# Schott extreme lightweight ZERODUR® mirror (ELZM) test results

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# Agenda

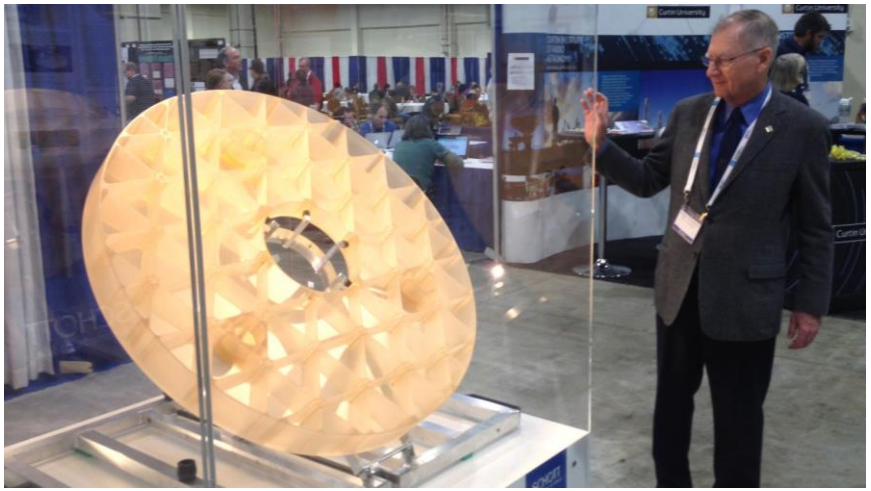
- Goals and motivations
- Schott ELZM
- Test facility
- Test setup
- Test results

# Goals and motivation

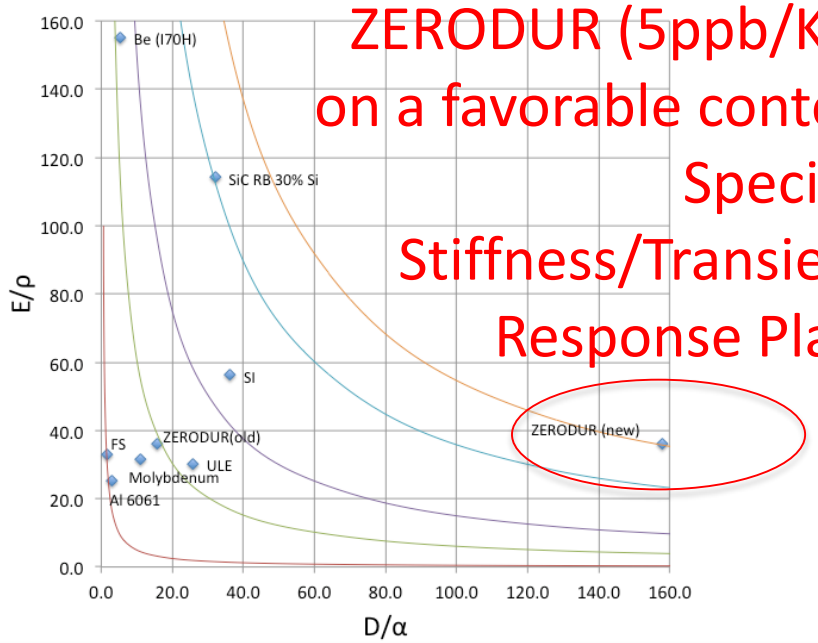
- R&D - develop/improve test methods to characterize lightweight mirror architecture for current and future telescopes
- Competition - using same test setup and facility to characterize competing mirror architecture
- Facility – utilize and add capabilities to existing environmental test facilities
- Model validation - test data used for model validation
- Personnel – testing is labor intensive
- Learning – working with vendors

# Lightweight ZERODUR Mirror Substrates by SCHOTT

## SCHOTT 88% Lightweighted ZERODUR Mirror

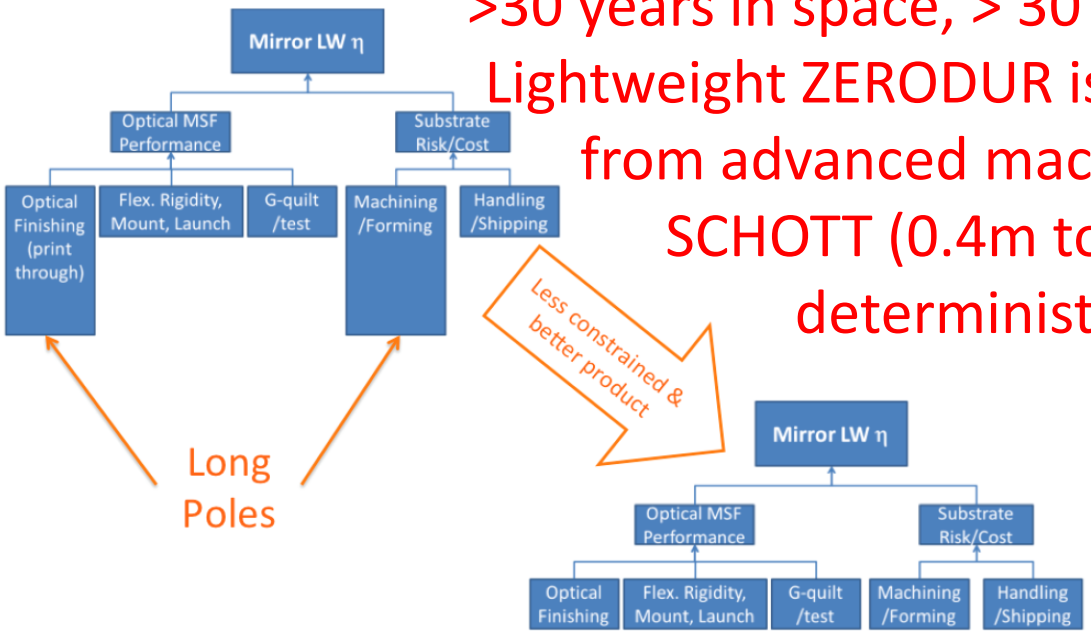


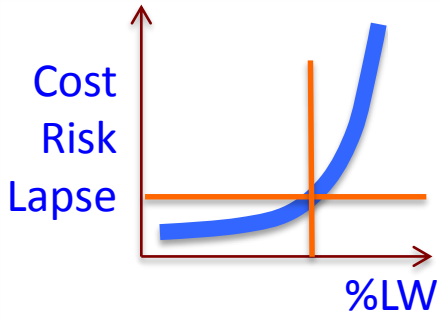
ZERODUR (5ppb/K) is on a favorable contour Specific-Stiffness/Transient-Response Plane




>30 years in space, > 30 missions

Lightweight ZERODUR is derived from advanced machining at SCHOTT (0.4m to 4.0m) + deterministic OpFab

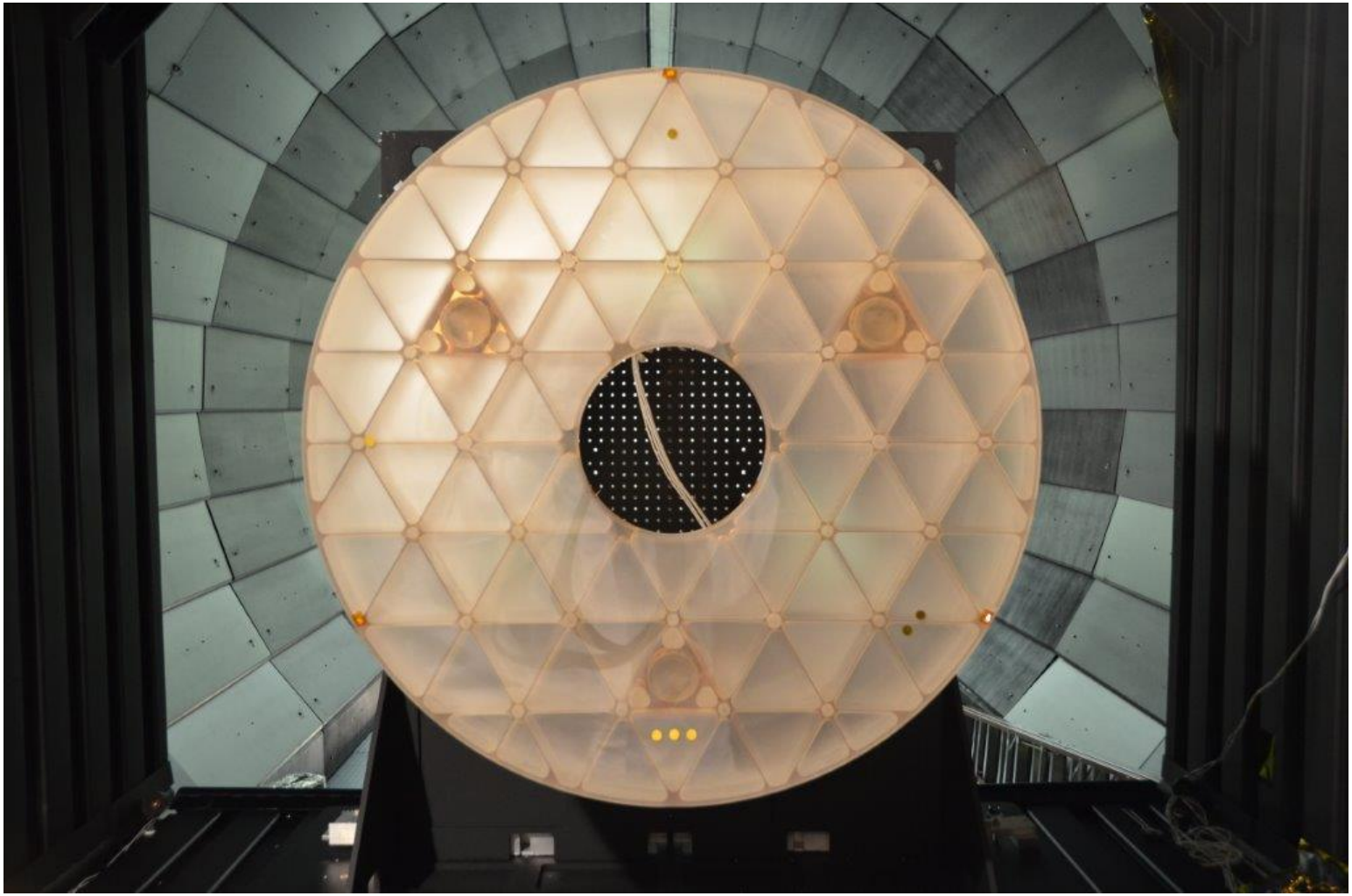


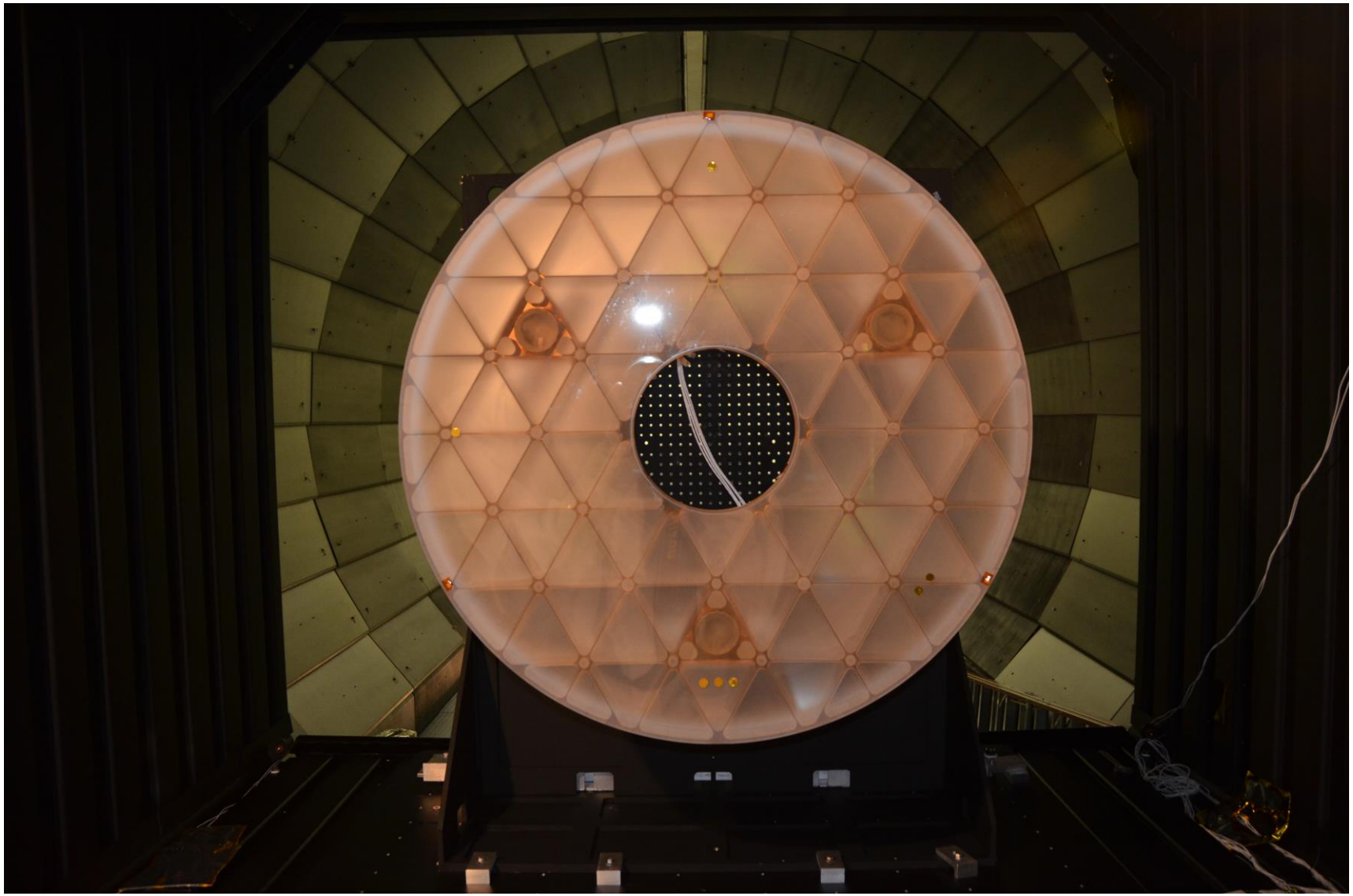

For 1.2m substrate
Roughly < $600K
in < 3 months

# Schott ELZM

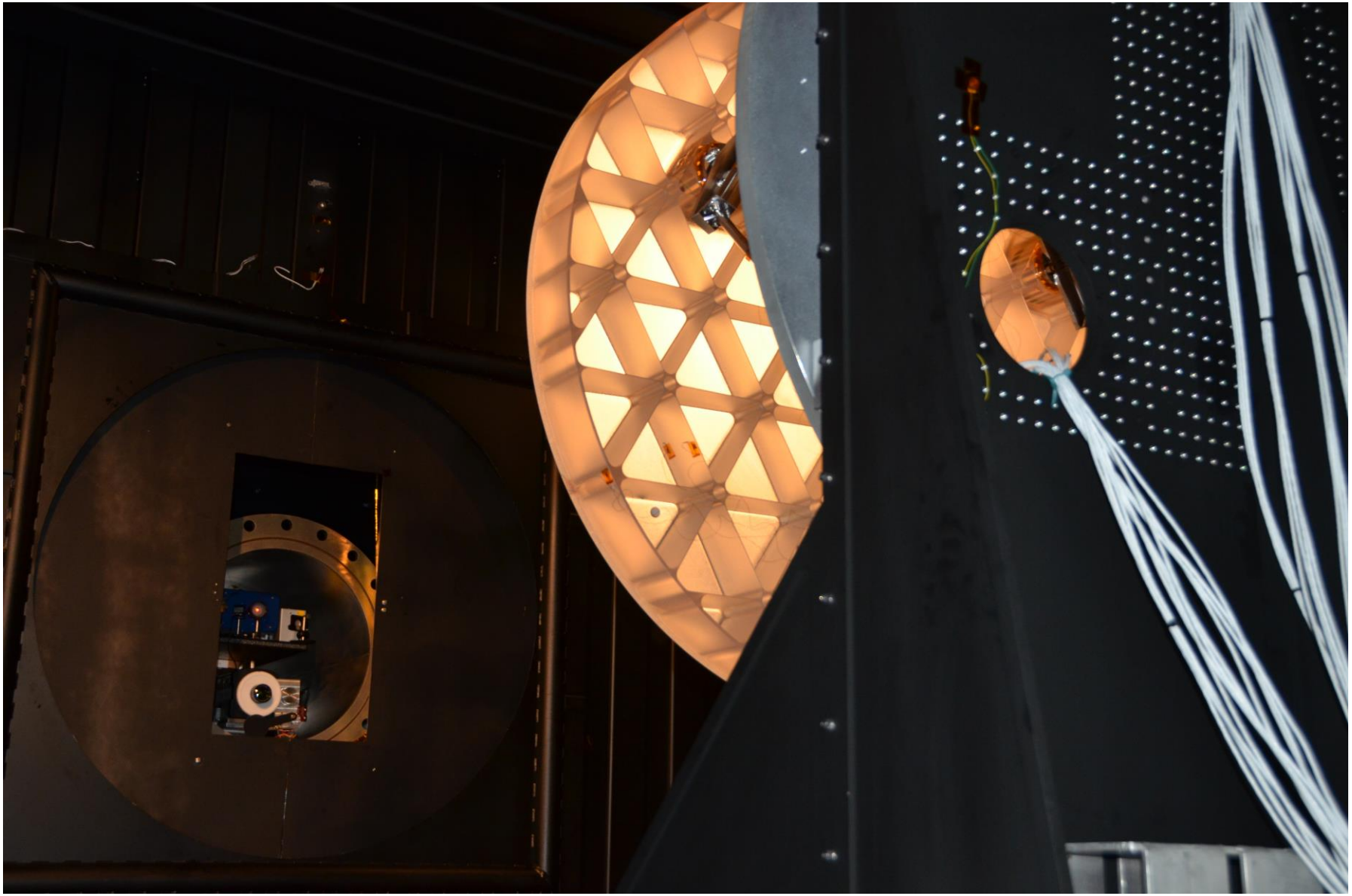
Diameter: 1.2m
ROC: 3.1m
Mass: 45kg; 88% lightweighted



# Schott ELZM



# Schott ELZM and test setup

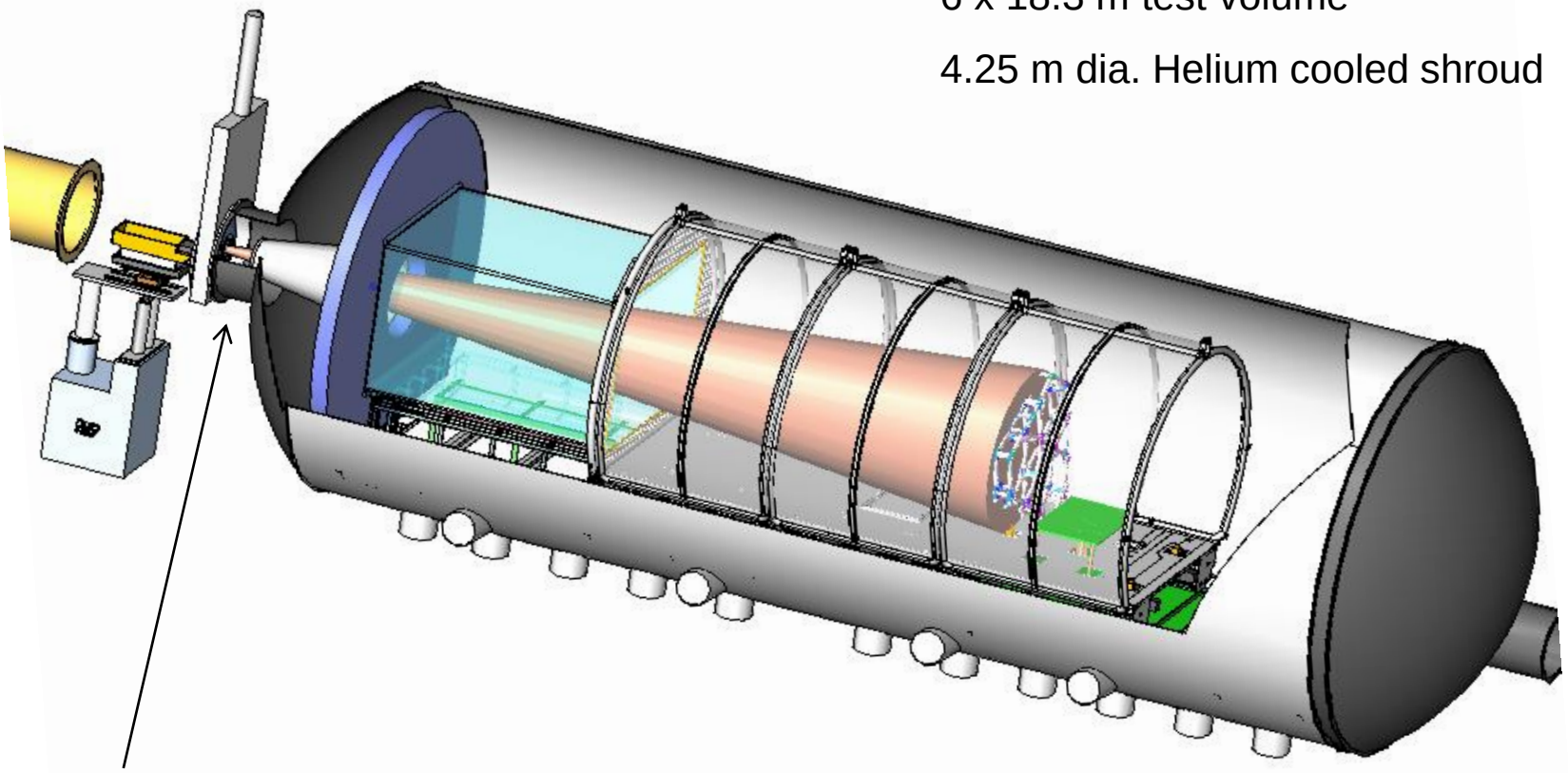


# JWST PMSA test configuration at XRCF

16 m ROC; ~4 m dia.

6 x 18.3 m test volume

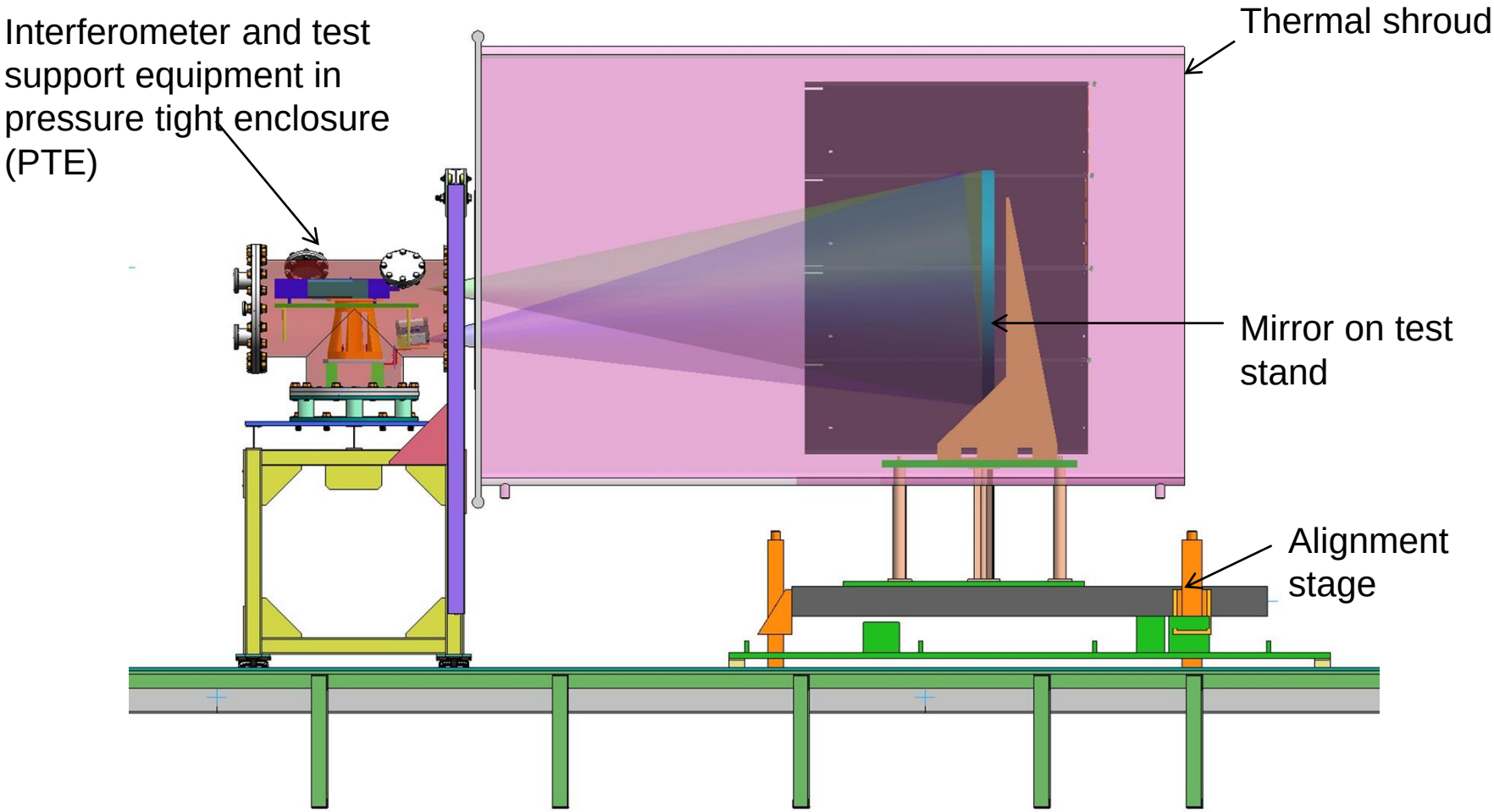
4.25 m dia. Helium cooled shroud



Existing structure prevents testing mirrors with ROC < 3.5 meters

A pressure tight enclosure (PTE) configuration to test mirror with short ROC < 3.5 meter

# Test configuration for short ROC mirrors




AMTD-2 test configuration with PTE

# Mirror temp avg 292º K

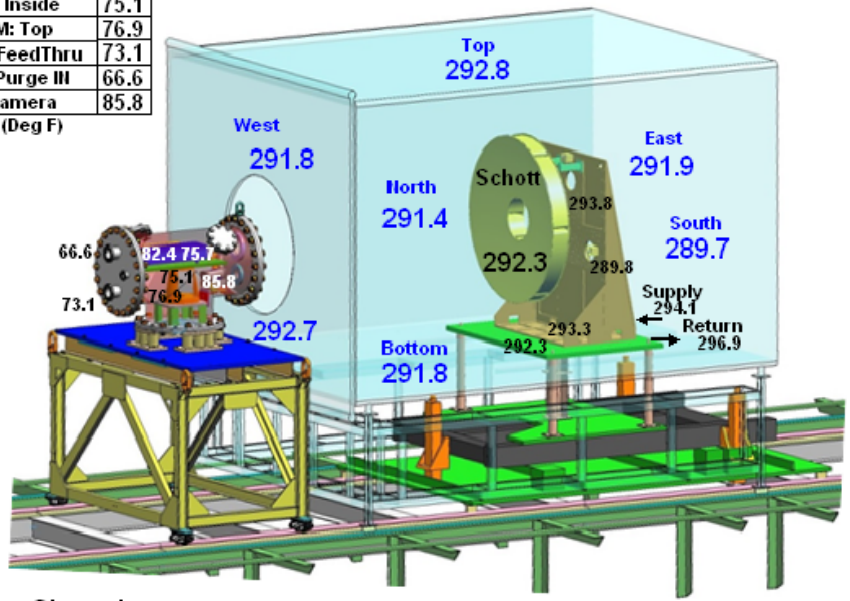
09/14/16 09:09:59

## AMTD2 / Schott Cryo Test

PTE

| | |
|---|---|
| PhaseCam East | 75.7 |
| PhaseCam West | 82.4 |
| PTE: Inside | 75.1 |
| ADM: Top | 76.9 |
| Cable FeedThru | 73.1 |
| PTE: Purge III | 66.6 |
| IR Camera | 85.8 |

(Deg F)

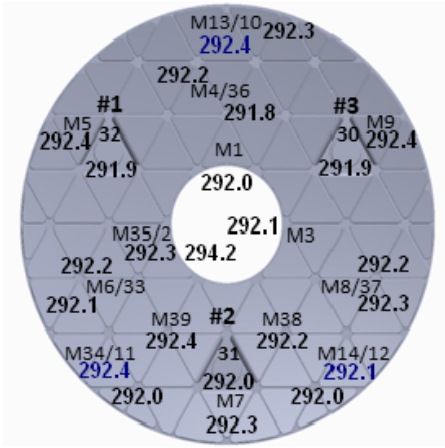



Shroud

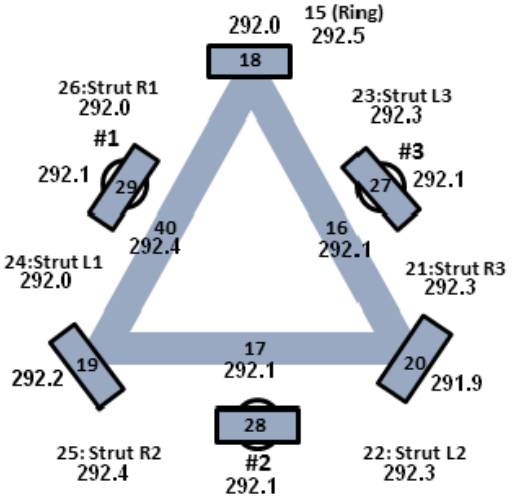
| | |
|---|---|
| Top | 292.8 |
| North | 291.4 |
| South | 289.7 |
| Bottom | 291.8 |
| West Top | 291.8 |
| West Bottom | 292.7 |
| East | 291.9 |

(Kelvin)

| Shroud | | | Schott | | |
|---|---|---|---|---|---|
| Average | 291.7 | K | Average | 292.3 | K |
| Rate | 0.0 | K/HR | Rate | 0.0 | K/HR |
| Max | 292.8 | K | Max | 294.2 | K |
| Min | 289.7 | K | Min | 291.8 | K |
| Grad | 3.1 | K | Grad | 2.3 | K |




North (Front View) South




| | |
|---|---|
| M1- Top Hole | 292.0 |
| M2 - North Hole | 294.2 |
| M3 - South Hole | 292.1 |
| M4 - 12:00 | 292.2 |
| M5 - 10:00 | 292.4 |
| M6 - 8:00 | 292.1 |
| M7 - 6:00 | 292.3 |
| M8 - 4:00 | 292.3 |
| M9 - 2:00 | 292.1 |
| M10- Top Edge | 292.3 |
| M11 - 8:00 Edge | 292.0 |
| M12 - 4:00 Edge | 292.0 |
| M13 - Top Front | 292.4 |
| M14 - 4:00 Front | 292.1 |
| M33 - 8:00 (w/M6) | 292.2 |
| M34 - 8:00 (w/M11) | 292.4 |
| M35 - 8:00 (w/M2) | 292.3 |
| M36 - 12:00 (w/M4) | 291.8 |
| M37 - 4:00 (w/M8) | 292.2 |
| M38 - 5:00 | 292.2 |
| M39 - 7:00 | 292.4 |
| 30 - South Pad | 291.9 |
| 31 - Bottom Pad | 292.0 |
| 32 - North Pad | 291.9 |
| 15 - 12:00 Ring | 292.5 |
| 16 - Delta_3 | 292.1 |
| 17 - Delta_2 | 292.1 |
| 18 - Top Bracket | 292.0 |
| 19 - South Bracket | 292.2 |
| 20 - North Bracket | 291.9 |
| 21 - Strut R3 | 292.3 |
| 22 - Strut L2 | 292.3 |
| 23 - Strut L3 | 292.3 |
| 24 - Strut L1 | 292.0 |
| 25 - Strut R2 | 292.4 |
| 26 - Strut R1 | 292.0 |
| 27 - South Mount | 292.1 |
| 28 - Bottom Mount | 292.1 |
| 29 - North Mount | 292.1 |
| 40 - Delta_1 | 292.4 |

(Kelvin)

# Mirror temp avg 230º K

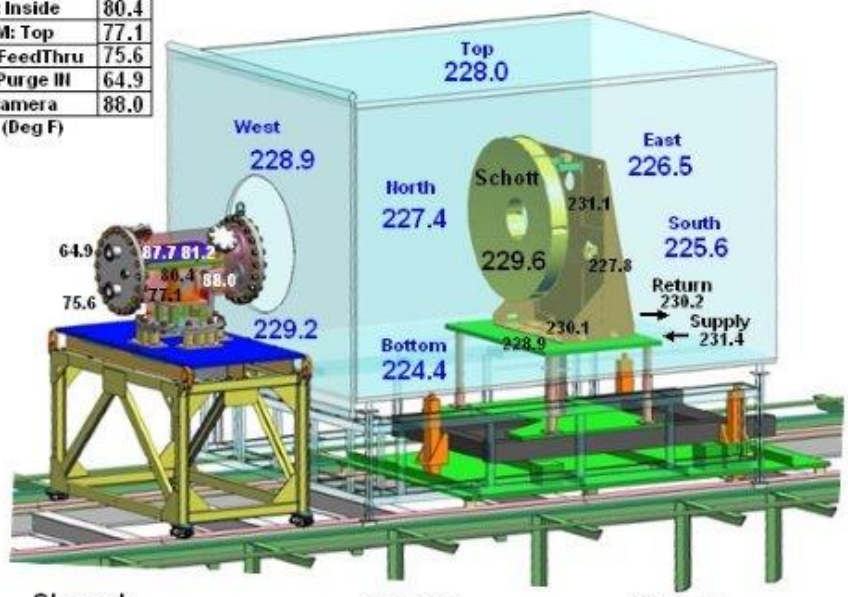
09/15/16 10:12:51

## AMTD2 / Schott Cryo Test

PTE

| | |
|---|---|
| PhaseCam East | 81.2 |
| PhaseCam West | 87.7 |
| PTE: Inside | 80.4 |
| ADM: Top | 77.1 |
| Cable FeedThru | 75.6 |
| PTE: Purge IN | 64.9 |
| IR Camera | 88.0 |

(Deg F)

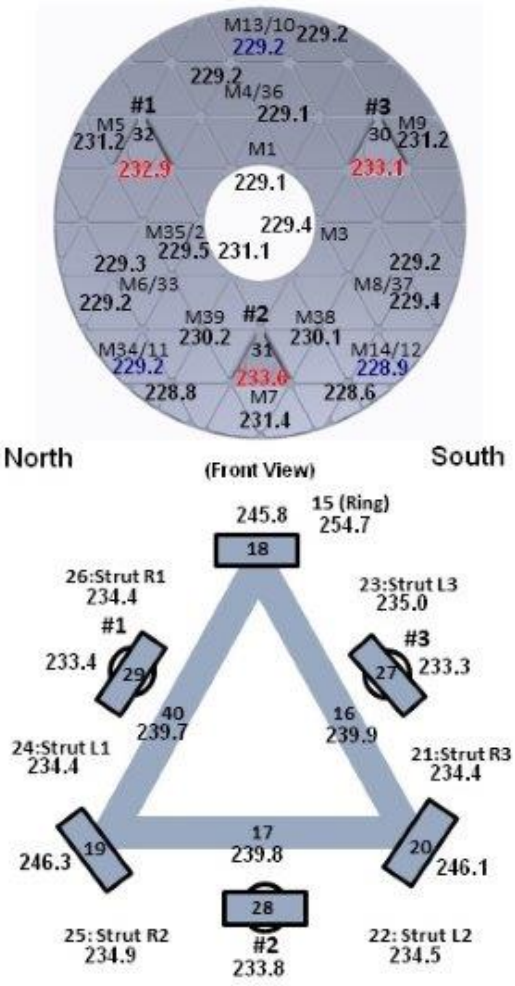



Shroud

| | |
|---|---|
| Top | 228.0 |
| North | 227.4 |
| South | 225.6 |
| Bottom | 224.4 |
| West Top | 228.9 |
| West Bottom | 229.2 |
| East | 226.5 |

(Kelvin)

| Shroud | | | Schott | | |
|---|---|---|---|---|---|
| Average | 227.1 | K | Average | 229.6 | K |
| Rate | -0.4 | K/HR | Rate | -0.7 | K/HR |
| Max | 229.2 | K | Max | 231.4 | K |
| Min | 224.4 | K | Min | 228.6 | K |
| Grad | 4.7 | K | Grad | 2.8 | K |




| | |
|---|---|
| M1- Top Hole | 229.1 |
| M2 - North Hole | 231.1 |
| M3 - South Hole | 229.4 |
| M4 - 12:00 | 229.2 |
| M5 - 10:00 | 231.2 |
| M6 - 8:00 | 229.2 |
| M7 - 6:00 | 231.4 |
| M8 - 4:00 | 229.4 |
| M9 - 2:00 | 230.9 |
| M10- Top Edge | 229.2 |
| M11 - 8:00 Edge | 228.8 |
| M12 - 4:00 Edge | 228.6 |
| M13 - Top Front | 229.2 |
| M14 - 4:00 Front | 228.9 |
| M33 - 8:00 (w/M6) | 229.3 |
| M34 - 8:00 (w/M11) | 229.2 |
| M35 - 8:00 (w/M2) | 229.5 |
| M36 - 12:00 (w/M4) | 229.1 |
| M37 - 4:00 (w/M8) | 229.2 |
| M38 - 5:00 | 230.1 |
| M39 - 7:00 | 230.2 |
| 30 - South Pad | 233.1 |
| 31 - Bottom Pad | 233.6 |
| 32 - North Pad | 232.9 |
| 15 - 12:00 Ring | 254.7 |
| 16 - Delta_3 | 239.9 |
| 17 - Delta_2 | 239.8 |
| 18 - Top Bracket | 245.8 |
| 19 - South Bracket | 246.3 |
| 20 - North Bracket | 246.1 |
| 21 - Strut R3 | 234.4 |
| 22 - Strut L2 | 234.5 |
| 23 - Strut L3 | 235.0 |
| 24 - Strut L1 | 234.4 |
| 25 - Strut R2 | 234.9 |
| 26 - Strut R1 | 234.4 |
| 27 - South Mount | 233.3 |
| 28 - Bottom Mount | 233.8 |
| 29 - North Mount | 233.4 |
| 40 - Delta_1 | 239.7 |

(Kelvin)

# Mirror temp avg 250º K

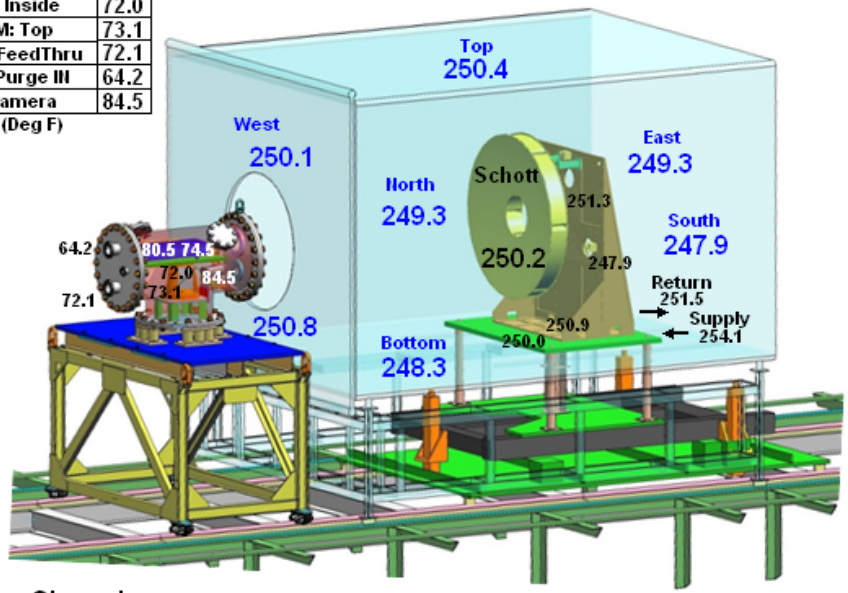
09/16/16 08:10:57

## 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 III | 64.2 |
| IR Camera | 84.5 |

(Deg F)

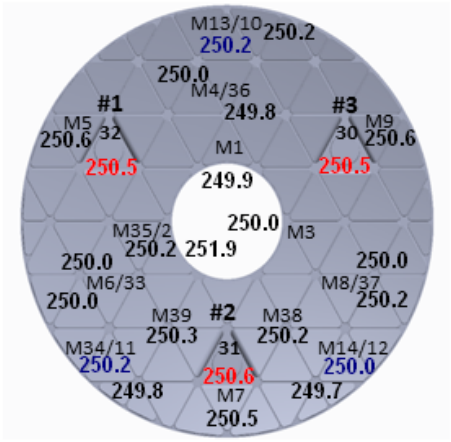



Shroud

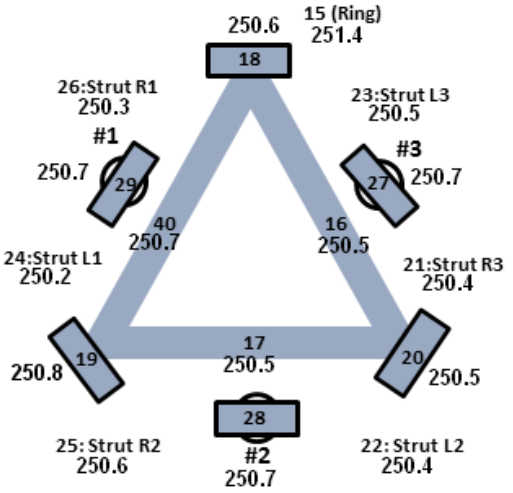
| | |
|---|---|
| Top | 250.4 |
| North | 249.3 |
| South | 247.9 |
| Bottom | 248.3 |
| West Top | 250.1 |
| West Bottom | 250.8 |
| East | 249.3 |

(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 |




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)

# Mirror temp avg 275º K

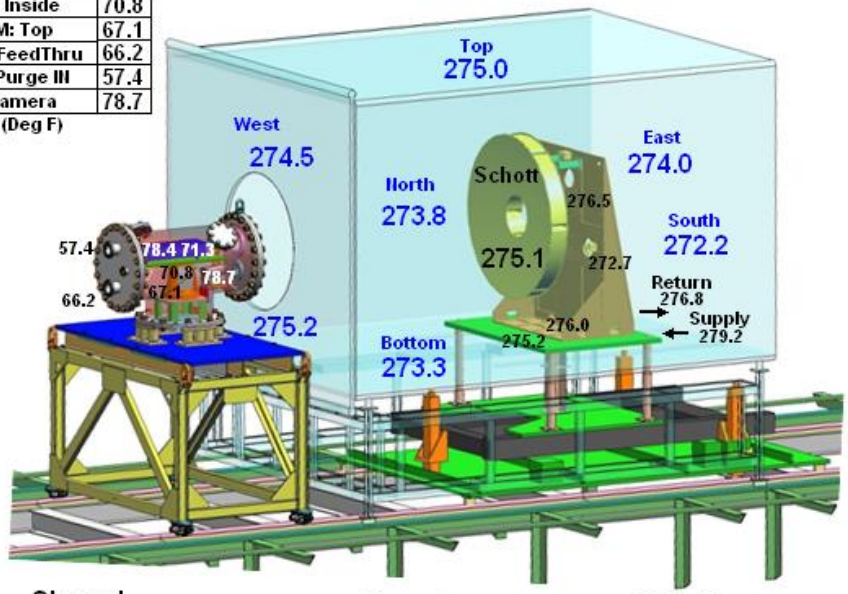
09/19/16 12:20:59

## AMTD2 / Schott Cryo Test

PTE

| | |
|---|---|
| PhaseCam East | 71.3 |
| PhaseCam West | 78.4 |
| PTE: Inside | 70.8 |
| ADM: Top | 67.1 |
| Cable FeedThru | 66.2 |
| PTE: Purge III | 57.4 |
| IR Camera | 78.7 |

(Deg F)

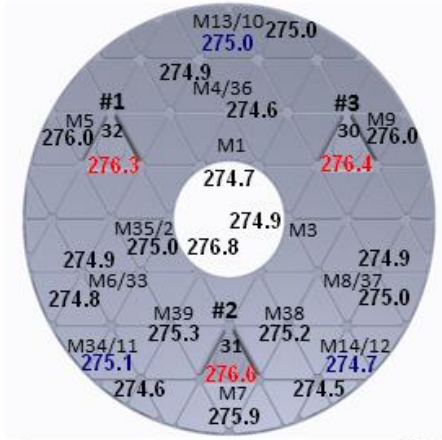



Shroud

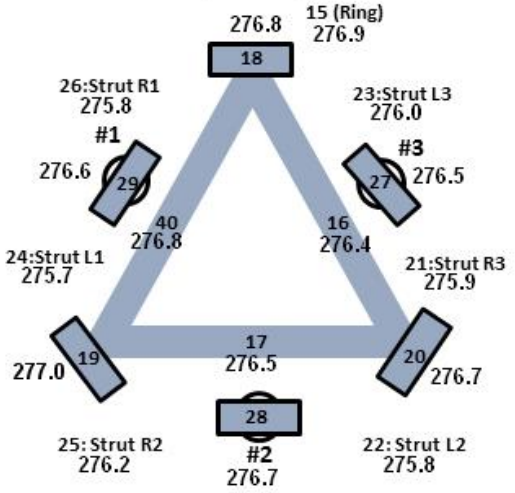
| | |
|---|---|
| Top | 275.0 |
| North | 273.8 |
| South | 272.2 |
| Bottom | 273.3 |
| West Top | 274.5 |
| West Bottom | 275.2 |
| East | 274.0 |

(Kelvin)

| Shroud | | | Schott | | |
|---|---|---|---|---|---|
| Average | 274.0 | K | Average | 275.1 | K |
| Rate | -0.2 | K/HR | Rate | -0.5 | K/HR |
| Max | 275.2 | K | Max | 276.8 | K |
| Min | 272.2 | K | Min | 274.5 | K |
| Grad | 3.0 | K | Grad | 2.3 | K |



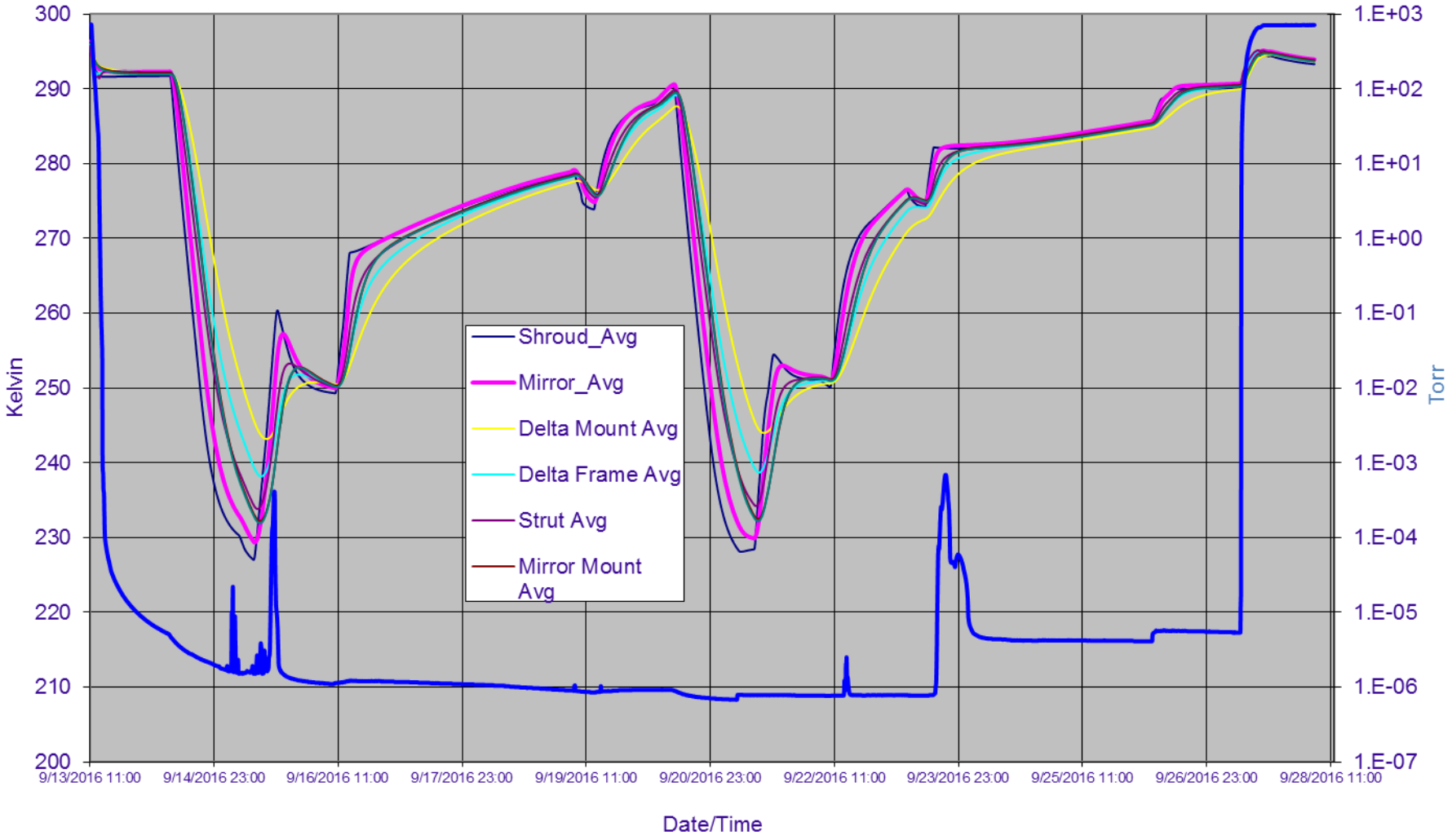

North (Front View) South




| | |
|---|---|
| M1- Top Hole | 274.7 |
| M2 - North Hole | 276.8 |
| M3 - South Hole | 274.9 |
| M4 - 12:00 | 274.9 |
| M5 - 10:00 | 276.0 |
| M6 - 8:00 | 274.8 |
| M7 - 6:00 | 275.9 |
| M8 - 4:00 | 275.0 |
| M9 - 2:00 | 275.7 |
| M10- Top Edge | 275.0 |
| M11 - 8:00 Edge | 274.6 |
| M12 - 4:00 Edge | 274.5 |
| M13 - Top Front | 275.0 |
| M14 - 4:00 Front | 274.7 |
| M33 - 8:00 (w/M6) | 274.9 |
| M34 - 8:00 (w/M11) | 275.1 |
| M35 - 8:00 (w/M2) | 275.0 |
| M36 - 12:00 (w/M4) | 274.6 |
| M37 - 4:00 (w/M8) | 274.9 |
| M38 - 5:00 | 275.2 |
| M39 - 7:00 | 275.3 |
| 30 - South Pad | 276.4 |
| 31 - Bottom Pad | 276.6 |
| 32 - North Pad | 276.3 |
| 15 - 12:00 Ring | 276.9 |
| 16 - Delta_3 | 276.4 |
| 17 - Delta_2 | 276.5 |
| 18 - Top Bracket | 276.8 |
| 19 - South Bracket | 277.0 |
| 20 - North Bracket | 276.7 |
| 21 - Strut R3 | 275.9 |
| 22 - Strut L2 | 275.8 |
| 23 - Strut L3 | 276.0 |
| 24 - Strut L1 | 275.7 |
| 25 - Strut R2 | 276.2 |
| 26 - Strut R1 | 275.8 |
| 27 - South Mount | 276.5 |
| 28 - Bottom Mount | 276.7 |
| 29 - North Mount | 276.6 |
| 40 - Delta_1 | 276.8 |

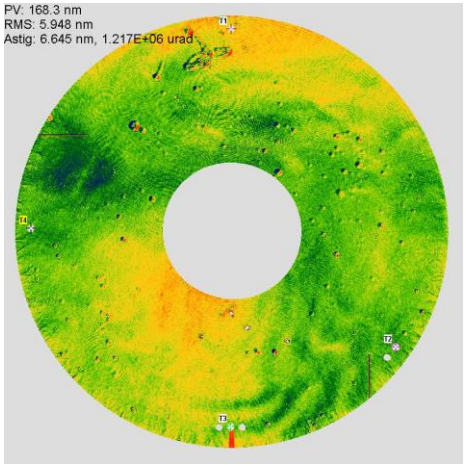
(Kelvin)

# test article temperature and pressure data

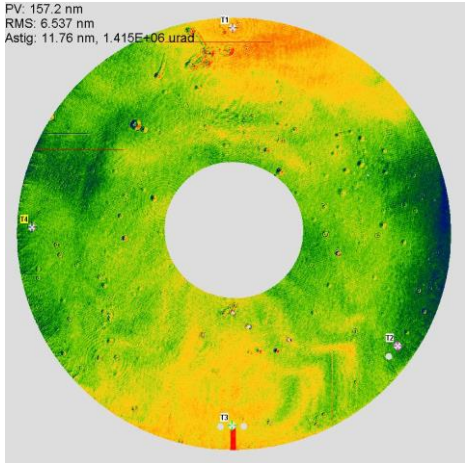


# rms Δ figures

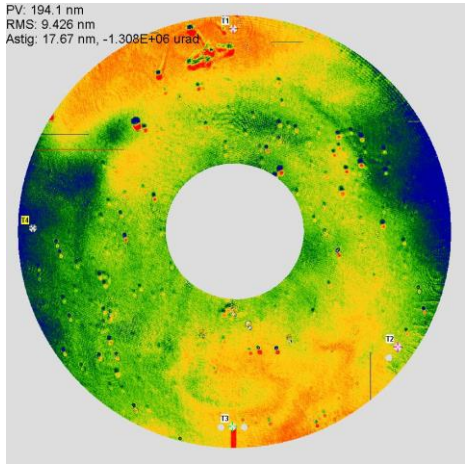
ΔT = 2º C  5.9nm rms



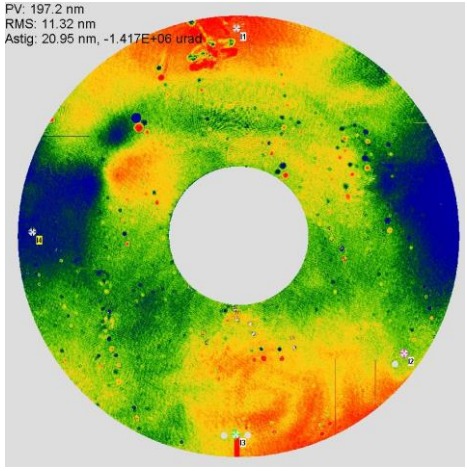

ΔT = 17  6.5nm




ΔT = 42  9.5nm

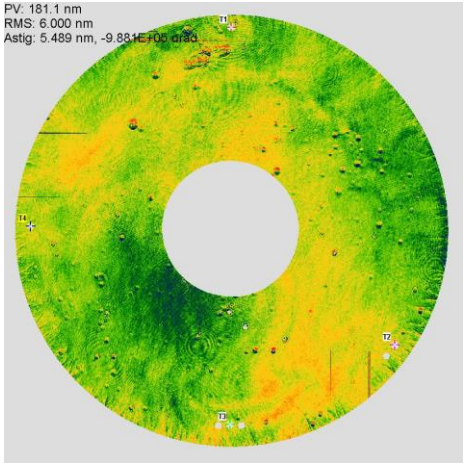



ΔT = 62  11.3nm

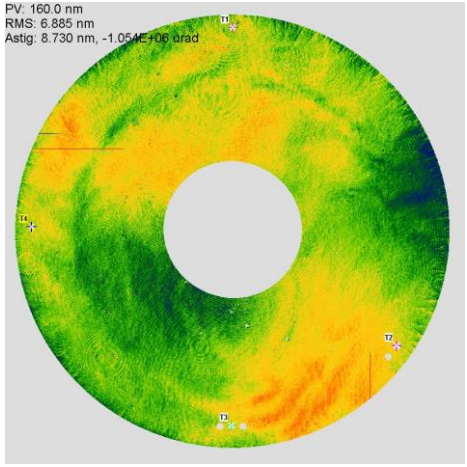



Cycle 1

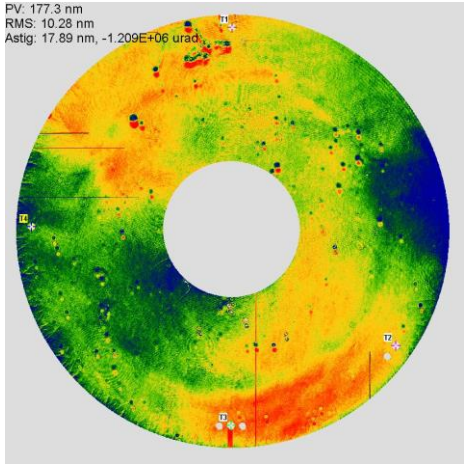
ΔT = 1  6nm



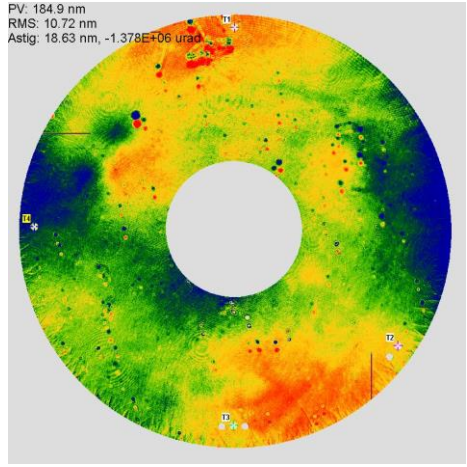

ΔT = 15  6.9nm




ΔT = 39  10.3nm

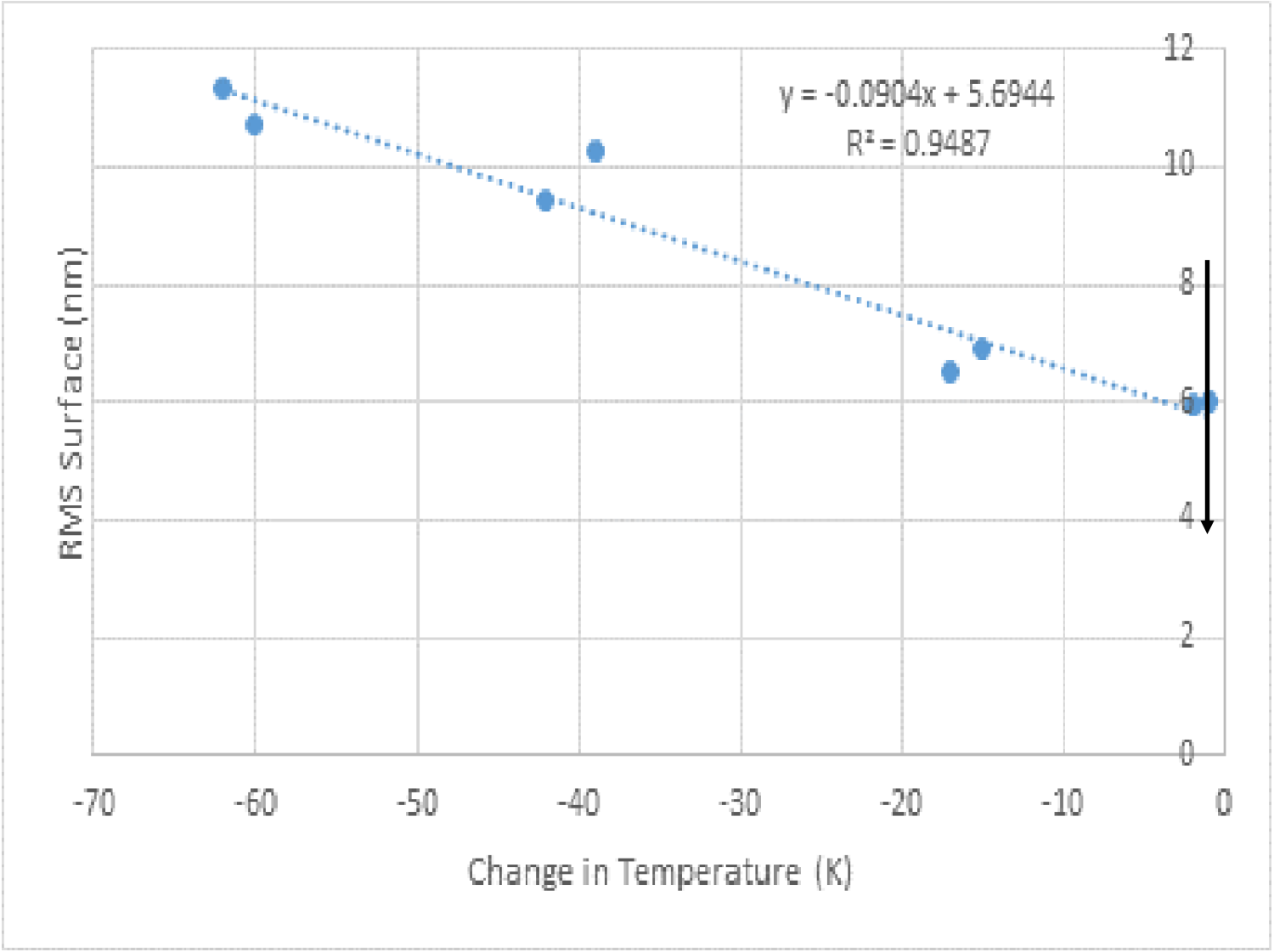



ΔT = 61  10.7nm



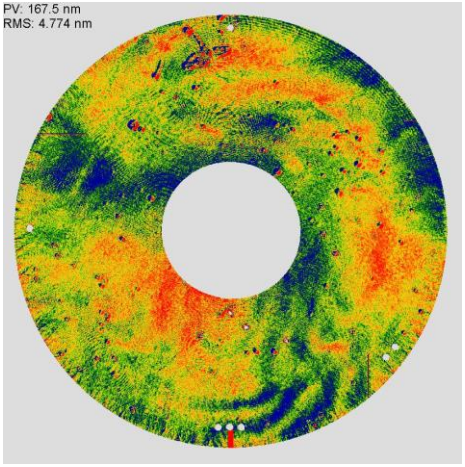

Cycle 2

# Delta surface rms vs temperature

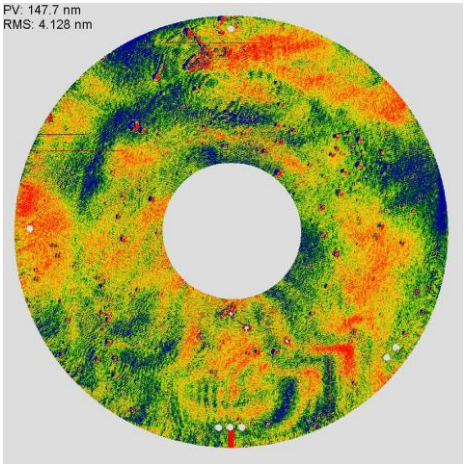


# 36 Zernike terms residual

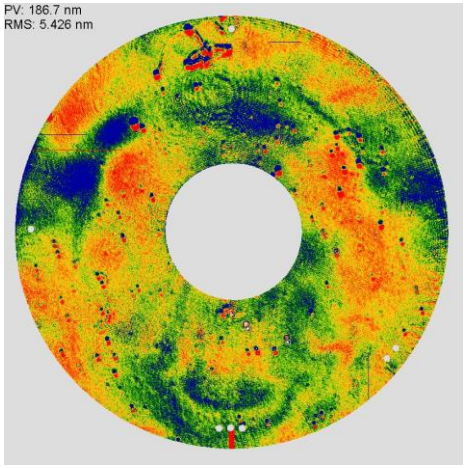
Cycle 1



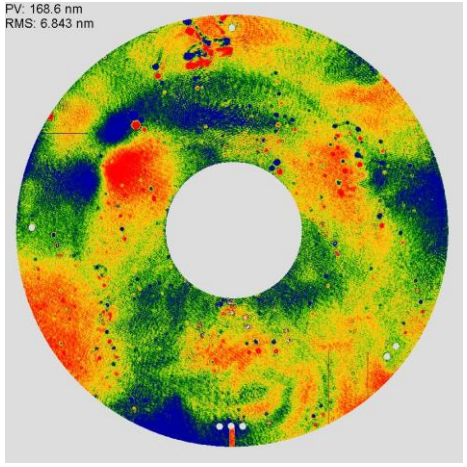

ΔT = 2º C




ΔT = 17

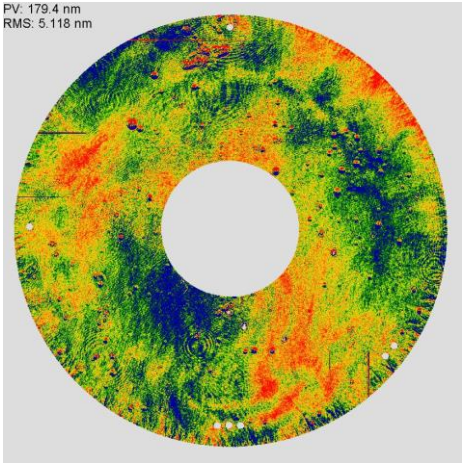



ΔT = 42

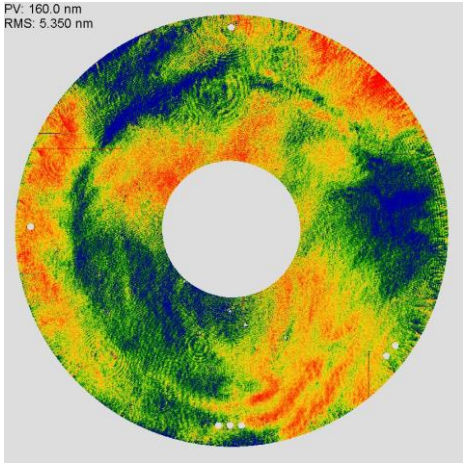



ΔT = 62

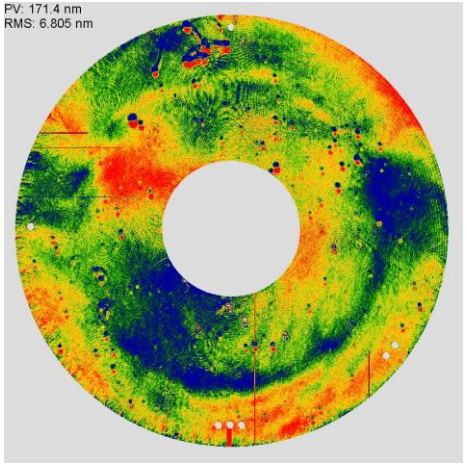
Cycle 2



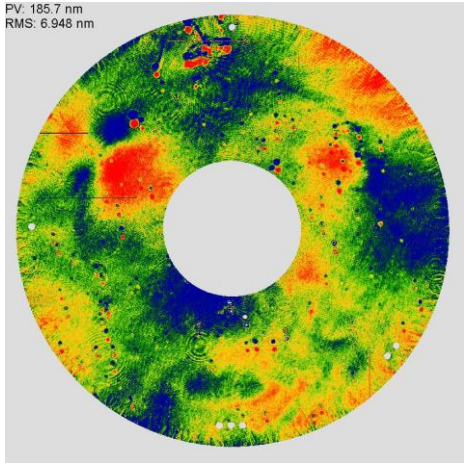

ΔT = 1




ΔT = 15



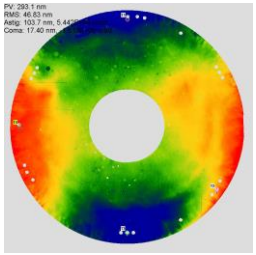

ΔT = 39



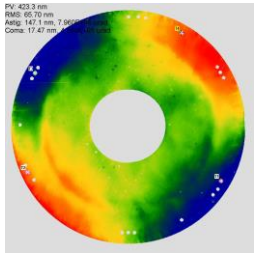

ΔT = 61

# mirror rotations at 0, 120, 240 deg.

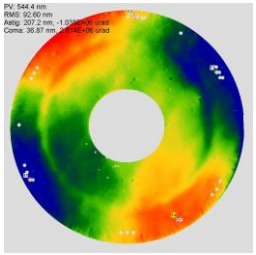
# Gravity backout



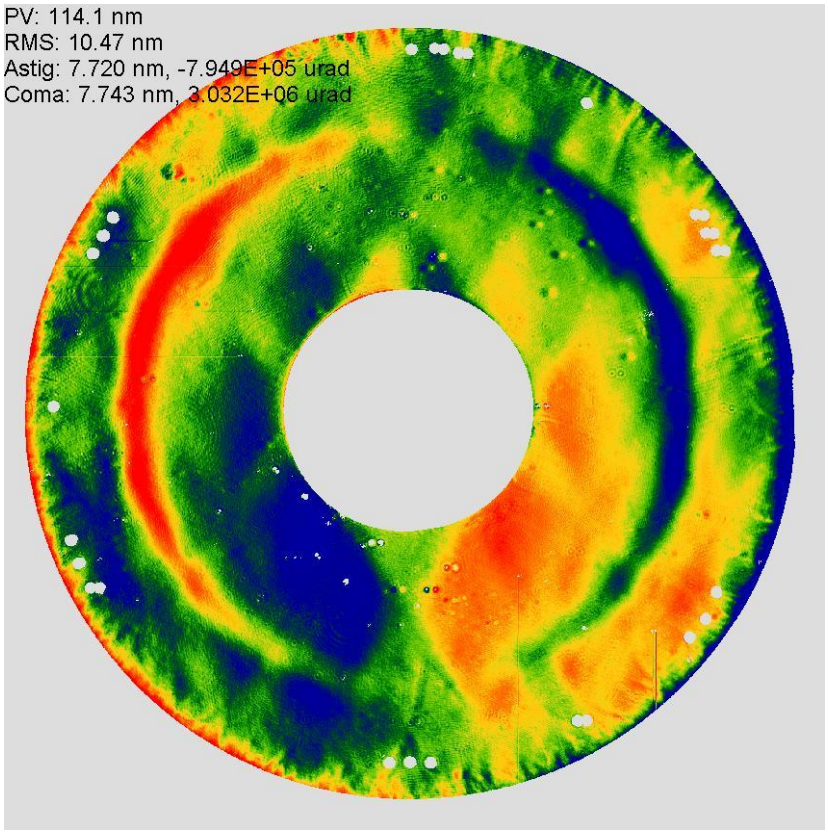
0 deg

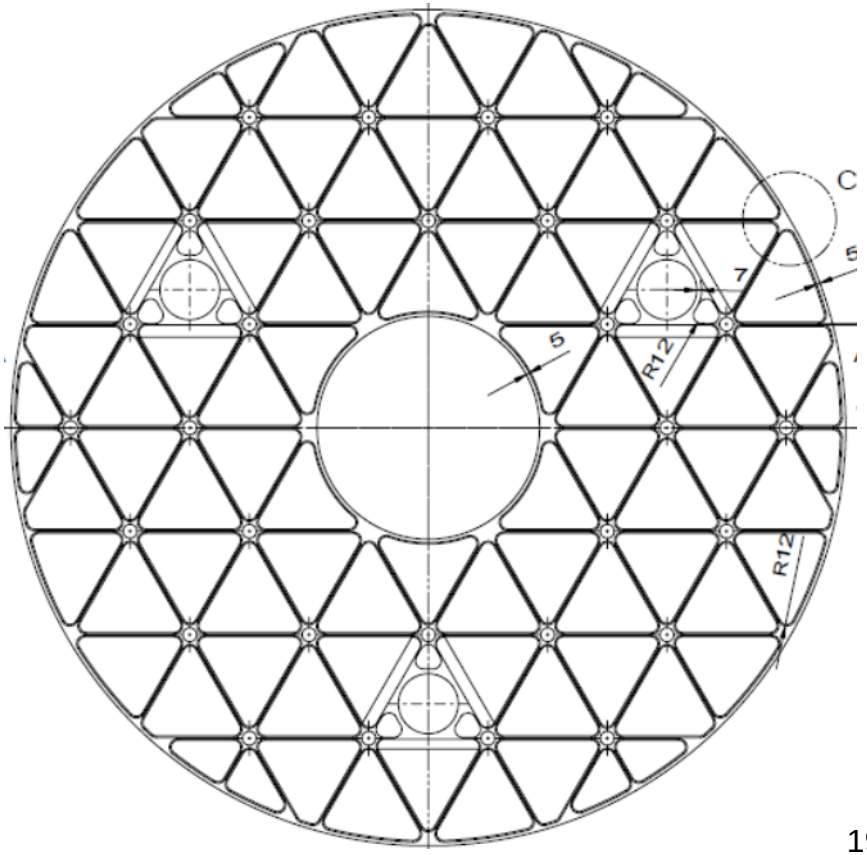


120 deg rotation

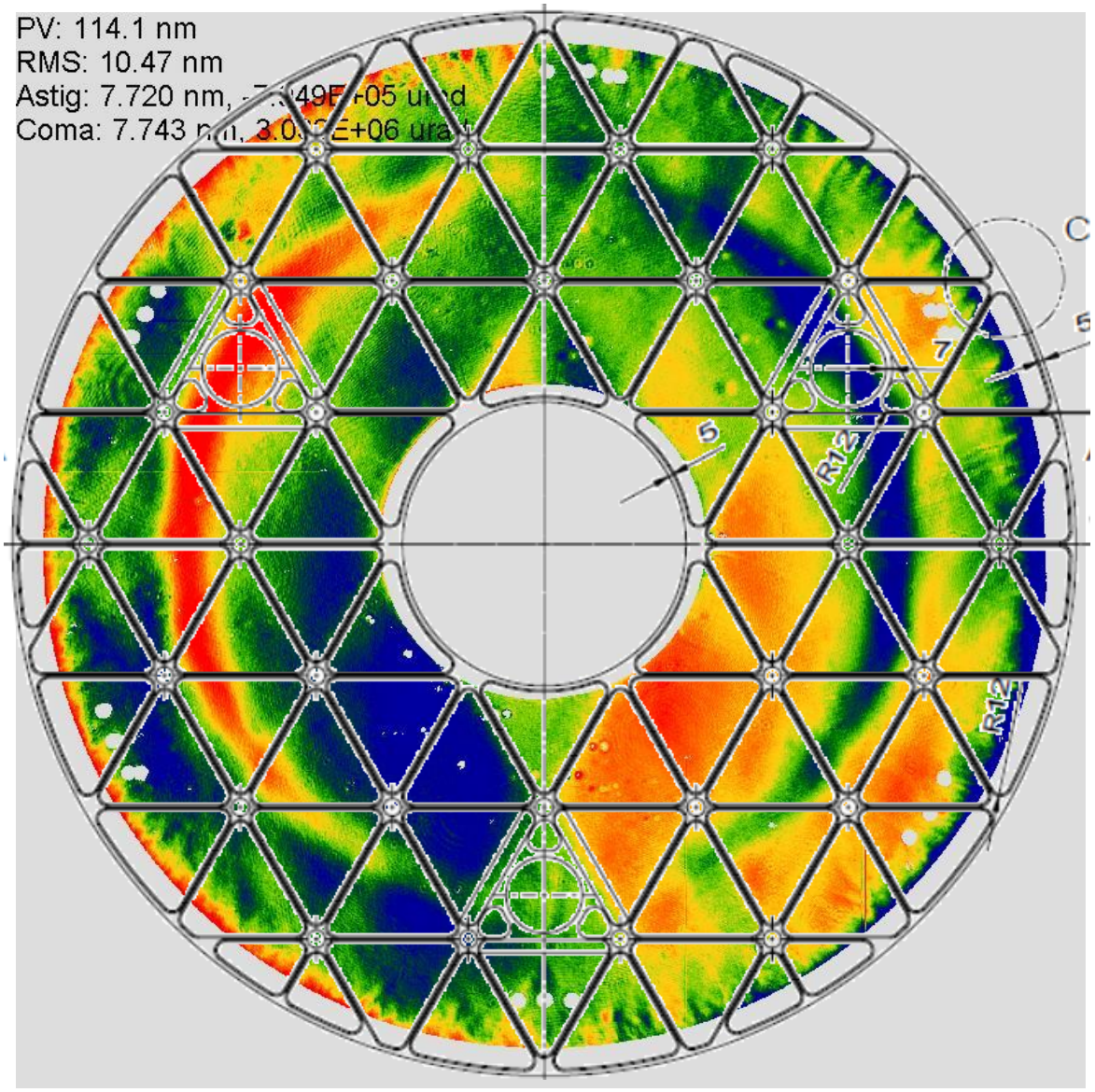


240 deg rotation

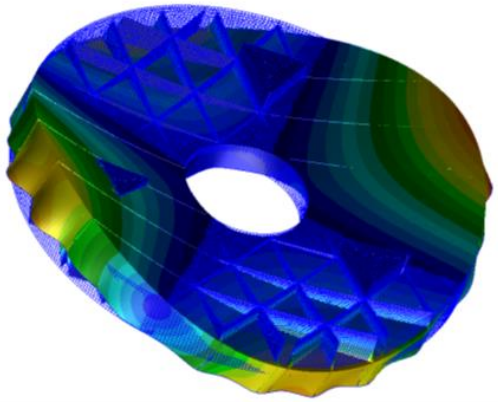


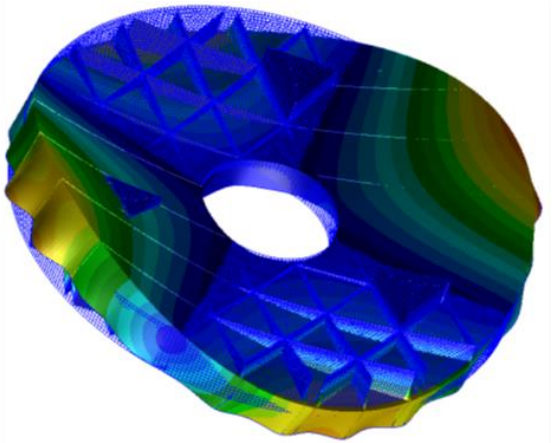
# Gravity backout



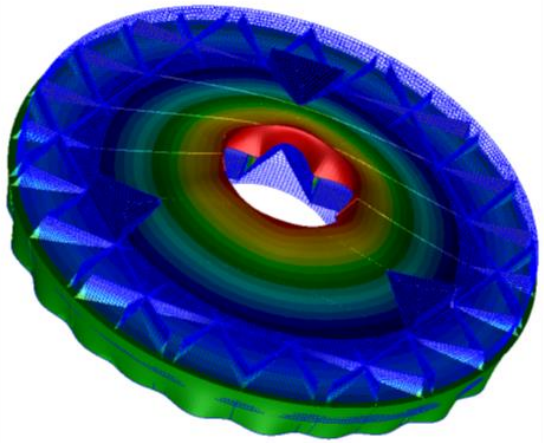
# Predicted modal frequencies and shapes



With foam blocks
F1 = 206.89 Hz

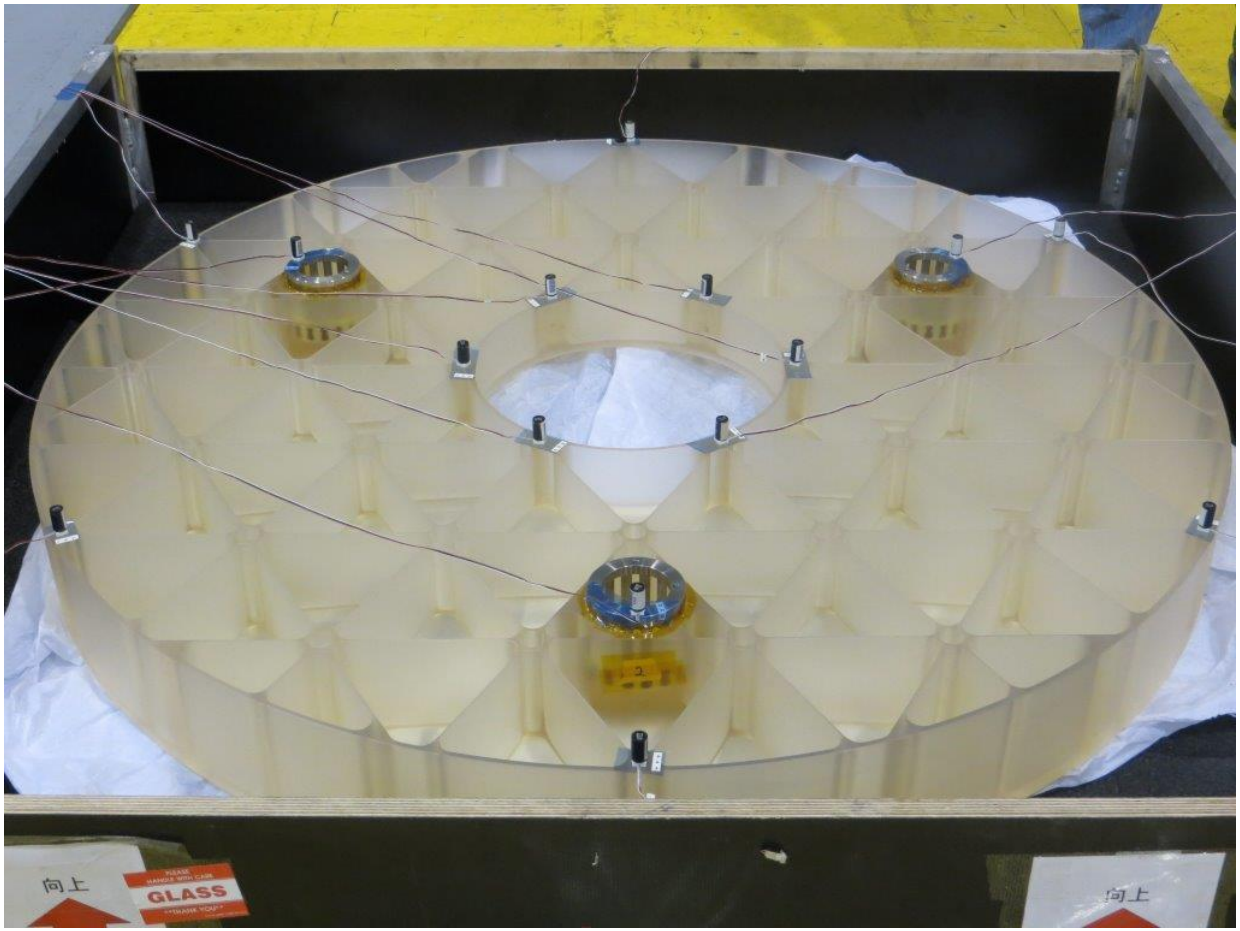


With foam blocks
F2 = 206.95 Hz



With foam blocks
F3 = 345.3 Hz

# Preliminary modal test results




196.07 Hz

# Acknowledgments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## Schott

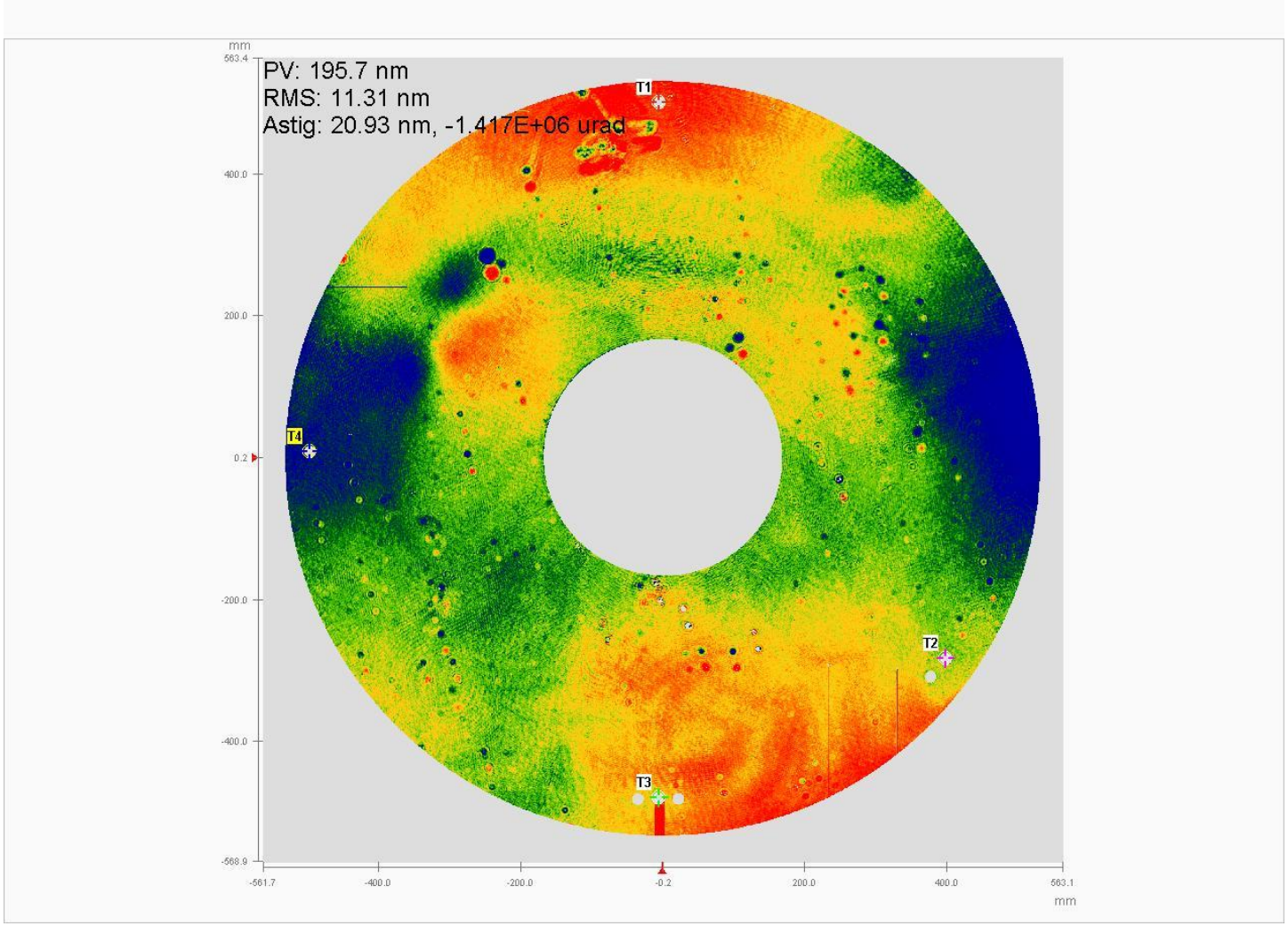
Tony Hull

## Arizona Optical Systems

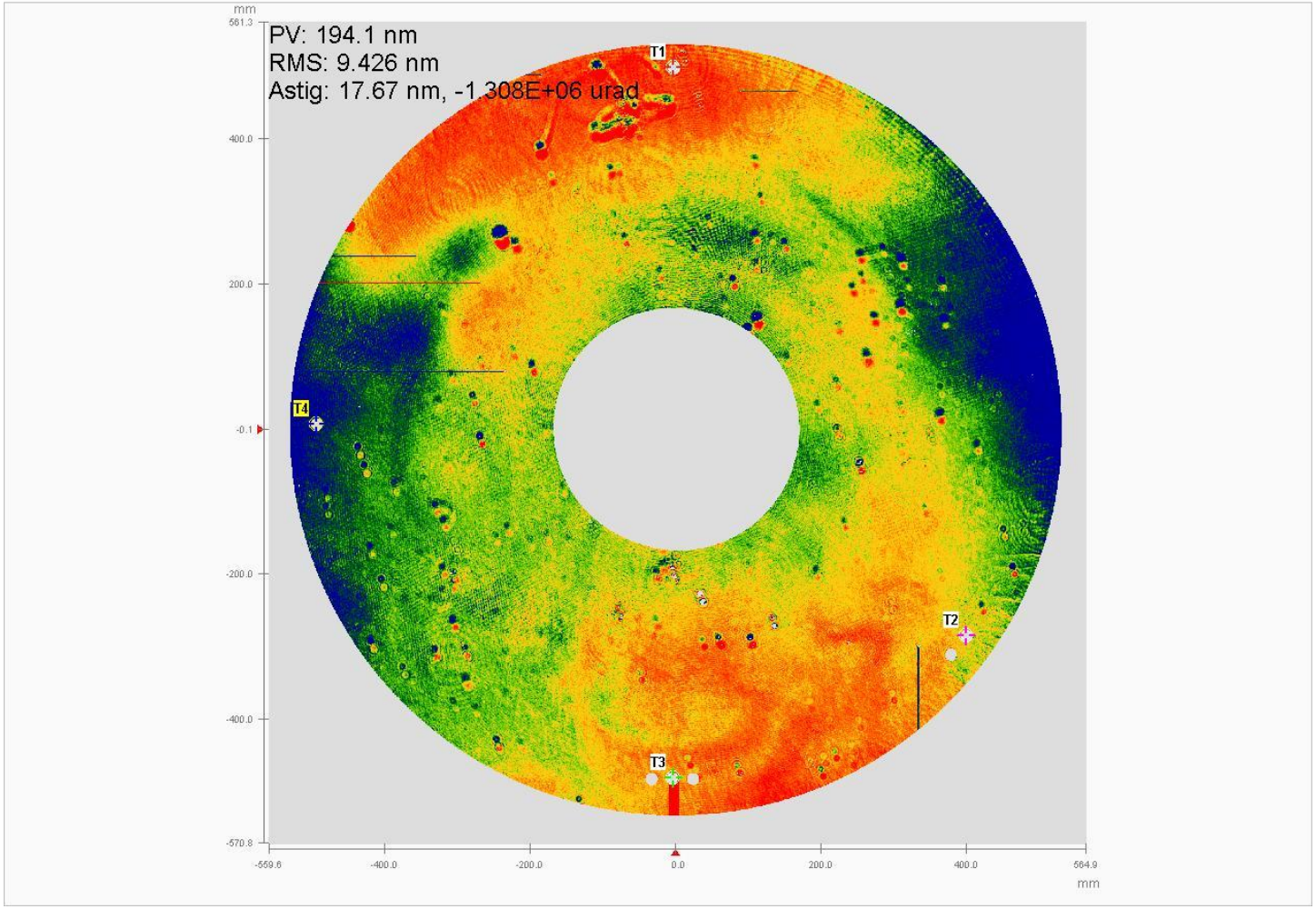
Marty Valente, David Tiss

# Backup slides

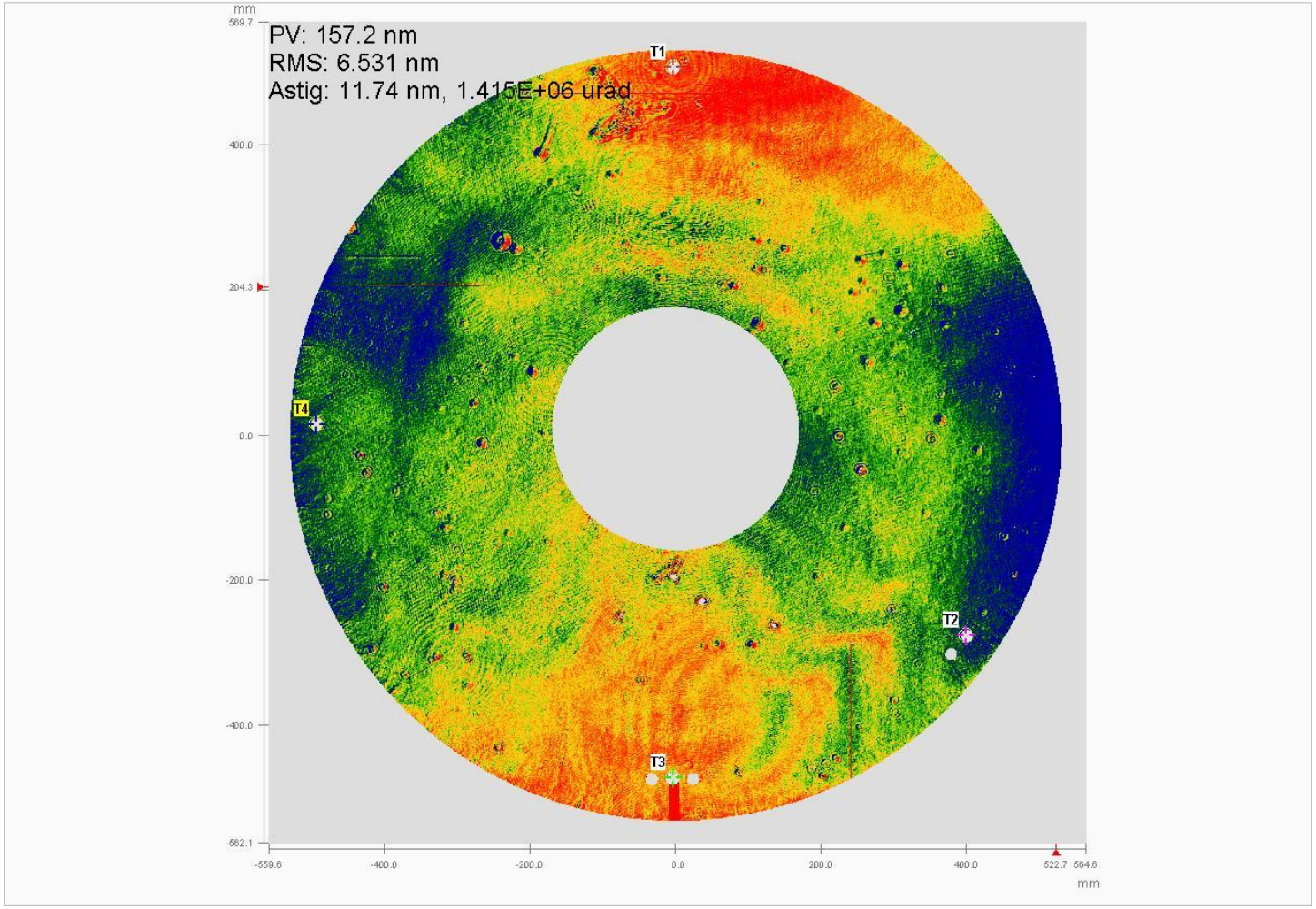
# Cycle 1, 230º - 292º Kelvin



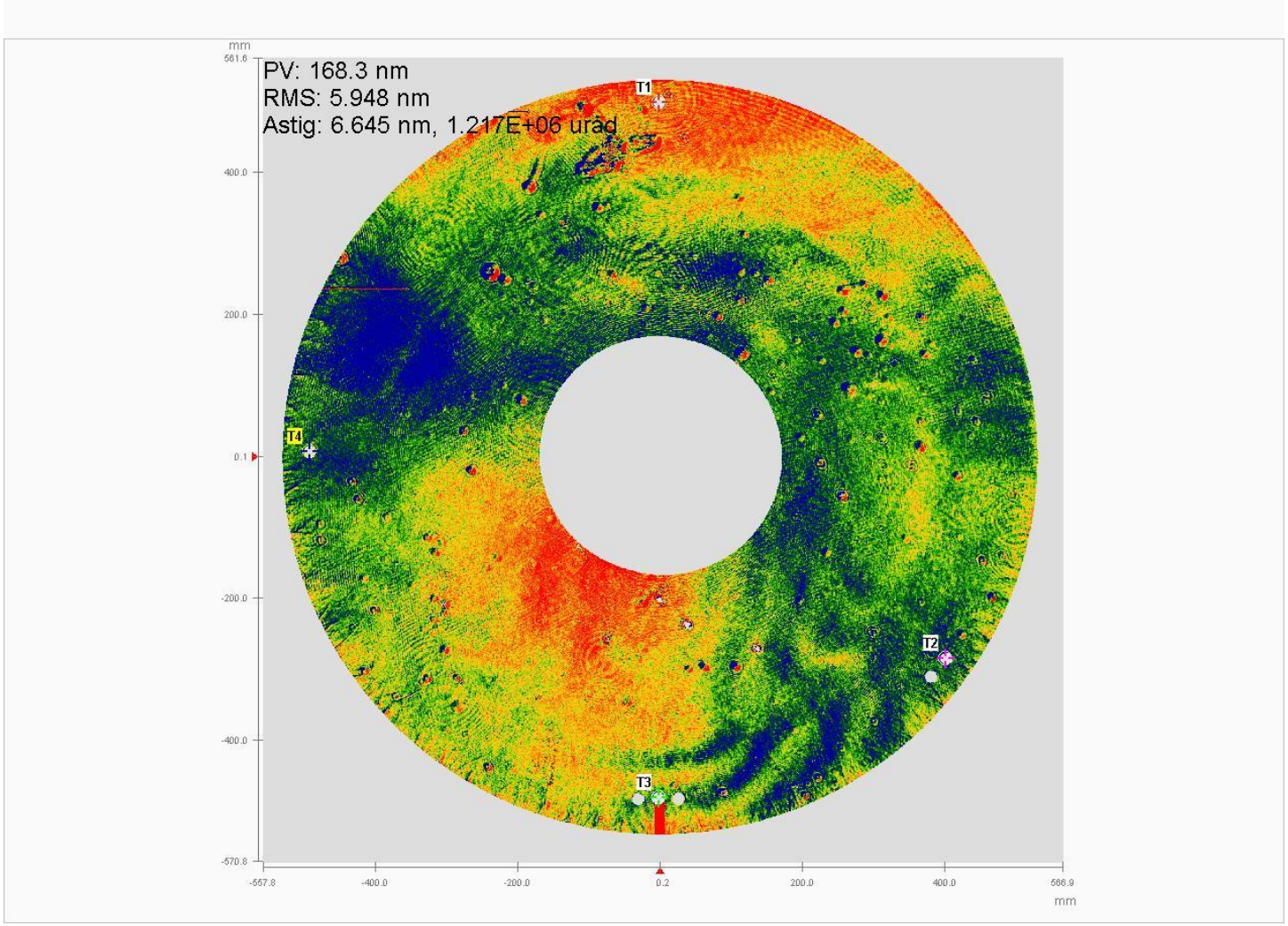
# Cycle 1, 250º - 292º Kelvin



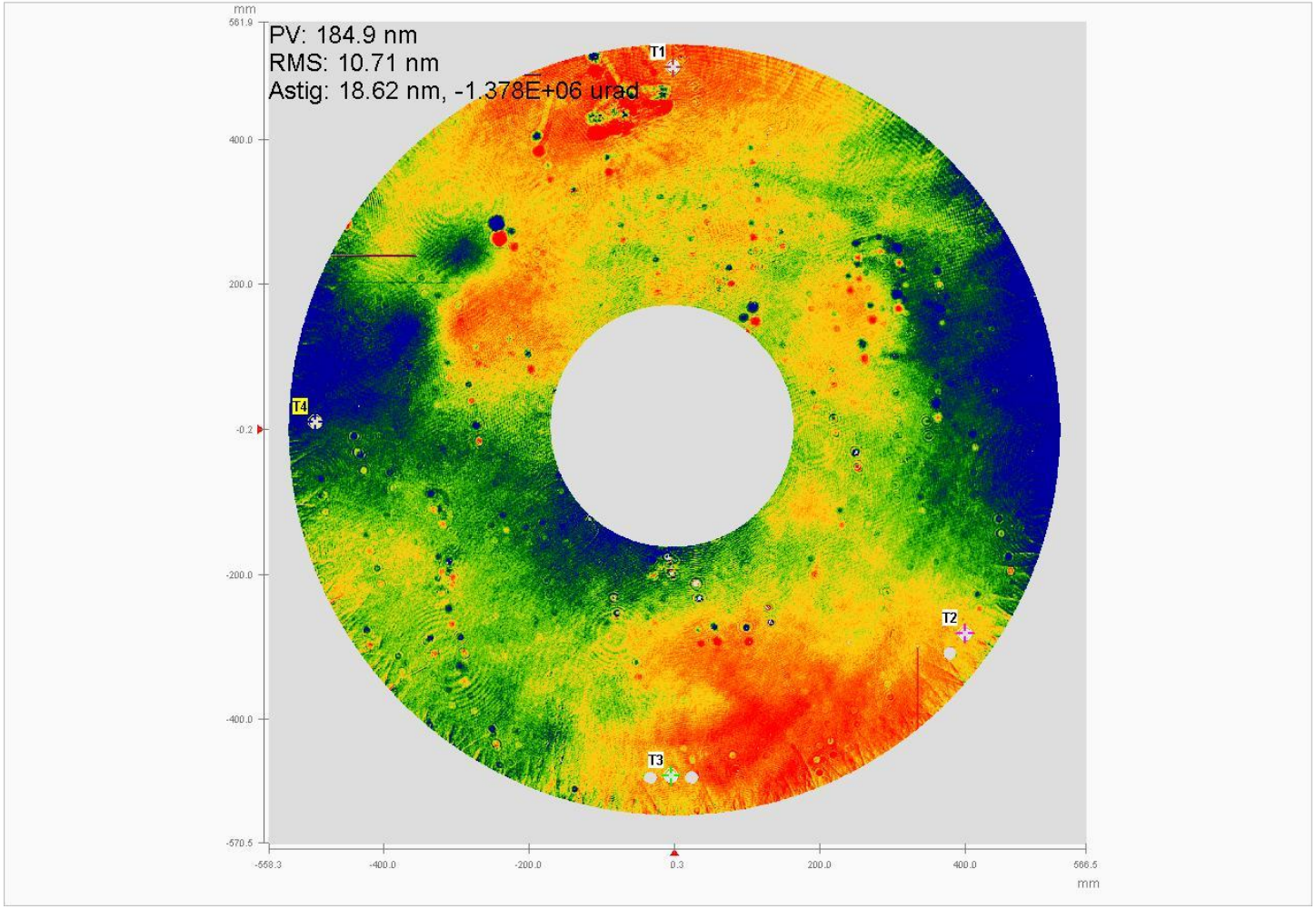
# Cycle 1, 275º - 292º Kelvin



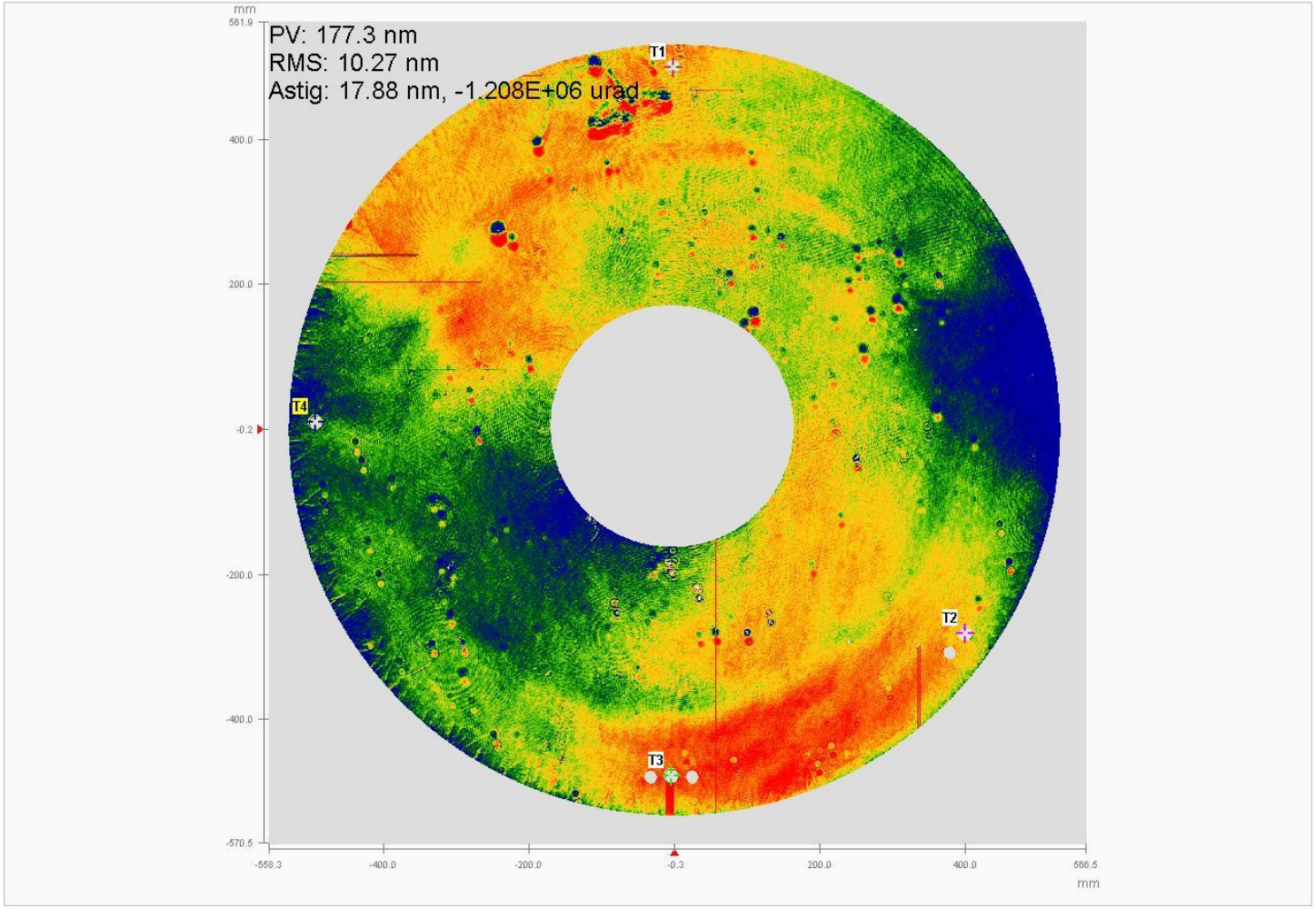
# Cycle 1, 290º - 292º Kelvin



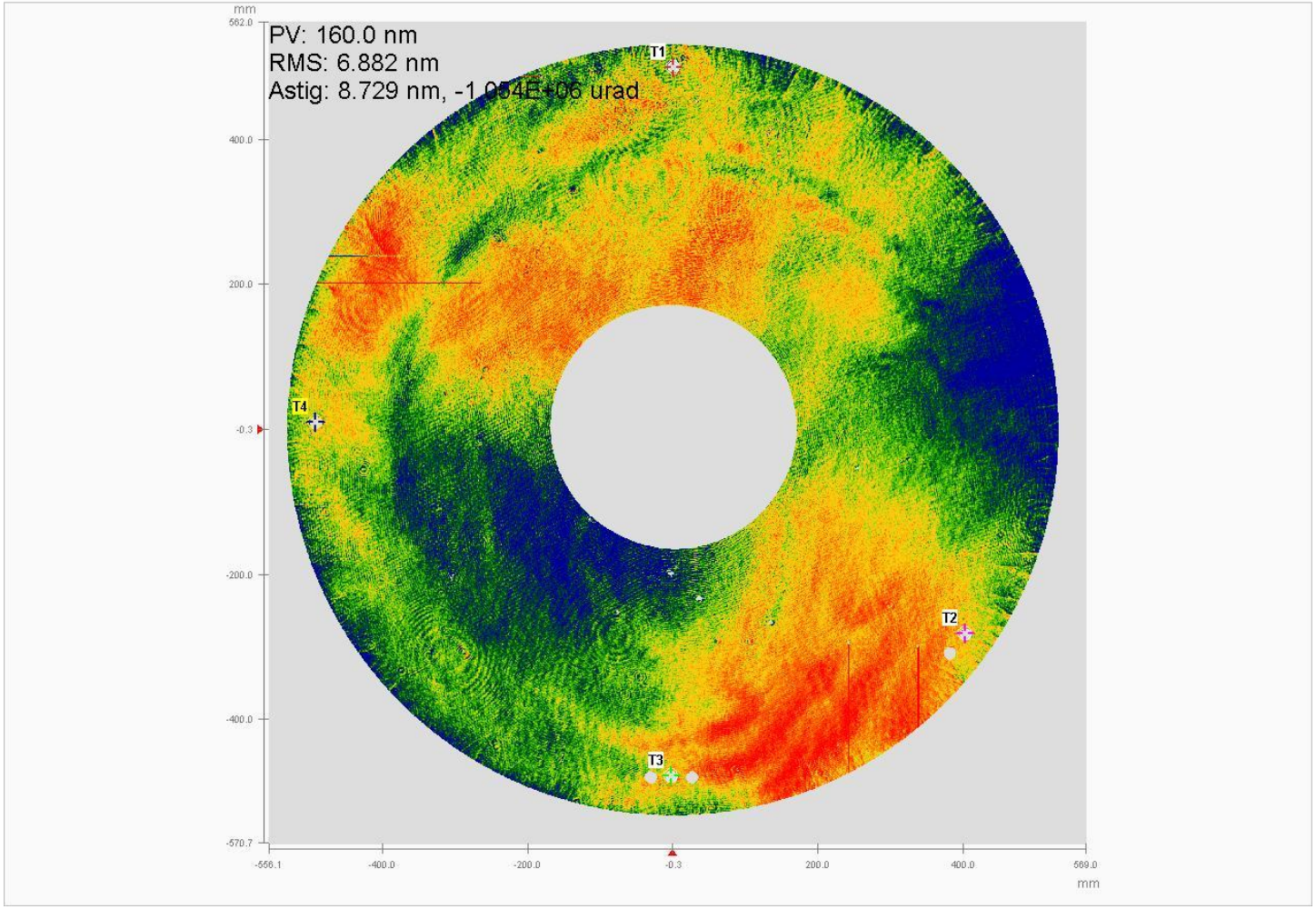
# Cycle 2, 230º - 290º Kelvin



# Cycle 2, 251º - 290º Kelvin



# Cycle 2, 275º - 290º Kelvin



# Cycle 2, 291º - 290º Kelvin