Modeling the Schott ELZM Thermal Soak Test

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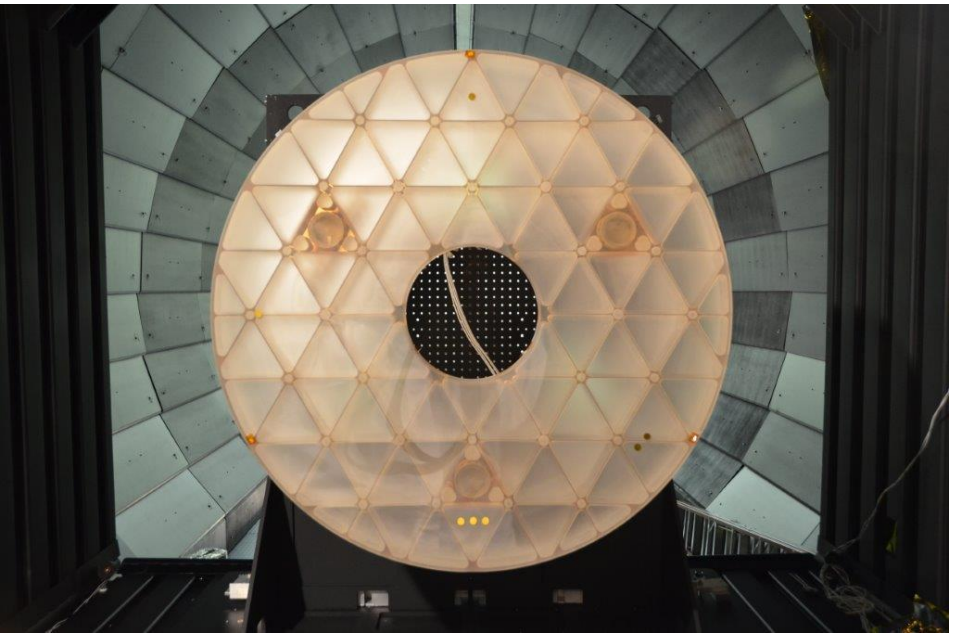
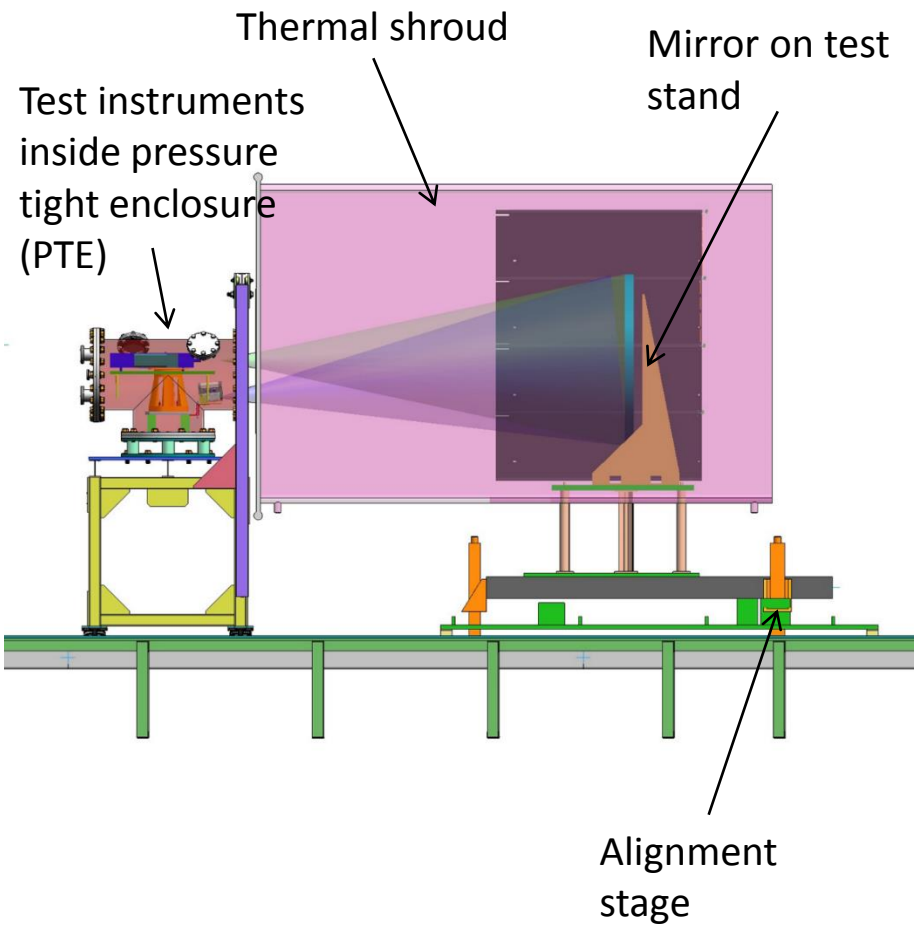
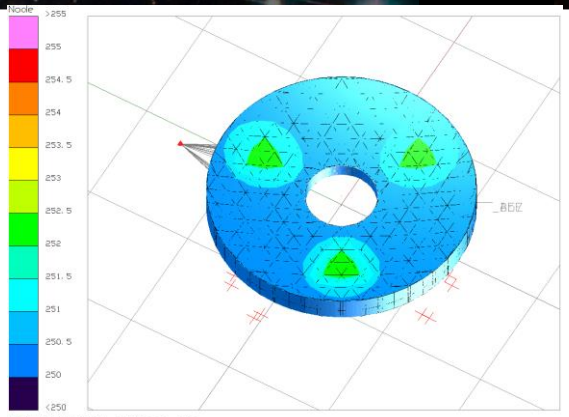
Opto-thermal test of Zerodur Mirror

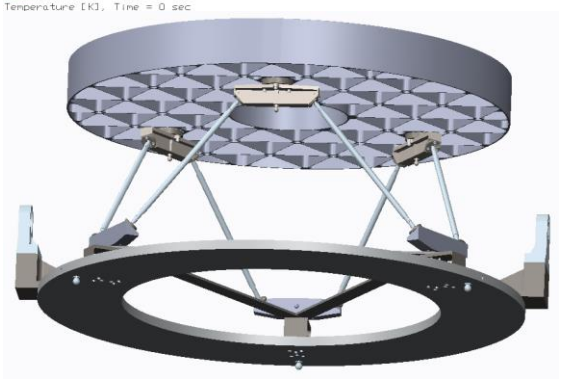


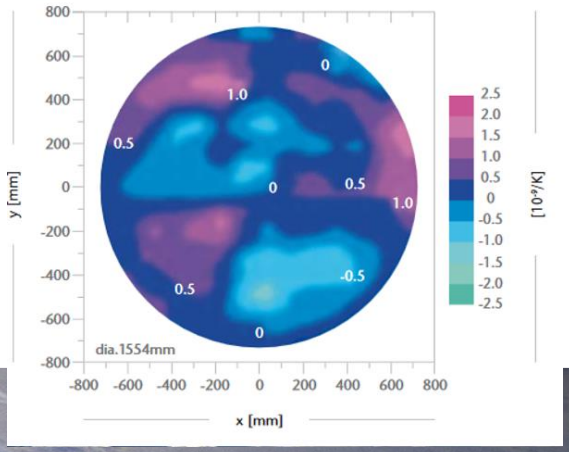


Surface Figure Error (SFE) Sources

- Error due to Thermal Gradients
  - Thermal gradients cause mirror to bend
  - Caused by non-zero CTE and gradients
- Error due to Mount Effects
  - Mirror mount not athermalized, but very compliant flexures
  - Hexapod legs grow and bend mirror
- Error due to CTE inhomogeneity
  - CTE gradients + isothermal temperature change bend the mirror
- Instrumentation Error

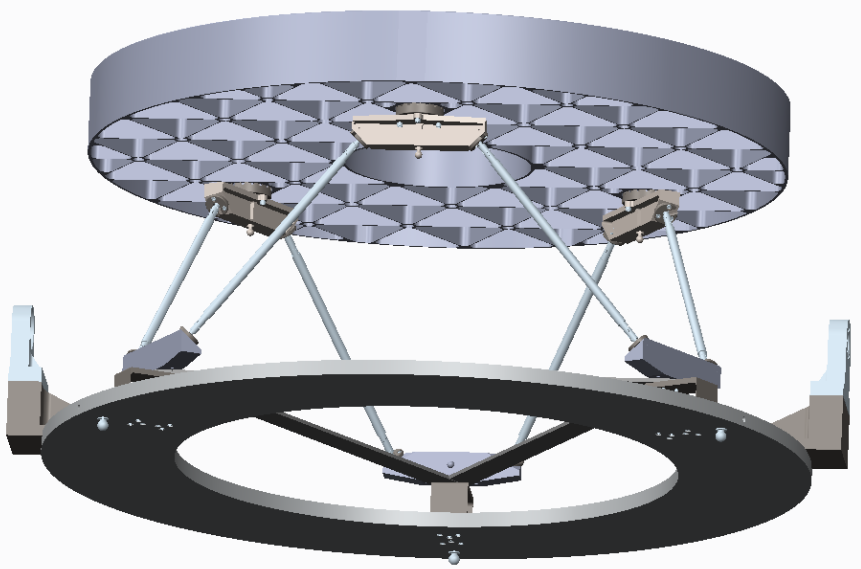




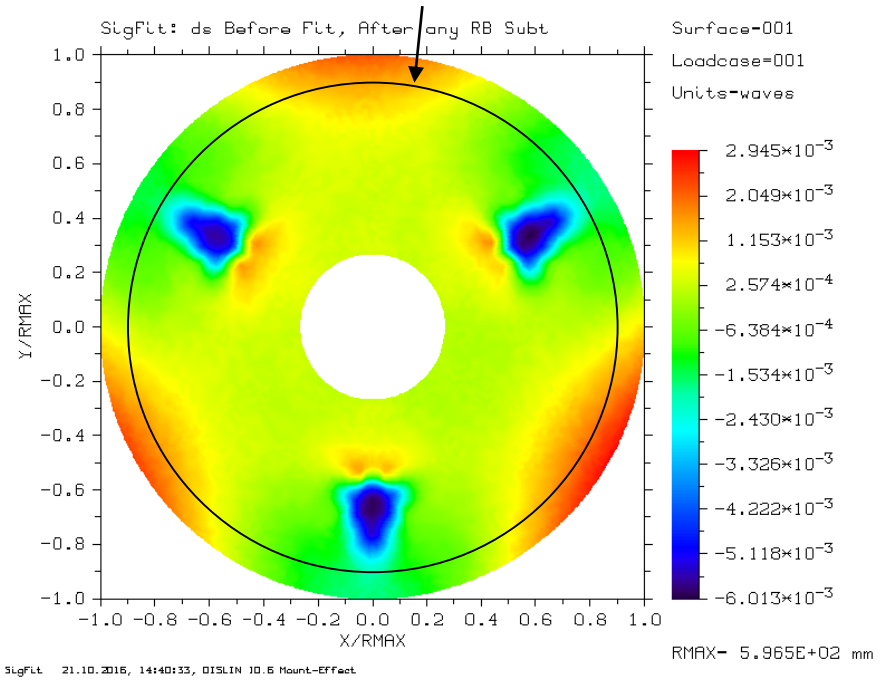


SFE due to Mount

- RMS SFE = 0.81nm
- Likely sources of error in analysis:
  - Incorrect material properties

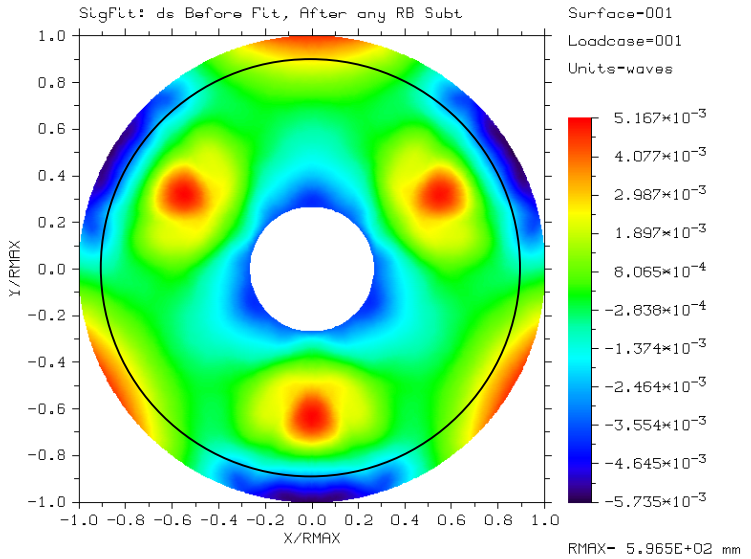


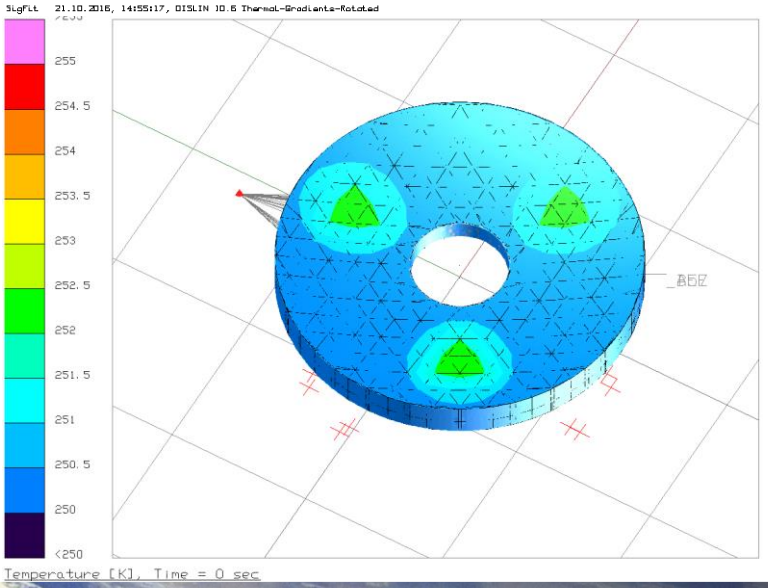
The test was sub-aperture and only the area enclosed in the circle was measured



SFE due to Thermal Gradients

- RMS SFE = 1.28nm
- Likely sources of error in analysis:
  - Different temperature distribution (~2K ΔT)
  - CTE(250K) of this Zerodur mirror (20ppb/K)





Test Measured Data at 250K

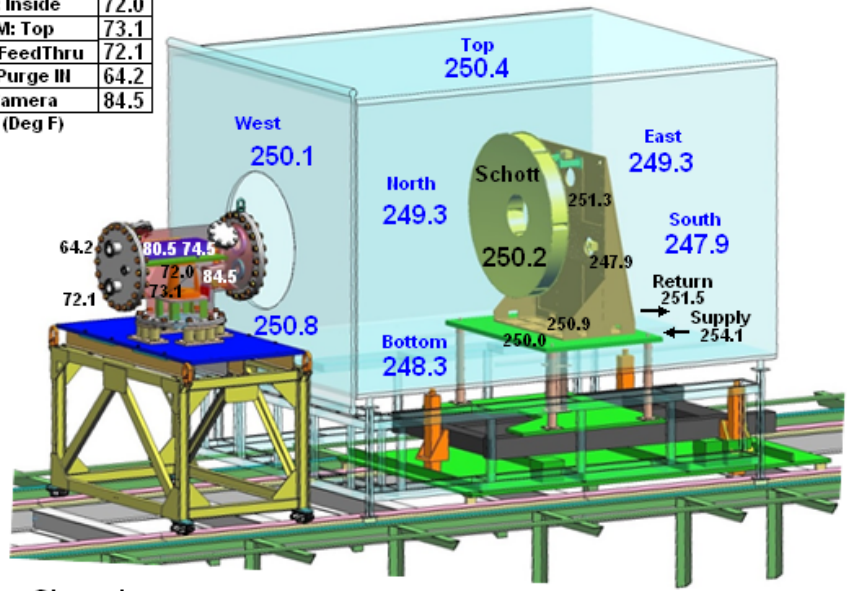
09/16/16 08:10:57

AMTD2 / Schott Cryo Test

PTE

PhaseCam East	74.5
PhaseCam West	80.5
PTE: Inside	72.0
ADM: Top	73.1
Cable FeedThru	72.1
PTE: Purge IN	64.2
IR Camera	84.5

(Deg F)



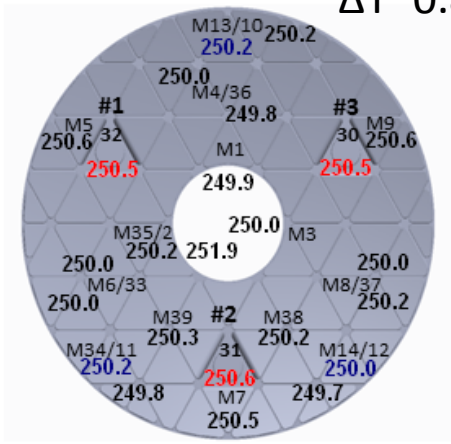
Shroud

Top	250.4
North	249.3
South	247.9
Bottom	248.3
West Top	250.1
West Bottom	250.8
East	249.3

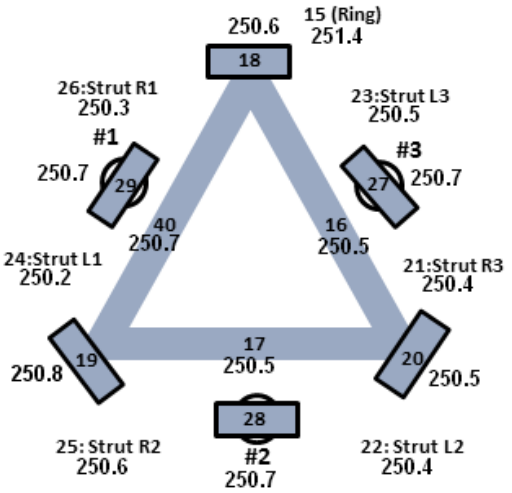
(Kelvin)

Shroud			Schott		
Average	249.4	K	Average	250.2	K
Rate	-0.1	K/HR	Rate	-0.1	K/HR
Max	250.8	K	Max	251.9	K
Min	247.9	K	Min	249.7	K
Grad	3.0	K	Grad	2.2	K

ΔT~0.8K*



North (Front View) South



M1- Top Hole	249.9
M2 - North Hole	251.9
M3 - South Hole	250.0
M4 - 12:00	250.0
M5 - 10:00	250.6
M6 - 8:00	250.0
M7 - 6:00	250.5
M8 - 4:00	250.2
M9 - 2:00	250.3
M10- Top Edge	250.2
M11 - 8:00 Edge	249.8
M12 - 4:00 Edge	249.7
M13 - Top Front	250.2
M14 - 4:00 Front	250.0
M33 - 8:00 (w/M6)	250.0
M34 - 8:00 (w/M11)	250.2
M35 - 8:00 (w/M2)	250.2
M36 - 12:00 (w/M4)	249.8
M37 - 4:00 (w/M8)	250.0
M38 - 5:00	250.2
M39 - 7:00	250.3
30 - South Pad	250.5
31 - Bottom Pad	250.6
32 - North Pad	250.5
15 - 12:00 Ring	251.4
16 - Delta_3	250.5
17 - Delta_2	250.5
18 - Top Bracket	250.6
19 - South Bracket	250.8
20 - North Bracket	250.5
21 - Strut R3	250.4
22 - Strut L2	250.4
23 - Strut L3	250.5
24 - Strut L1	250.2
25 - Strut R2	250.6
26 - Strut R1	250.3
27 - South Mount	250.7
28 - Bottom Mount	250.7
29 - North Mount	250.7
40 - Delta_1	250.7

(Kelvin)

*Likely anomalous measurement ignored

SFE due to CTE Inhomogeneity

CTE (0°C; 50°C) Homogeneity tolerances	
up to 18 tons	< 0.03 · 10⁻⁶/K
up to 6 tons	< 0.02 · 10⁻⁶/K
up to 0.3 tons	< 0.01 · 10⁻⁶/K

Table 2.3
CTE homogeneity tolerances

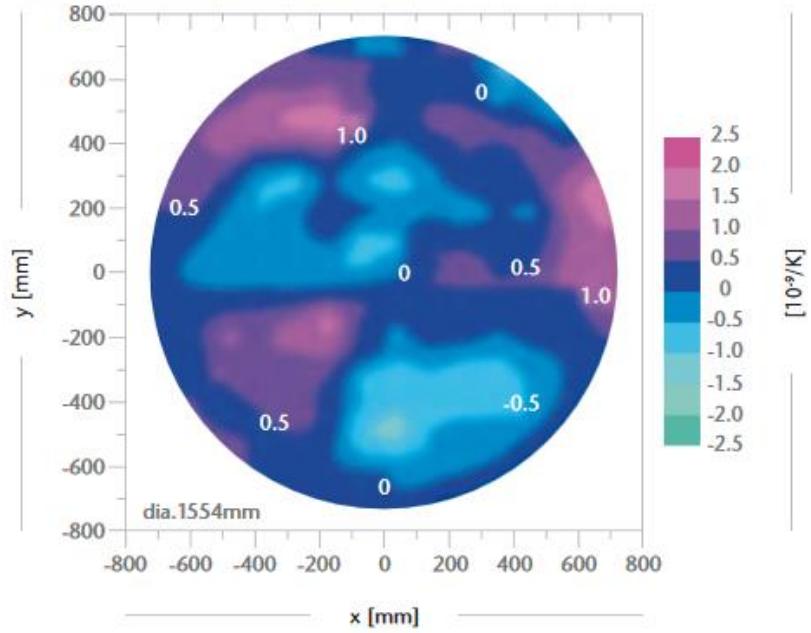
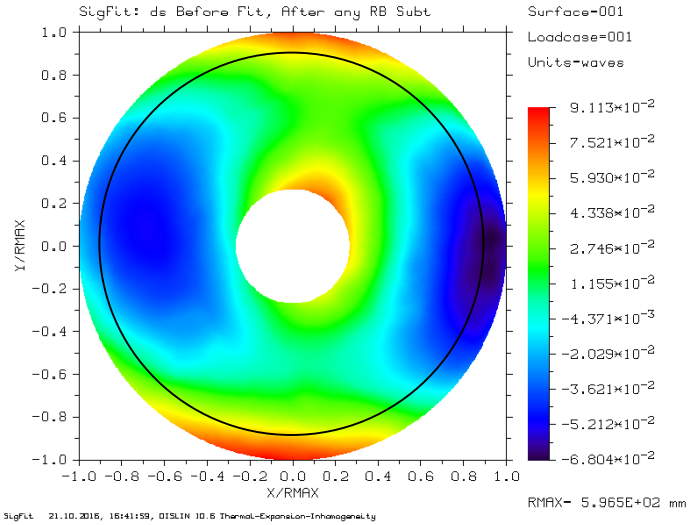


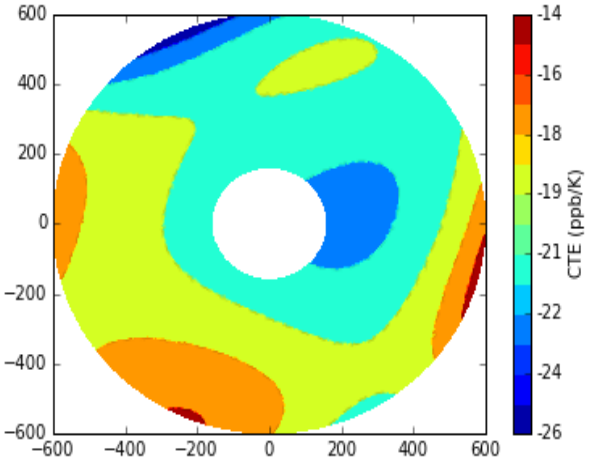
Figure 2.2
CTE distribution within a 1.5 m diameter blank with a measured CTE homogeneity of 0.004 · 10⁻⁶/K

From the Schott Zerodur July 2011 Katalog [sic]

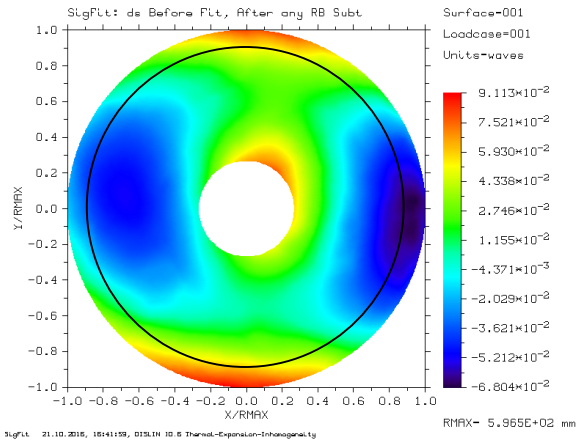
SFE due to CTE Inhomogeneity

- RMS SFE = 21.4 nm
- Likely sources of error in analysis:
  - Incorrect “randomly generated” CTE inhomogeneity shape
  - Incorrect CTE inhomogeneity P-V (assumed 10ppb/K)

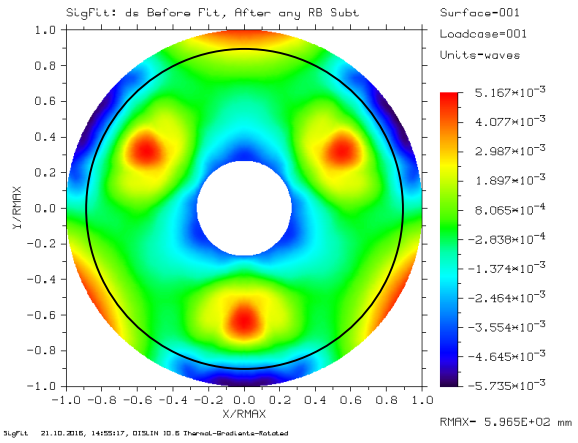




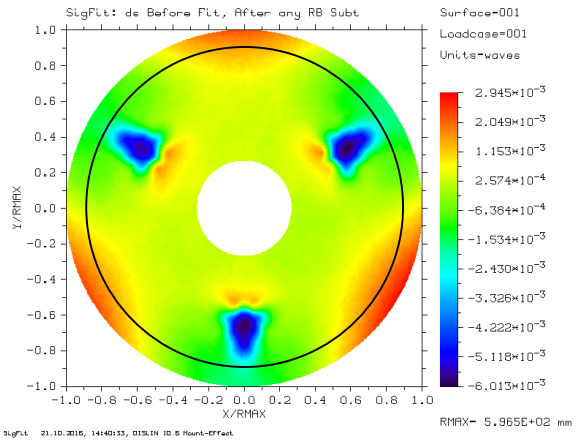
SFE Budget



CTE Inhomogeneity + Bulk Temperature Change



Mirror Temperature Gradient + CTE



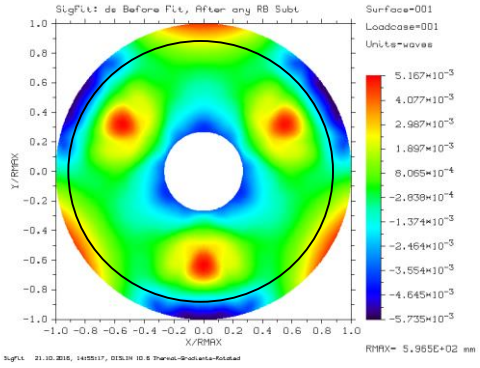
Mount Stiffness and CTE + Bulk Temperature Change

Total SFE (nm)	Inhomogeneity SFE (nm)	Gradient SFE (nm)	Mount SFE (nm)
21.45	21.4	1.28	0.81

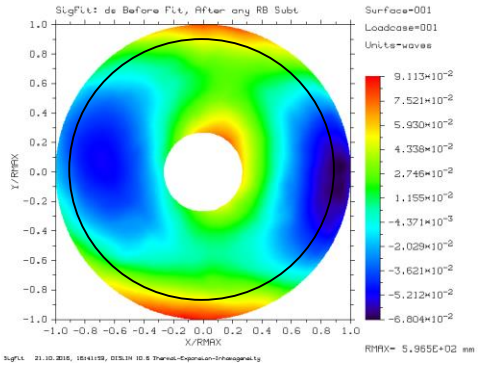
Disclaimer: some material properties were unknown and assumed; large uncertainty in epoxy properties.

294K to 250K

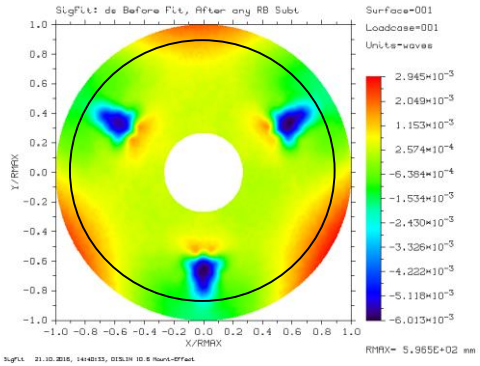
A Prior Analysis Results



Thermal Gradients*
(1.28 nm RMS)



Inhomogeneity**
(21.4 nm RMS)

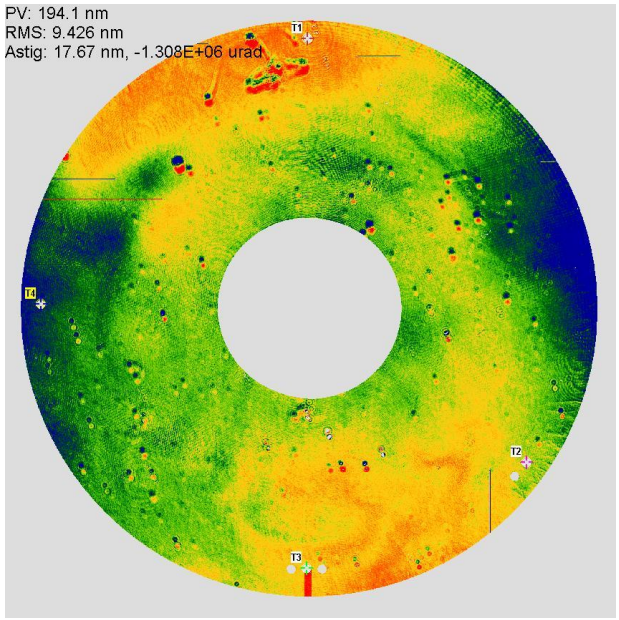


Mount Effects
(0.81 nm RMS)

*Exact temperature distribution could not be known in advance. CTE(T) was not known in advance (0.02ppm/K assumed at all temperatures)

**CTE Inhomogeneity was not known a priori. A random CTE map was generated that had a 10ppb/K peak to valley.

Test Results



Measured SFE (9.4 nm RMS)

Conclusion

Analysis can match measured SFE by adjusting the assumed CTE inhomogeneity to a new CTE inhomogeneity that is roughly 5ppb/K peak to valley. This is within the range of measured Zerodur CTE inhomogeneity peak to valleys.

New Zerodur Homogeneity

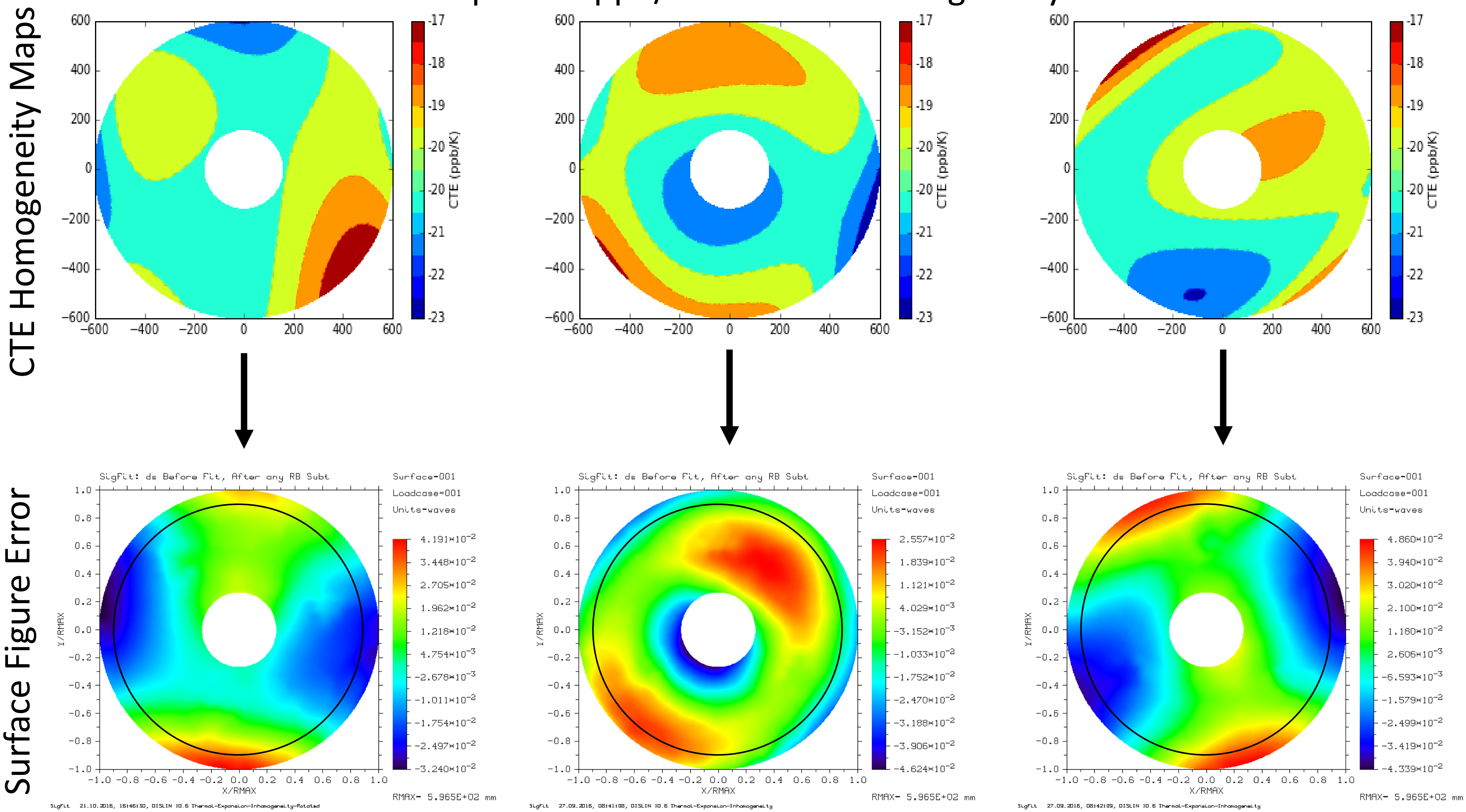
	Dimension	Number of Samples	CTE (0°; 50°) absolute value [ppb / K]		CTE (0°; 50°) homogeneity [ppb / K]	
Year	[mm]	#	Specification	Achieved	Specification	Achieved
2003	4100 x 171	18	+/- 50	66	20	18[1]
2005	3610 x 370	12	+/- 100	80	30	25[1]
2009	3700 x 163	36	+/- 150	54	40	9
2010	3400 x 180	12	+/- 100	42	30	5
2012	4250 x 350	16	+/- 30	60	40	5
2014	4250 x 350	16	+/- 30	0	40	3
2016	4060 x 103	16	+/- 50	36	20	7
2016[2]	4000 x 100	12	+/- 150	15	20	4

First two were measured with the old dilatometer metrology. All others measured with the new dilatometer metrology.

Ralf Jedamzik, et al.
" Effects of thermal inhomogeneity on 4m class mirror substrates ", *Proc. SPIE* 9912, Advances in Optical and Mechanical Technologies for Telescopes and Instrumentation II, 99120Z (July 22, 2016); doi:10.1117/12.2234287; http://dx.doi.org/10.1117/12.2234287

Generated Multiple Homogeneities

All maps are 5ppb/K P-V CTE Inhomogeneity

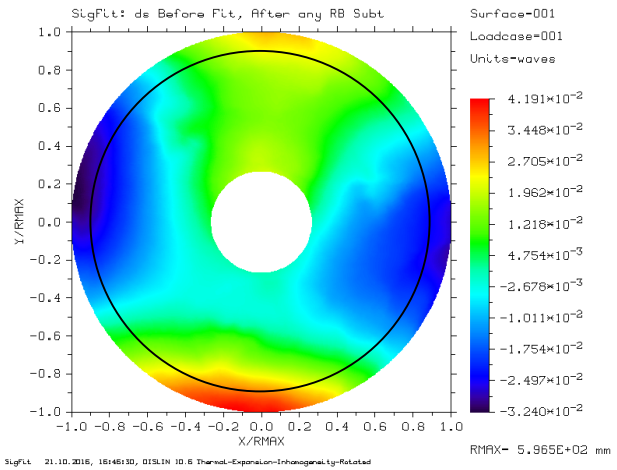


9.5 nm RMS SFE

8.7 nm RMS SFE

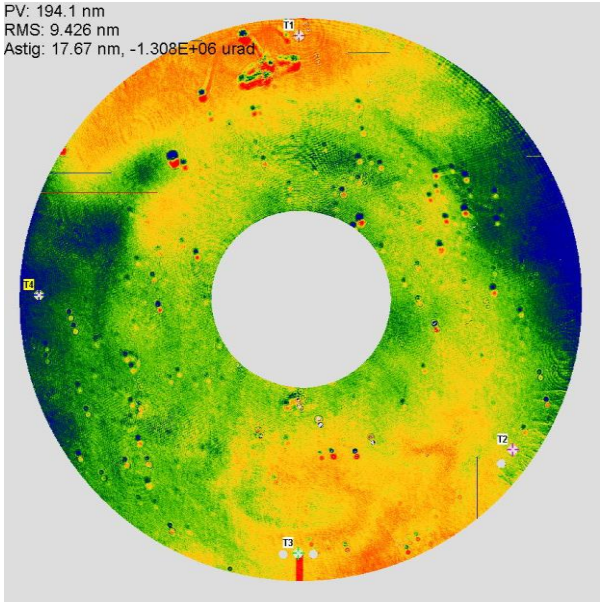
13.1 nm RMS SFE

New 294K to 250K



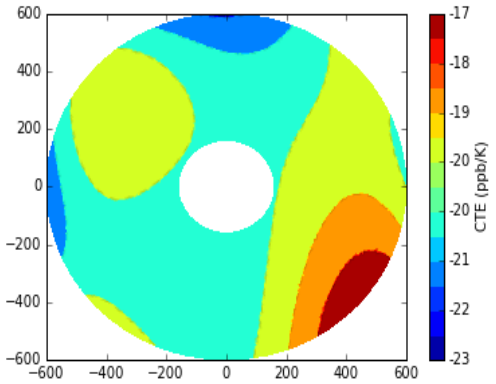
New Homogeneity* (9.55 nm RMS)

*CTE Inhomogeneities randomly generated until one matched. P-V homogeneity changed to 5 ppb/K.



Measured SFE (9.4 nm RMS)

Homogeneity Map. CTEs in ppb/K



Conclusion

- A 5 ppb/K peak-to-valley inhomogeneity produced 9.55nm RMS of SFE and a root-sum-squared SFE estimate of 9.6nm RMS.
- Zerodur boules have been measured to have a 5 ppb/K peak-to-valley CTE inhomogeneity, therefore, 5ppb/K peak-to-valley inhomogeneity is reasonable.
- Further investigation will match test results to an even greater extend.

Acknowledgements

Marshall Space Flight Center (MSFC)

- Ron Eng and the XRCF team for setting up and performing the test
- Phil Stahl for helping design the test and interpret results

University of New Mexico (UNM)

- Tony Hull for helping design the test and interpret results

Schott

- Provided the mirror

Arizona Optical Systems (AOS)

- Designed the support structure

Questions or Comments?