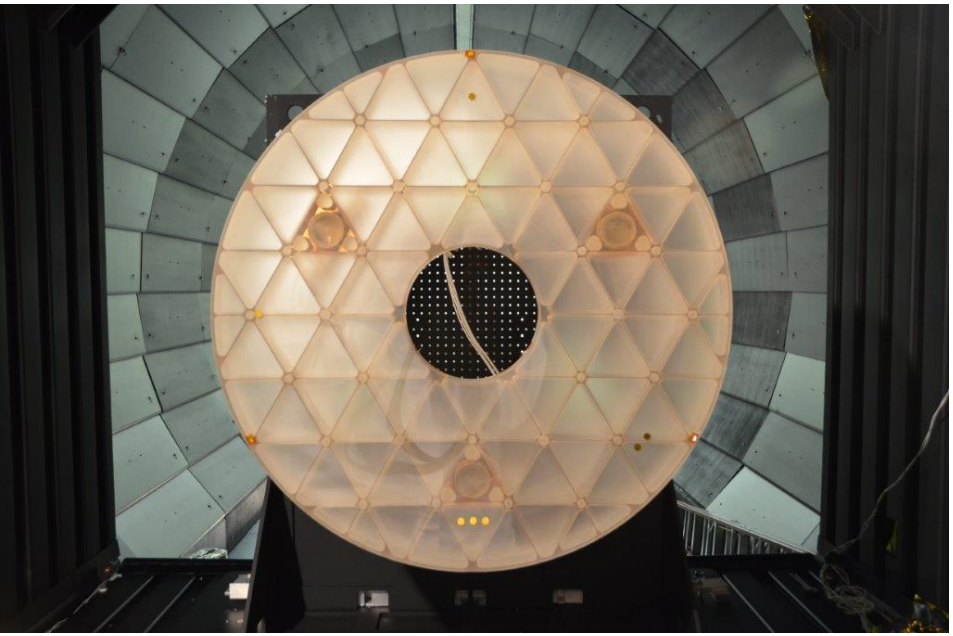
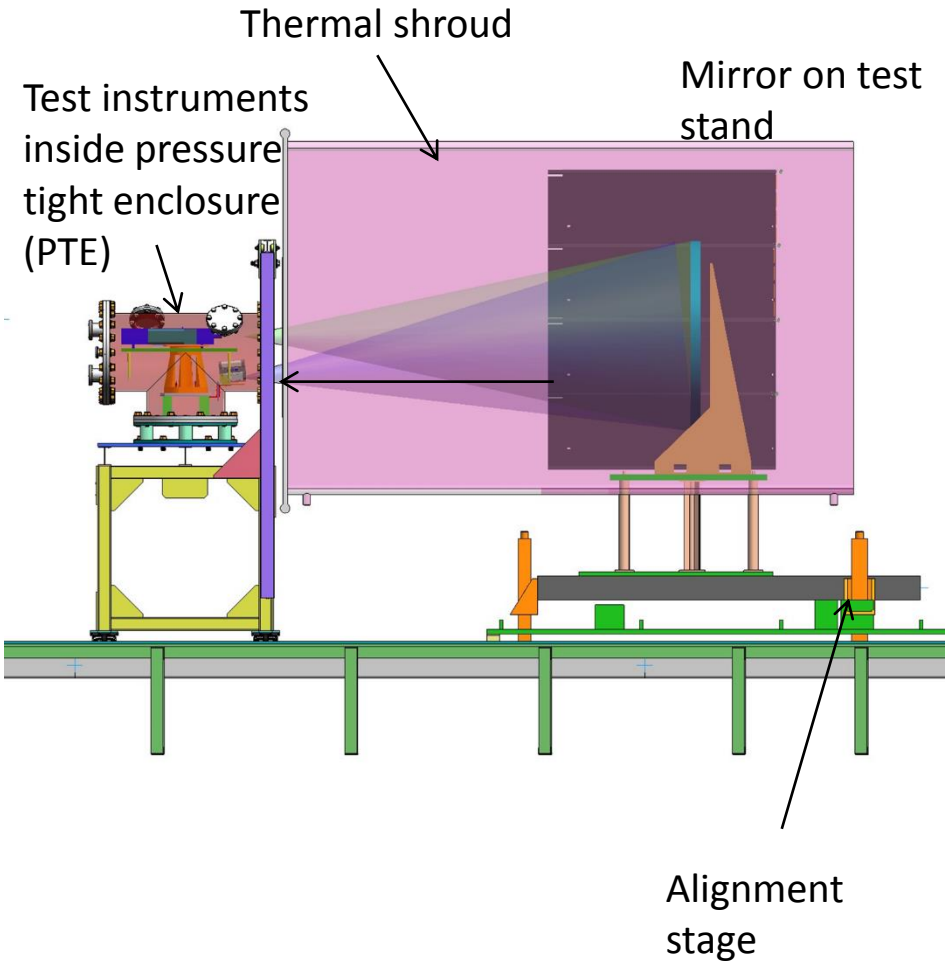
Modeling the Extremely Lightweight Zerodur Mirror (ELZM) thermal soak test

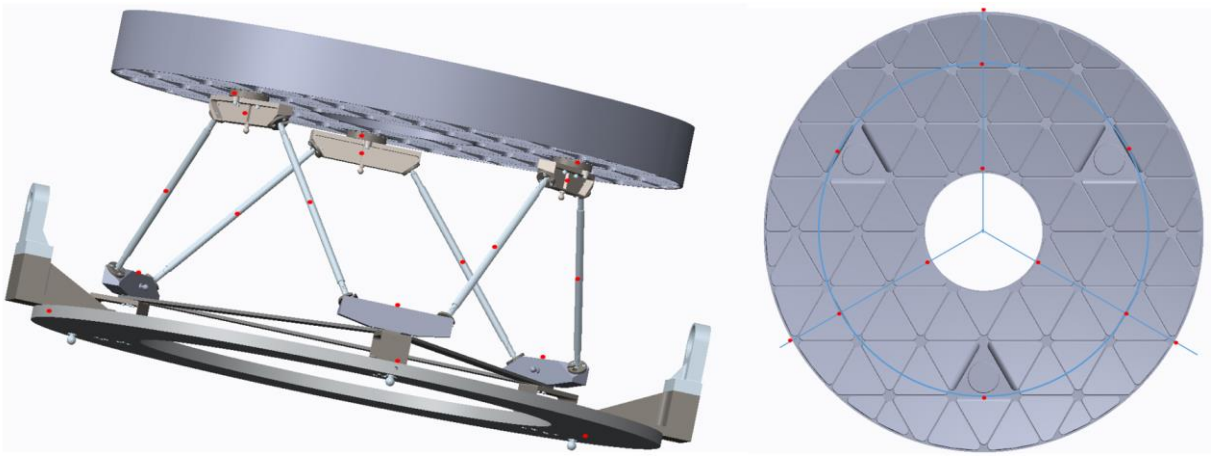
Thomas Brooks
Marshall Space Flight Center
256.797.3147

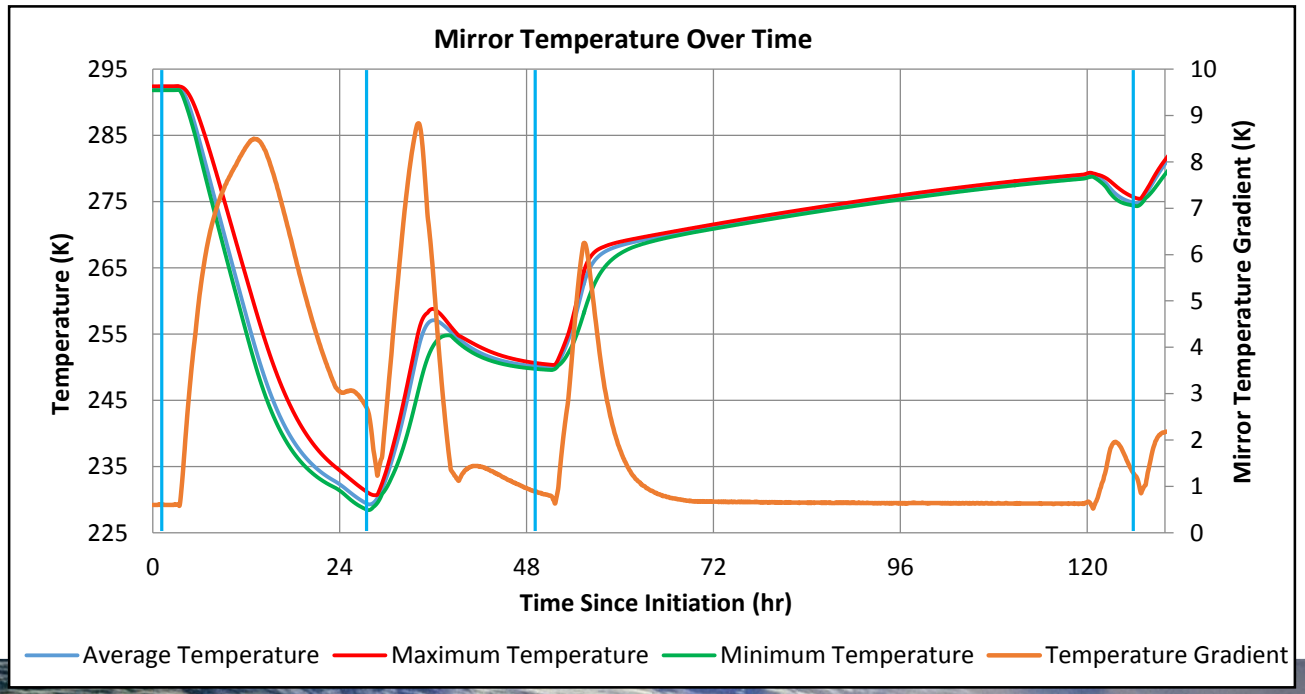
Opto-thermal test of Zerodur Mirror



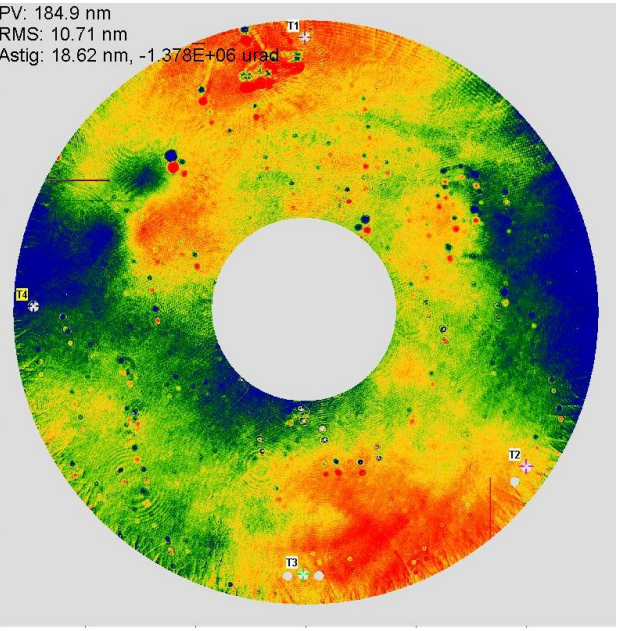


Temperature Measurements

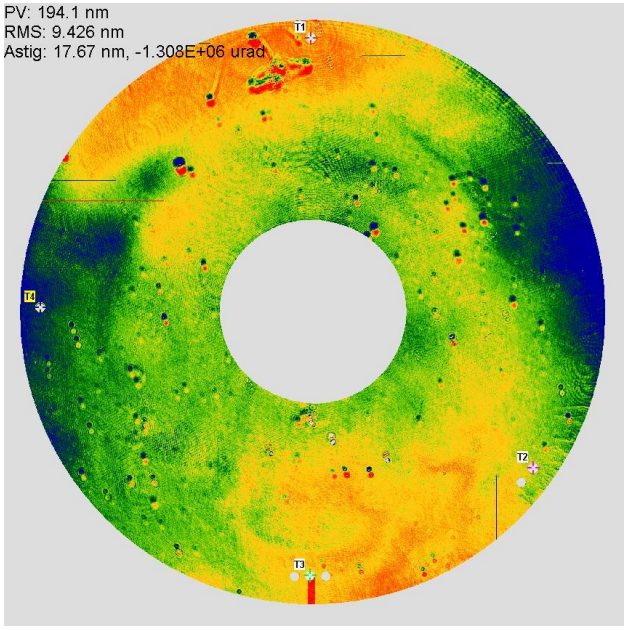




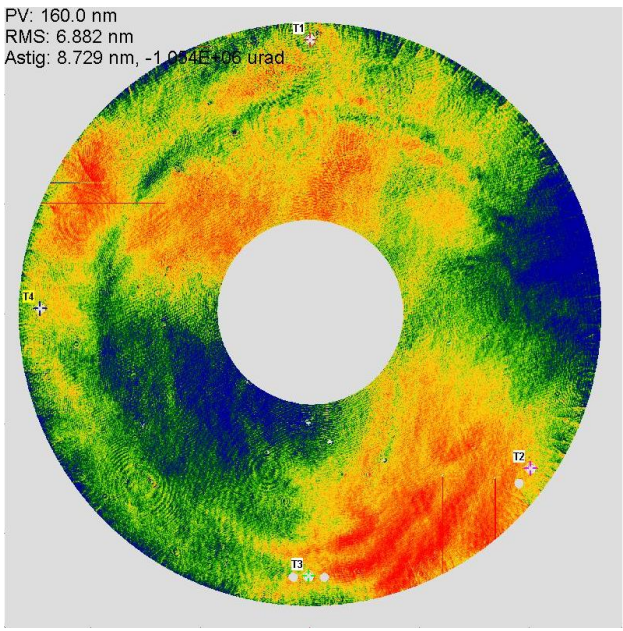
Surface Measurements



Surface at 230K - Surface at 292K
RMS SFE = 10.7nm
P-V SFE = 185nm



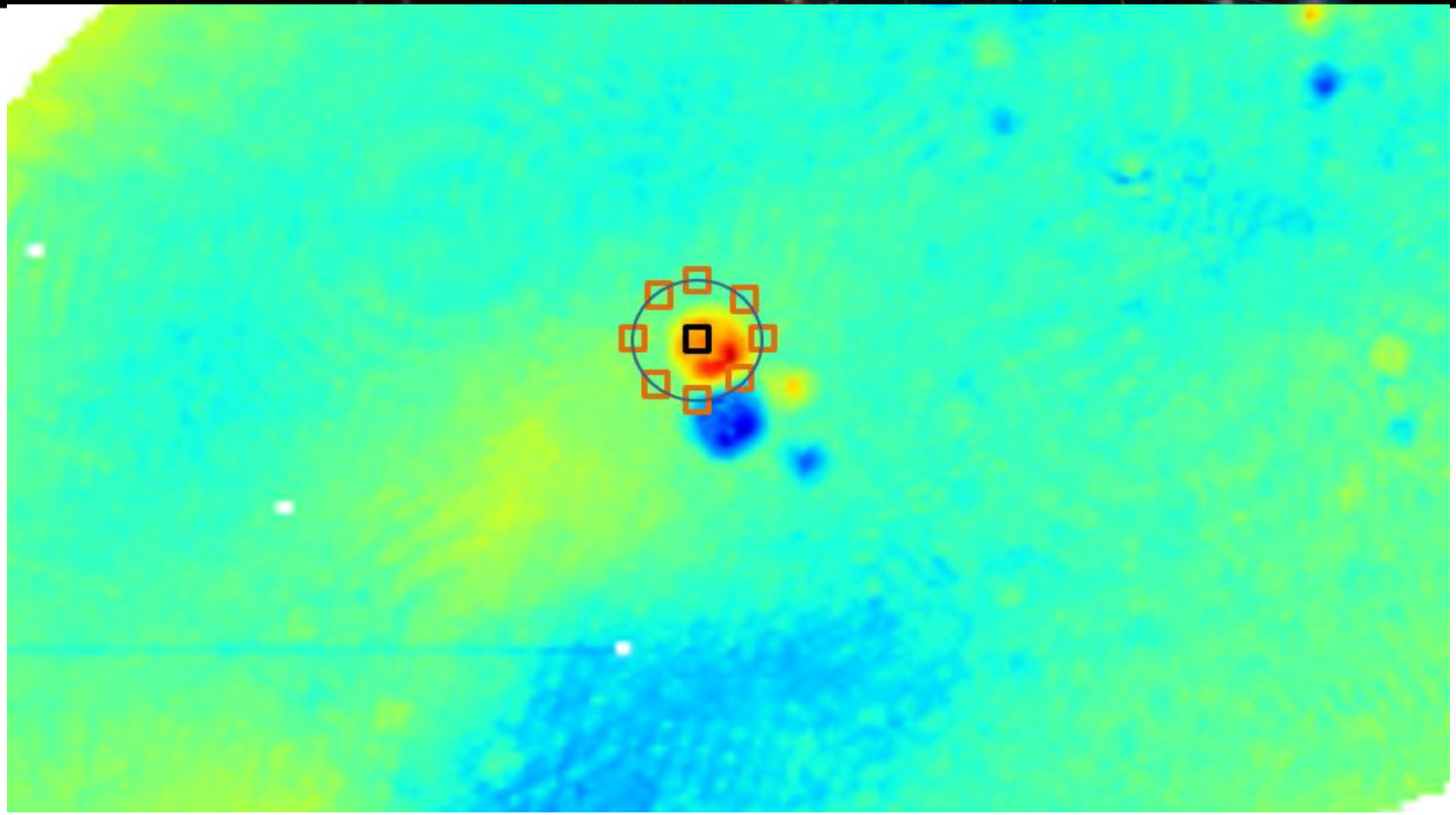
Surface at 250K - Surface at 292K
RMS SFE = 9.4nm
P-V SFE = 194nm



Surface at 275K - Surface at 292K
RMS SFE = 6.9nm
P-V SFE = 160nm

Test Repeatability of 6nm

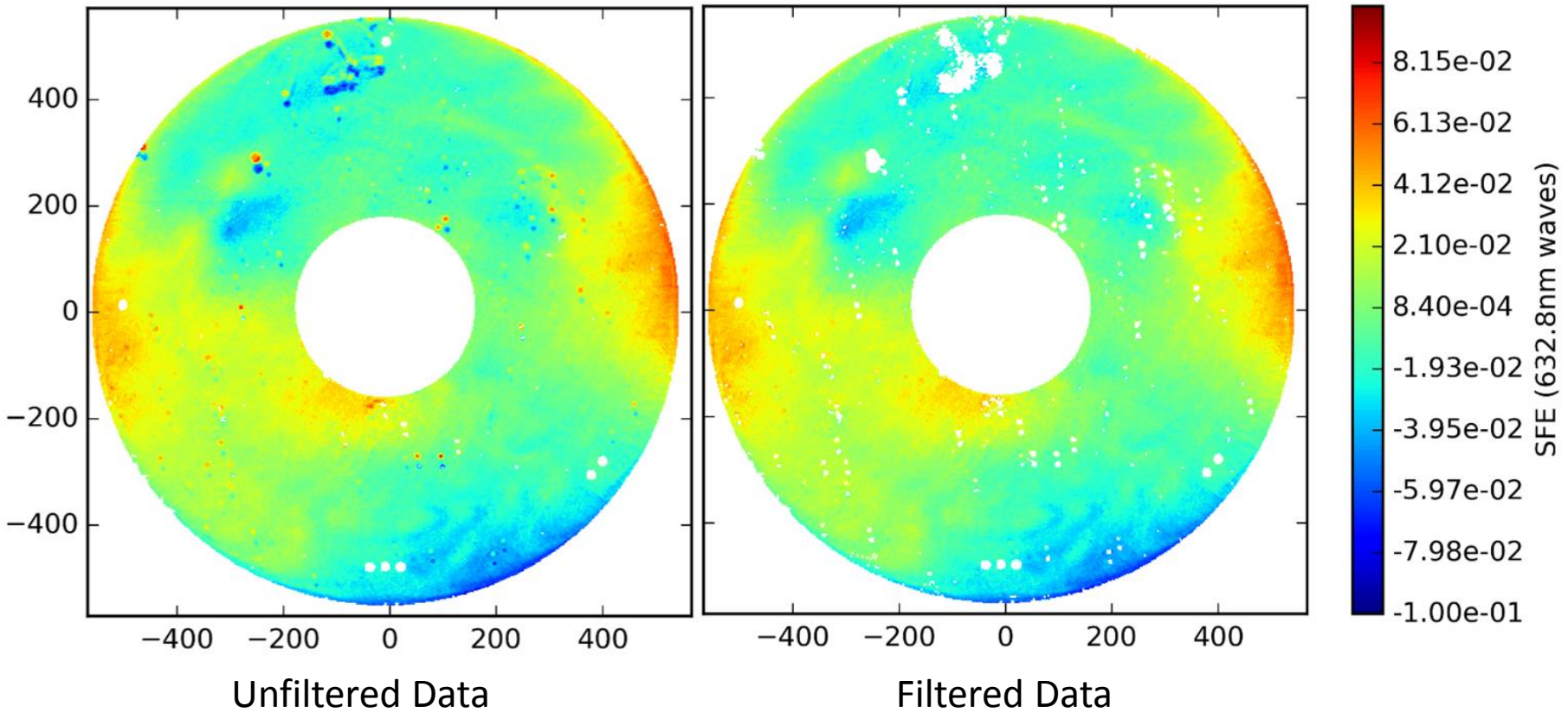
Surface Filtering



Gradient Method

If the black pixel is too different than more than half of the orange pixels then throw out the black pixel

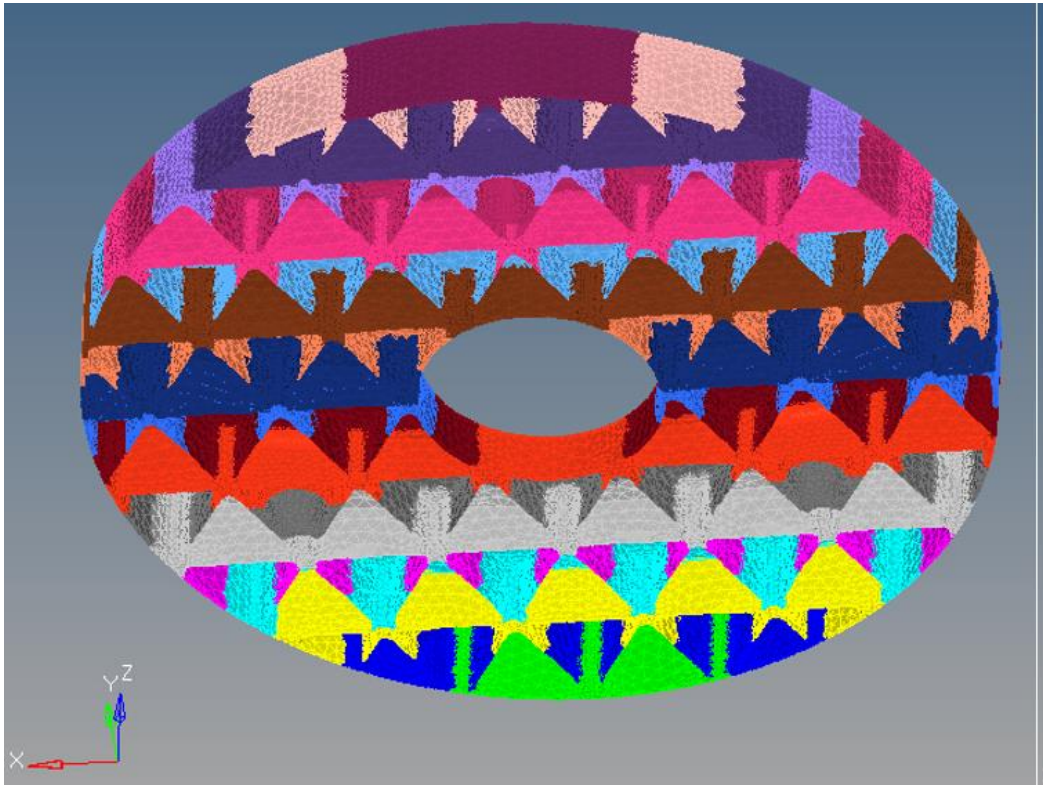
Surface Filtering



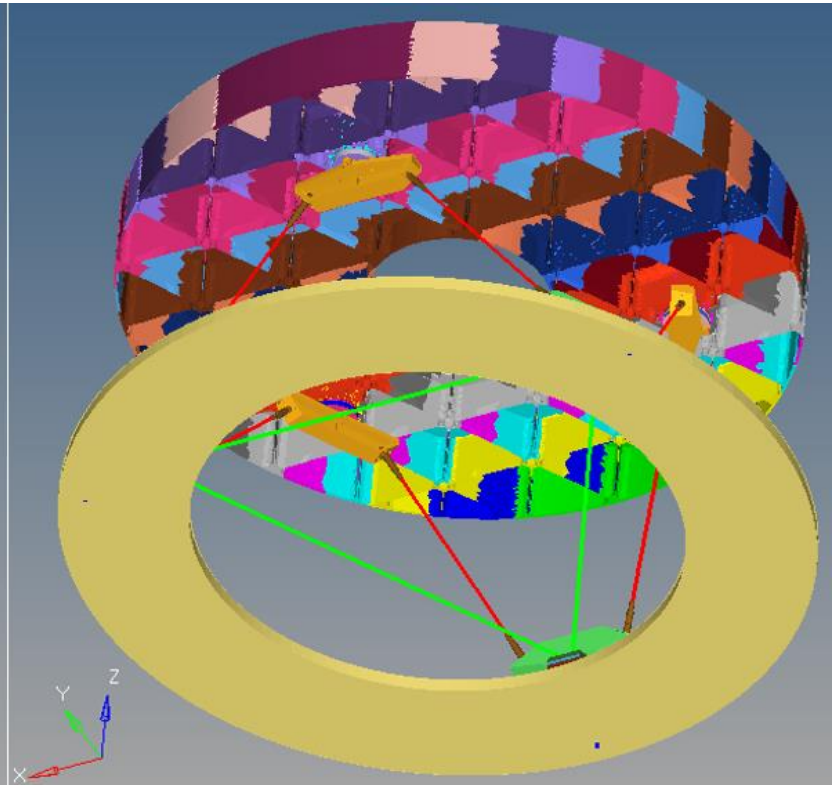
Unfiltered Data

Filtered Data

Analysis



Mirror with lateral CTE gradient



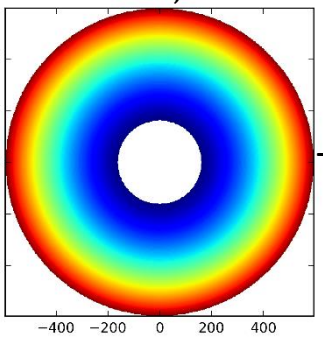
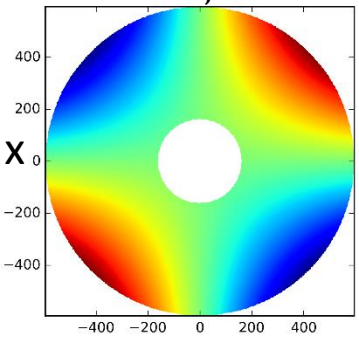
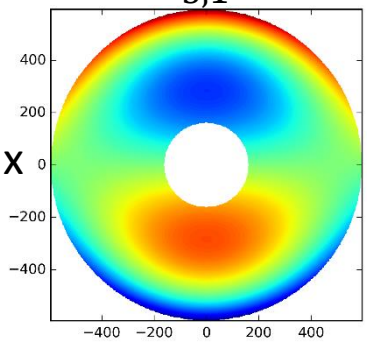
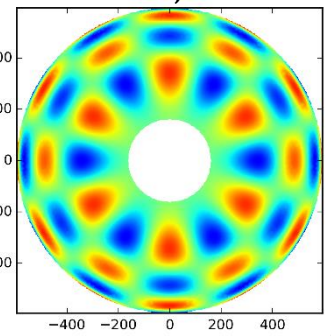
Model with Mount

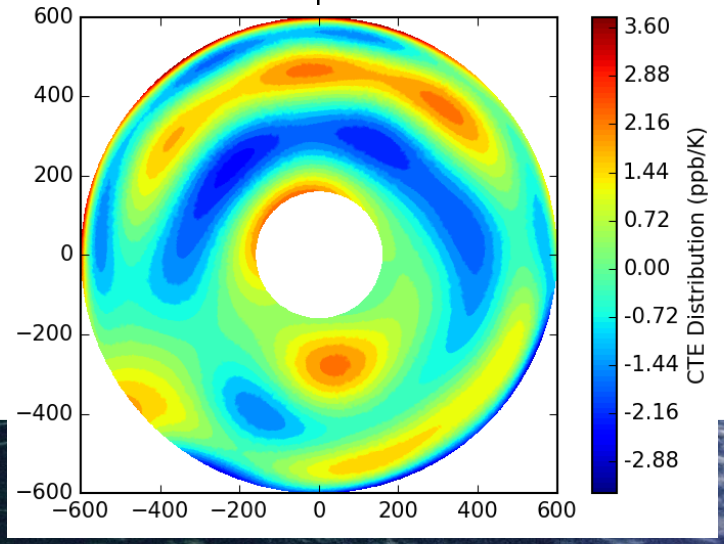
Correlation Process

Produce CTE Map from Zernike Shapes: $$[\propto_{x,y}] = \sum_{n=2}^{12} \sum_{m=0}^{n} C_{n,m} [U_{n,m}]$$

$[\propto_{x,y}]$ *is the CTE Map*

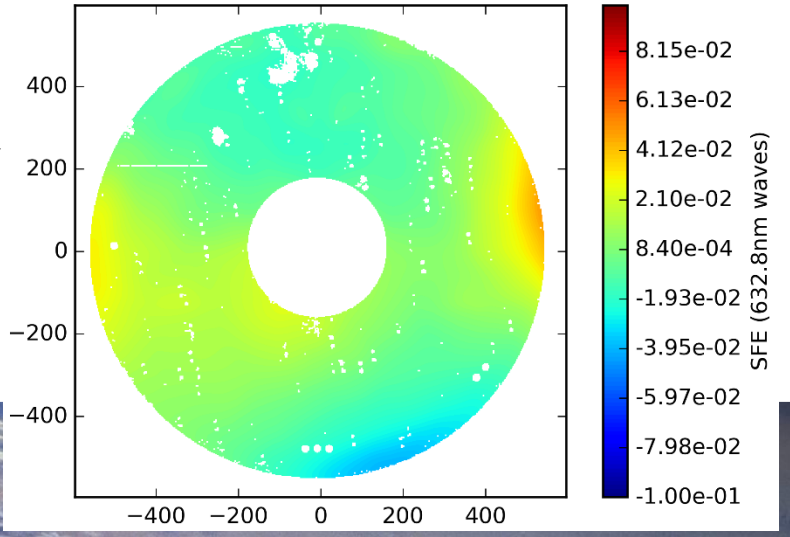
$U_{2,0}$ $U_{2,2}$ $U_{3,1}$ $U_{12,6}$

$C_{2,0}$ x  + $C_{2,2}$ x  + $C_{3,1}$ x  +… $C_{12,6}$ x 



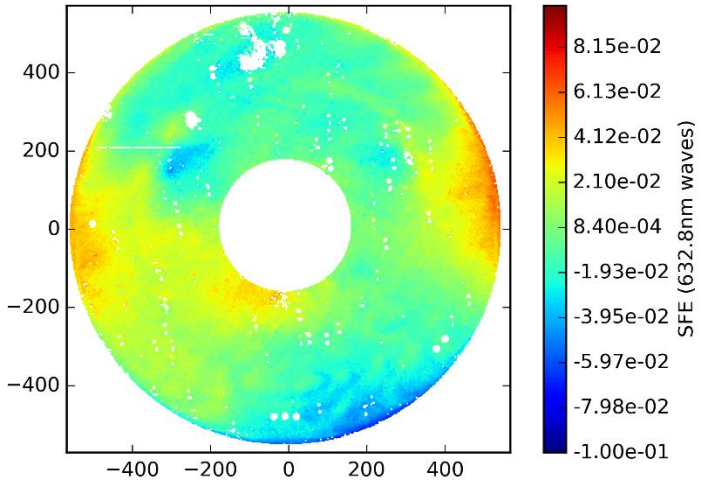
-60 ˚C Soak

Same aperture and filtering as test data

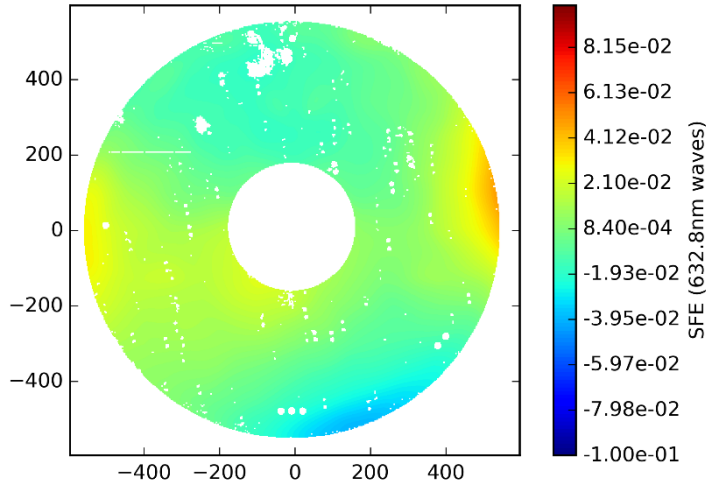


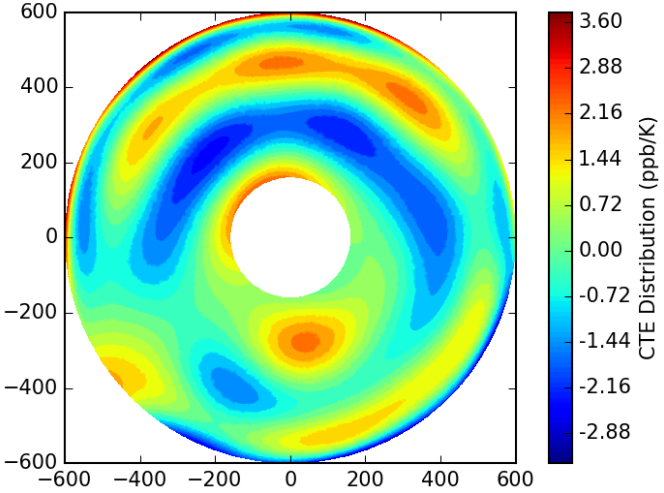
Test and Correlation Delta

Measured soak effect

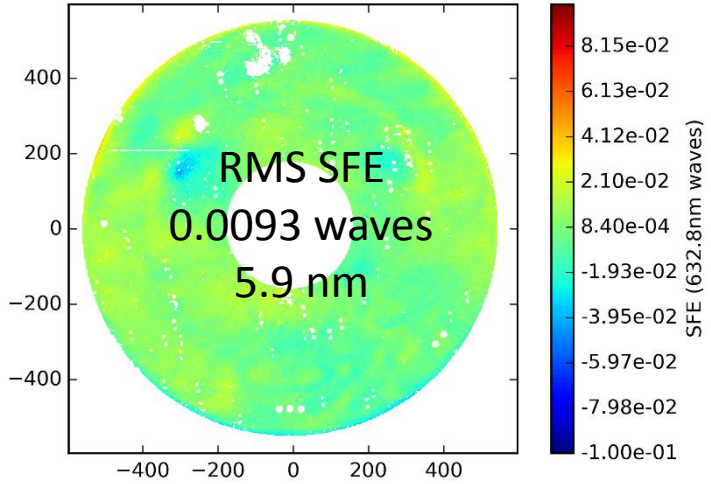


Analysis soak effect





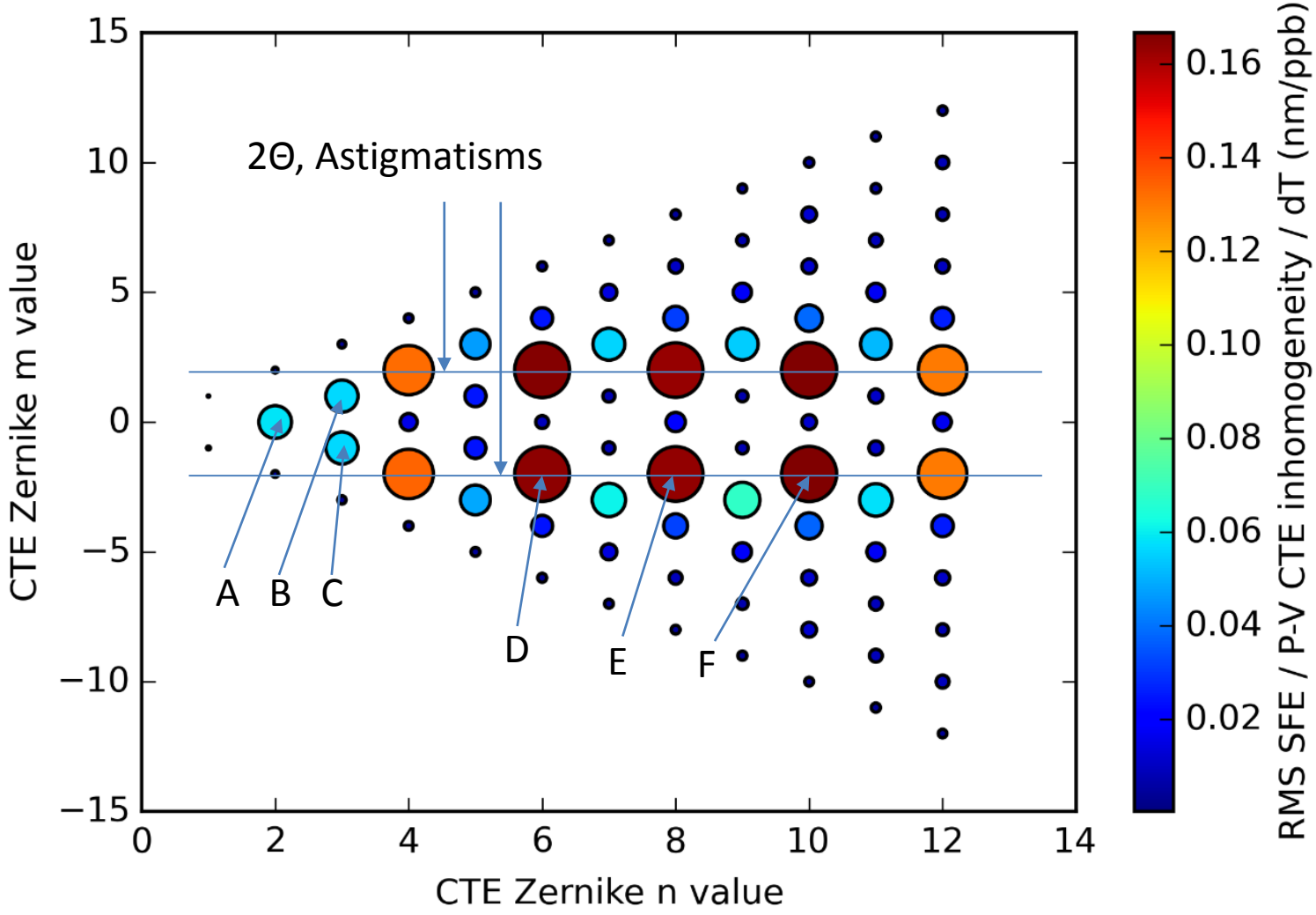
CTE Map



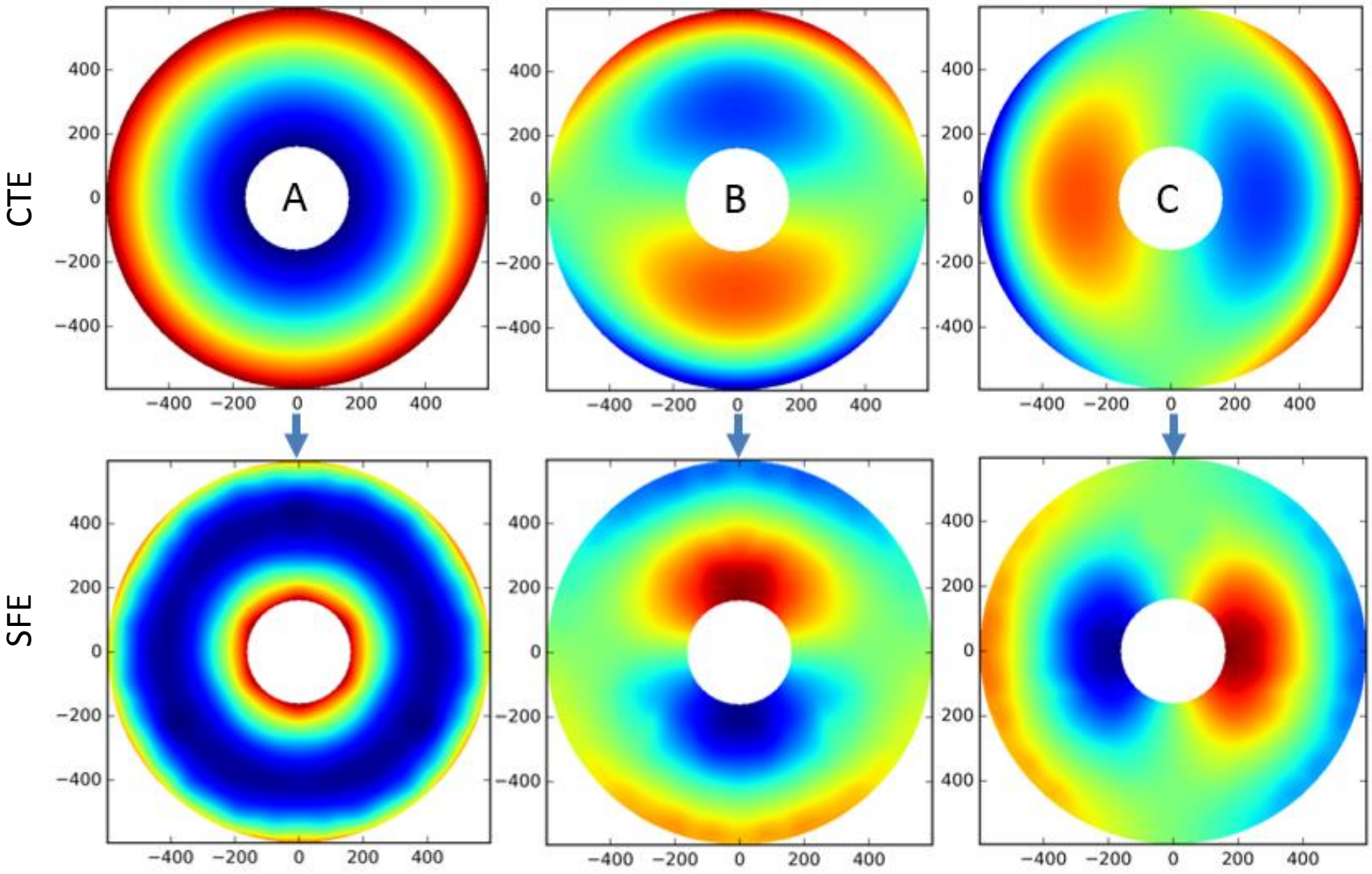
Measured – Analysis

5.9 nm < repeatability

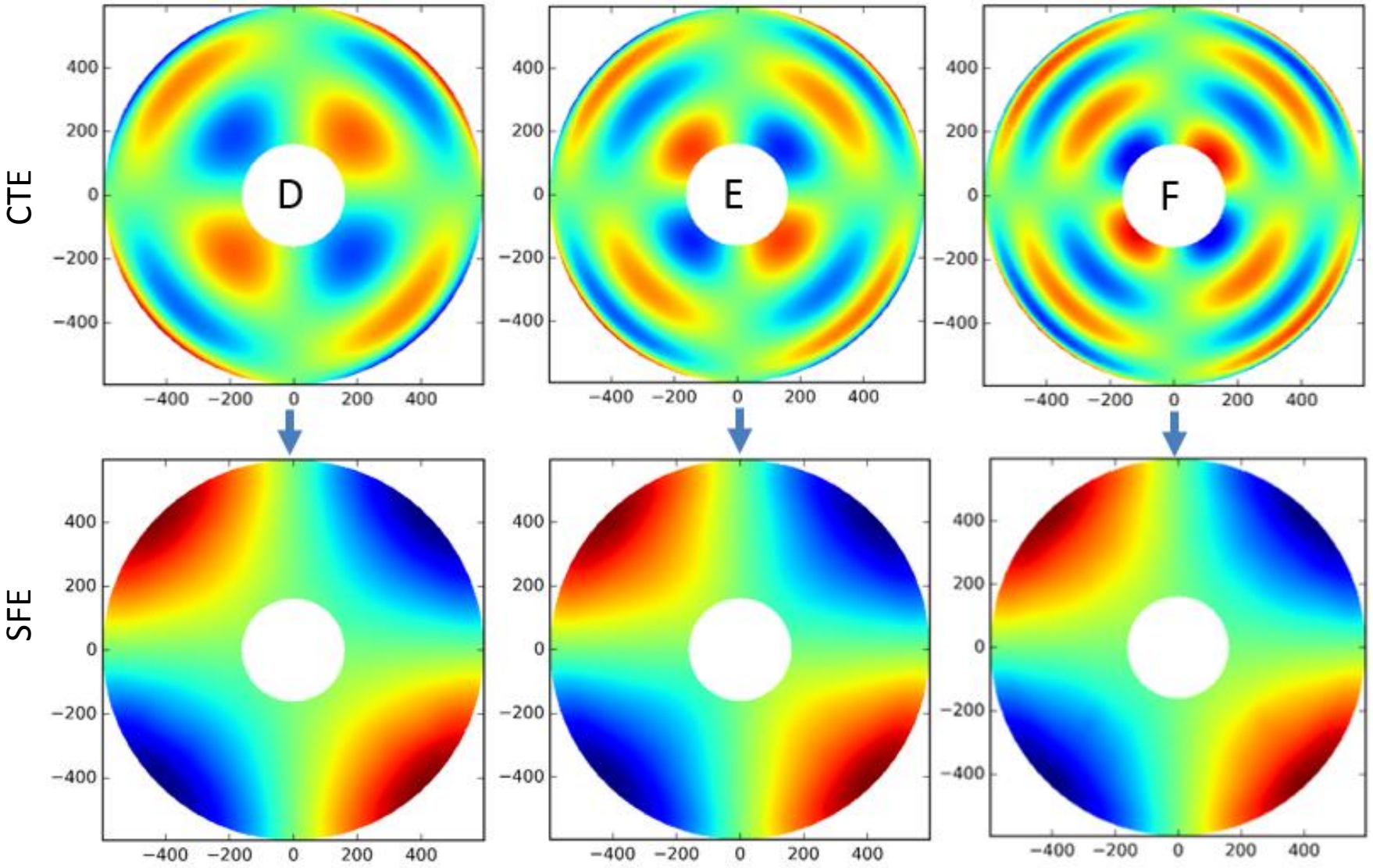
SFE Sensitivities



SFE A, B, and C Sensitivities



SFE D, E, and F Sensitivities



Sensitivity Tables

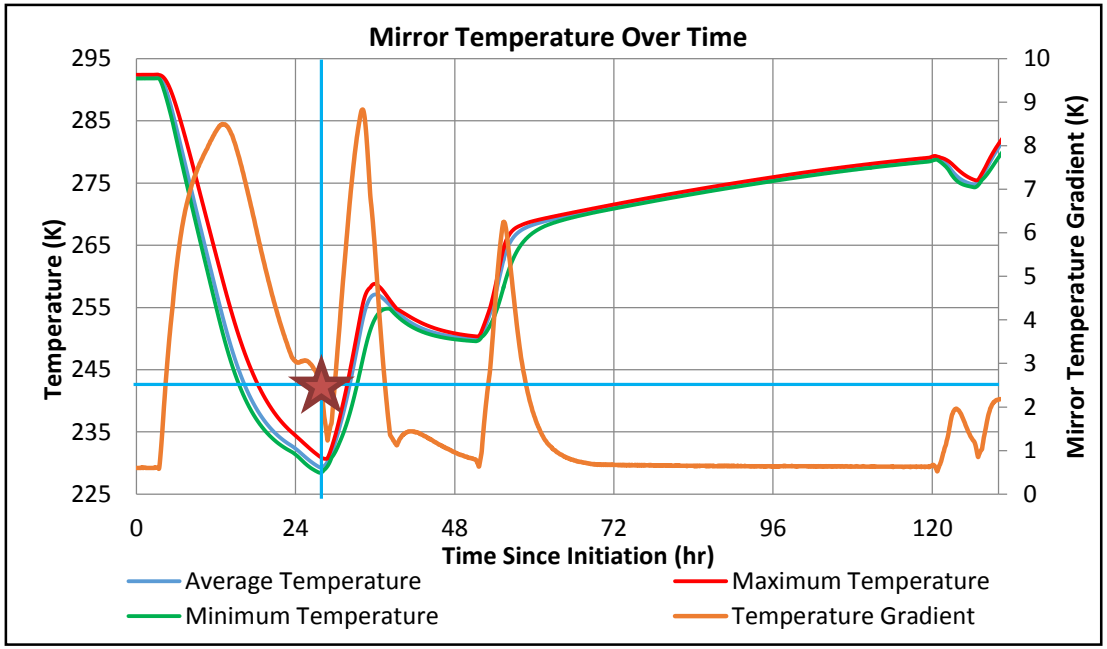
SFE Sensitivities, c (nm RMS SFE/(ppb/C)/(C)/m											
n\ m	**-5**	**-4**	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**	**5**
1					0.007		0.003				
2				0.02		0.47		0.02			
3			0.03		0.45		0.45		0.03		
4		0.03		1.07		0.13		1.06		0.03	
5	0.03		0.39		0.19		0.20		0.38		0.04

$$SFE = ch\alpha T_{p-v}$$

SFE = RMS SFE after removing power (nm)
c = SFE sensitivity coefficient found in the table
h = mirror's depth (m)
α = mirror's CTE (ppb/K)
T_{p-v} = P-V mirror temperature (K).

SFE Hand Calculation Example

How much SFE is caused by the temperature gradient at the 230K measurement?

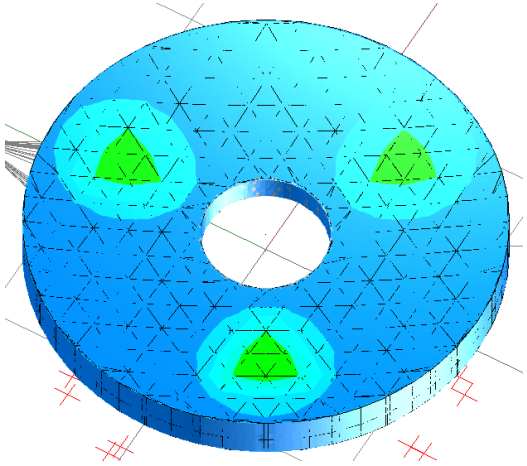


The mirror's depth is 0.125m, assume its CTE is 20ppb/K, and the T_{p-v} is 2.5 K:

$$h = 0.125 \text{ m}$$
$$\alpha = 20*10^{-9} \text{ 1/K}$$
$$T_{p-v} = 2.5 \text{ K}$$

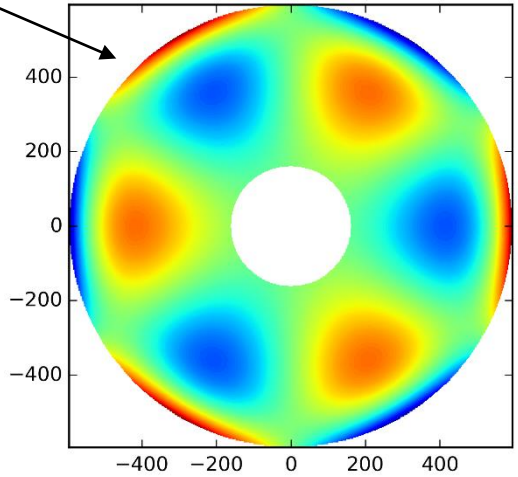
SFE Hand Calculation Example

SFE Sensitivities, c (nm RMS SFE/(ppb/C)/(C)/m											
n\ m	-5	-4	-3	-2	-1	0	1	2	3	4	5
1					0.007		0.003				
2				0.02		0.47		0.02			
3			0.03		0.45		0.45		0.03		
4		0.03		1.07		0.13		1.06		0.03	
5	0.03		0.39		0.19		0.20		0.38		0.04



Expected Temperature Distribution

Closest Zernike



h =0.125 m

$\alpha = 20*10^{-9}$ 1/K

T_{p-v} = 2.5 K

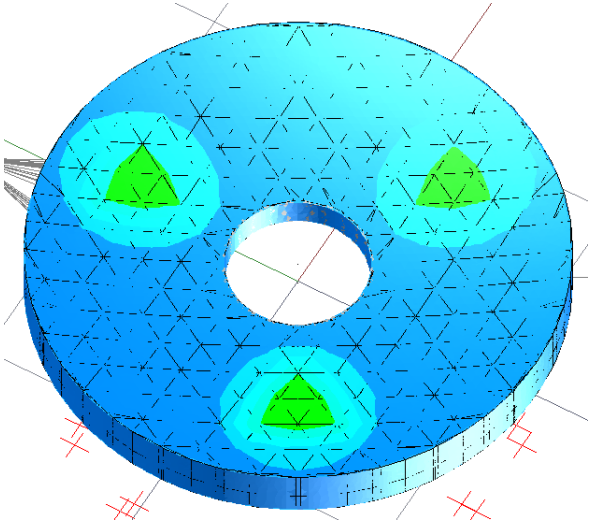
$$SFE = ch\alpha T_{p-v}$$

$$SFE = 0.39 * 0.125 * 20 * 10^{-9} * 2.5 \left[m \frac{1}{℃} ℃\right]$$

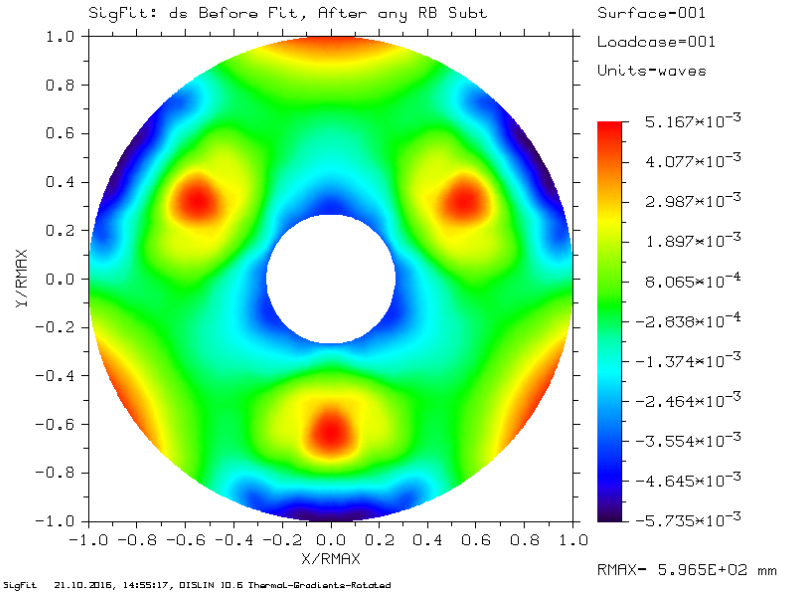
$$= 2.43nm\ RMS\ SFE$$

Hand Calculation Compared to FEA

Temperature Distribution

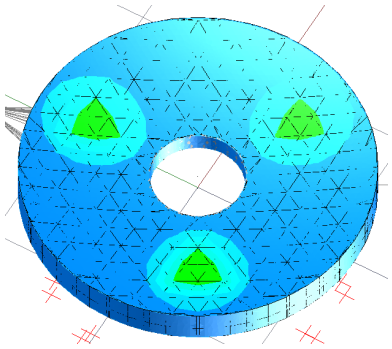


RMS SFE = 1.28nm

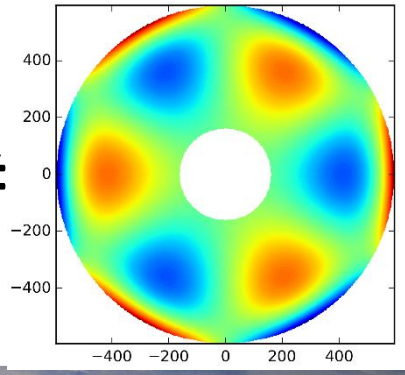


Hand Calculation	2.4 nm RMS SFE
Numerical STOP Analysis	1.3 nm RMS SFE

Why different?



≠



Questions or Comments?

Contact Information
Thomas Brooks
Thomas.brooks@nasa.gov
Work - (256) 544 -5596
Cell - (256) 544 -5596