AMTD thermal characterization and model correlation

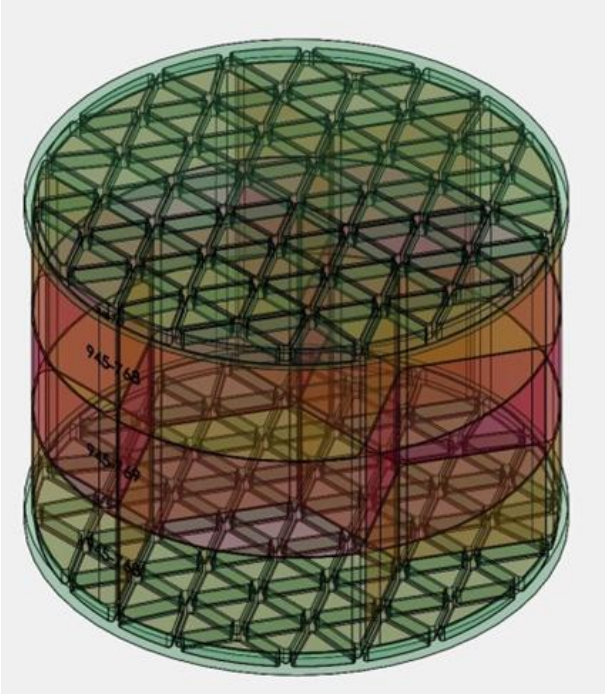
Ron Eng, William Arnold, Marcus Baker, Ryan Bevan, Michael Effinger, Darrell Gaddy, Brian Goode, William Hogue, Jeffrey Kegley, Richard Siler, Scott Smith, Phil Stahl, John Tucker, Ernest Wright
NASA Marshall Space Flight Center

Gregory Burdick, Craig Hanson, Charlie Kirk, Steven Maffett, Gary Matthews
ITT Exelis

Mirror tech days

10-1-2013

Stacked core demo mirror



Objectives:

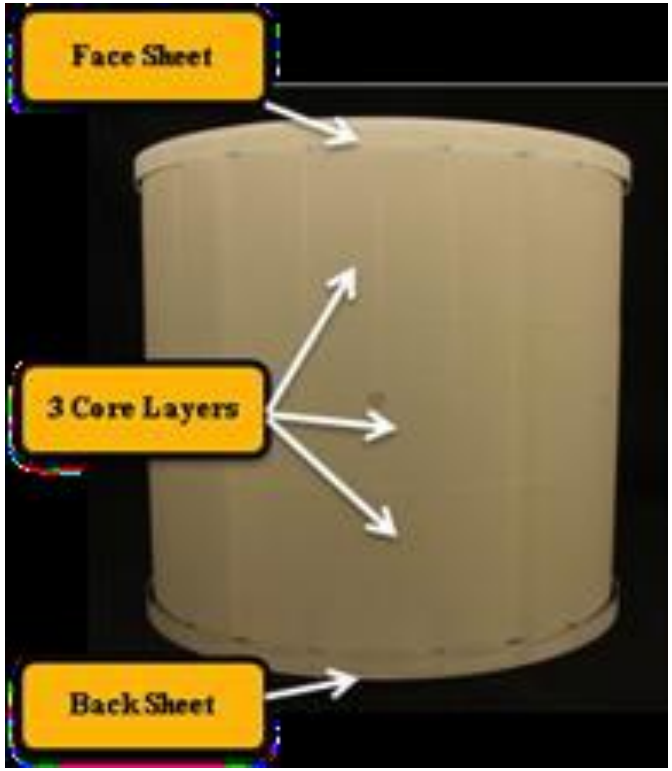
- Demonstrate feasibility of stack core mirror technology for 4-m class mirror
- Validate thermal deformation models.

  Operational temp: 275K (2ºC).
  Test temp: 293 to 253K (RT to -20ºC).

Status:

- Fabricated at ITT Exelis.
- Delivered to MSFC in Dec 2012.
- Cryo tested at MSFC in Jan-Feb 2012.

Stacked core mirror dimensions



43	cm	diameter
1.6	cm	face sheet
33.4	cm	3 core layers
1.7	cm	back sheet
36.7	cm	total edge thickness

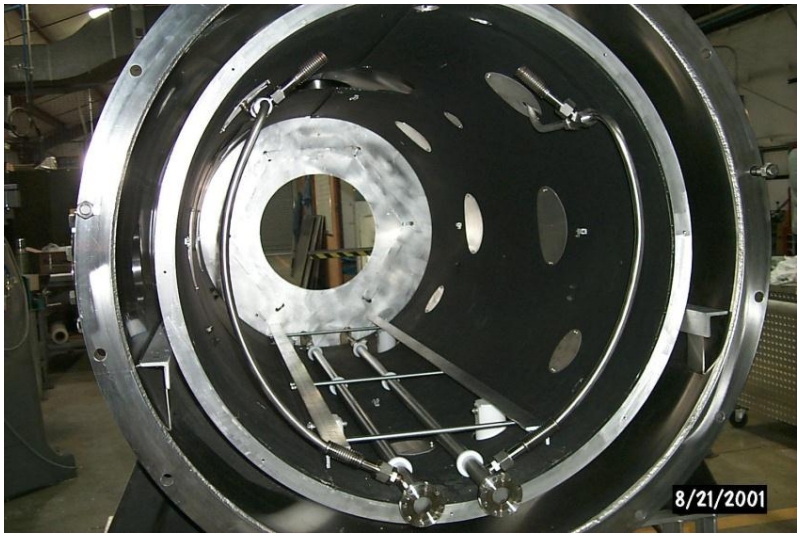
Mass: 6.7 kg

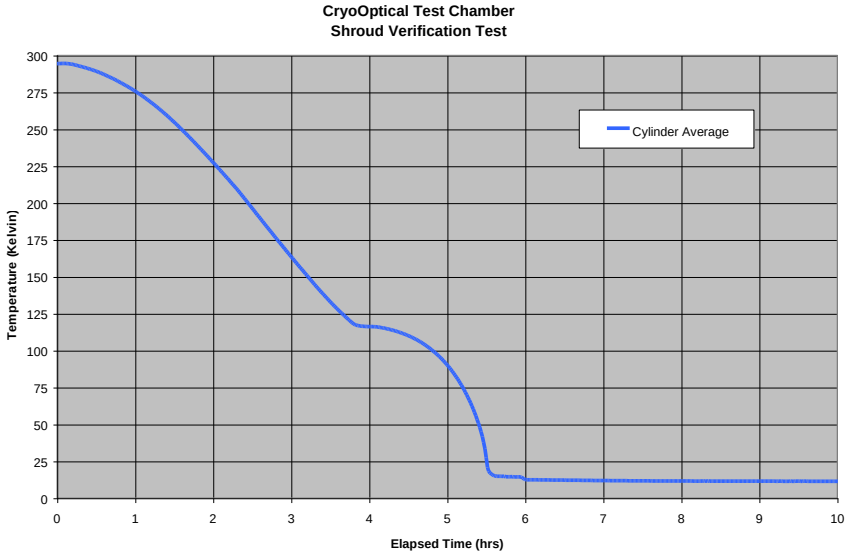
- 7% of equivalent solid ULE
- 93% lightweighting

2.5 m radius of curvature

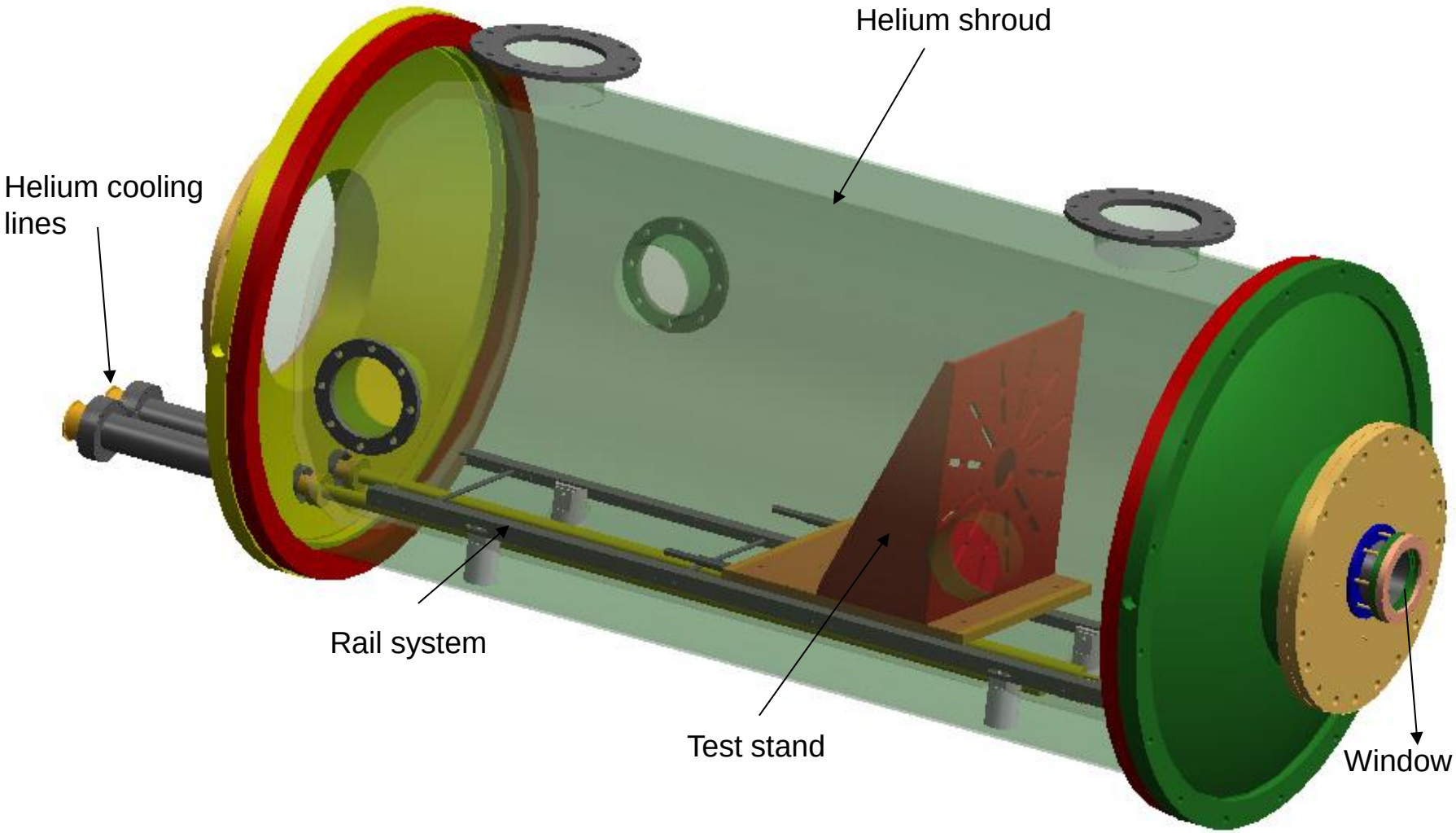
1x3 m optical test chamber

Vacuum Chamber: 1x3 m cylinder with helium shroud.
Optical View Ports: BK7 window; 150 mm dia. clear aperture.
Precision stage to provide interferometer pointing and alignment.
Operational Pressure: < 5 E-6 Torr
Temperature Range: 300 to 12K
Typical cryo optical test: 290, 200, 100, 70, 50, 30K, 2 cycles; 3 weeks duration.

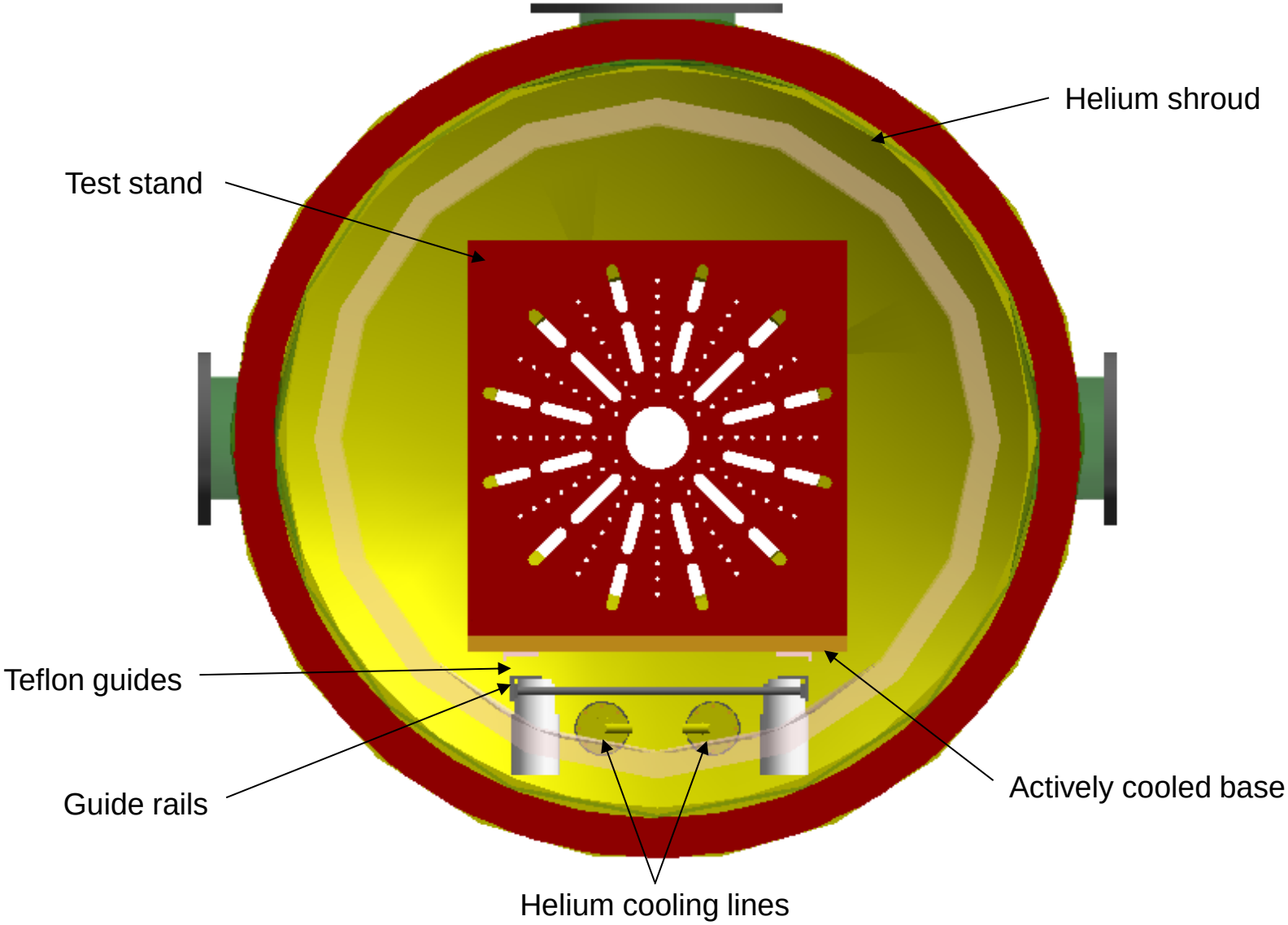




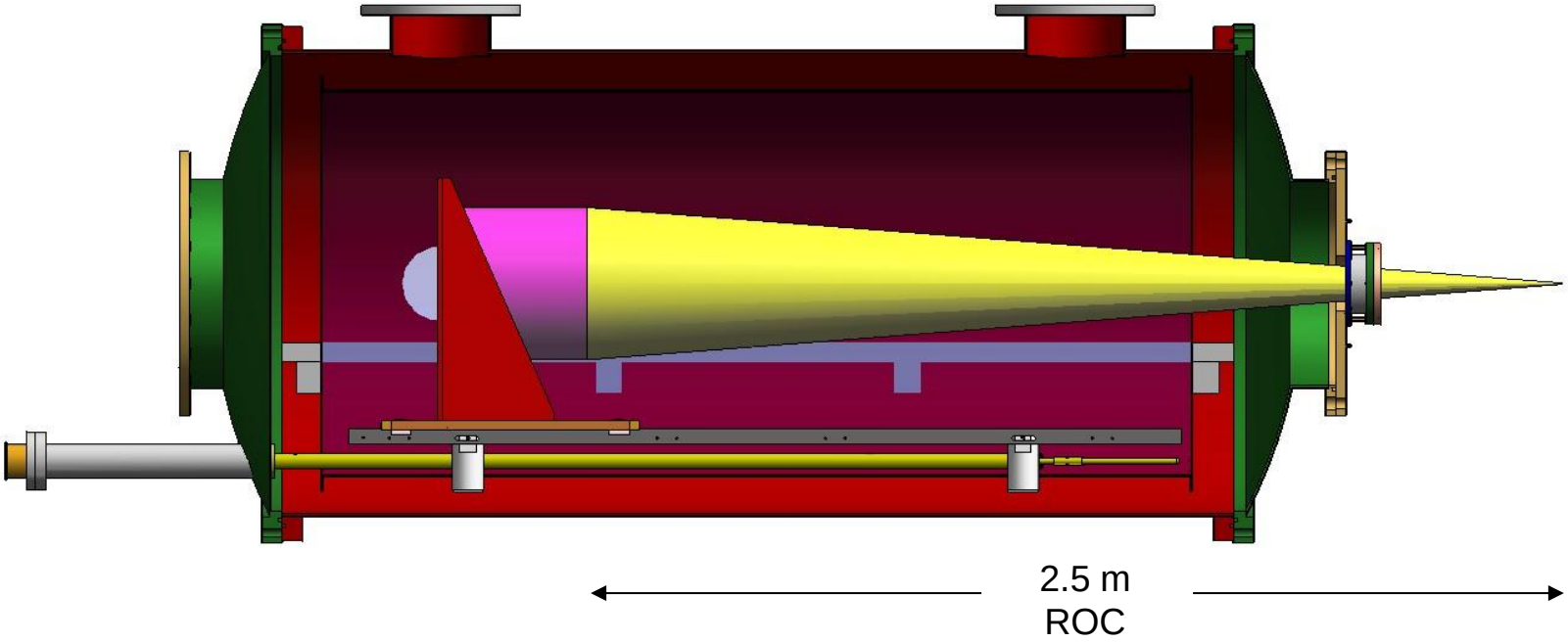
Side view of cryogenic chamber



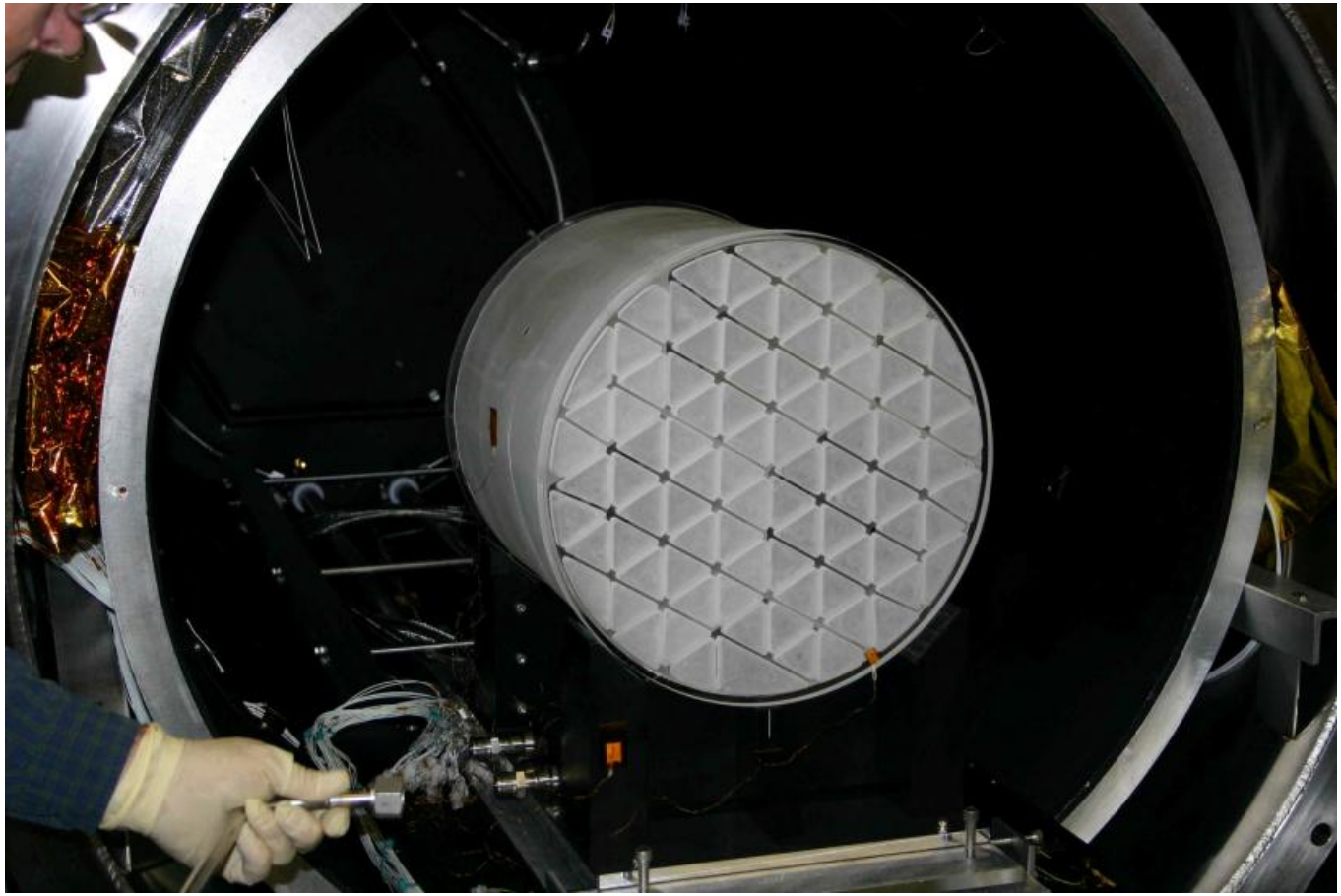
Front view of cryogenic chamber



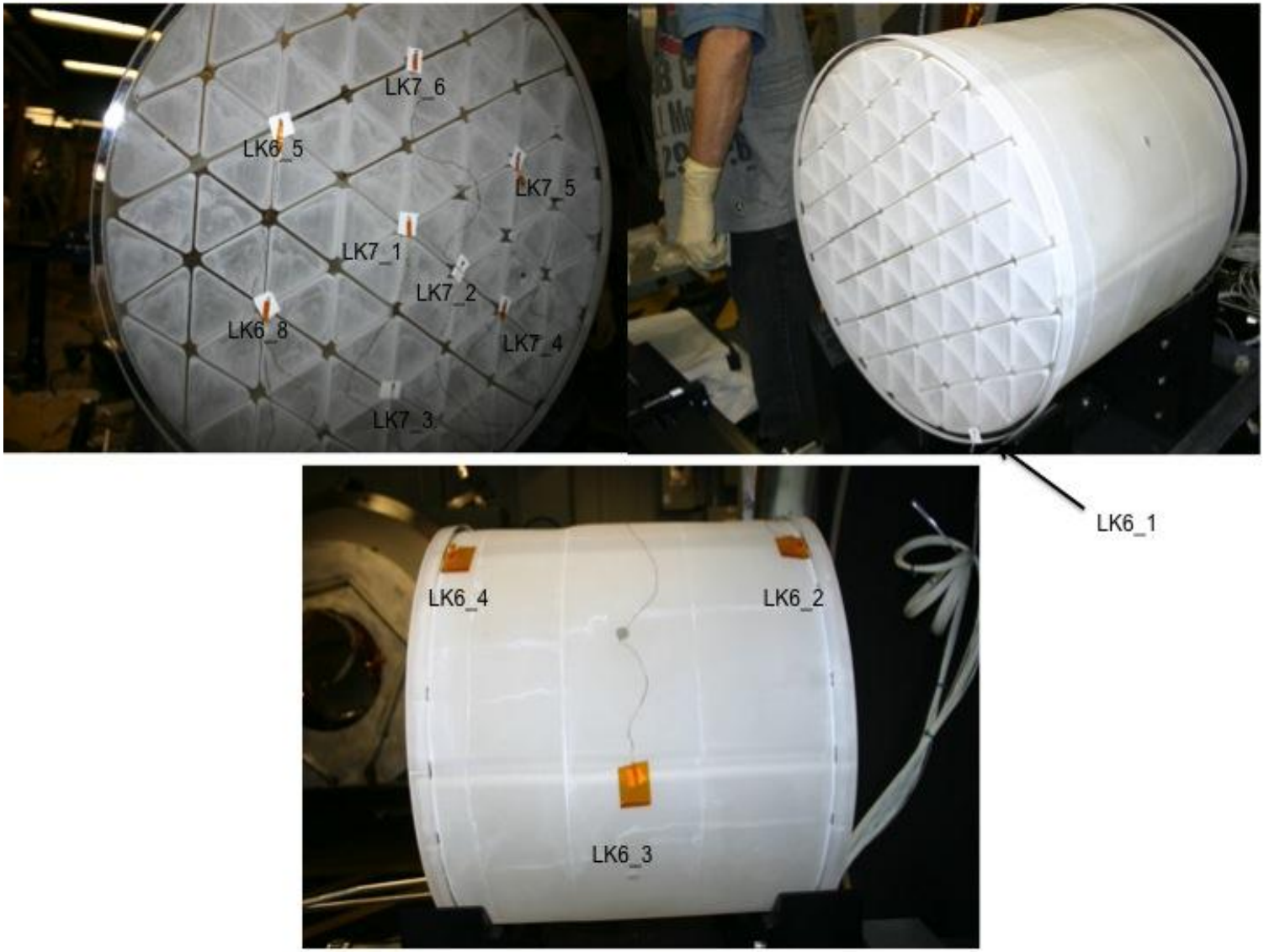
Mirror in chamber



Stacked core mirror in chamber



Temperature sensor locations



Mirror and chamber temperature sensors

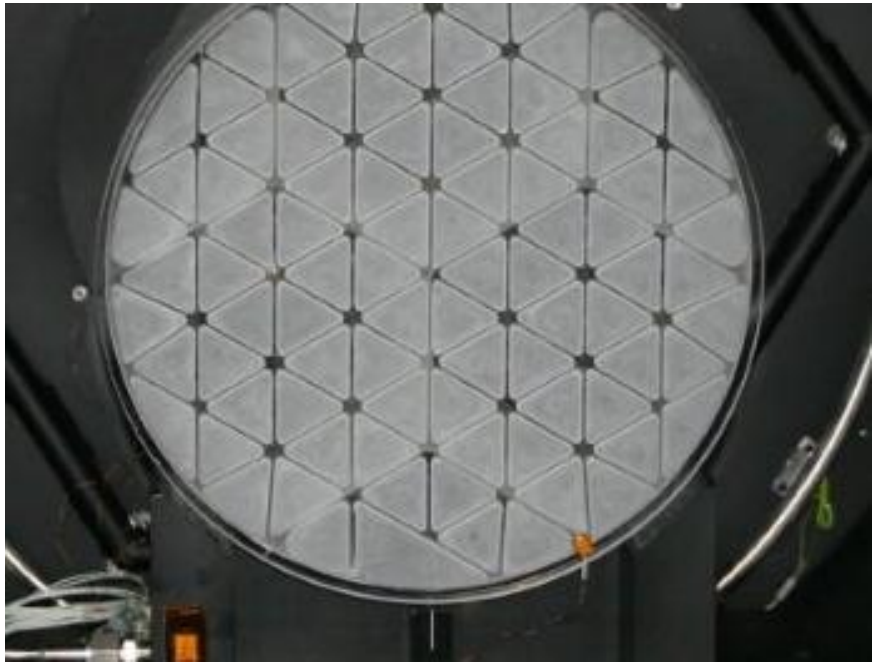
Sensors	Locations
LK6_1	Front Face 5:00
LK6_2	North Side West End
LK6_3	North Side Center
LK6_4	North Side East End
LK6_5	Back Face 11:00
LK6_8	Back Face 9:00
LK7_1	Back Face Center 9:00
LK7_2	Back Face Center
LK7_3	Back Face 7:00
LK7_4	Back Face 5:00
LK7_5	Back Face 3:00
LK7_6	Back Face 1:00
LK7_7	Cold Plate
LK7_8	Test Stand NW Leg

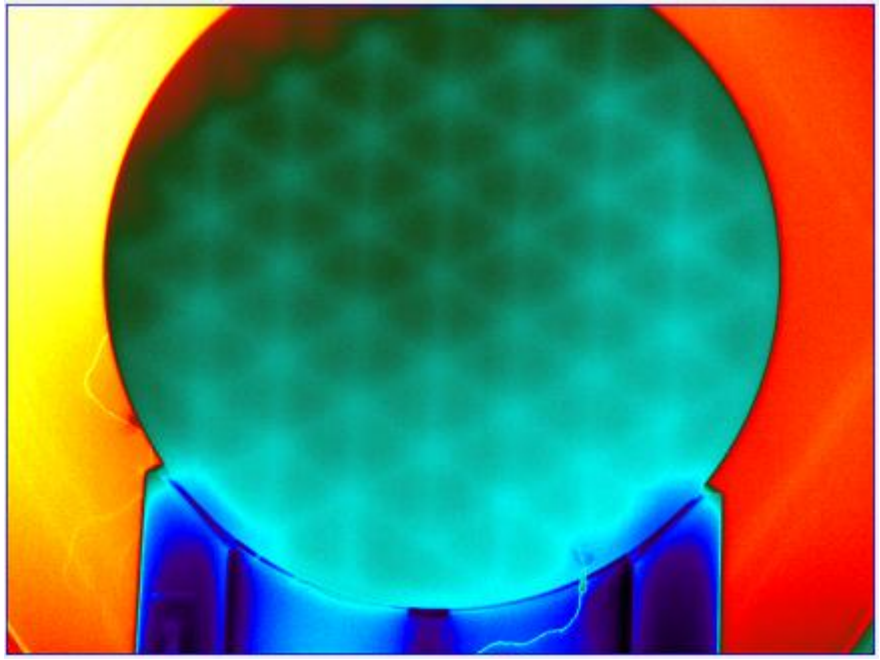
Silicon diodes: Lake Shore DT-670
~1°accuracy

12 diodes on mirror
12 diodes on test stand & chamber

Controller: Lake Shore LK218
0.25°accuracy

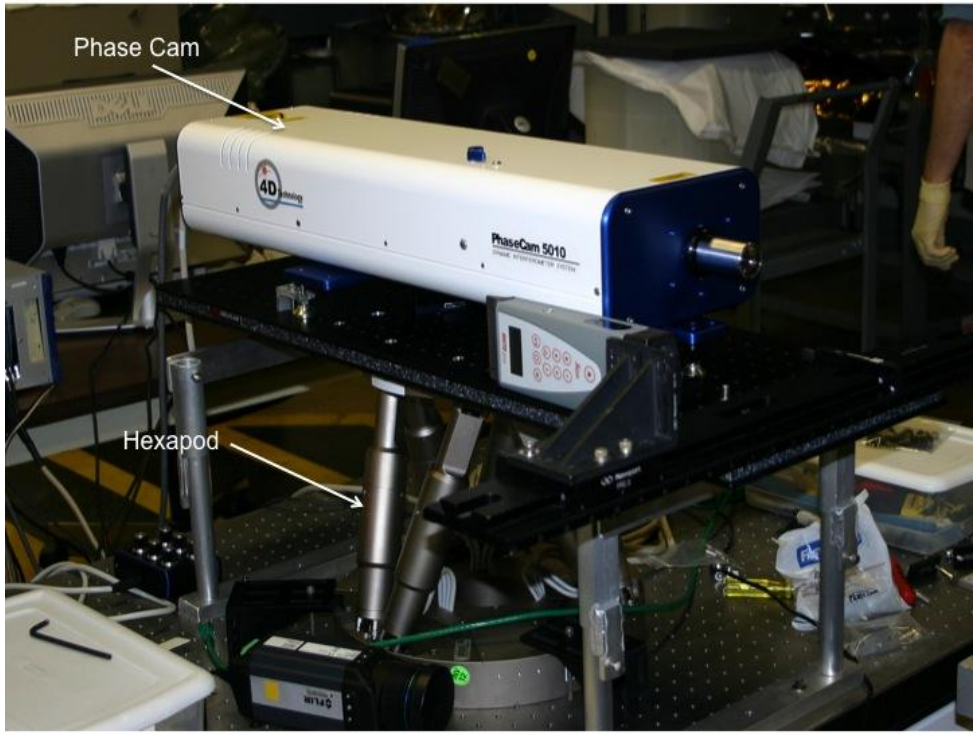
Thermal IR image





- FLIR SC655 640x480 16-bit uncooled microbolometer
- 7.5–14 µm spectral range.
- A 130mm clear aperture ZnSe window.
- IR image recorded on 1st cryo cycle @ ~285K during warmup

Optical test instrument



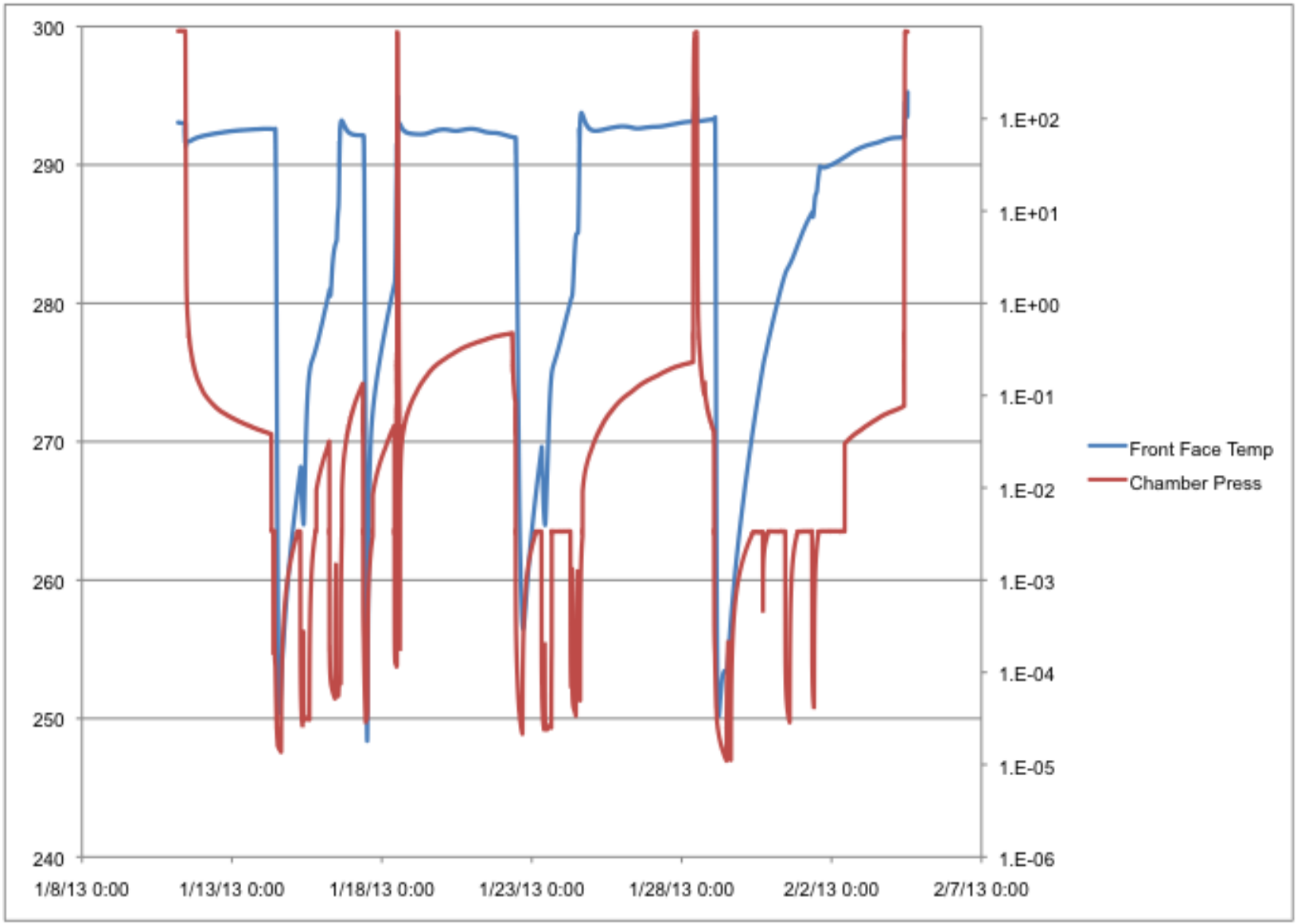
PhaseCam 5010 interferometer

- 1954 x 1967 pixels
- Effective array: 977 x 983 pixels
- diverger: f/6; R/6.25 mirror
- PV uncalibrated accuracy: 15 nm
- RMS uncalibrated accuracy: 3 nm
- PV repeatability: 0.24 nm
- RMS repeatability: 0.05 nm
- PV precision: 2.64 nm
- RMS precision: 0.51 nm

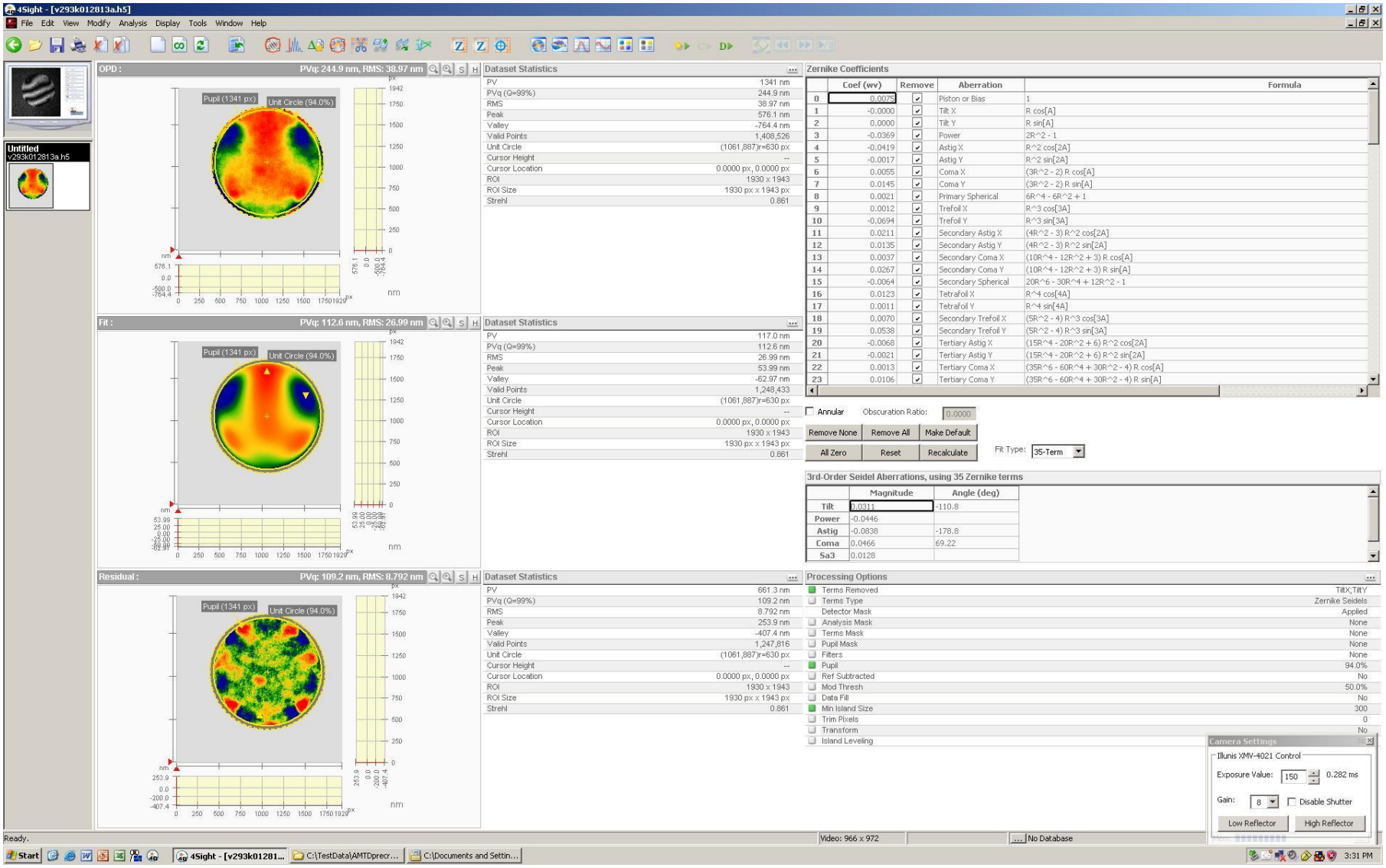
Test process

- Evacuate chamber with roughing pump to 5×10^{-2} Torr.
- Turbomolecular pump to 10^{-5} Torr.
- Helium refrigerator to drive the cryo shroud to ~200K.
- Mirror temperature stabilize overnight for minimum gradient.
- Optical measurements at 255K, 265K, 275K, 285K and ambient.
- 3 cryo cycles.

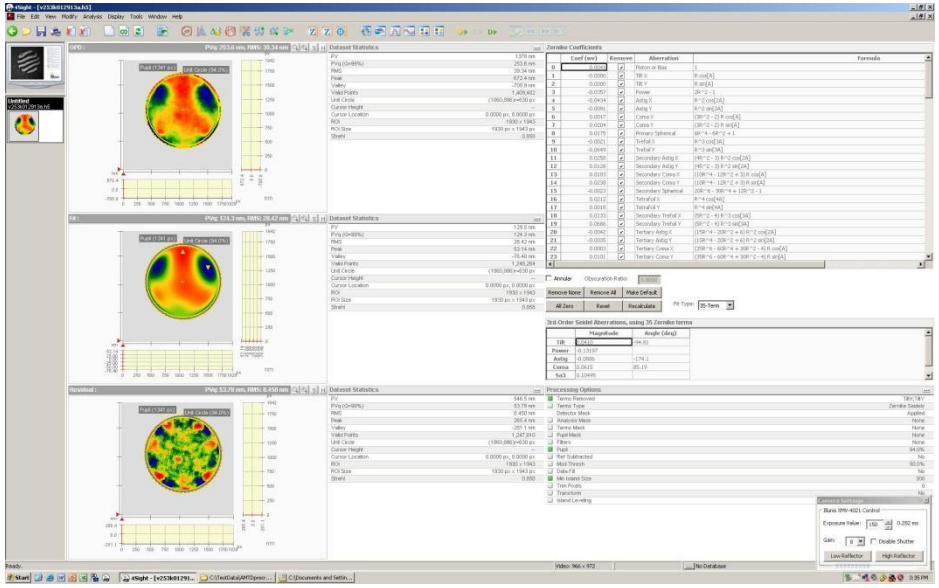
Mirror test temperature and pressure profile



Cycle 3, 293K, 8.8 nm rms

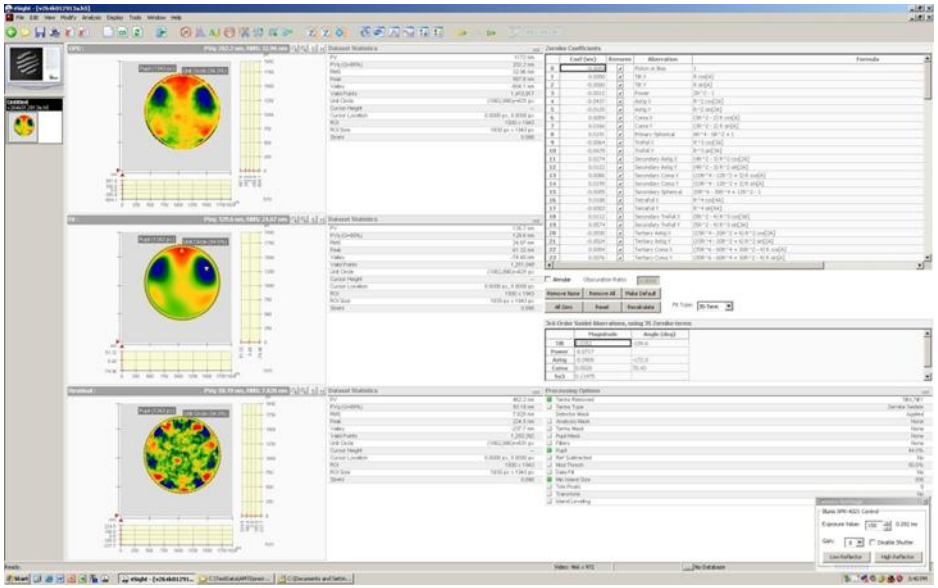


253K
8.5 nm rms

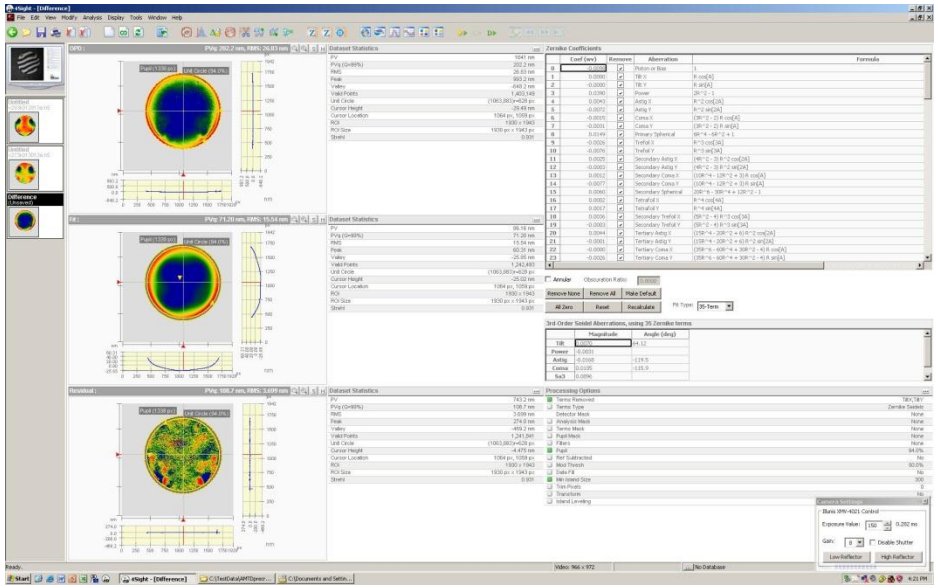


253-293K
4.0 nm rms

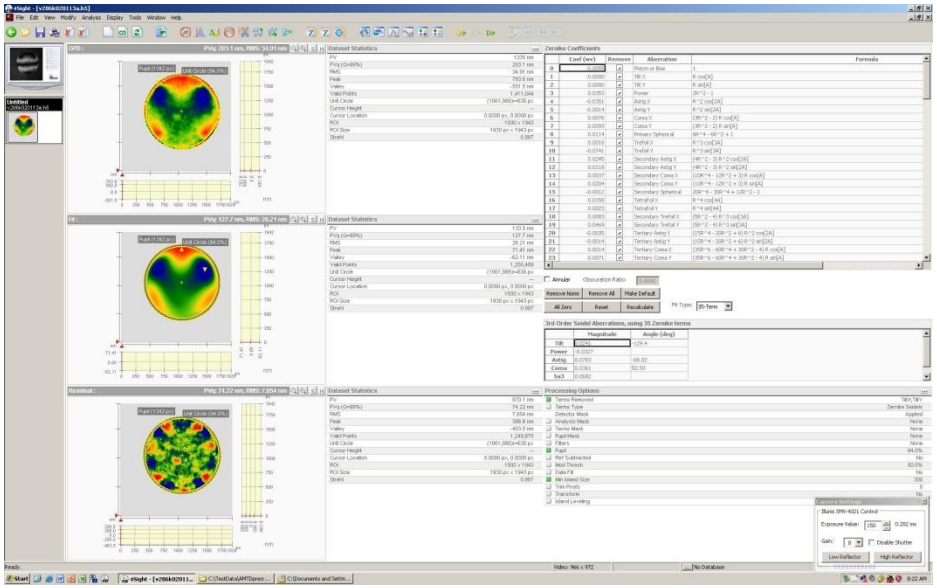
273K
8.0 nm rms



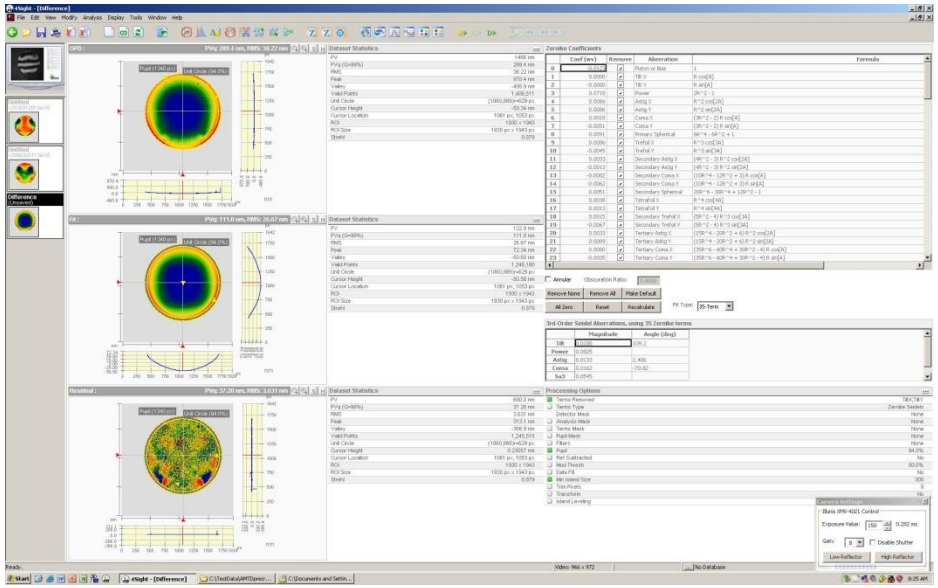
273-293K
3.7 nm rms



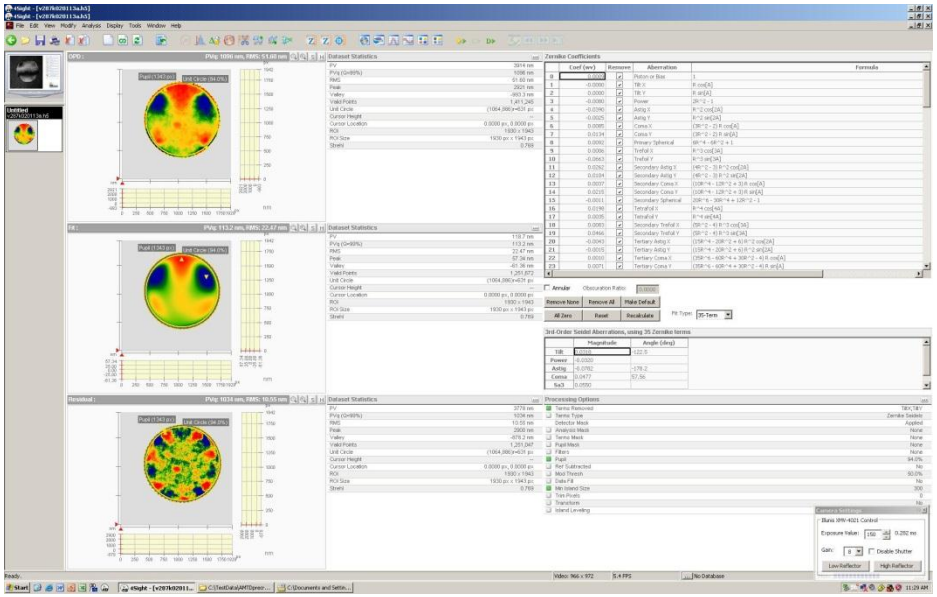
286K
7.9 nm rms



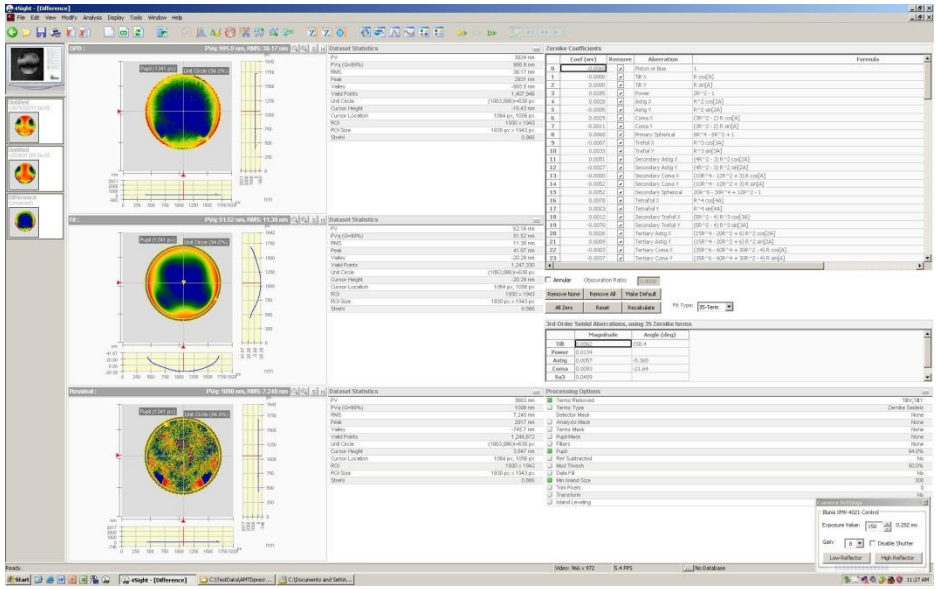
286-293K
3.6 nm rms



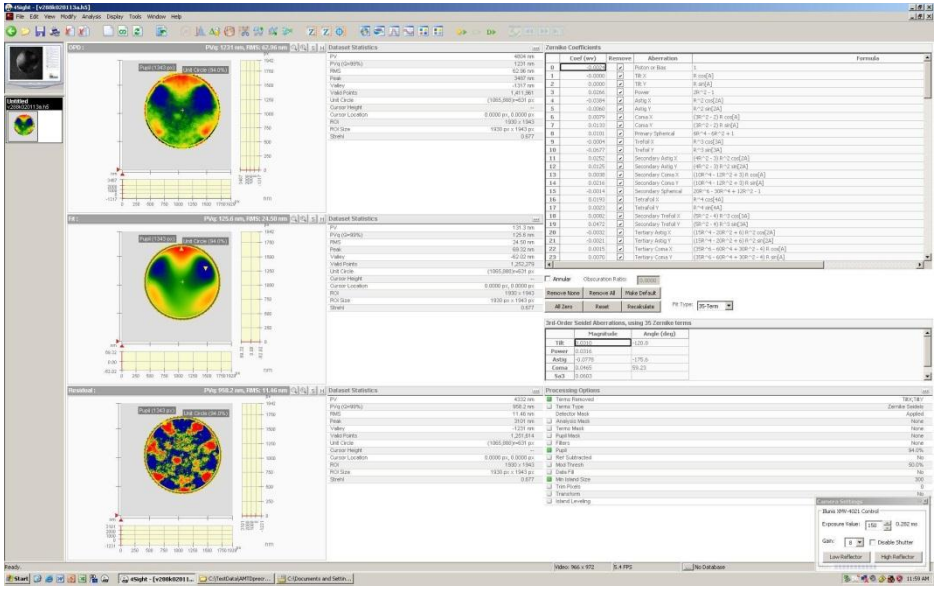
287K
10.6 nm rms



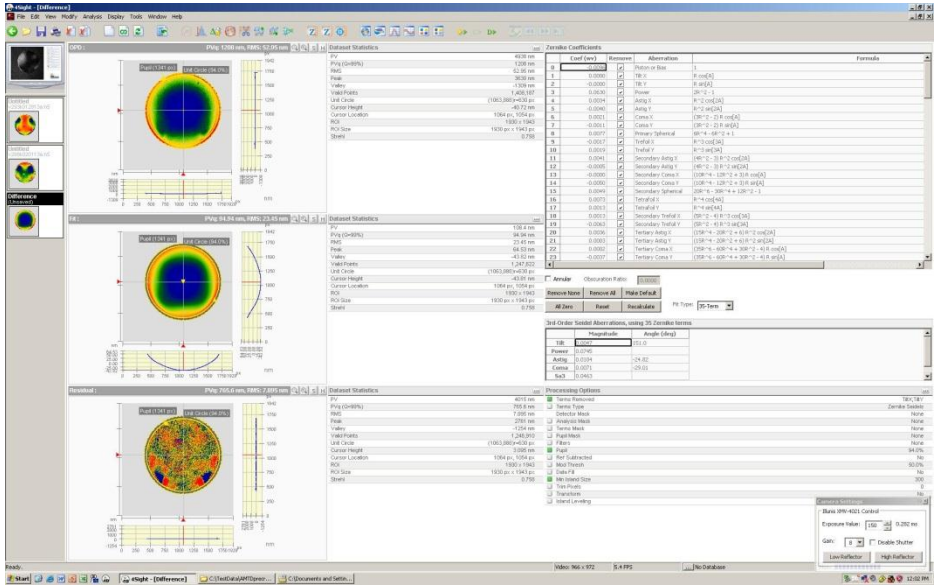
287-293K
7.2 nm rms



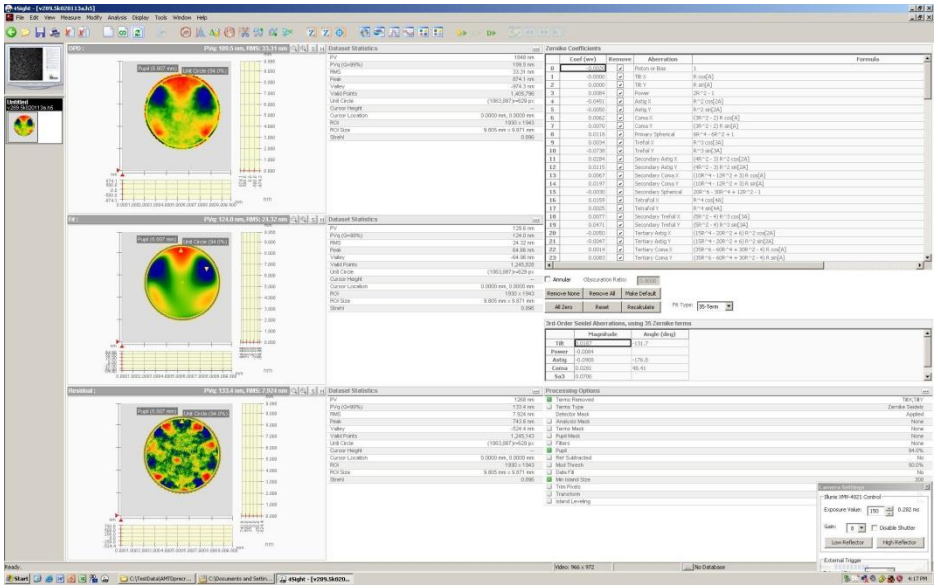
288K
11.5 nm rms



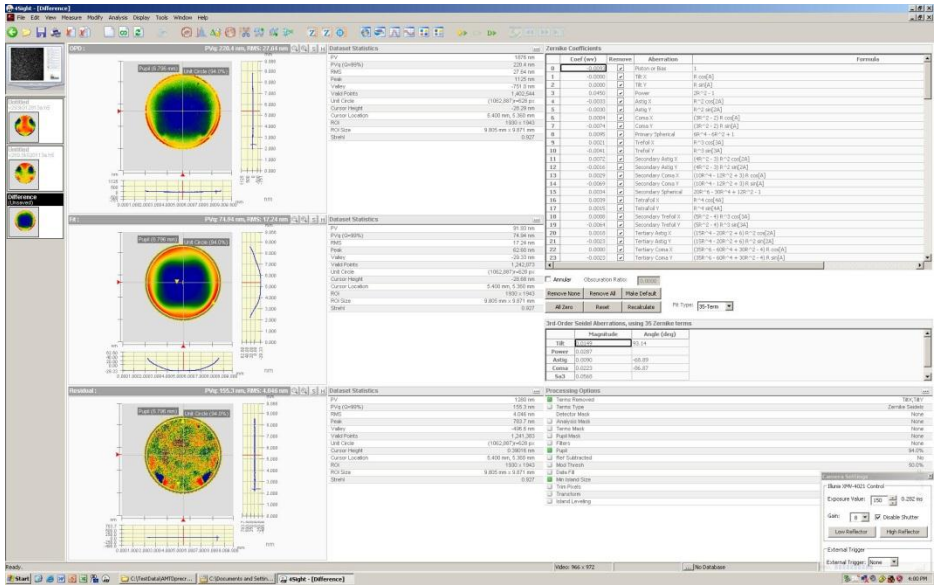
288-293K
7.9 nm rms



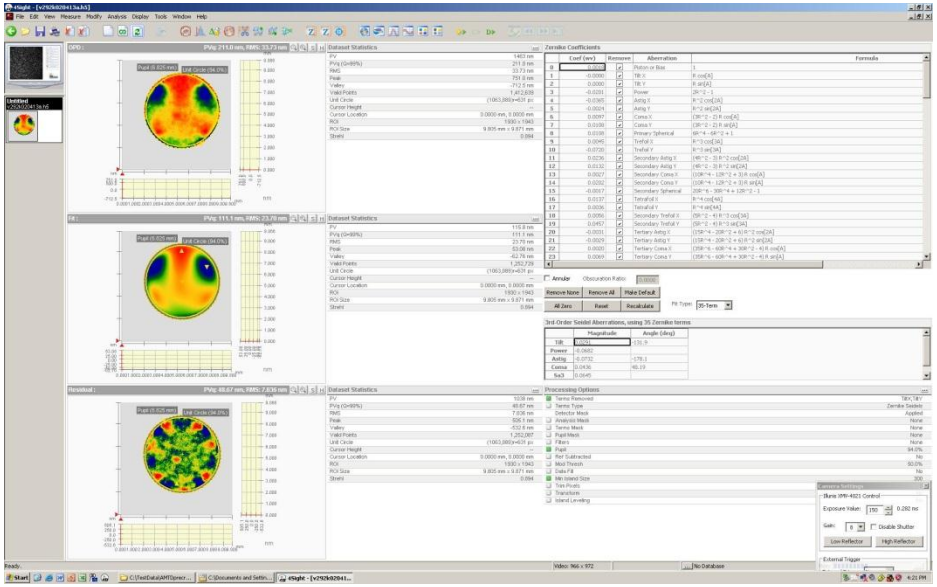
289.5K
7.9 nm rms



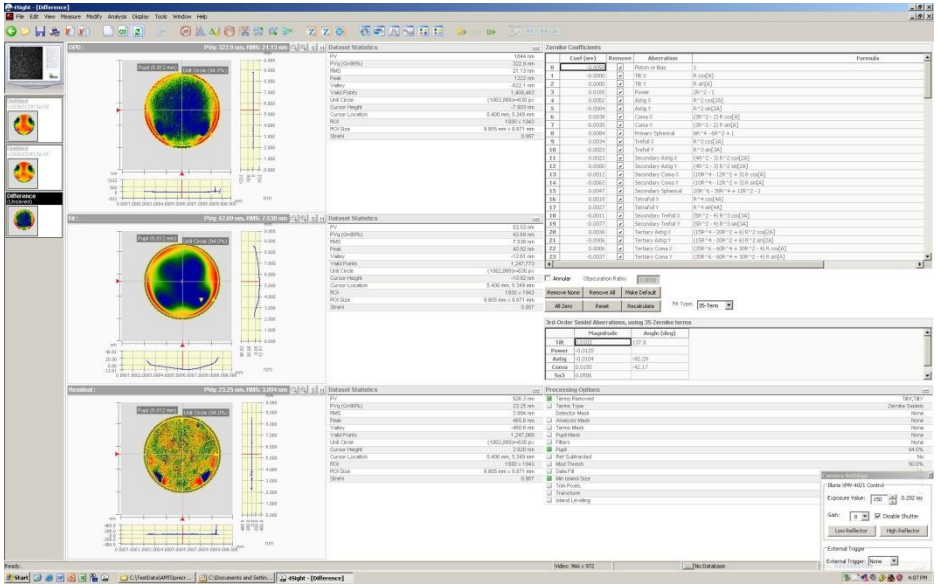
289.5-293K
4.0 nm rms



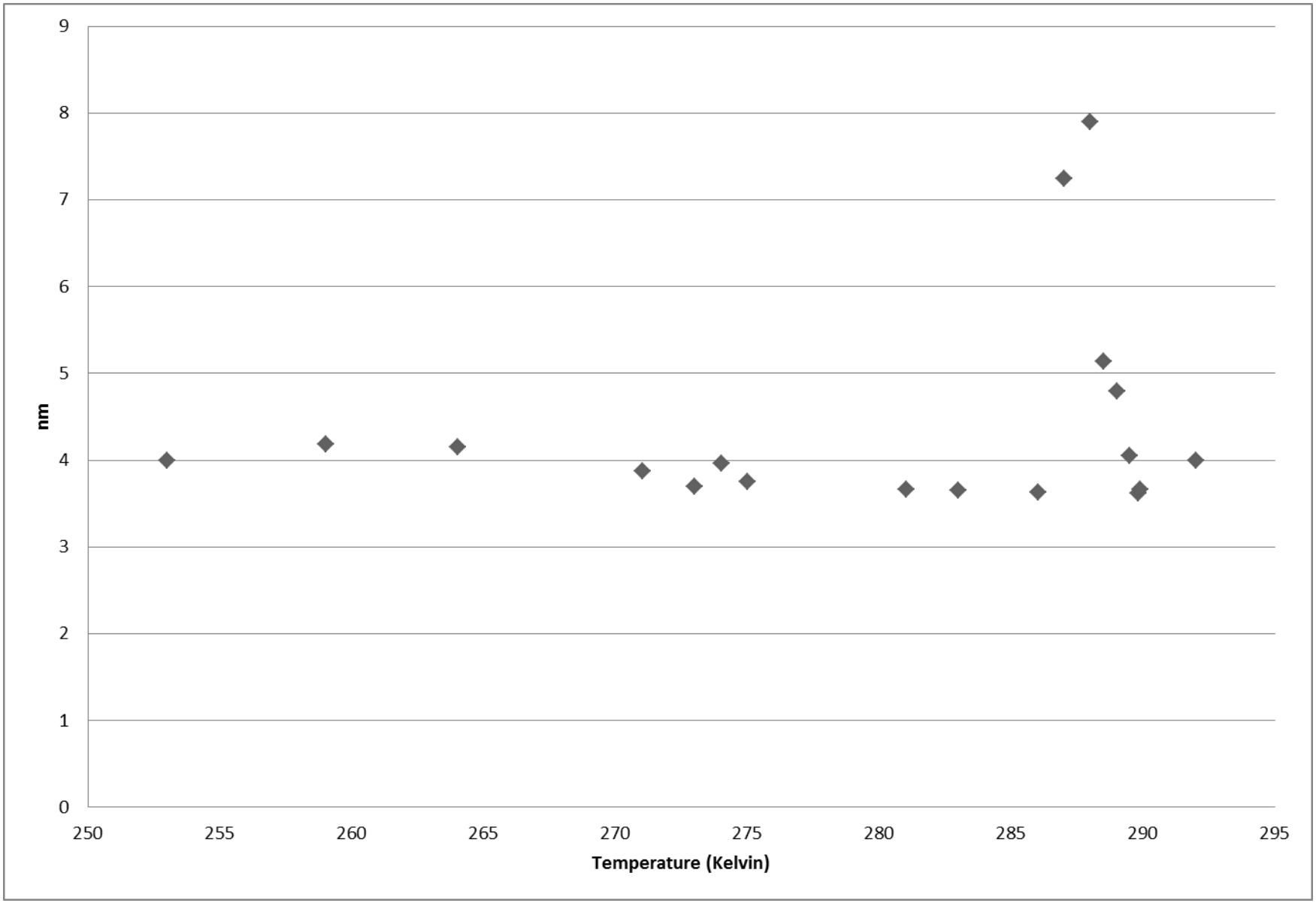
292K
7.8 nm rms



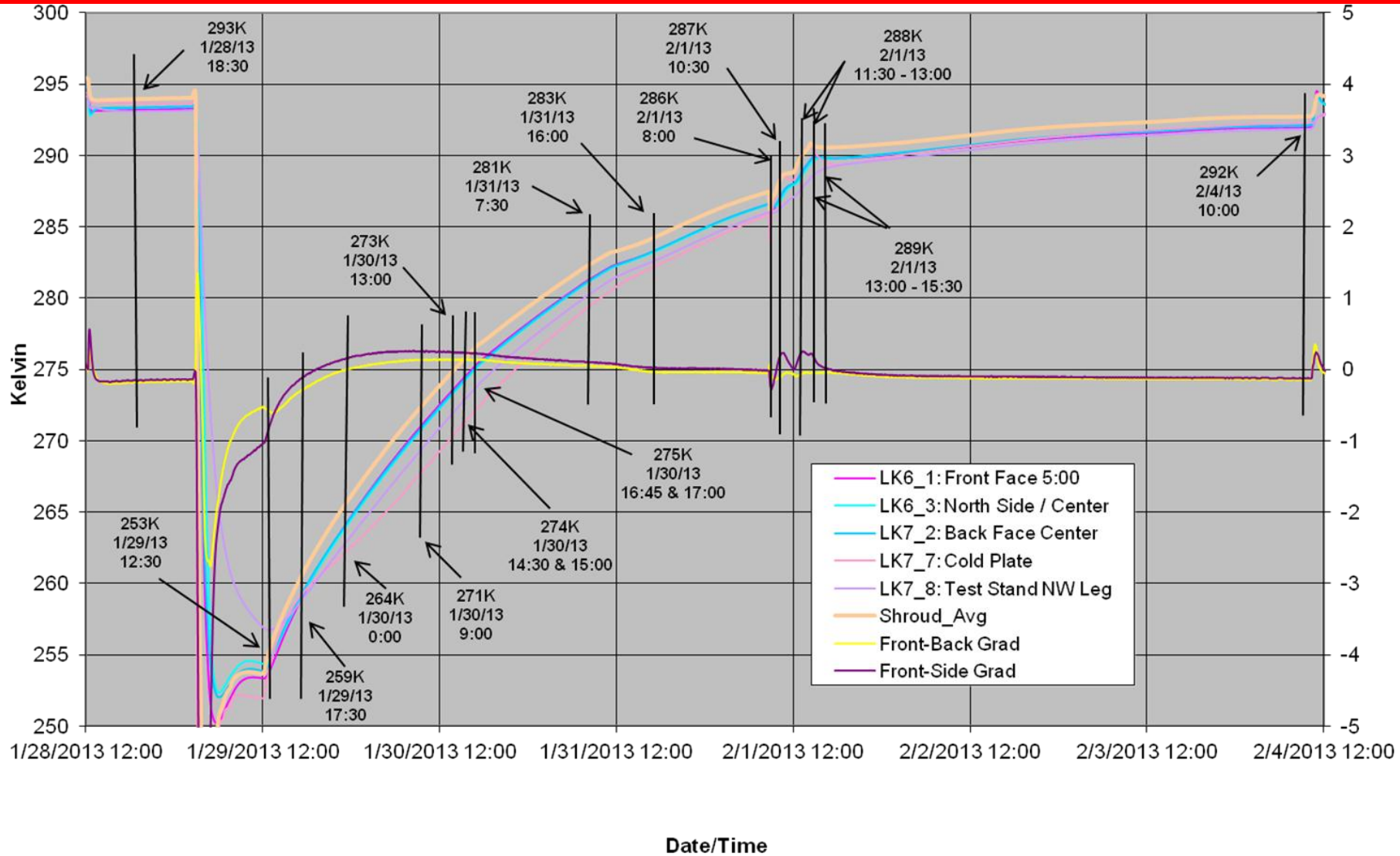
292-293K
4.0 nm rms



Cycle 3 -293K residual rms (nm)



AMTD
Cycle 3

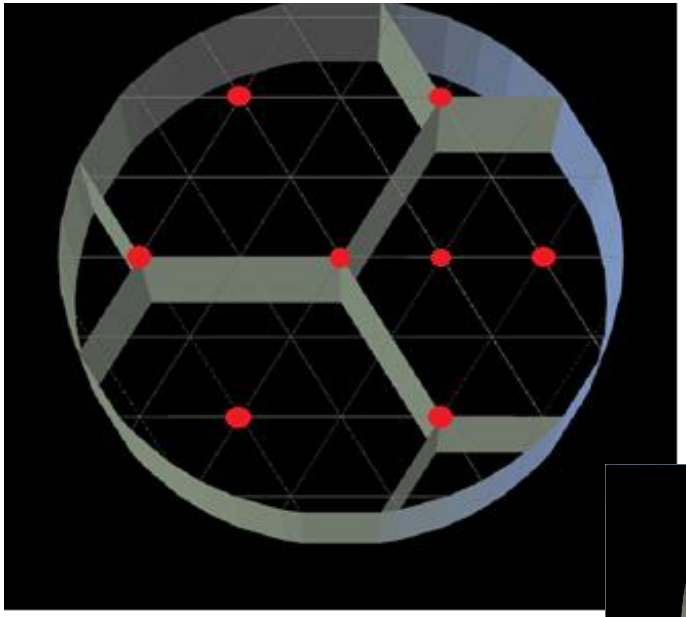

293K
1/28/13
18:30
287K
2/1/13
10:30
288K
2/1/13
11:30 - 13:00
283K
1/31/13
16:00
286K
2/1/13
8:00
281K
1/31/13
7:30
292K
2/4/13
10:00
273K
1/30/13
13:00
289K
2/1/13
13:00 - 15:30
275K
1/30/13
16:45 & 17:00
253K
1/29/13
12:30
274K
1/30/13
14:30 & 15:00
264K
1/30/13
0:00
271K
1/30/13
9:00
259K
1/29/13
17:30
LK6_1: Front Face 5:00
LK6_3: North Side / Center
LK7_2: Back Face Center
LK7_7: Cold Plate
LK7_8: Test Stand NW Leg
Shroud_Avg
Front-Back Grad
Front-Side Grad
Kelvin
300
295
290
285
280
275
270
265
260
255
250
5
4
3
2
1
0
-1
-2
-3
-4
-5
1/28/2013 12:00
1/29/2013 12:00
1/30/2013 12:00
1/31/2013 12:00
2/1/2013 12:00
2/2/2013 12:00
2/3/2013 12:00
2/4/2013 12:00
Date/Time

Thermal optical model

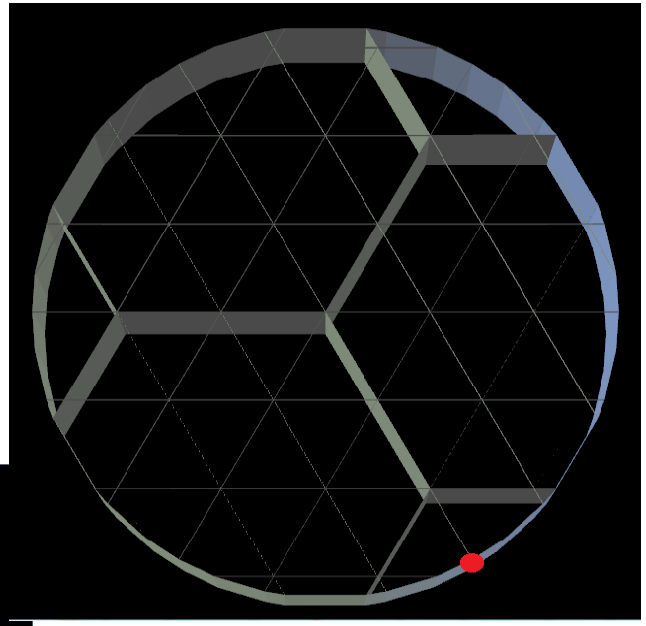
Arnold Lightweight Mirror Modeler (ALWMM)

- Expedites modeling for complex lightweighted mirror design
- Model any type of mirror of any configuration
- Store load cases directly and calculate bending modes
- Common mirror substrates includes: ULE, Zerodur, SiC
- Hexapod and bond pads design
- Perform parametric trade studies
- Determine thermal diode locations
- ANSYS thermal model
- Validate cryo test results
- Predict gravity sag

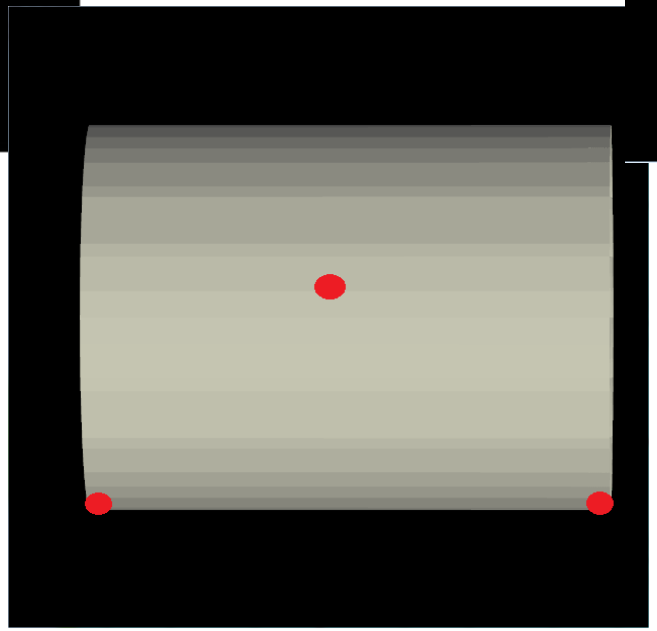
Thermal diode locations



Diodes on back sheet

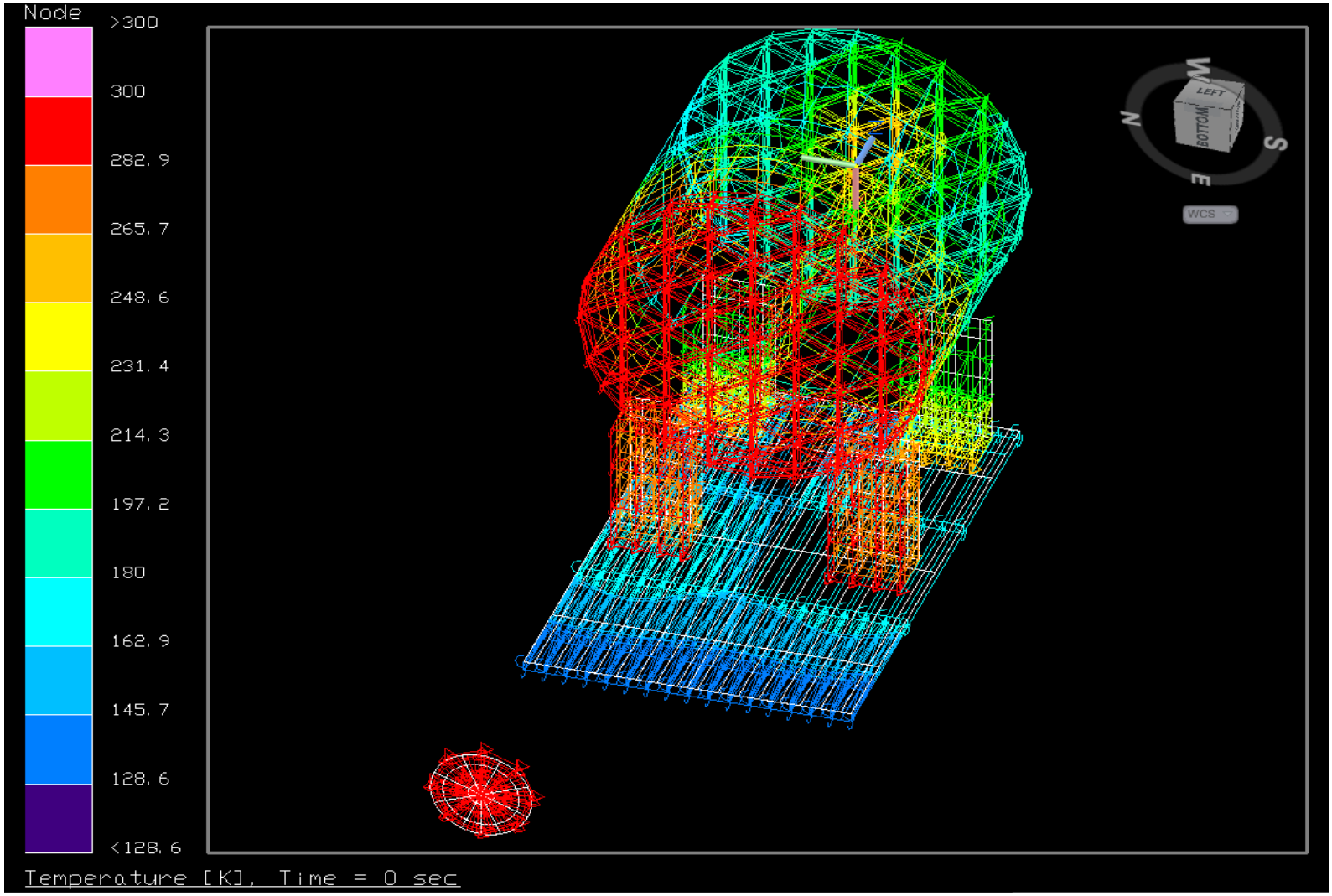


Diodes on face sheet



Diodes on side

Stacked core mirror thermal model



Summary

- During cycle 3, heat was introduced after 286K measurements to induce thermal gradient, resulting in higher residual rms values for 287K and 288K.
- Thermal-elastic expansion generates unwanted surface deformation.
- Non-linear FEA analysis to compute thermal-elastic response as the system changes temperature.
- Minimal surface deformation seen during steady state thermal transition.

Future work

- Qualify a 1/3 scale of 4-m class, 1.2-m, 400 mm thick, lightweight Zerodur mirror from ambient to 250K.
- Qualify a 1.5-m AMSD ULE mirror.
- Perform modal test with cryo shaker and interferometer to relevant vibro-acoustic level.
- Improve IR thermal capability to record face sheet temperature.
- Enhance ALWMM capabilities.

X-ray cryogenic facility (XRCF)

History

Testing grazing-incidence x-ray telescopes (Chandra, Solar X-ray Imager, Solar B) since 1992.

Cryogenic optical interferometric testing of normal incidence, visible & IR telescope optics & components since 1999.

Capabilities

Thermal vacuum test chamber:

7.3 x 22.9 m (O.D. x L) horizontal cylinder

6 x 18.3 m (I.D. x L) test volume

527 m: x-ray guide tube

5 x 9.4 m (I.D x L) Helium shroud

Cryo shroud enclosure: 20K to 320K

Refrigeration system: 2 gaseous helium refrigerators; each capable of ~1 kW at 20K.

Vacuum systems: 10^{-8} Torr

Clean Rooms:

6000 sq. ft. Class 2,000

2000 sq. ft. Class 10,000

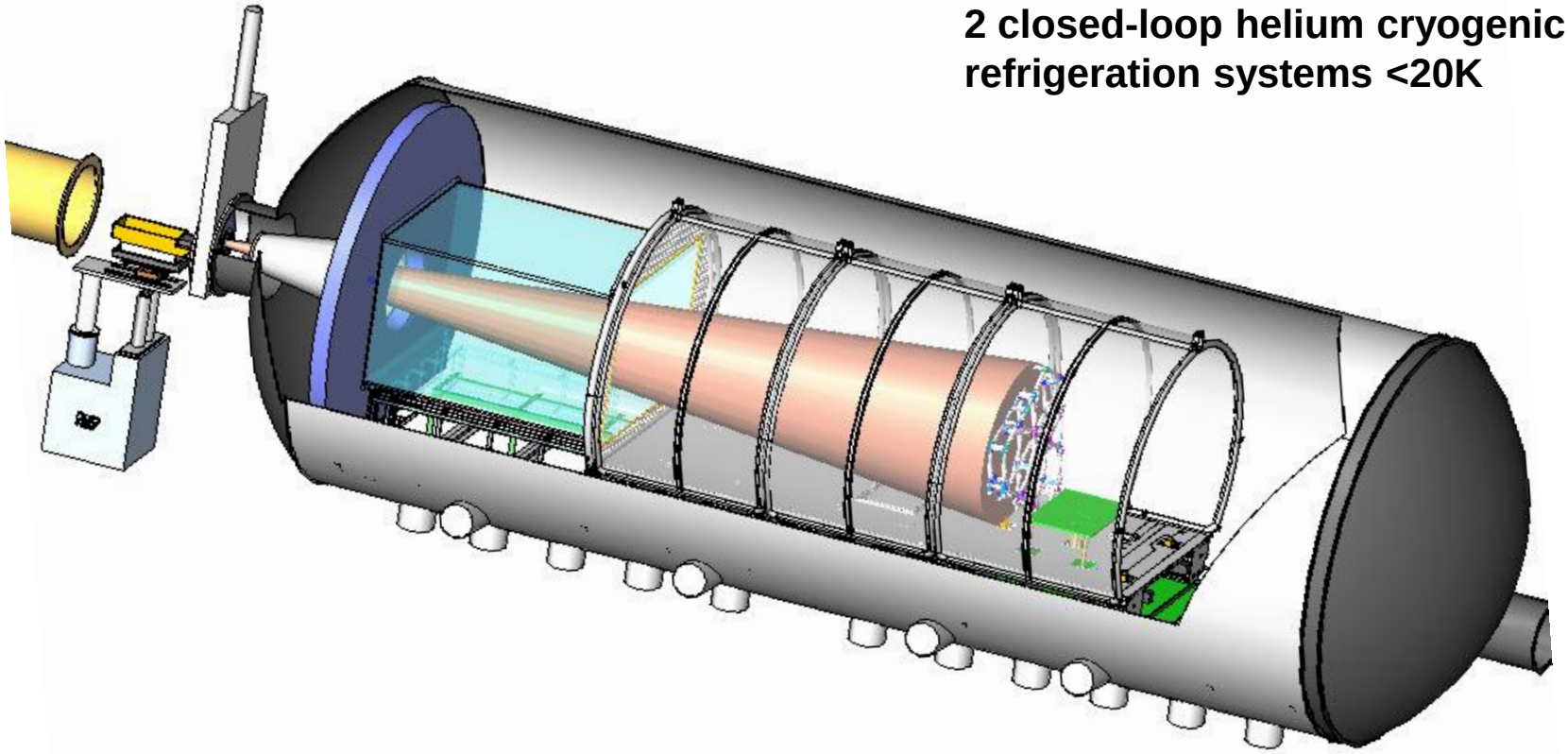
Onsite machine shop

Cryogenic optical test configuration

7.3 x 22.9 m vacuum chamber

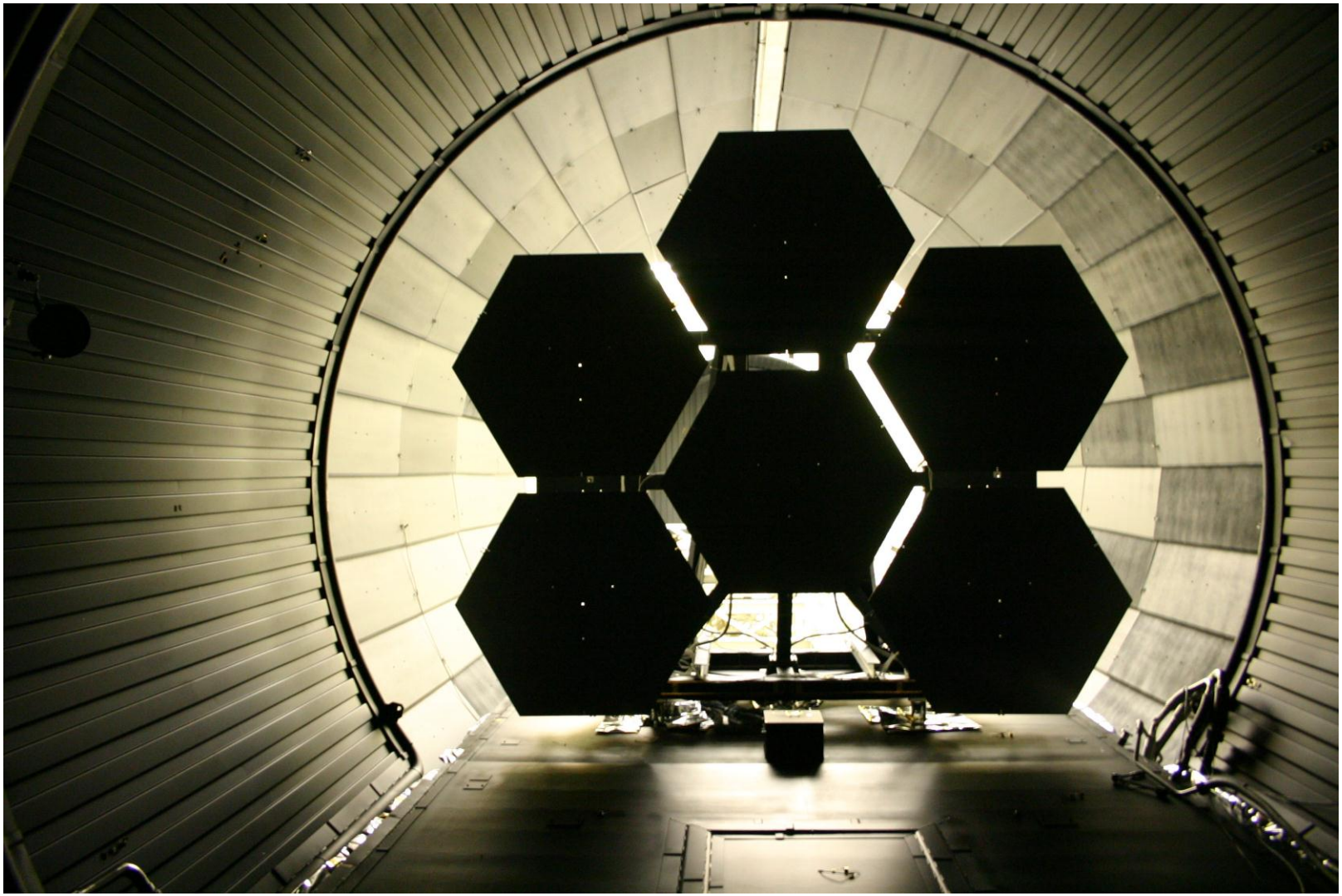
5 m dia. gaseous helium-cooled shroud

2 closed-loop helium cryogenic refrigeration systems <20K



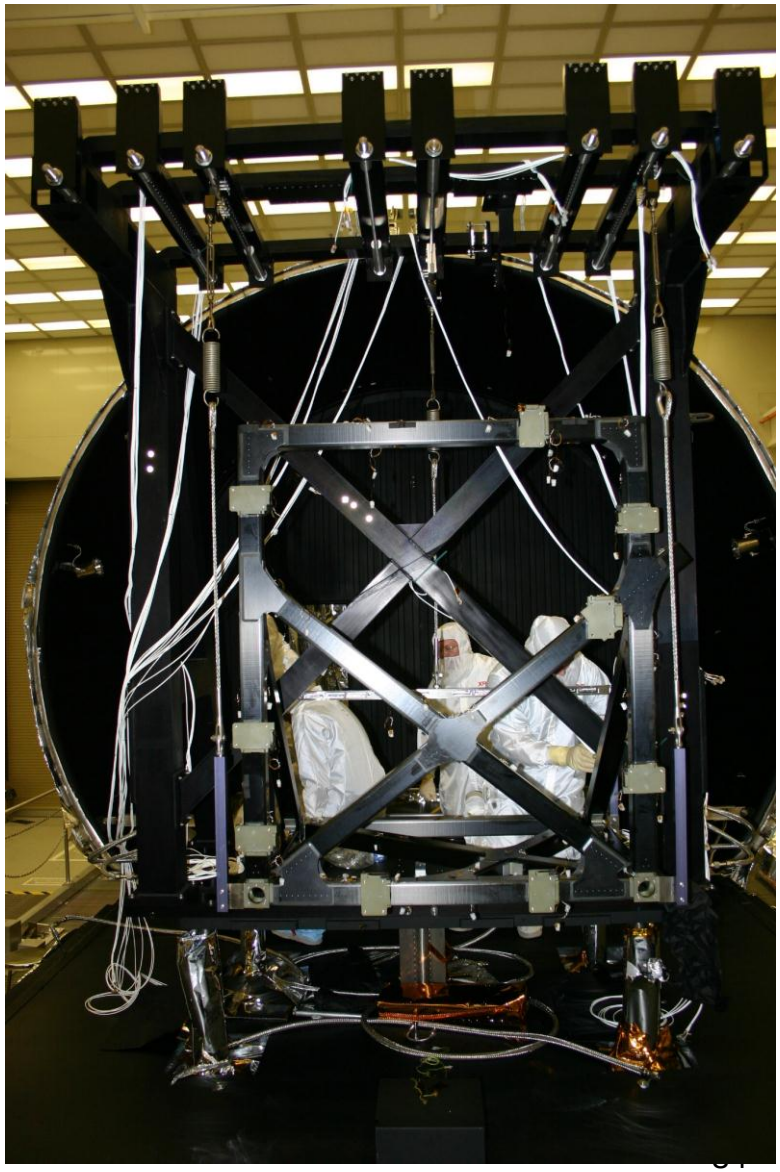
XRCF clean room

JWST mirror segments cryo tests



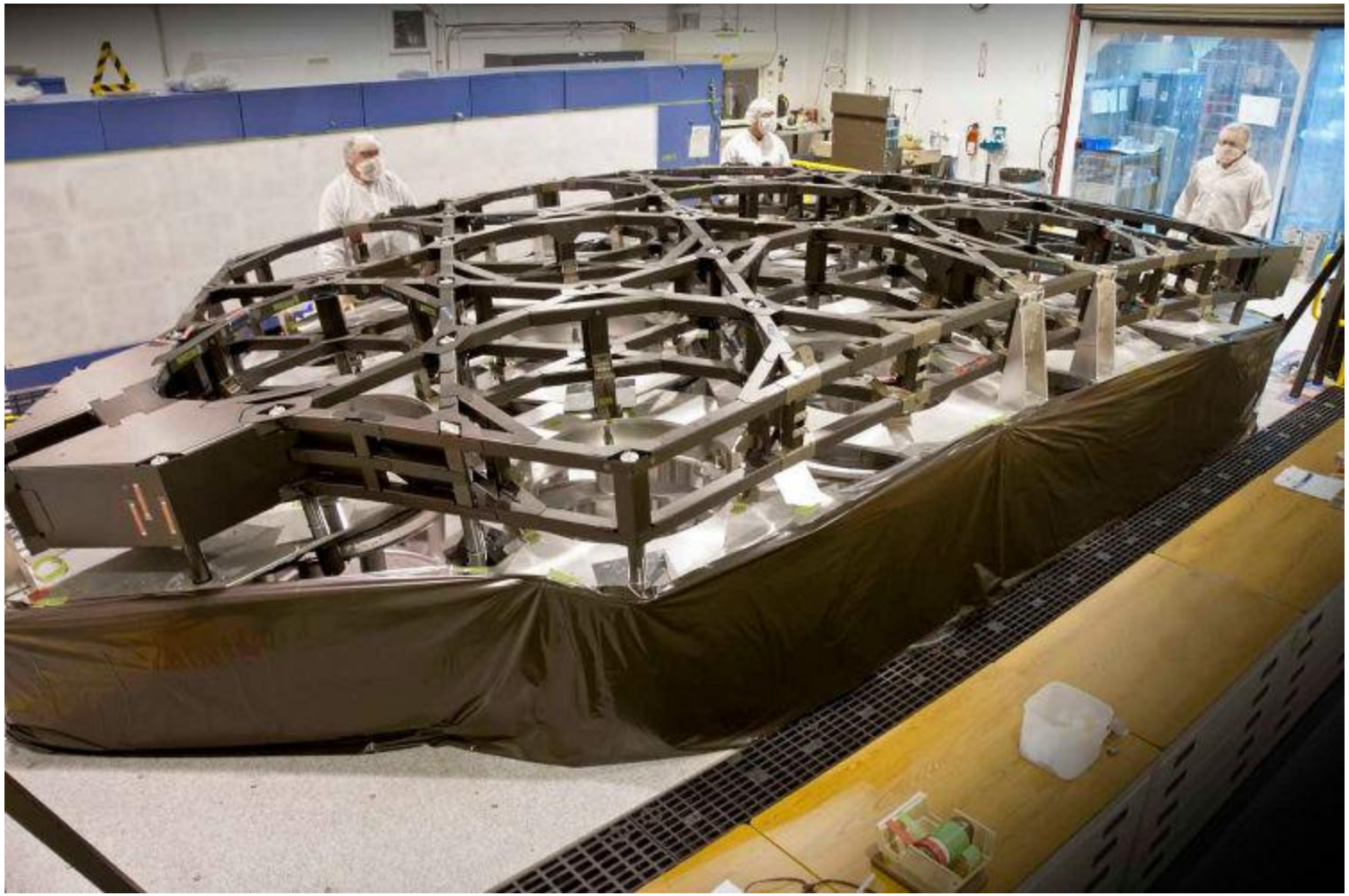
JWST composite hardware cryo tests

Backplane stability test article (BSTA)



Integrated science instrument module (ISIM)

JWST mirror backplane center section at ATK

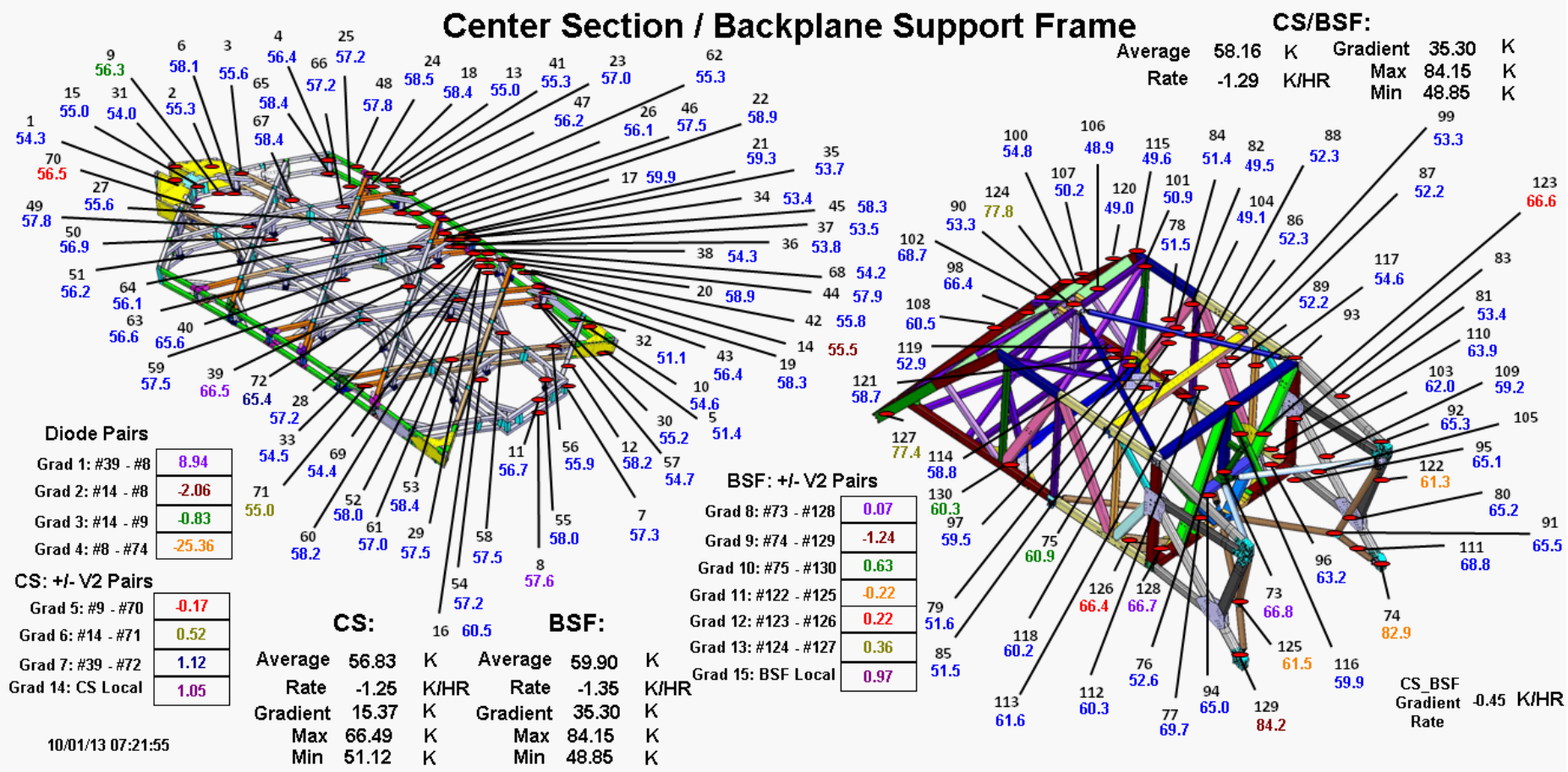


Backplane center section arrival on C-5

Unloading off C-5

Backplane center section/support frame installation

Backplane center section / support frame



Thank you

Ron Eng

256-544-3603

ron.eng@nasa.gov