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Processing of a stacked core mirror for UV applications [8837-10]

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Work completed under NASA contract number NNM12AA02C

Advanced UVOIR Mirror Technology Development (AMTD) Program

- Develop mirror blank technology applicable to building a cost effective, large (4m-8m class), passive, monolithic mirror capable of imaging in the UV spectrum
  - 0.43m demonstration mirror fabricated
  - 5.5nm RMS overall surface figure demonstrated

- Current limitations regarding a 4m class mirror
  - Significant mirror depth required to achieve stiffness
  - Core depth drives up cutting costs, schedule, risk, and areal density
  - Stack sealing of boules to achieve overall depth is very expensive and time consuming

- AMTD program addresses these issues to reduce the cost and lead time for building a 4m class mirror blank and demonstrates the ability to polish and test the blank to UV quality

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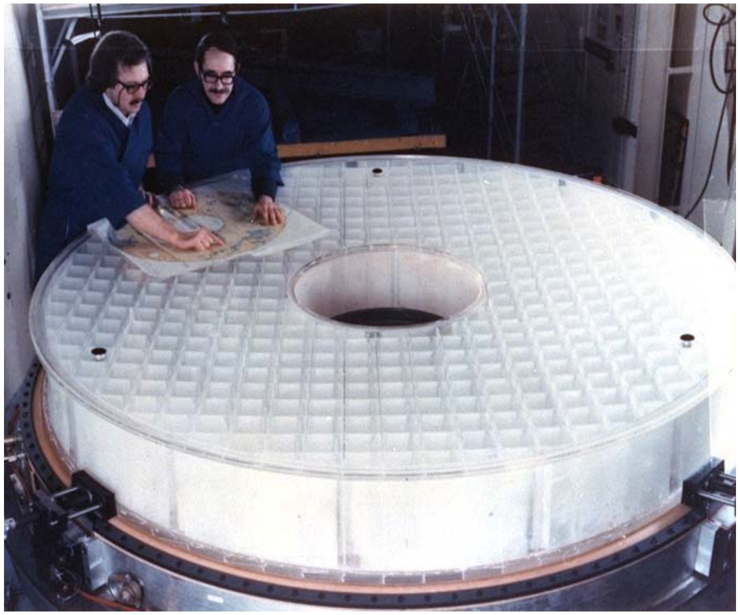
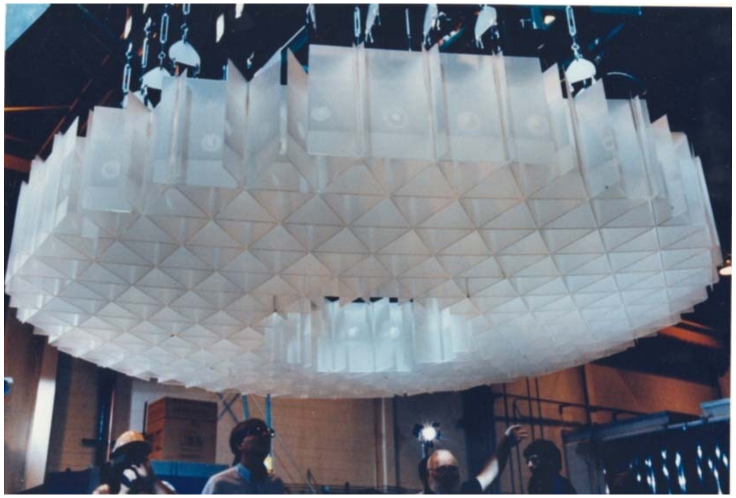
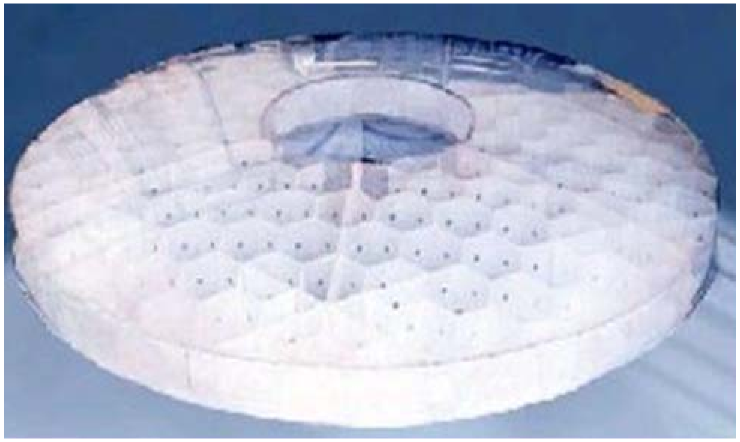
Large Lightweight ULE® Primary Mirrors at Exelis



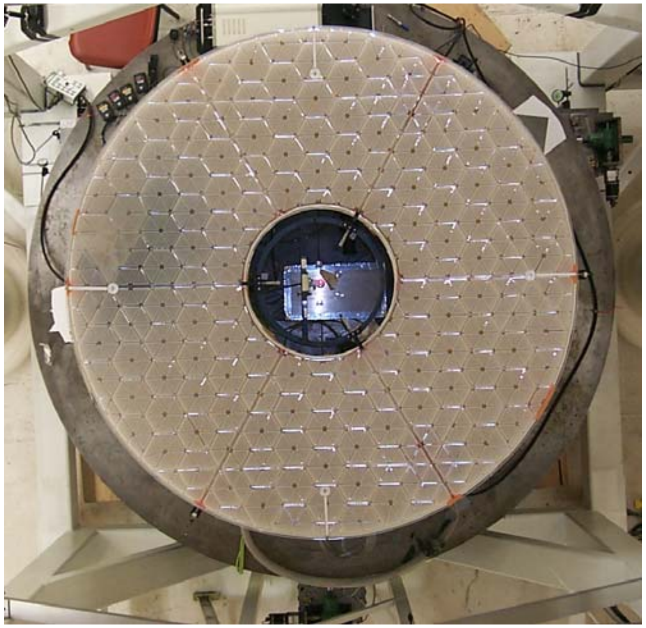
High Temperature Fusion – 1970's
(Hubble Primary Mirror)



Frit Technology with Flame Welded Core – 1980's

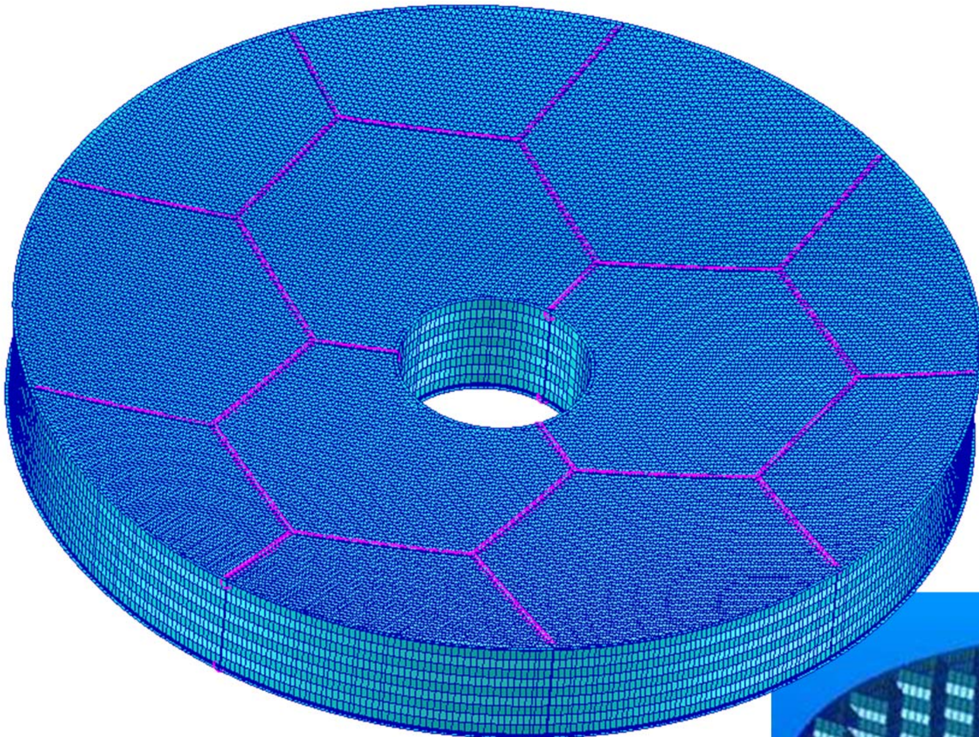


ATT – Waterjet Cut Core – Low Temp Fusion – 1990's



Primary Mirror – Low Temp Fusion – 2000's

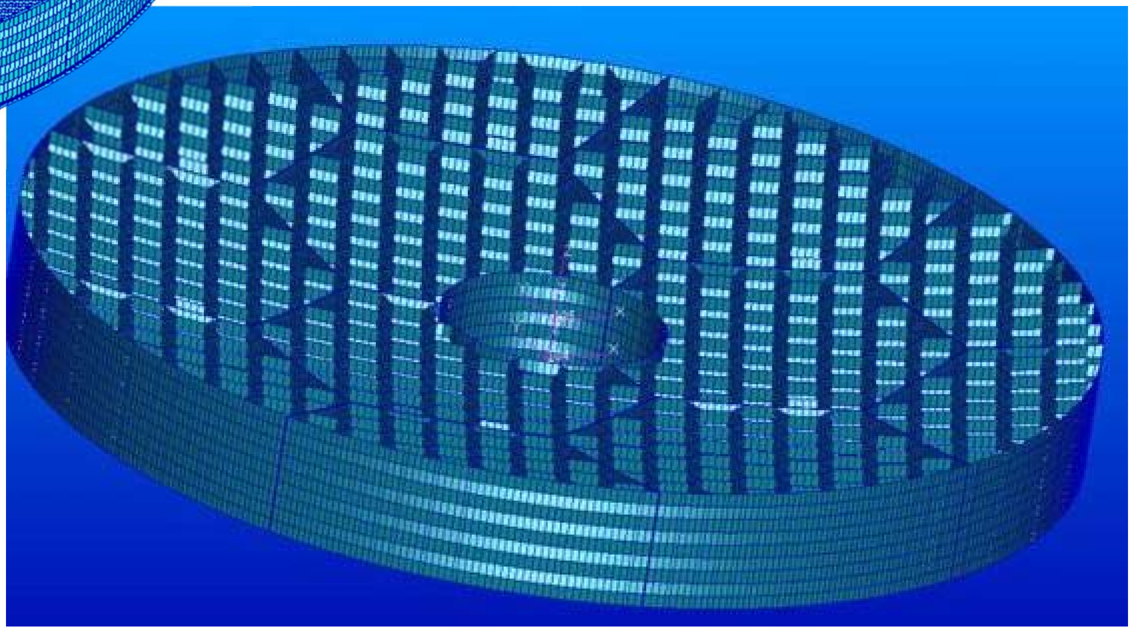
4m Mirror Concept



4m Mirror Physical Attributes

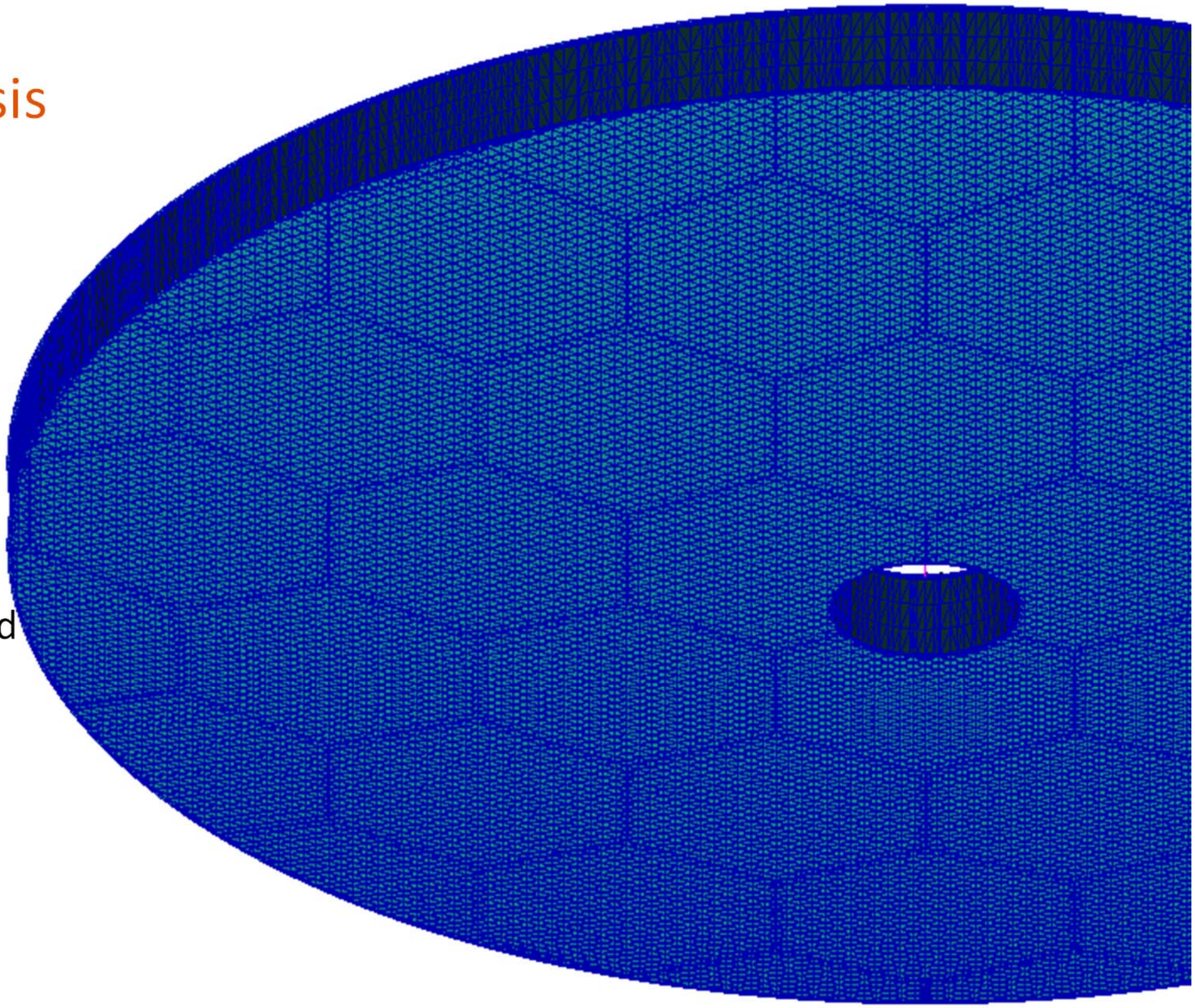
- Pocket Milled Facesheet allows larger core cells while controlling quilting
- 12 Core Segments
- 3 Stacked Core Deep
- 10m RoC (F#1.25)

- Fabrication risk reduced by eliminating stack sealing and deep core cutting
- Reduced glass needs for tooling glass

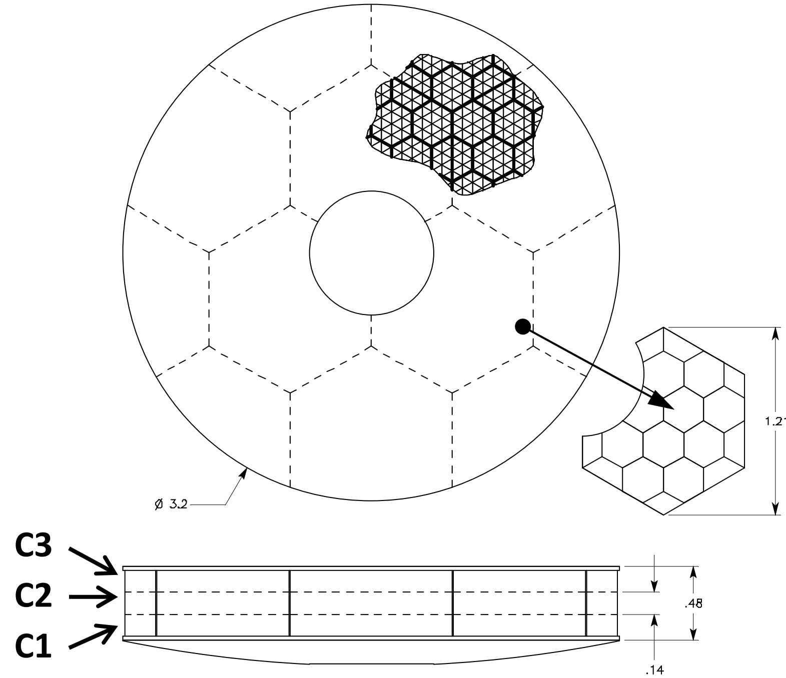


AMTD 8m Mirror Design and Analysis

- Stacked core and Pocket milled facesheet design
- 24.2m RoC (f#1.5)
- The 8 meter mirror modeled to assess performance
  - Model includes light-weighted face plates joined to a light-weighted core.
  - 5% additional mass added to light-weighted sections to account for corner radii.
- Total mass was 3042 kg, 60 kg/m^2
- First Free-Free mode at 33 Hz

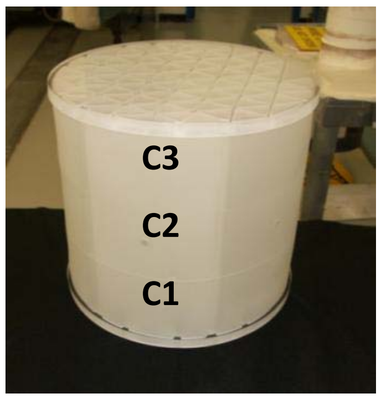


AMTD is Developing Technologies for Near Term Large Lightweight Primary Mirrors



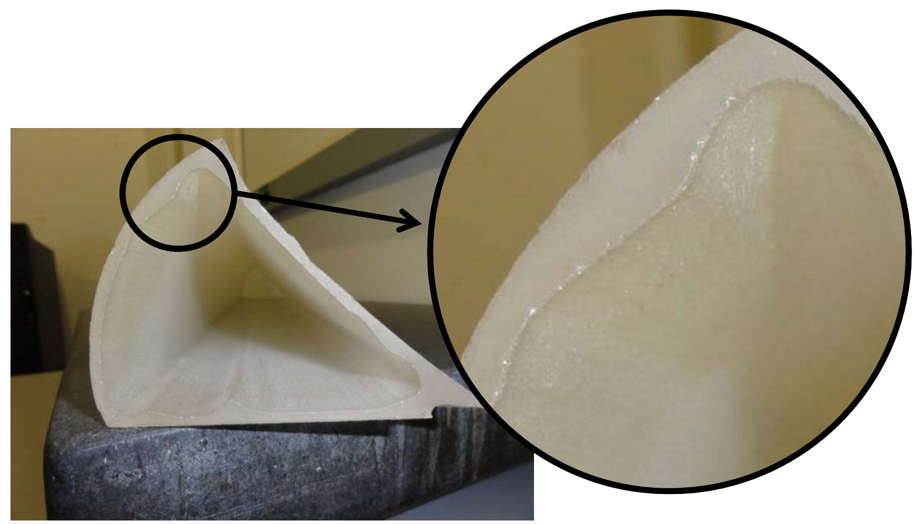
Stacked core

- Core segments are fabricated from standard thickness boules, then stacked & fused during blank assembly to achieve a deep core
- Eliminates need for stack sealing of boules and deep AWJ cutting of cores
- Enables lighter weight cores and reduces cost & schedule for blank fab



Deep AWJ Cutting

- Extend AWJ cutting depth for LW cores from current 300mm (11.6 in) up to 480mm (19 in) depending on mirror stiffness
- More difficult to control exit surface parameters



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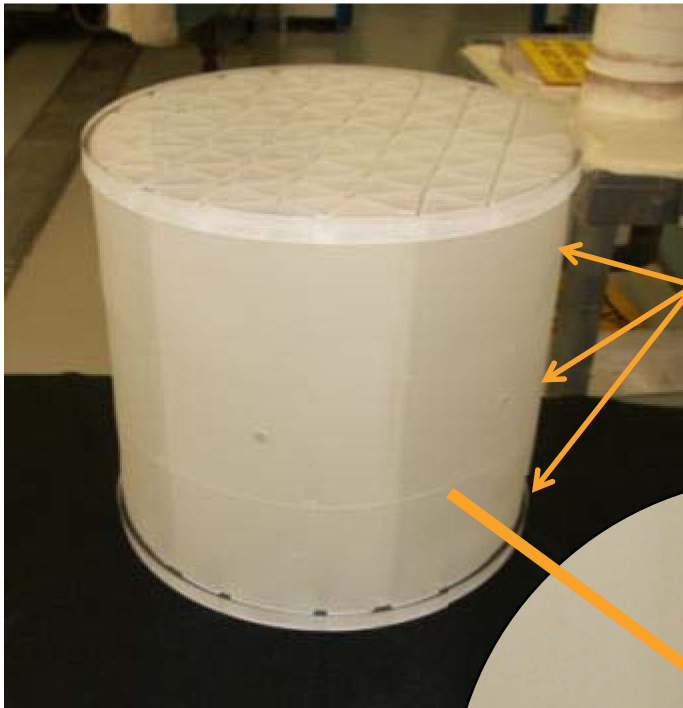
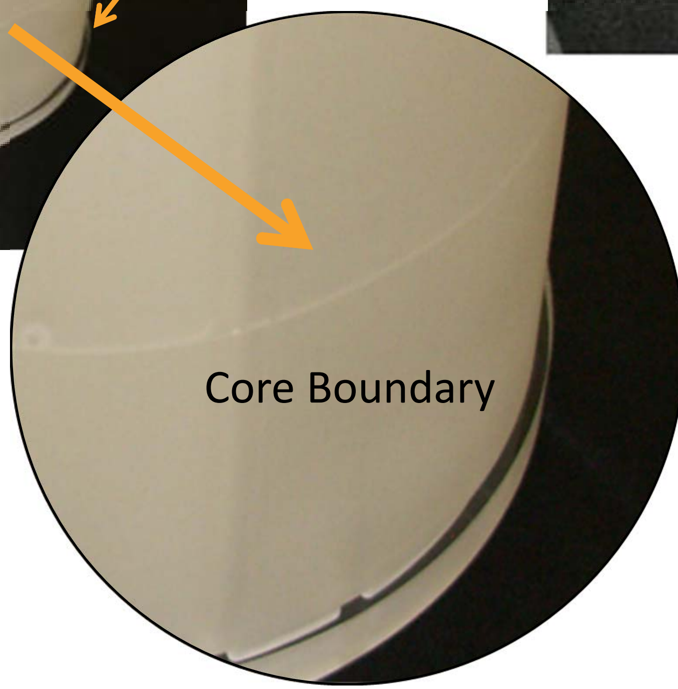
Stacked Core Mirror Demonstration

0.4m Demonstration part fabricated



Mirror Blank is 3 cores high



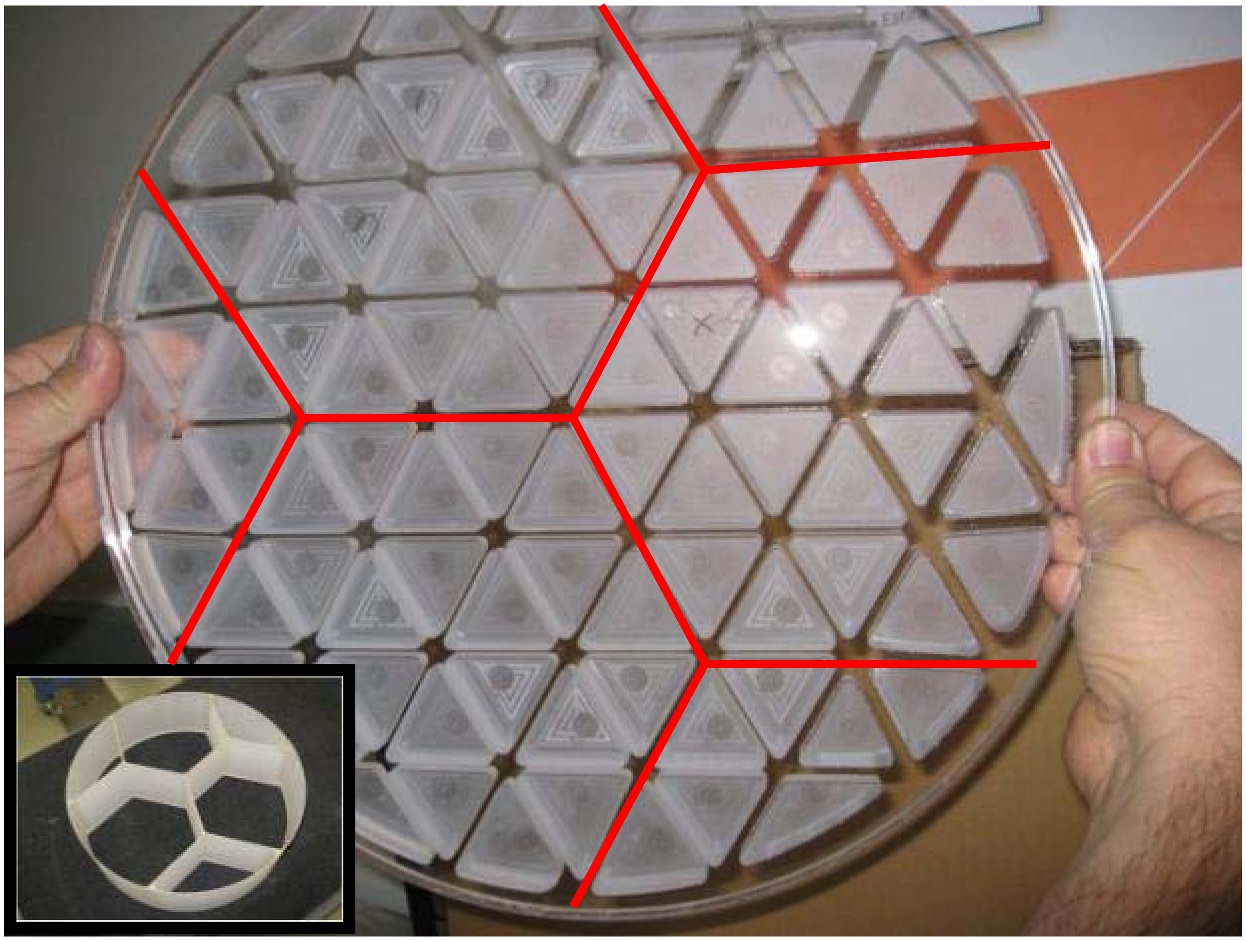
Single Mirror Core
(Note large cell size)

- The individual core segment surfaces are polished and AWJ just like traditional LTF mirrors
- During Low Temperature Fusion (LTF), the faceplates **and** the core segments are fused together (Co-Fired)

Faceplate Pocket Milling

- Pocket milled facesheets have been used on other mirrors to provide additional stiffness between cell supports
- Allow for much larger core cell size to reduce overall areal density
- Extended to 24 pockets to enhance UV performance

Pocket Milled Facesheet



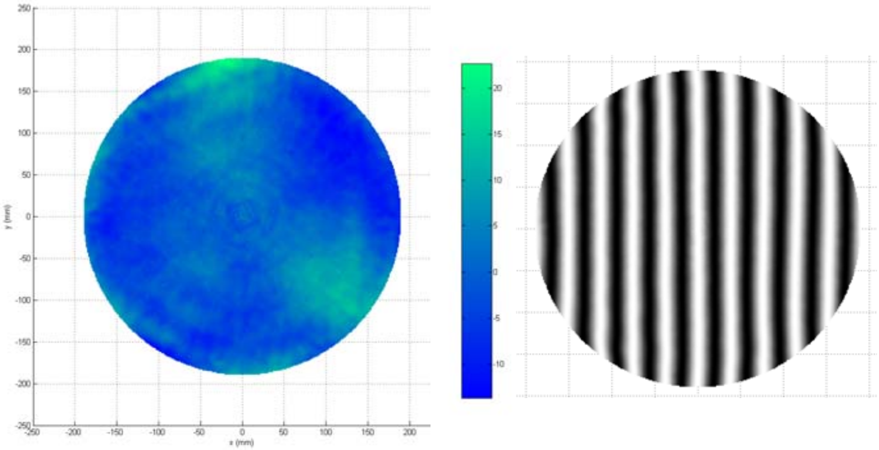
Pocket Milled Facesheet
Core cells locations shown in red
(Core shown for reference)

Processing Quality

Processing completed to demonstrate that UV quality (5nm RMS) could be achieved

Multiple orientation test minimized test errors and analytical backouts

- Some minimal trefoil did not cancel out during testing
- Mount repeatability ultimately limited final performance

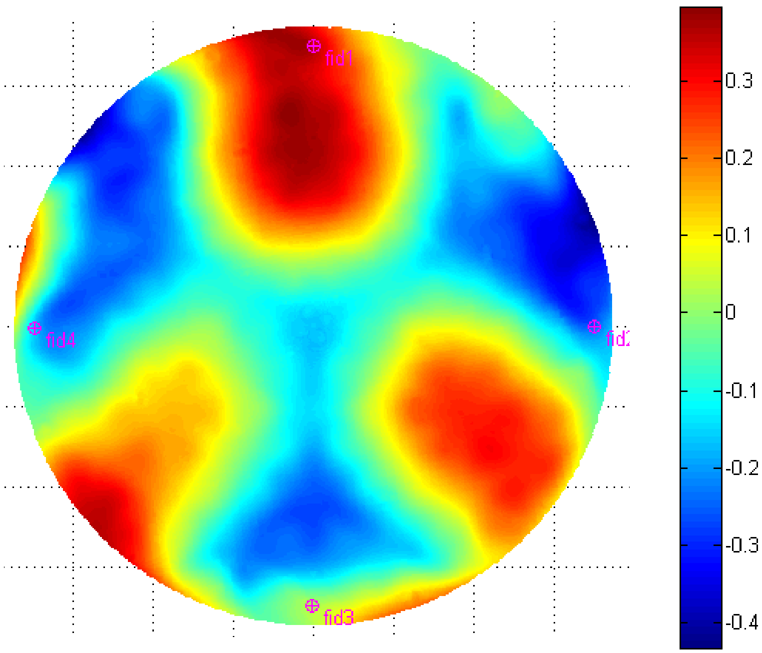


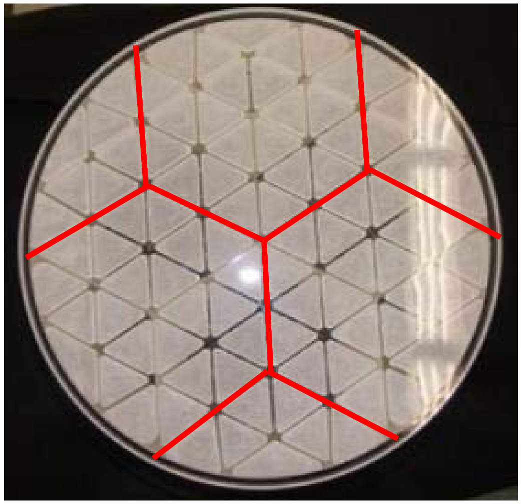
Final Optical Test – 5.5nm RMS

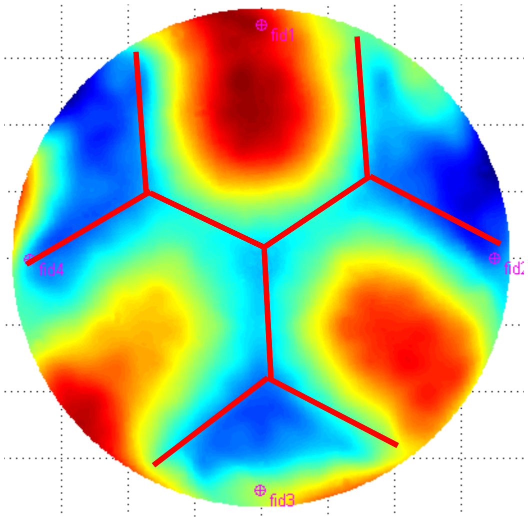
Demo Part in V-Block for Horizontal Testing

First Light Test

117nm RMS – 524nm P-V
Power Removed



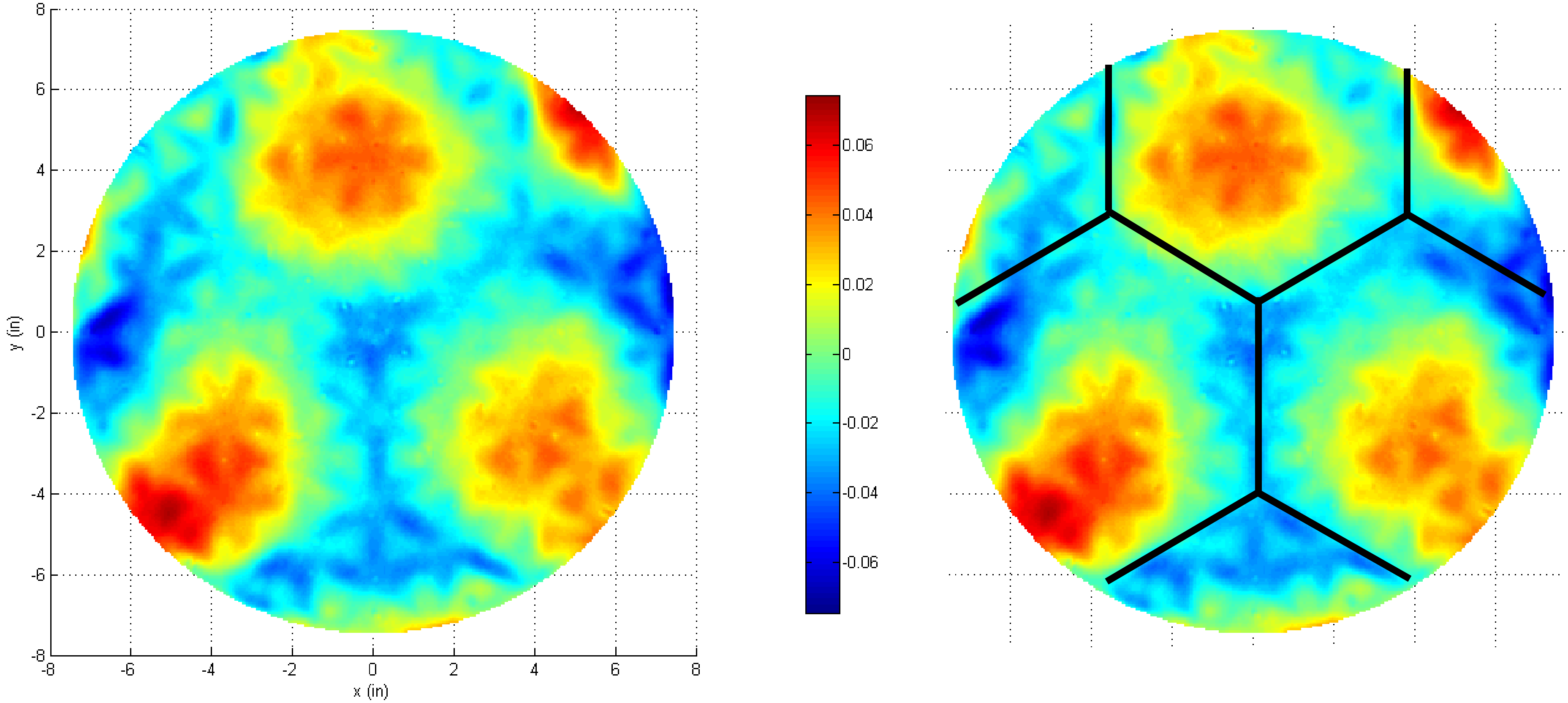




Global polishing quilting over the large cells is observed after initial polishing

Post Ion Figuring #1

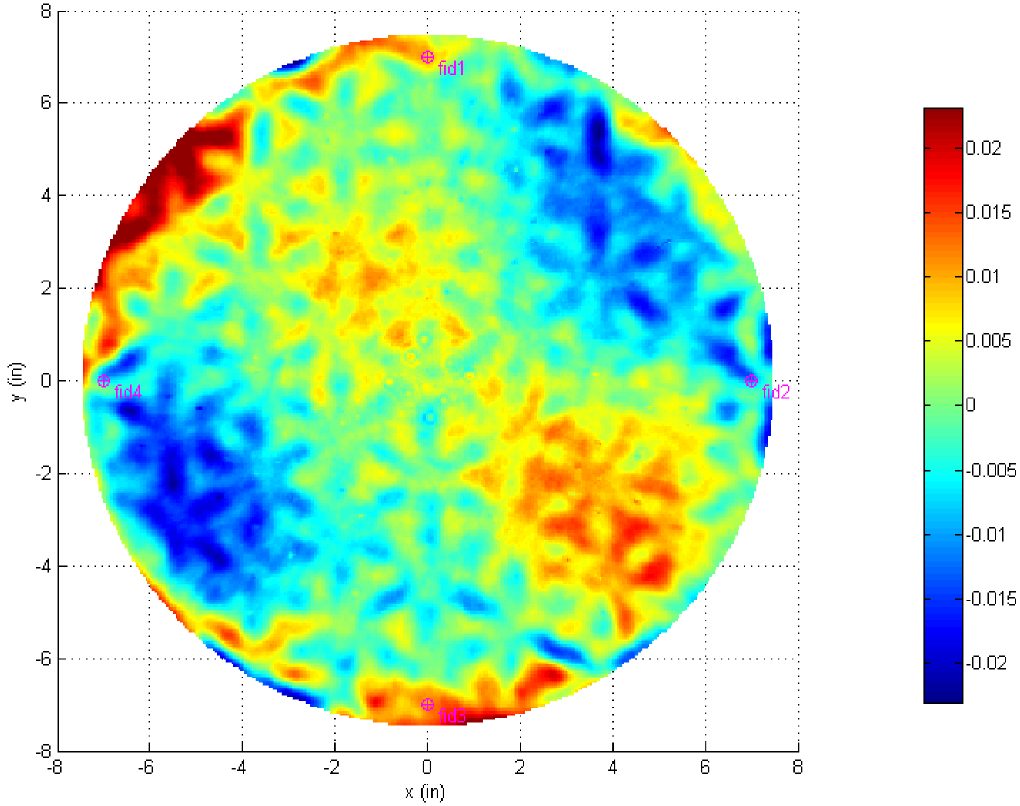
16nm RMS – 87nm P-V
Power Removed

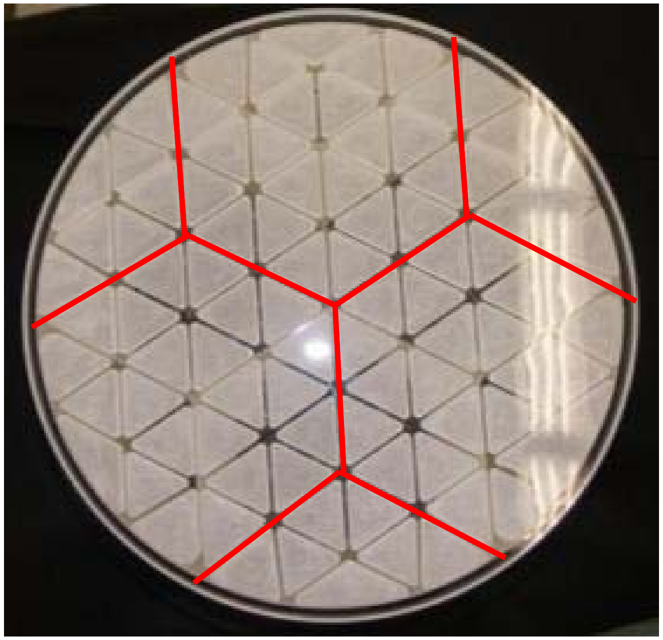


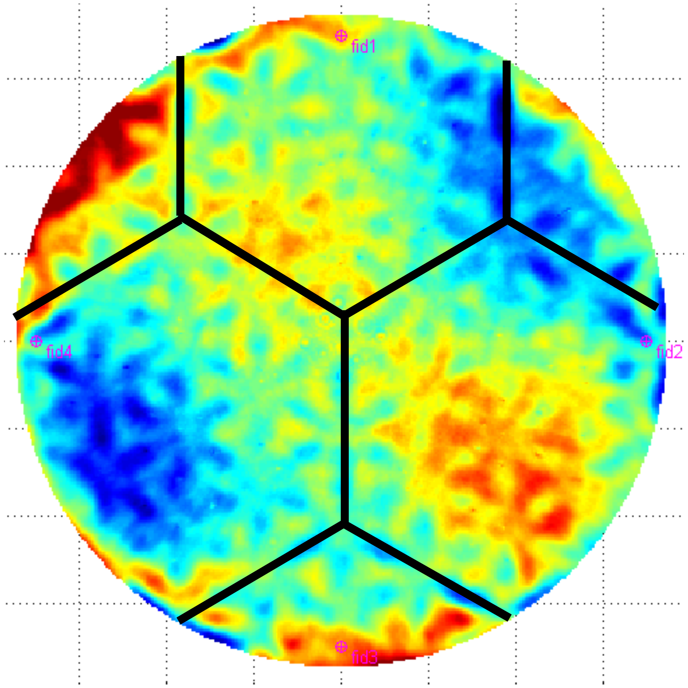
- First ion cycle greatly reduced the global figure error by 86%.
- Some cell quilting still visible

Post Ion Figuring #2

4.9nm RMS – 37nm P-V
Power Removed







- Second ion cycle further reduced the global figure errors by an additional 68%
- Pocket milled quilting becomes visible

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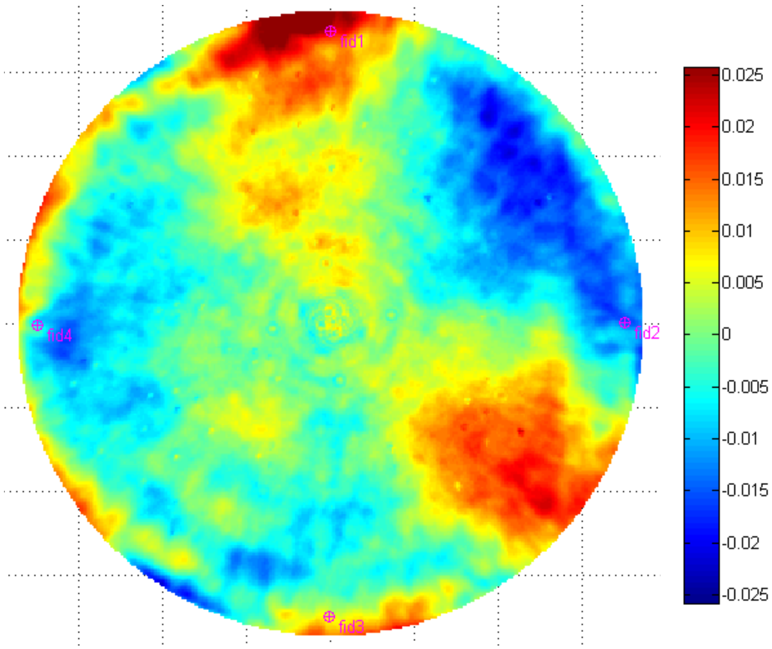
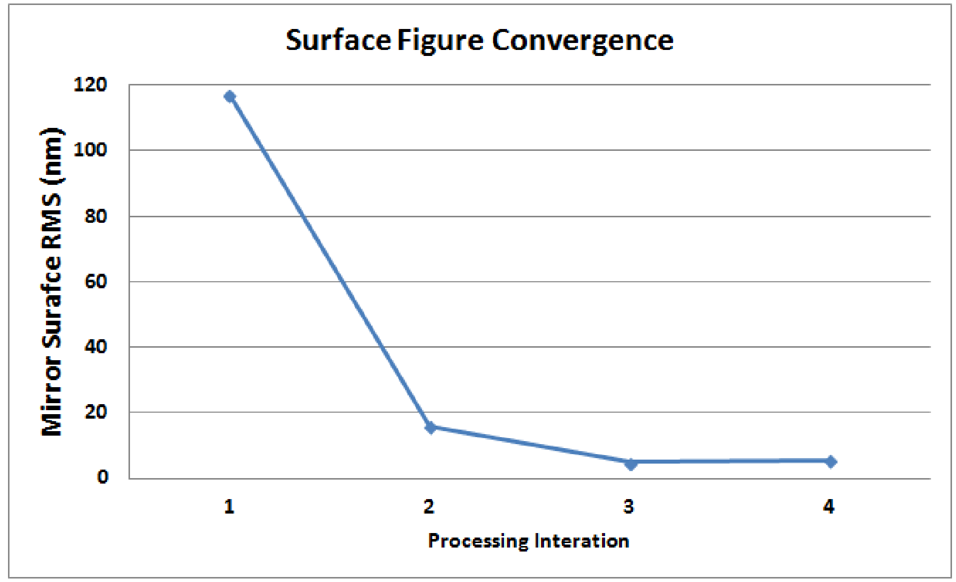
Post Ion Figuring #3

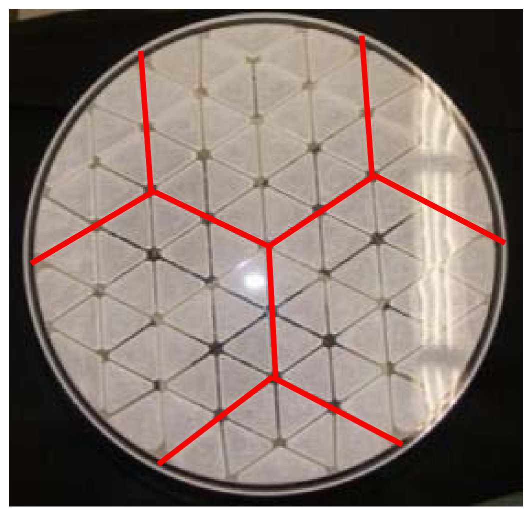
5.4nm RMS – 37nm P-V
Power Removed

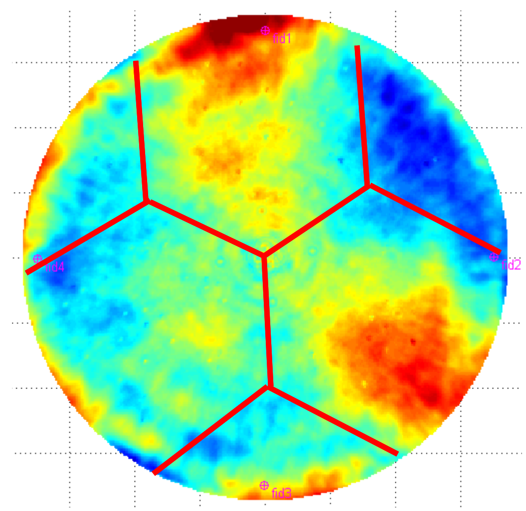


- Final ion figuring run focused on pocket quilting errors
- Mount repeatability limits overall surface quality



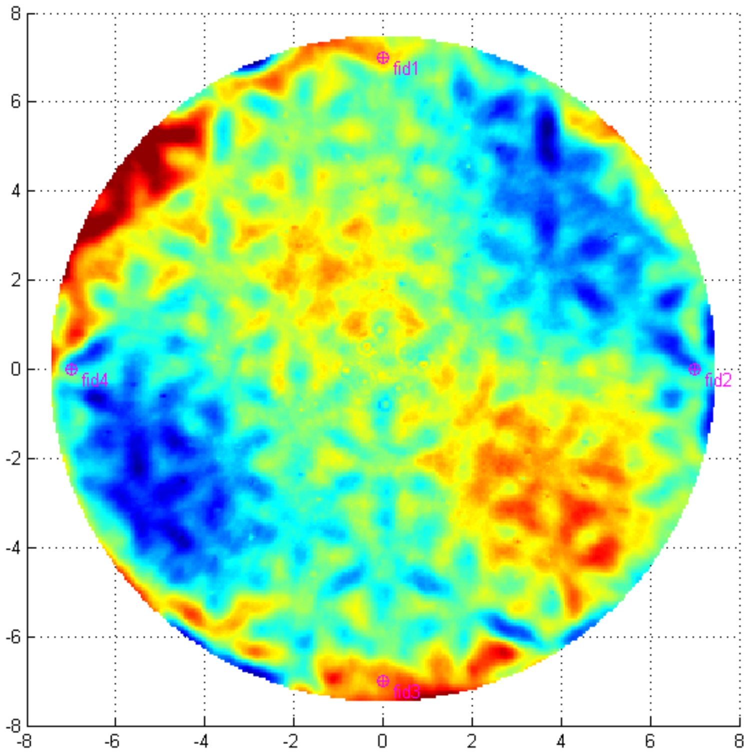
- Rapid convergence to final surface quality
- Deterministic processes reduce schedule time



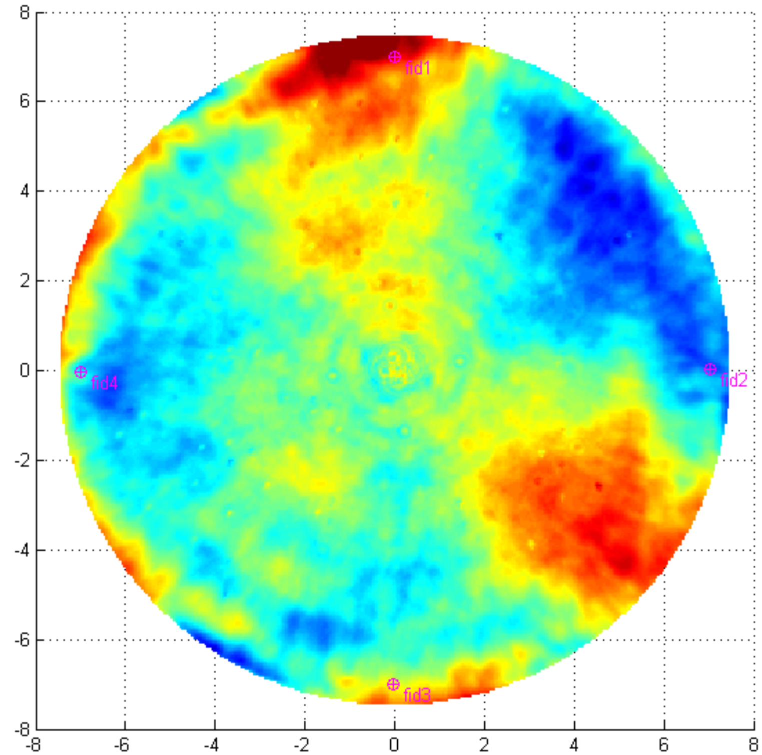


AMTD PSD Testing Summary

- Data collected using Zygo Verifire and White Light Interferometer
- Ion Figuring successfully removed most of the polishing quilting artifacts
- Results show no significant PSD change due to ion figuring in spatial periods smaller than 20mm.



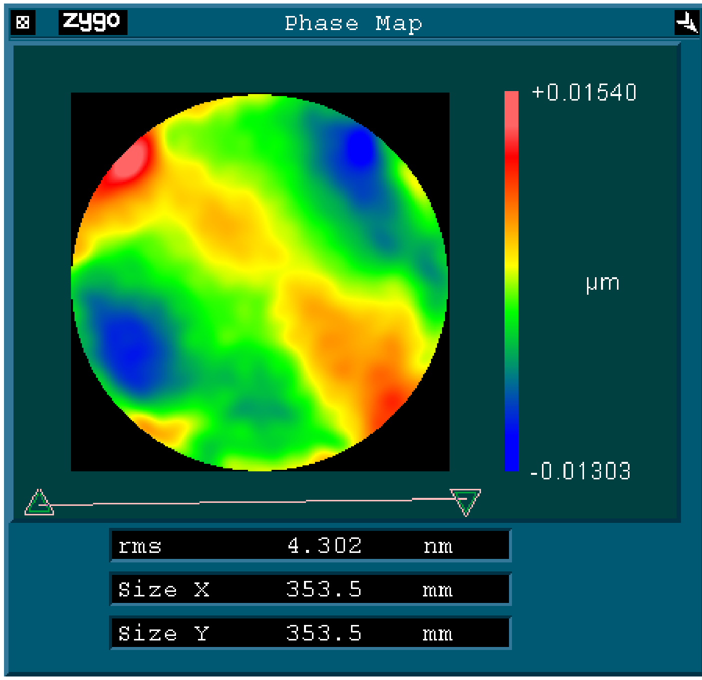
Polishing Quilting



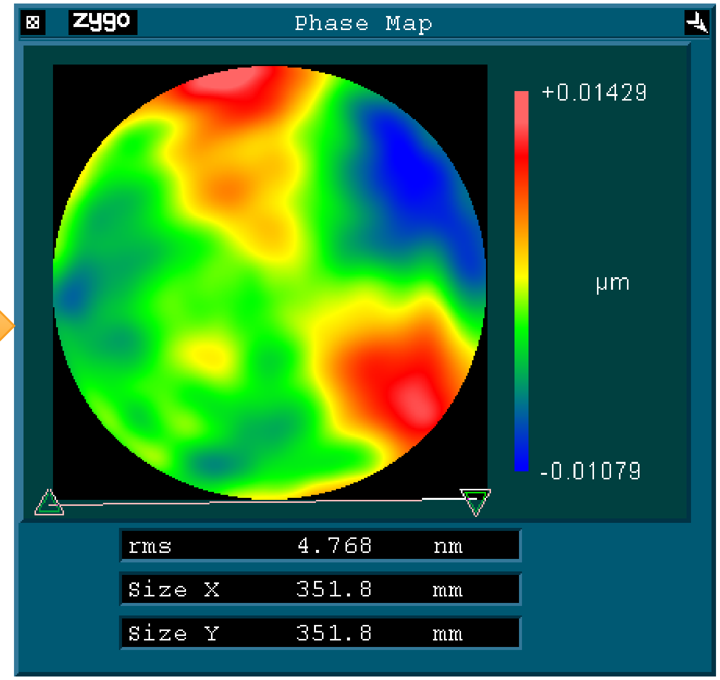
Finished

50mm FFT Low Pass Filter (Final Ion Iteration)

Before Ion Figuring



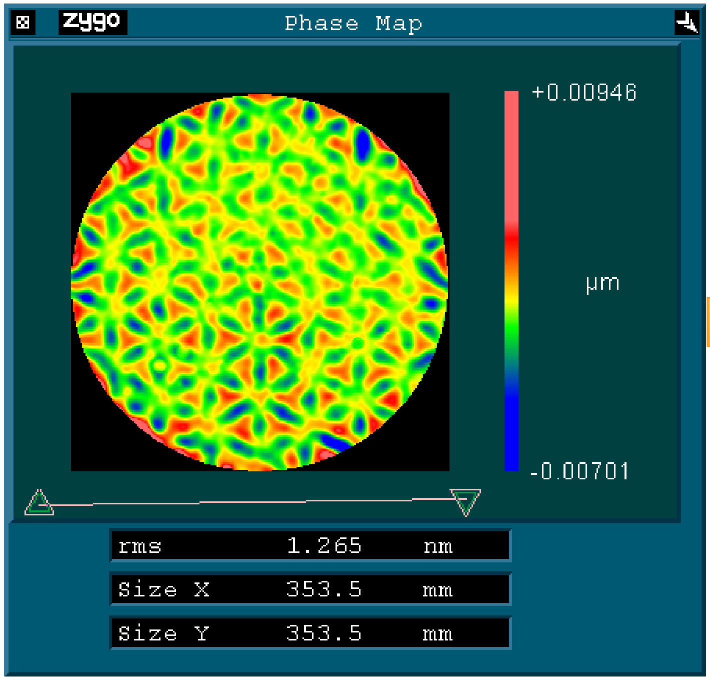
After Ion Figuring



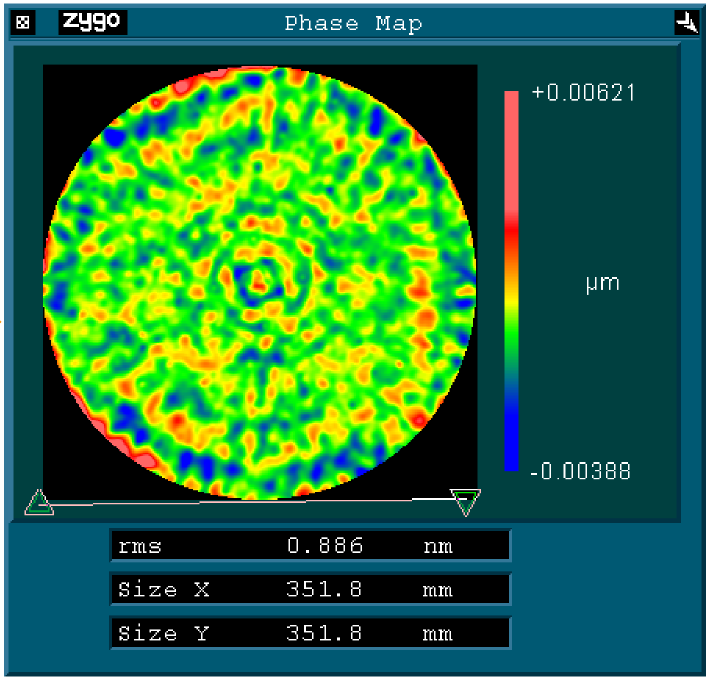
- Low order figure error has reached the current metrology reproducibility limit in the current configuration leading to no improvement in figure errors with spatial periods longer than 50mm
- Low order figure error present in the measurement after ion figuring is driven by mount reproducibility
- Metrology reproducibility and accuracy could be improved with an optimized mount design and additional part rotations

50mm-10mm FFT Band Pass Filter (Final Ion Iteration)

Before Ion Figuring



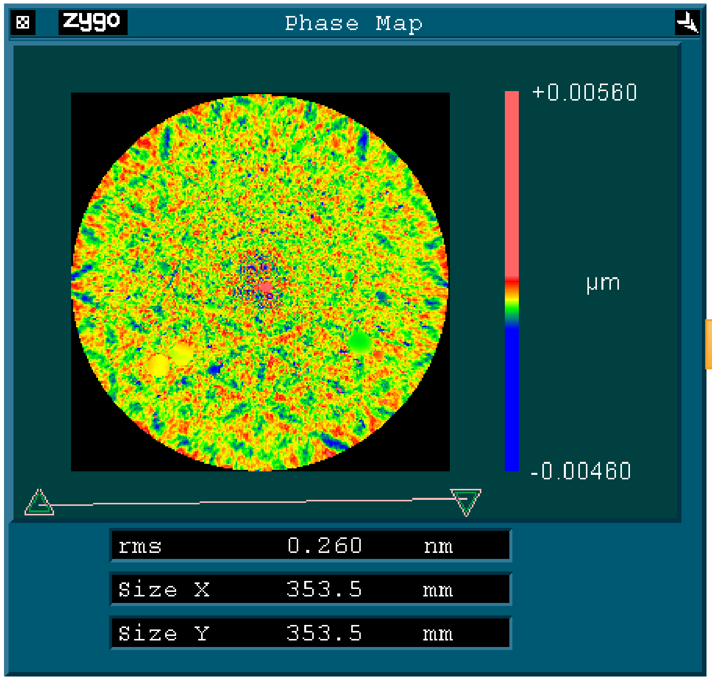
After Ion Figuring



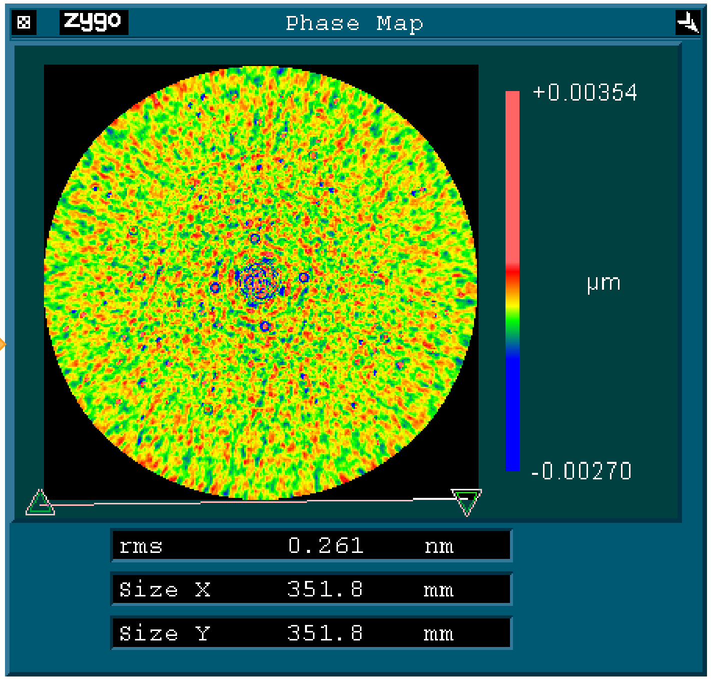
- The quilting period appears at ~20-30mm spatial periods before final ion figuring
- Ion figuring improved the rms in the 50-10mm spatial period band eliminating most of the quilting structure

10mm FFT High Pass Filter (Final Ion Iteration)

Before Ion Figuring



After Ion Figuring

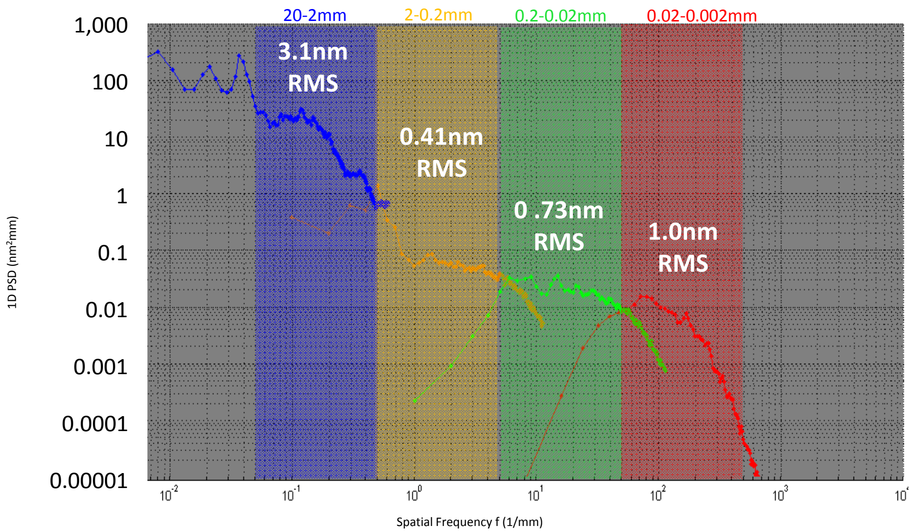


- The shorter spatial periods, <10mm, were negligibly affected by ion figuring
- Super polishing to improve the micro-roughness could be done if needed for the UV application

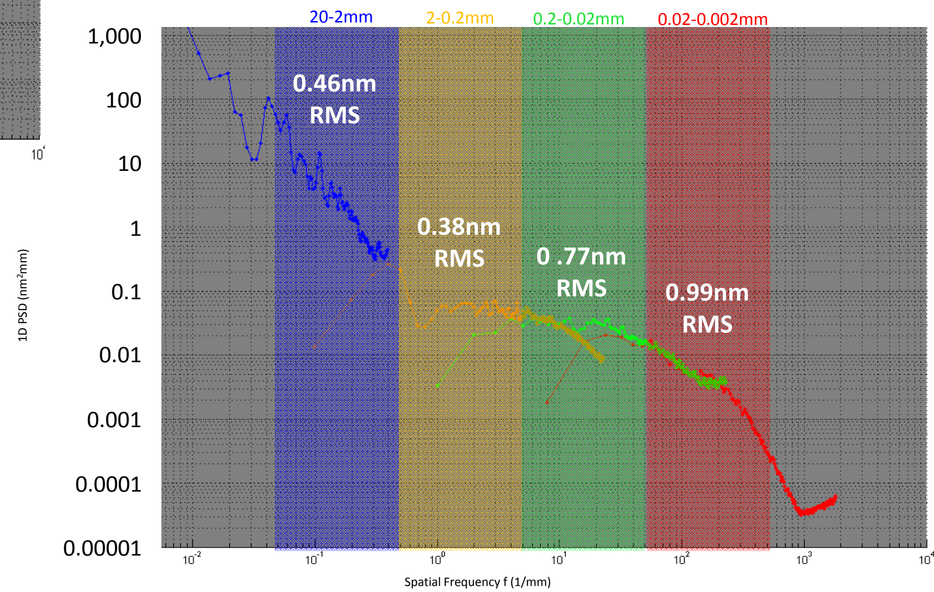
AMTD PSD Assessment (Final Ion Iteration)

- Blue:
  - Zygo Verifire
  - Full Aperutre
- Green:
  - Zygo NewView
  - 5X Objective; 1X relay
  - 1 mm aperture; 2um pixel
- Orange:
  - Zygo NewView
  - 1X Objective; 0.5X relay
  - 10 mm aperture; 22um pixel
- Red:
  - Zygo NewView
  - 20X Objective; 2X relay
  - 0.13mm aperture; 0.23um pixel

Before Ion Figuring



After Ion Figuring



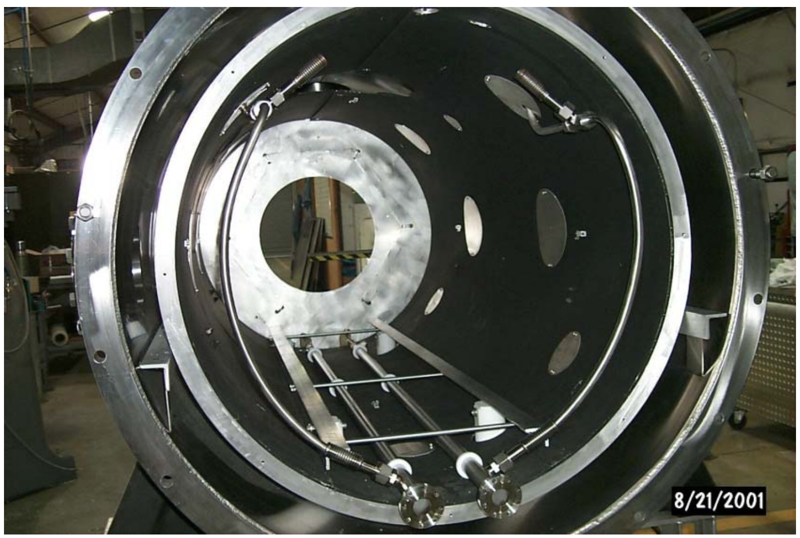
> Bands were analyzed at >5X above Nyquist limit with ~5 cycles per test aperture

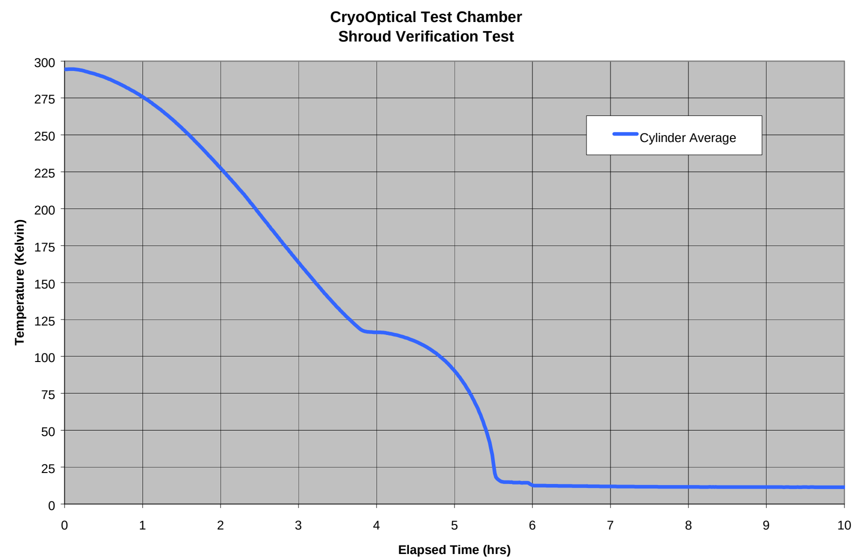
> Hanning window used for PSD analysis with magnitude re-scale

> Spatial periods smaller than 20mm were negligibly affected by ion figuring as evident in the PSD plot

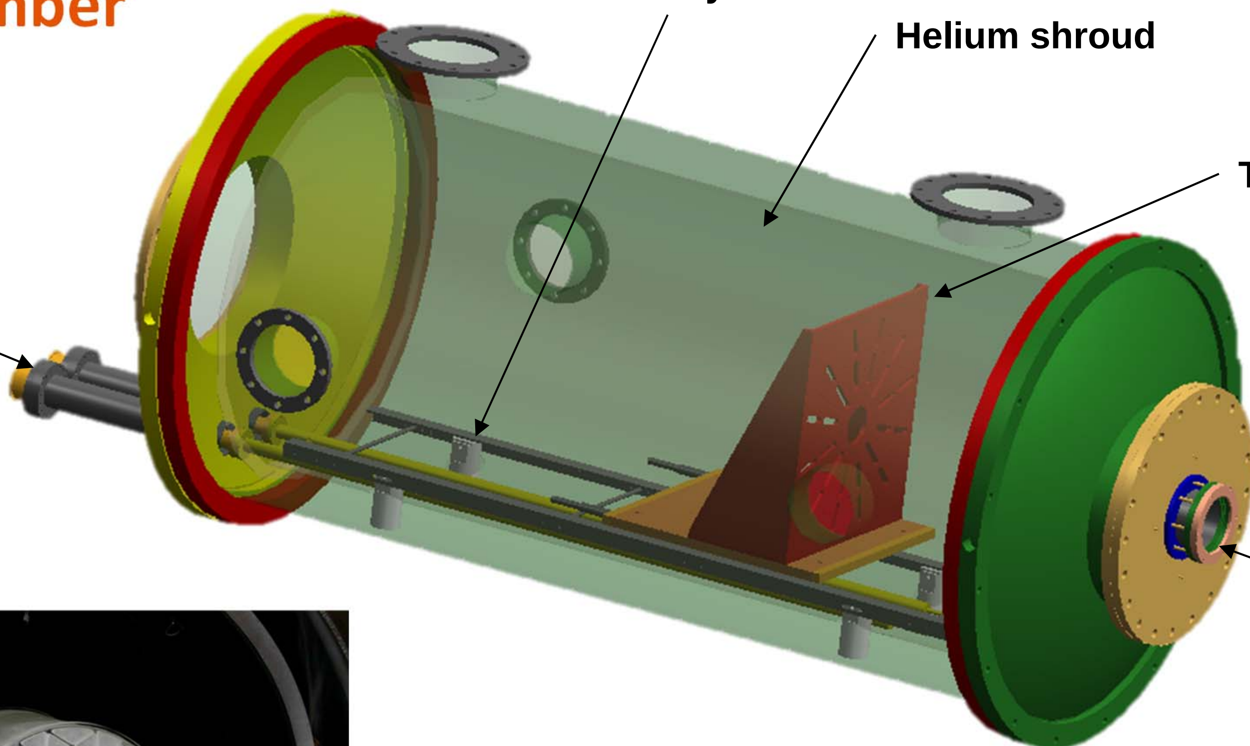
1m x 3m Optical Test Chamber at MSFC was used for cold

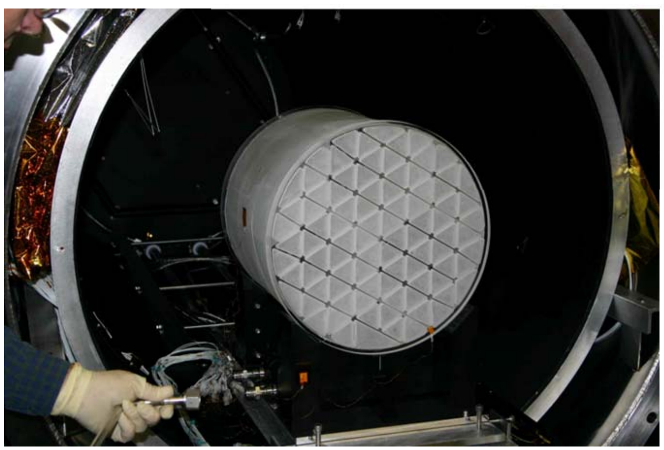
- **Vacuum Chamber: 1x3 m cylinder with helium shroud.**
- **Optical View Ports: BK7 window; 150 mm dia. clear aperture.**
- **Precision stage to provide interferometer pointing and alignment.**
- **Operational Pressure: < 5 E-6 Torr**
- **Temperature Range: 300 to 12K**
- **Typical cryo optical test: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



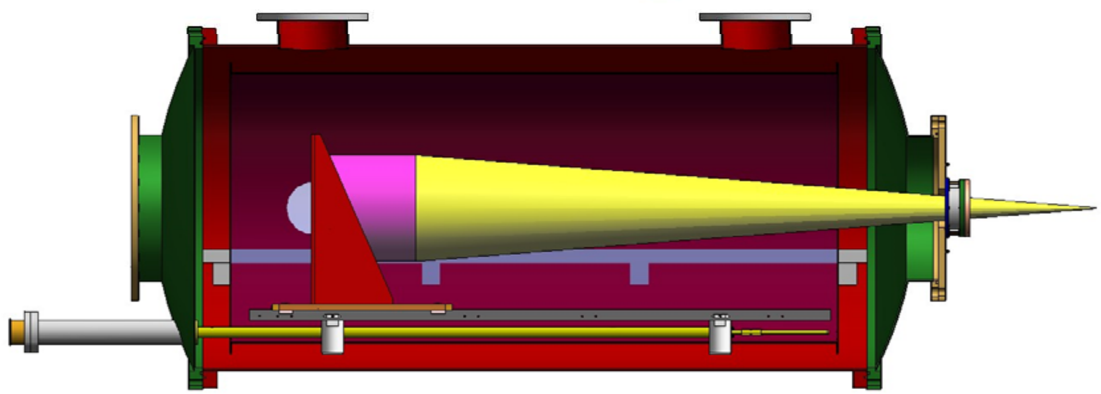


Test Chamber





AMTD-I Mirror in the V-Block Mount inside the vacuum chamber



Side View of Chamber and Center of Curvature Configuration

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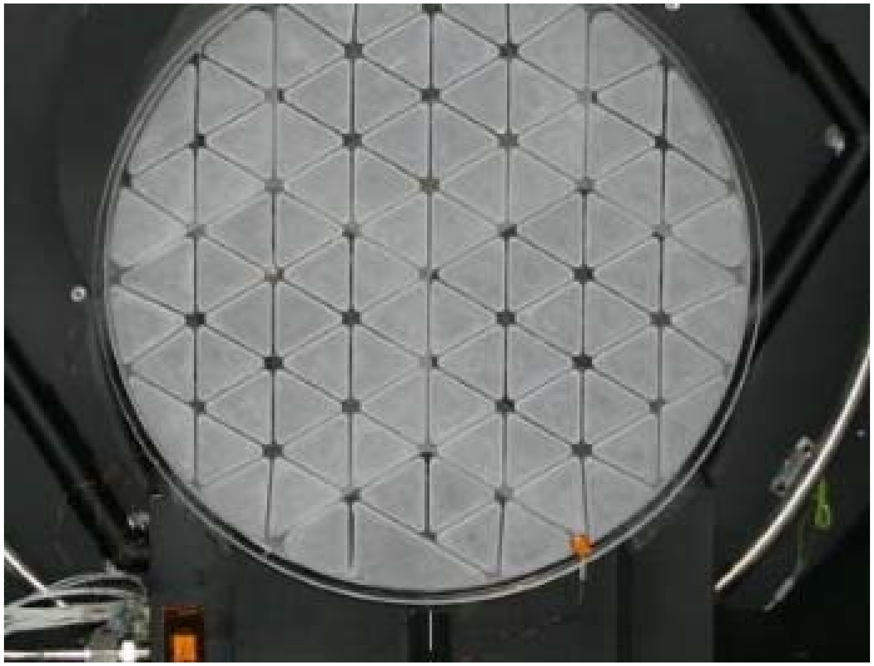
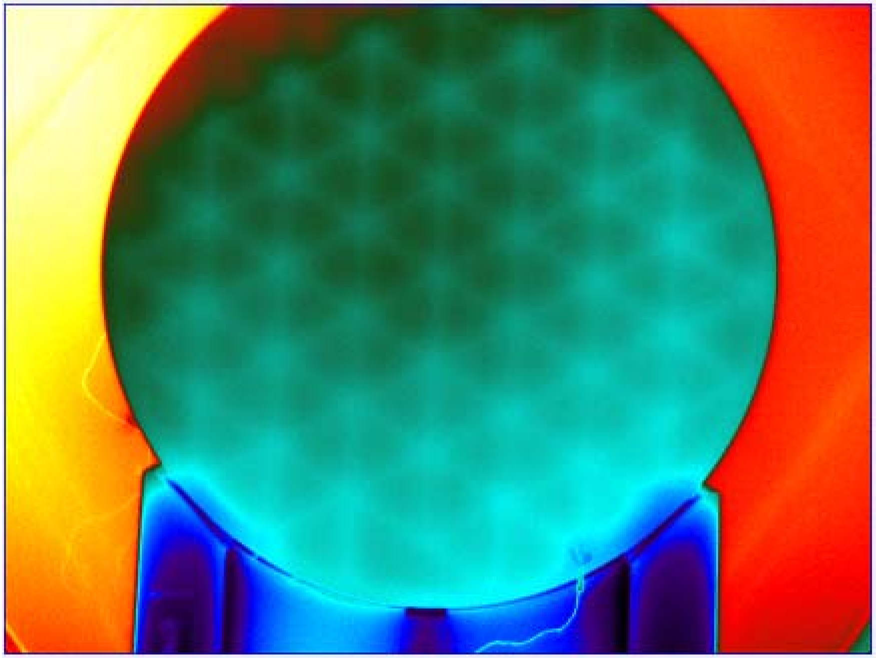
Thermal IR image During Temperature Transition





- **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**

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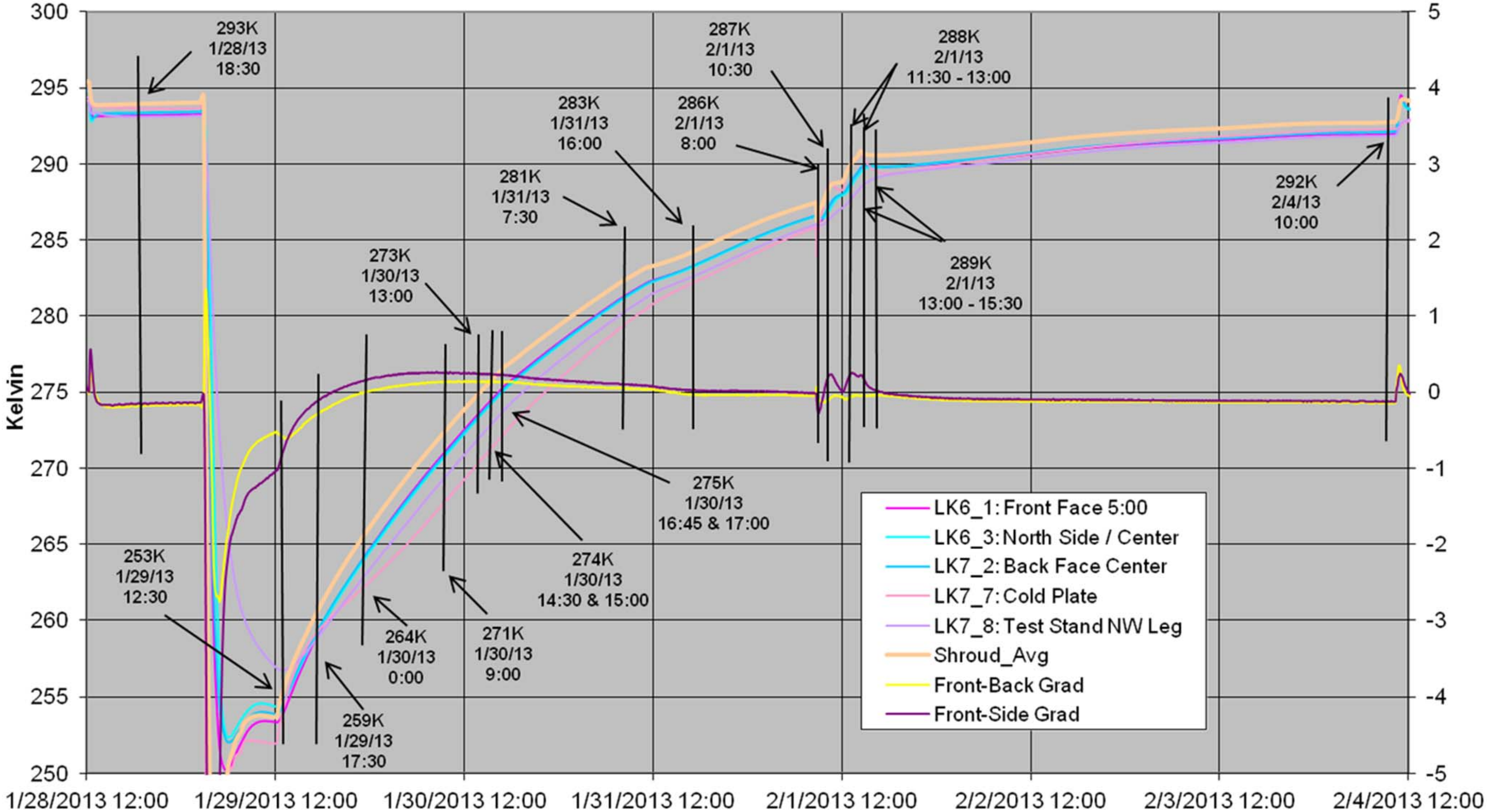
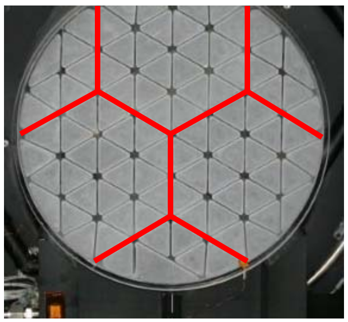
Typical Cold Cycle for Optical Testing



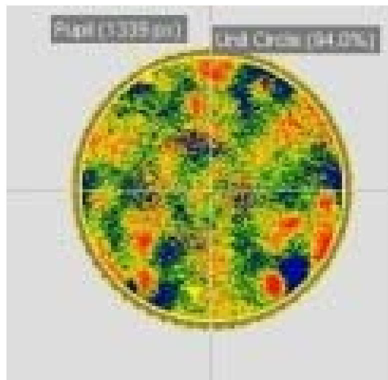
- **Mirror temperature stabilize overnight for minimum gradient.**
- **Optical measurements at 255K, 265K, 275K, 285K and ambient.**

Thermal Changes from Room Temperature

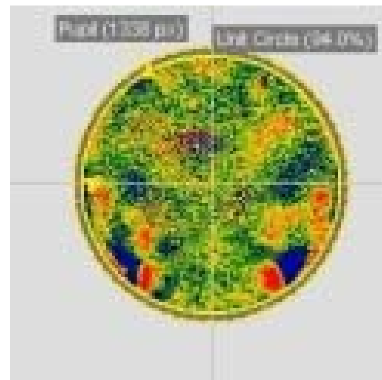
Mirror Reference Picture



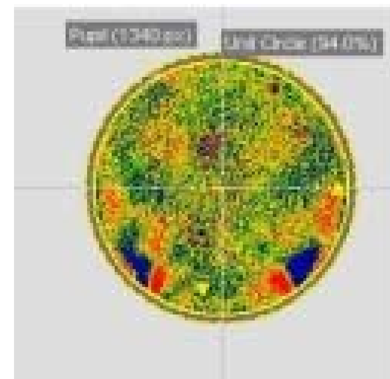
253-293K
4.0 nm rms



273-293K
3.7 nm rms



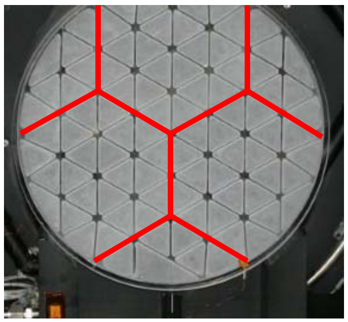
286-293K
3.6 nm rms



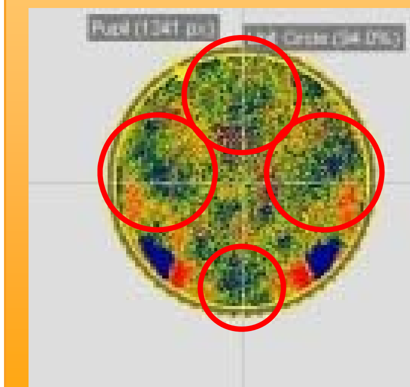
- **Thermal gradients allowed to stabilize overnight**
- **Very small changes in surface figure were observed during thermal testing down to 253K**
- **Figure change was dominated by the non-kinematic V-block mount**

Thermal Gradients Driven into Mirror

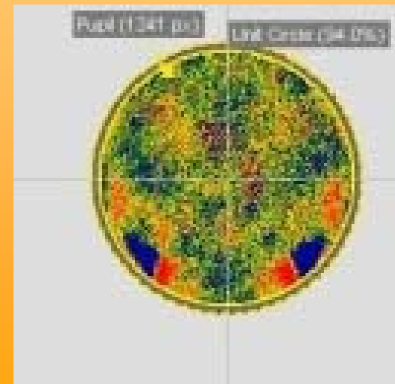
Mirror Reference Picture



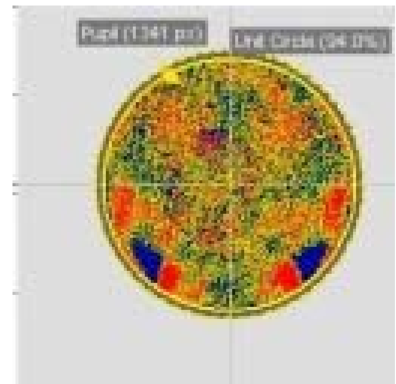
287-293K
7.2 nm rms



287-293K
7.2 nm rms



288-293K
7.9 nm rms



- **Thermal gradients driven into mirror during temperature transitions**
- **Changes were larger due to gradients in the mirror structure**
- **Figure change was still dominated by the non-kinematic V-block mount**

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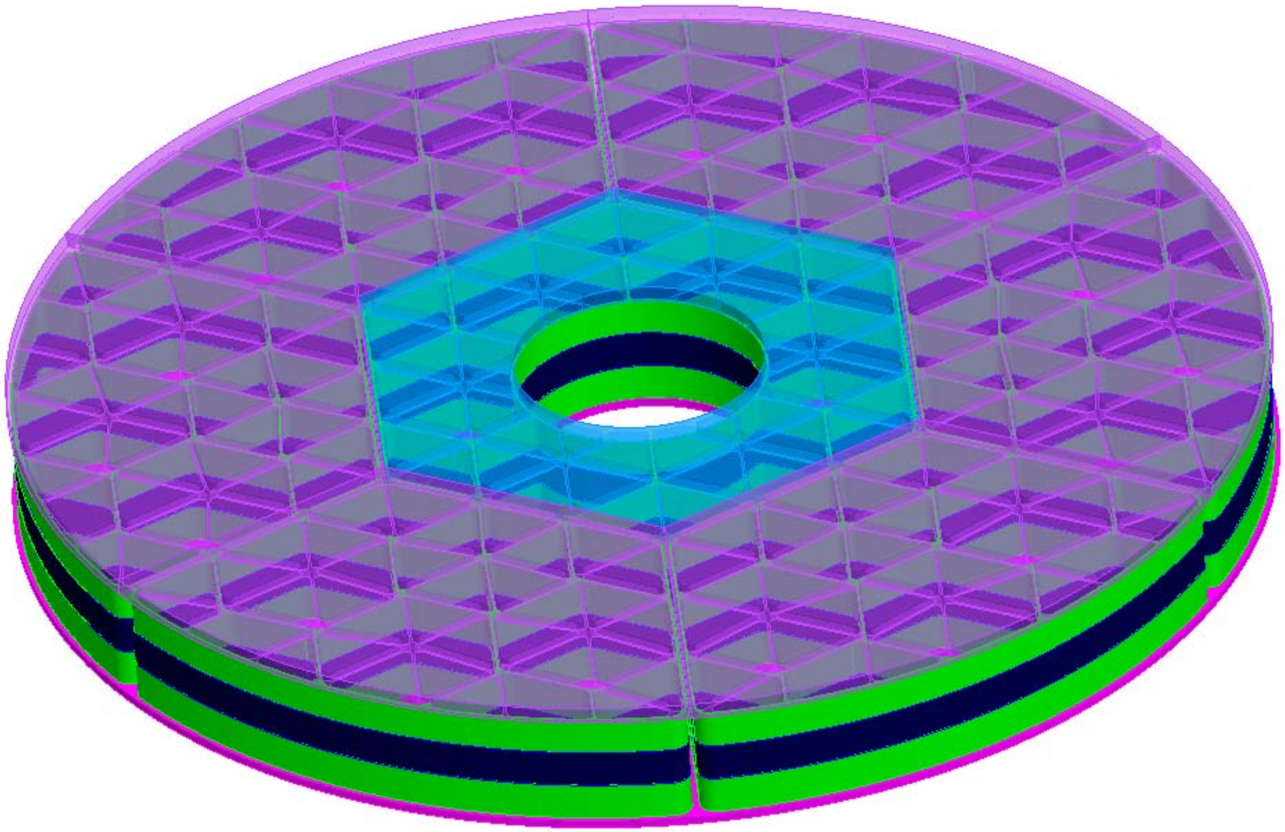
1.5m, AMTD Phase II Mirror Program



- **Phase II Contract awarded to the NASA/Exelis team**
- **Plan to build and test a 1.5m on-axis mirror using the stacked core approach**
- **Mirror Blank will be fabricated in 2015**

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AMTD Testing Summary

- Processing of the stacked core mirror converged very quickly using ion figuring
- Results show no significant PSD change due to ion figuring in spatial periods smaller than 10mm.
- Global surface figure limited by mount repeatability
- Demonstrated that UV quality (5nm RMS) could be achieved and verified
- During cycle 3, heat was introduced after 286K measurements to induce thermal gradient, resulting in higher residual rms values for 287K and 288K.
- Minimal surface deformation seen during steady state thermal transition.
- All work performed under NASA contract number NNM12AA02C
  - COTR: Michael R. Effinger

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