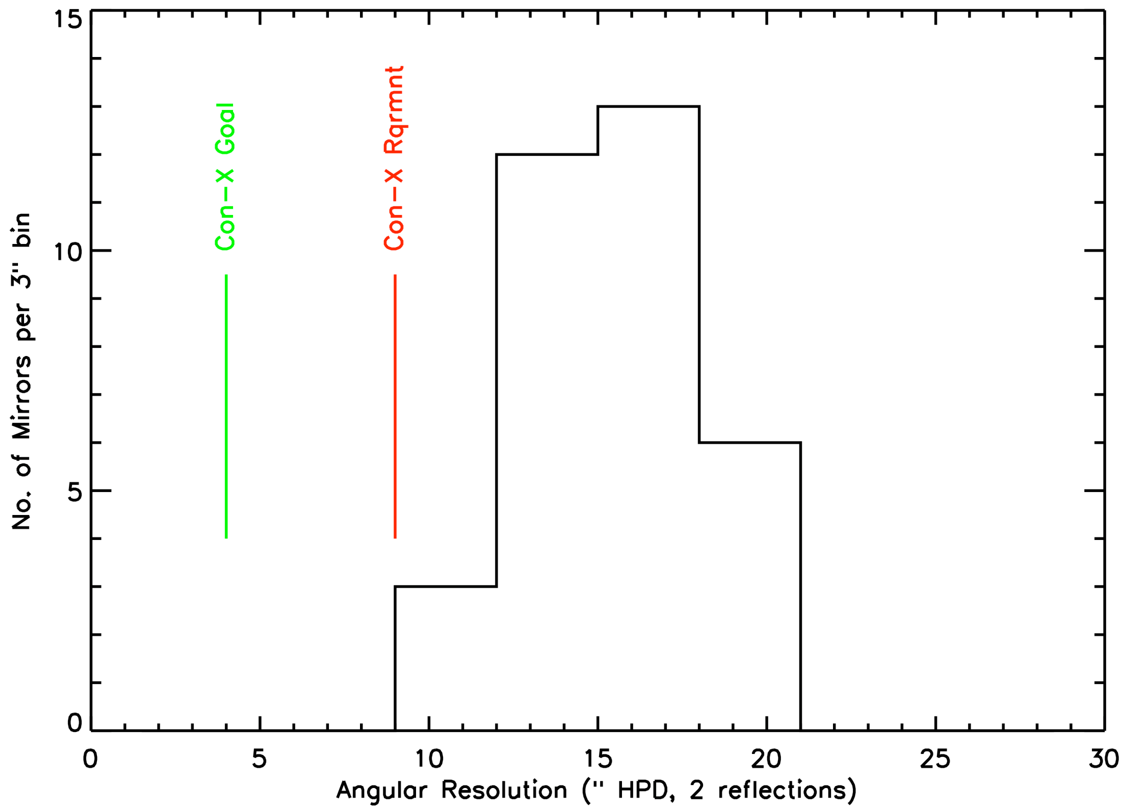


Mirror Apparent Axial Figure Error

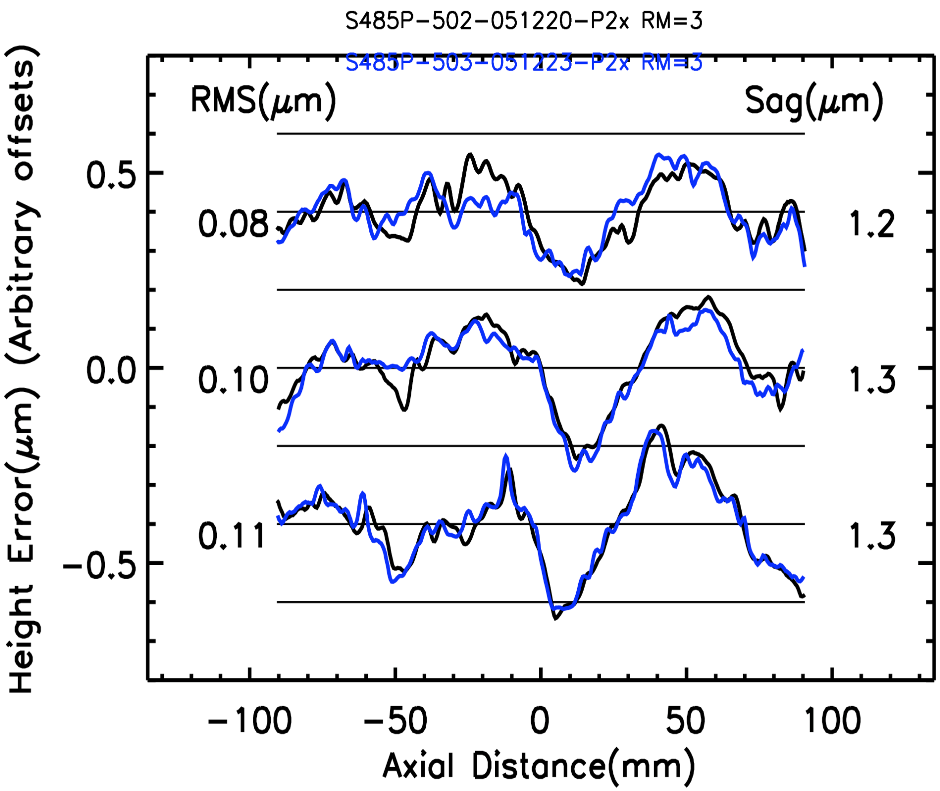


Distribution of Apparent Mirror Quality

(all mirrors produced between Jan and Apr 2006)



Repeatability: Slumping is a *deterministic* process



Necessary Conditions to Have Repeatability

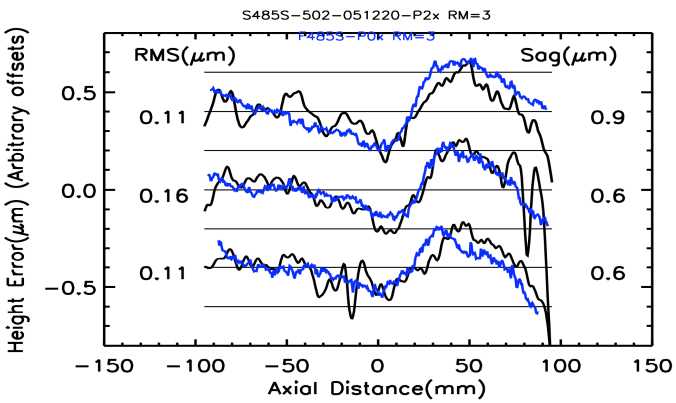
- Forming has to be good
- Metrology registration has to be good
- Distortion has to be very small or nearly identical

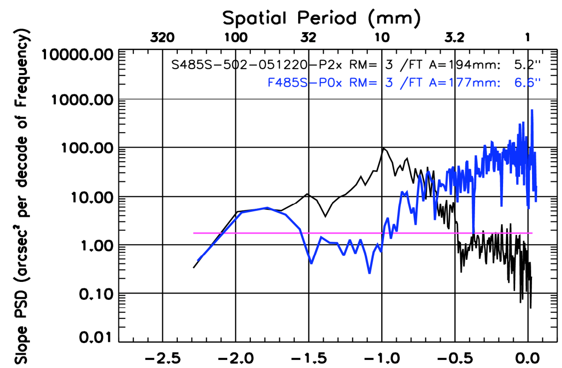
Best: 21nm RMS   Typical: 50nm RMS

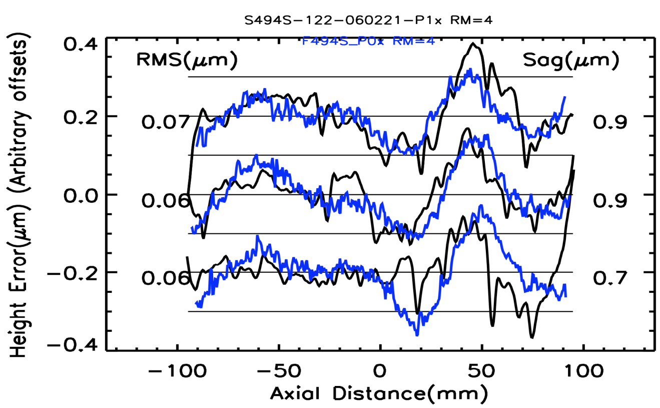
These numbers are most likely dominated by a lack of accurate cross registration, therefore should be considered as upper limits

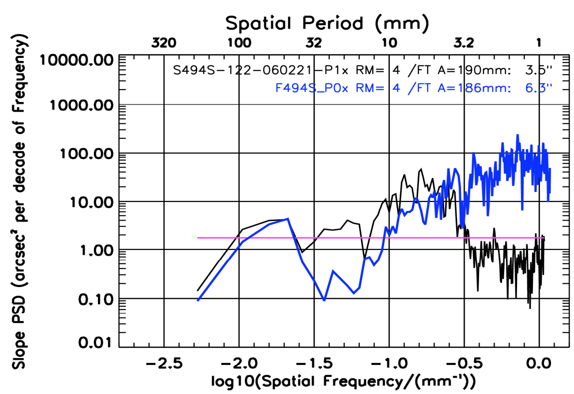
Comparison between Mandrel and Mirror

Black=Mirror; Blue=Mandrel

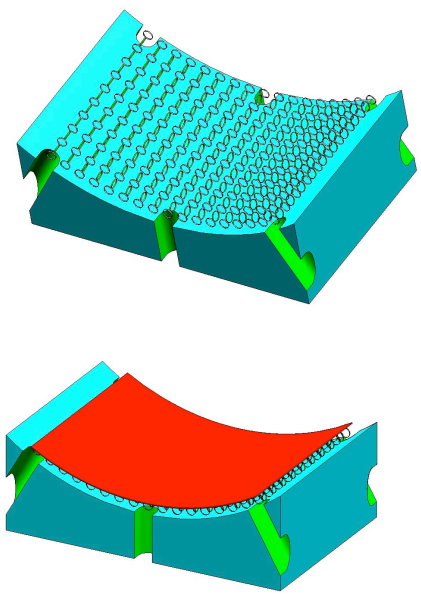


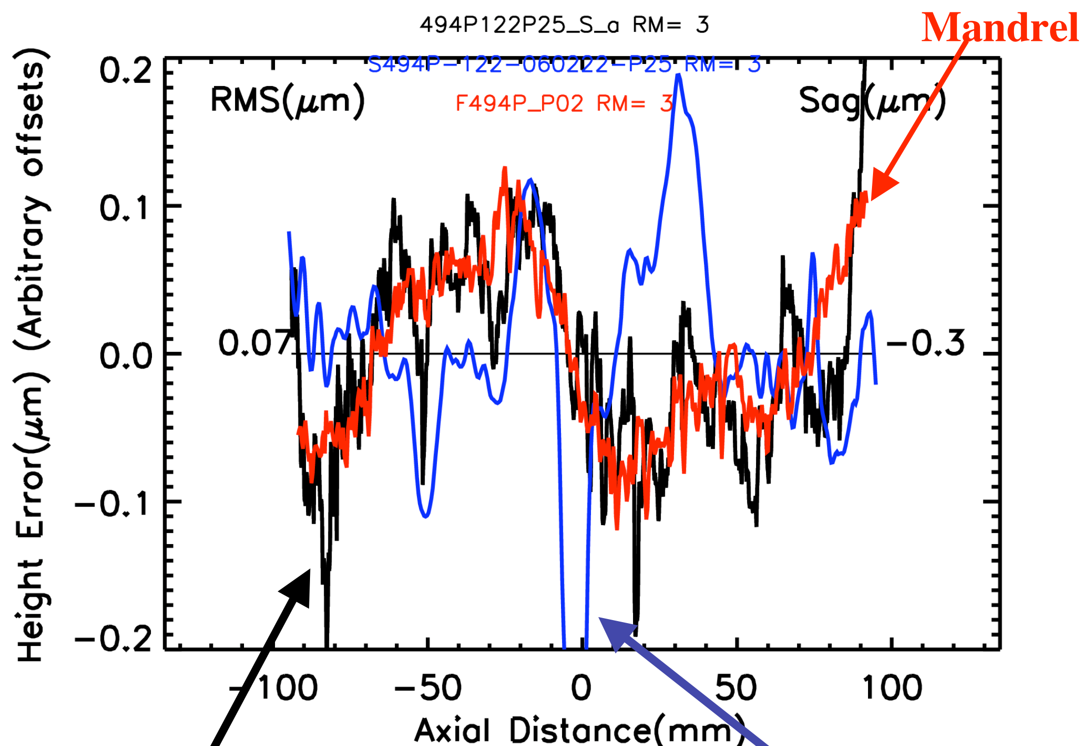






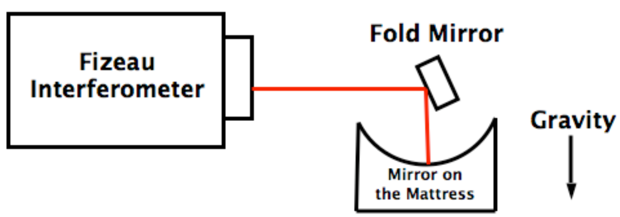
Result from a new mirror support





Black: with new support

Blue: with 3-point support



Error Decomposition Estimate

Overall Axial Figure	14.9			
	Mandrel	6.0		
	Metrology	10.0		
		Reference Optics	7.0	Easy to solve
		Gravity Distortion	7.0	Relatively easy
	Forming	9.2		
		Low Order Figure	2.0	
		Mid-Frequency Figure	8.5	No. 1 Issue
		Random Error	3.0	Potential of this technology

Summary of Status and Issus

- We have achieved excellent repeatability in slumping substrates
  - Typical: 50nm RMS
  - Best: 20nm RMS
  - These mirrors, when properly integrated, are expected to perform better than 20 arcsec (HPD, 2 reflections)
- We need to address the following issues
  - Metrology
    - Use better reference optics: commission of a new 10-in interferometer
    - Construct better mirror holding fixture: mattress
  - Understand, reduce/eliminate the mid-frequency error

Mid-frequency Problem and Its Solution

- Cause: dust from the slumping environment and detritus resulting from the release layer
- Solution:
  - Better slumping environment: clean oven
  - Improved mandrel surface release layer

Prospects

- Almost all technological aspects of the mirror fabrication are understood and going very well:
  - Problems are well defined
  - Solutions are being implemented
- In all likelihood, we will be able to do significantly better than the SXT baseline requirements. By the end of this year we should be able to quantitatively gauge
  - whether the present technology can achieve the SXT goal of 5 arcsec
  - What specific things we need to do to reach the goal

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SXT Mandrel Challenge in Perspective

	Con-X	XMM	Chandra	JWST
No. of Assy.	4	3	1	1
No. of Shells per Assy.	216	58	4	NA
Total Mirror Area (m^2) of the Observatory	883	158	19	36
Total Mandrel Area (m^2)	28	53	19	36

Manufacture of SXT mandrels is NOT challenging in historic terms.

- Comparable to, or easier than, XMM's mandrels because of smaller area
- Much easier than Chandra's mirrors because of much less stringent figure requirements
- Much easier than JWST mirrors because there are no lightweighting or cryogenic requirements

Mirror Segment Description

Interferometer

Coordinate Measuring Machine

$$\rho(z,\phi) = \rho_0(\phi) + z\cdot\tan\theta(\phi) - \left(\frac{2z}{L}\right)^2 \cdot s(\phi) + R(z,\phi)$$

$$\rho_0(\phi) = \rho_0 + \Delta\rho(\phi)$$

$$\theta(\phi) = \theta_0 + \Delta\theta(\phi)$$

$$s(\phi) = s_0 + \Delta s(\phi)$$

By definition/convention, all the Delta terms (azimuth dependent) have zero means. So does also the R(z,phi) term.

Mirror Parameters

Mirror Parameter		Metrology Equipment	Challenge	Comment	Status
Radius	Average Radius ($\rho_0 + \Delta\rho_0$)	Cylindrical coordinate measuring machine	Gravity distortion Mount distortion	Single number	Work in progress; Current measurements unreliable due to gravity and mount distortion
	Radius Variation ($\Delta\rho(\phi)$)			Having frequency content	
Cone Angle	Average Cone Angle ($\theta_0 + \Delta\theta_0$)			Single number	
	Cone Angle Variation ($\Delta\theta(\phi)$)			Having frequency content	
Axial Figure	Average Sag ($S_0 + \Delta S_0$)	Fizeau phase measuring interferometer, as shown in Figure 3	Gravity distortion Mount distortion	Single number	Current measurements unreliable due to gravity and mount distortion
	Sag Variation ($\Delta S(\phi)$)			Having frequency content	
	Low Frequency Figure (0.005 – 0.05 mm^{-1}) or (200 – 20 mm period)			Having frequency content	**Current measurements probably affected by gravity and mount distortion**
	Middle Frequency Figure (0.05 – 0.5 mm^{-1}) or (20 – 2 mm period)		Reference optics figure error	Having frequency content	**Current measurements slightly affected by mid-frequency errors on reference optics**
	High Frequency Figure ($>$ 0.5 mm^{-1}) or ($<$ 2 mm period)	Interferometric surface profiler	None	Having frequency content	Work in progress

Application to Normal Incidence Optics