Development of stacked core technology for the fabrication and processing of deep lightweight UV quality space mirrors

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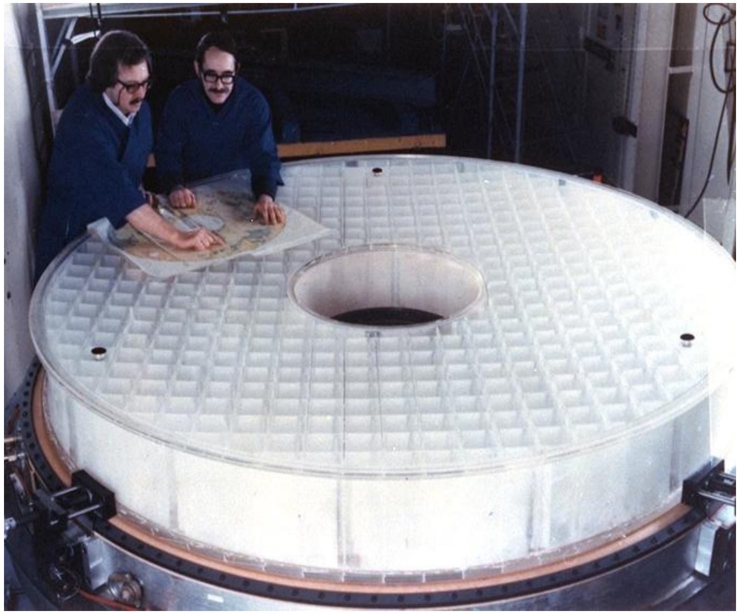
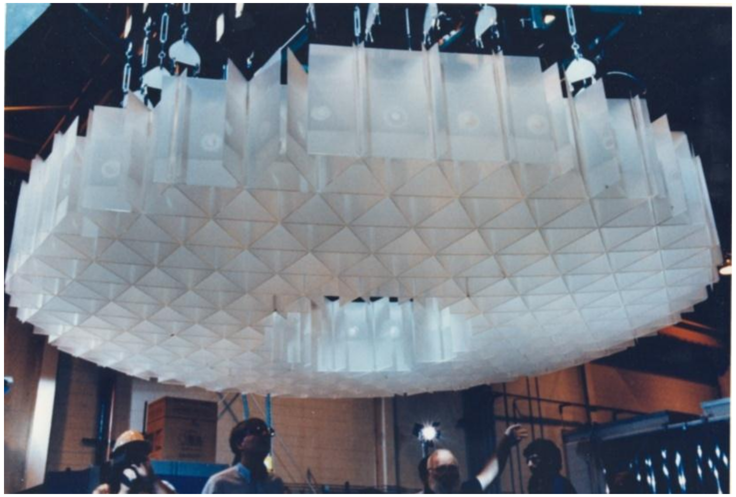
Advanced UVOIR Mirror Technology Development (AMTD) Program

- 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

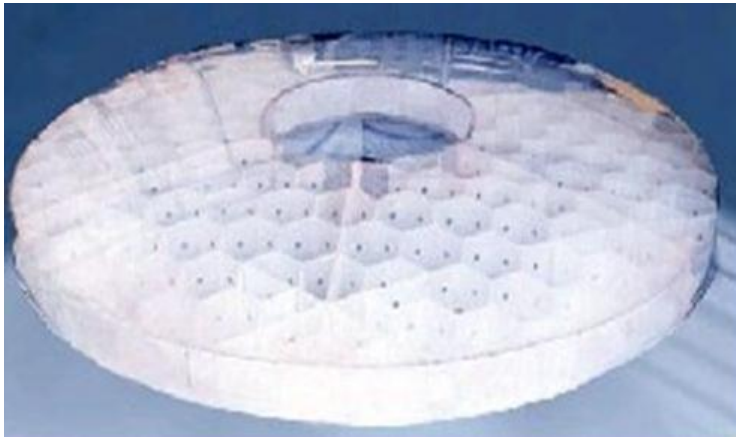
Large Lightweight ULE® Primary Mirrors at Exelis



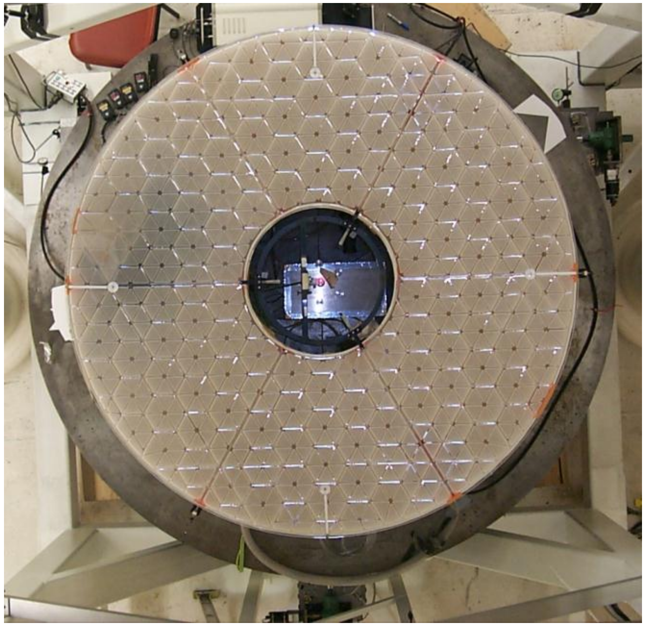
High Temperature Fusion – 1970's
(Hubble Primary Mirror)



Frit Technology with Flame Welded Core – 1980's



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



Primary Mirror – Low Temp Fusion – 2000's

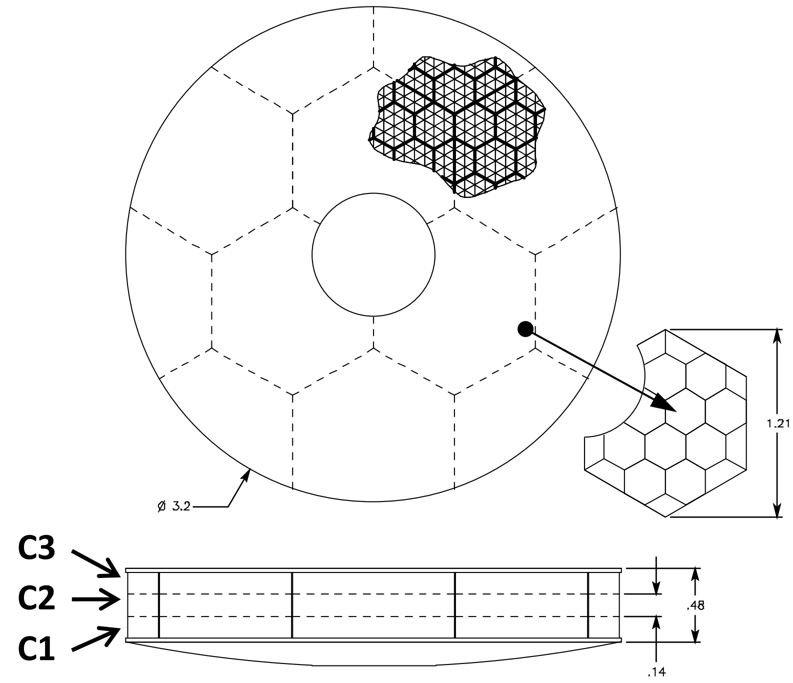
AMTD is Developing Technologies for Near Term Large Lightweight Primary Mirrors

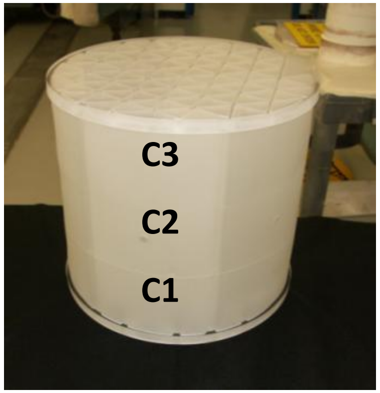
Stacked core

> 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 Abrasive Water Jet (AWJ) cutting of cores

> Enables lighter weight cores and reduces cost & schedule for blank fab

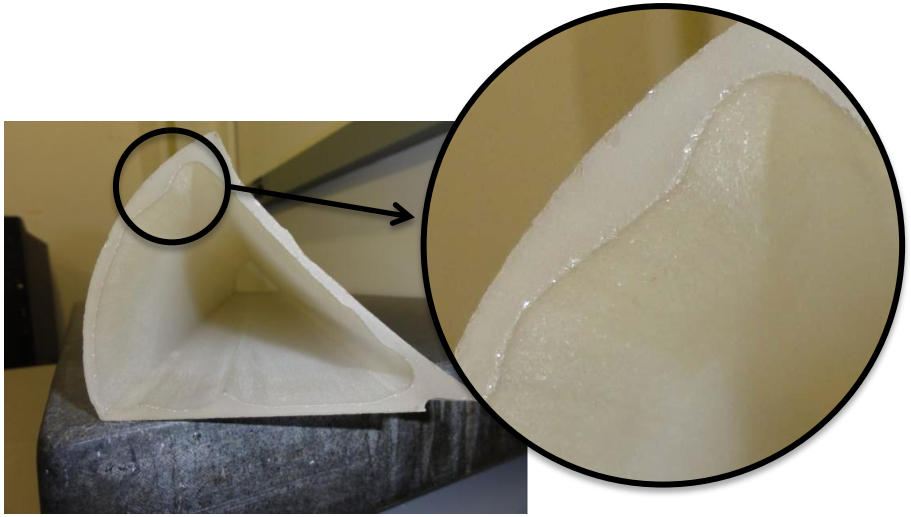




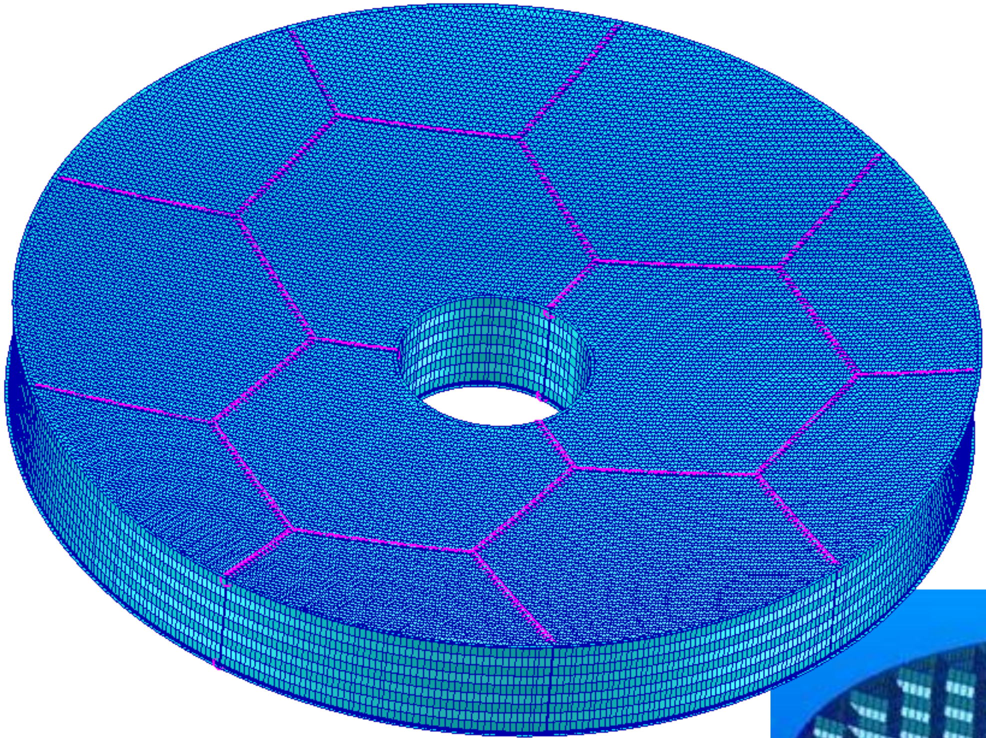
Deep AWJ Cutting

> 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

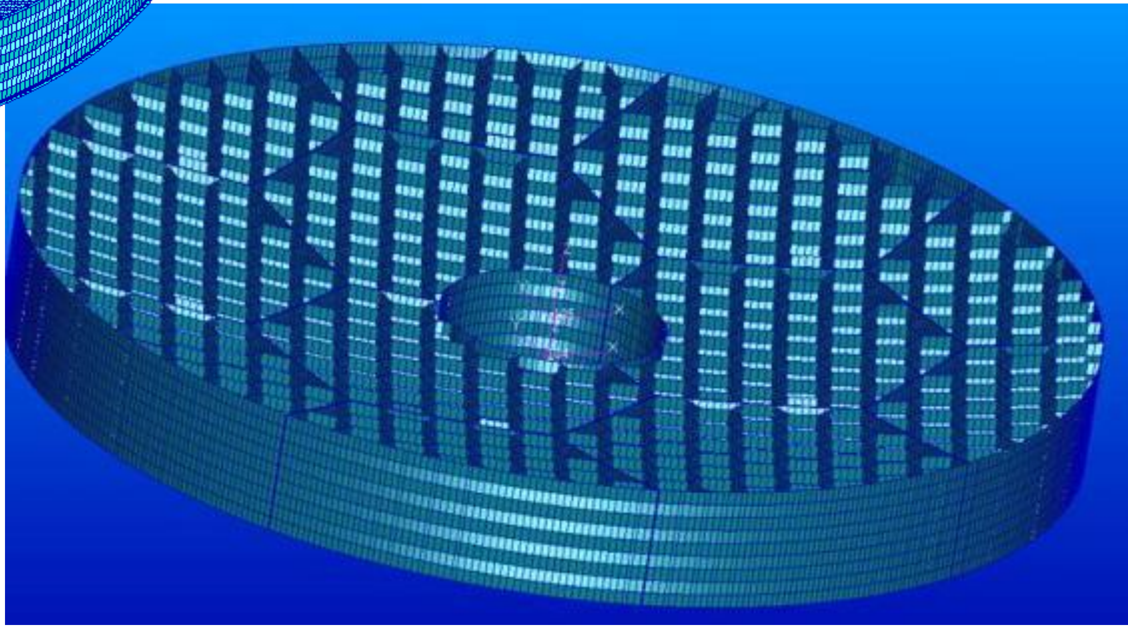


4m Mirror Concept



<u>4m Mirror Physical Attributes</u>

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



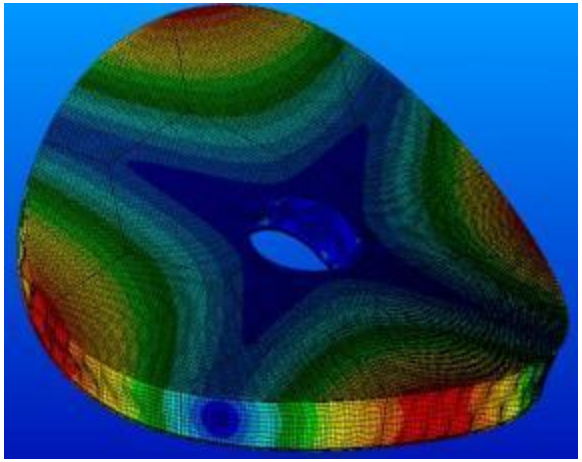
- **Fabrication risk reduced by eliminating stack sealing and deep core cutting**
- **Reduced glass needs for tooling glass**

Dynamic Considerations

4m Dynamic Performance

- *3 layer core*
  - *35 kg/m²*
  - *137 Hz First Free-Free Mode*
- *4 layer core*
  - *43 kg/m²*
  - *150 Hz First Free-Free Mode*

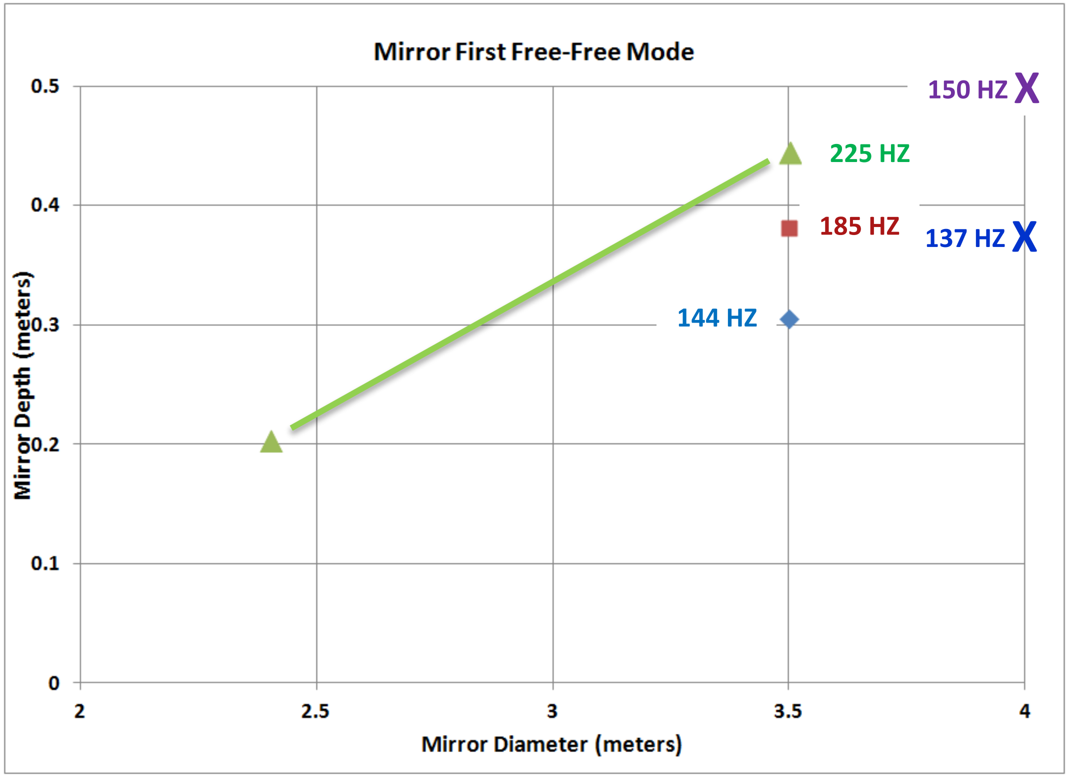
- Limited leverage at this scale to increase first mode frequency
- Active Dynamic Control measures likely needed at system level



First Mode

Mirror Dynamic Sensitivity

- *First order first mode frequency generated for a variety of mirrors*
- *Provides some insight into sensitivity of thickness and first mode*
- *Some impact to areal density and limit to overall frequency*



System Dynamic Control

- *At large sizes, the mirror dynamics may not be the biggest problem*
- *A system approach is recommended*
- *Exelis active dynamic control is at TRL8*

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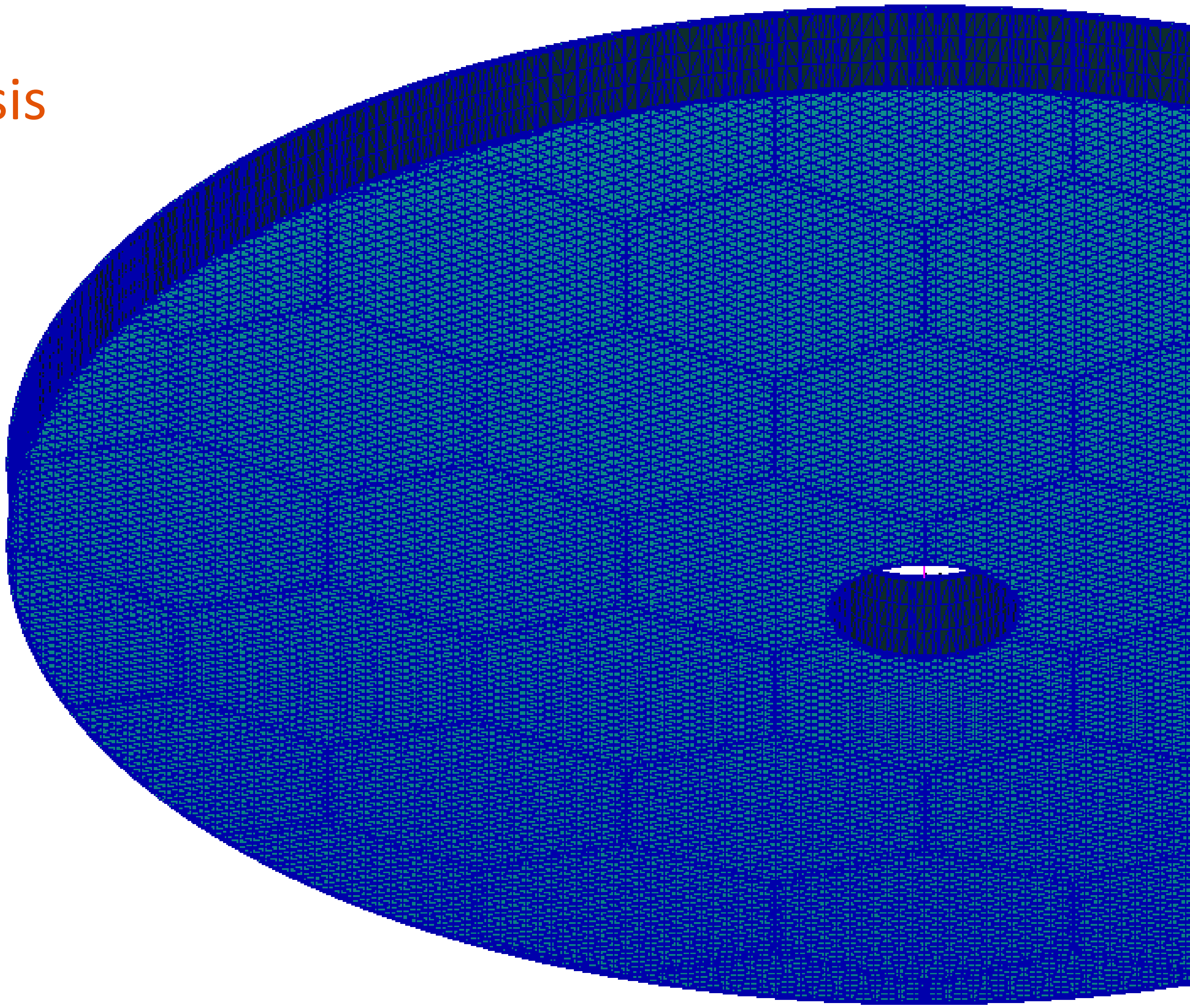
AMTD 8m Mirror Design and Analysis

- 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



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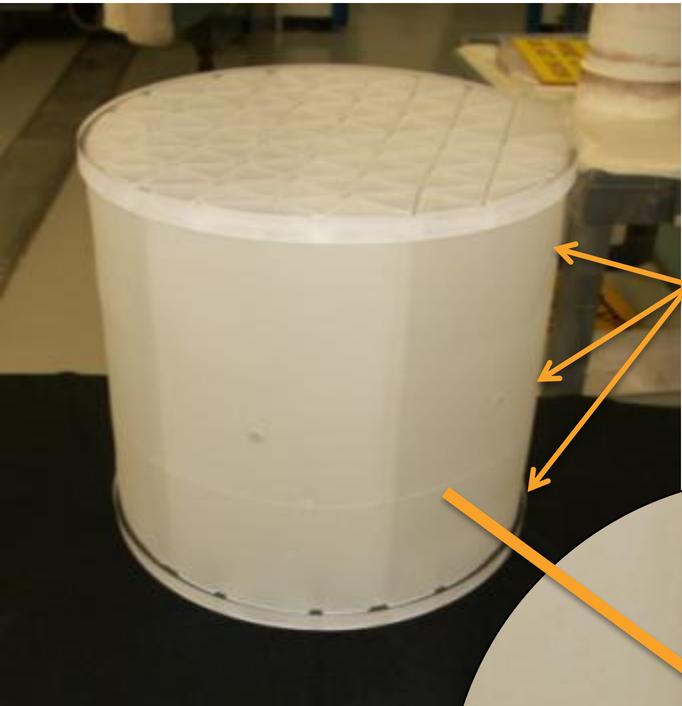
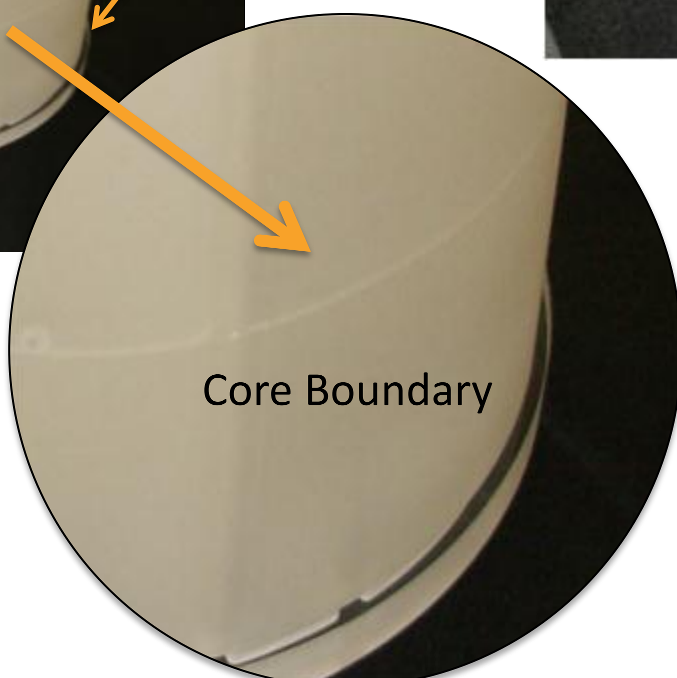
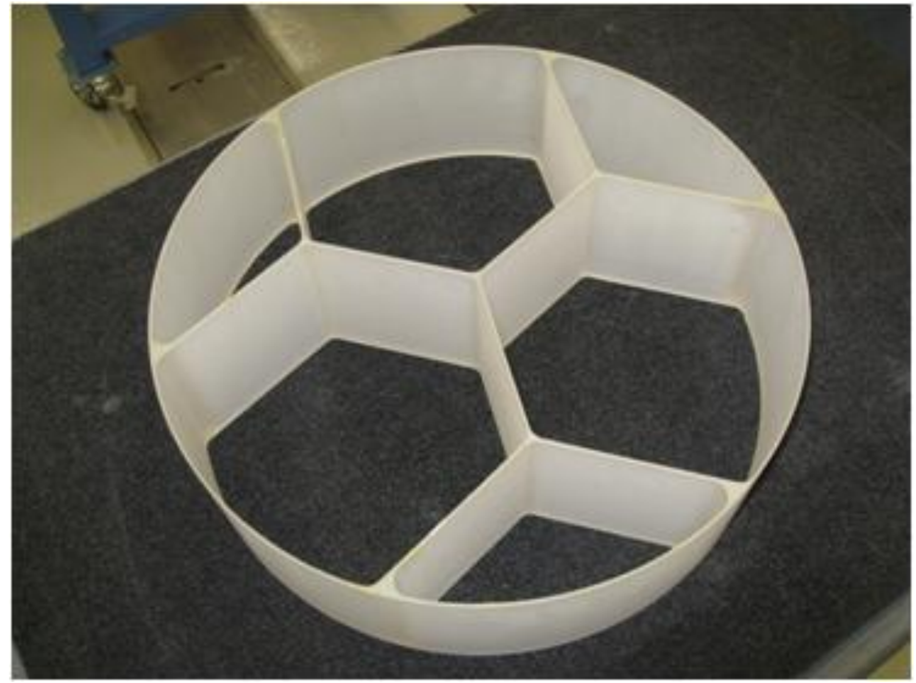
Stacked Core Mirror Demonstration

0.4m Demonstration part fabricated



Mirror Blank is 3 cores high





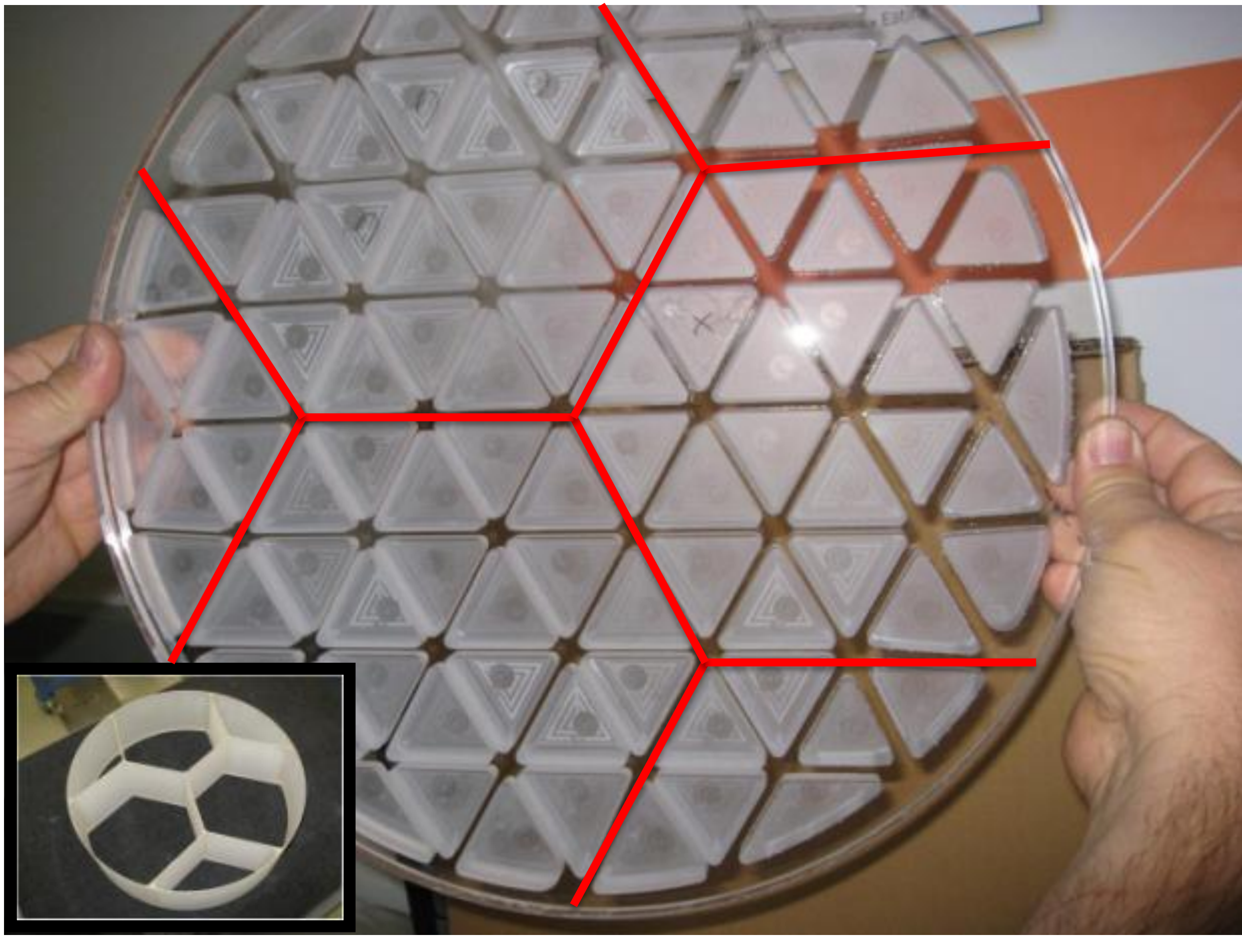
Single Mirror Core
(Note large cell size)

- 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)

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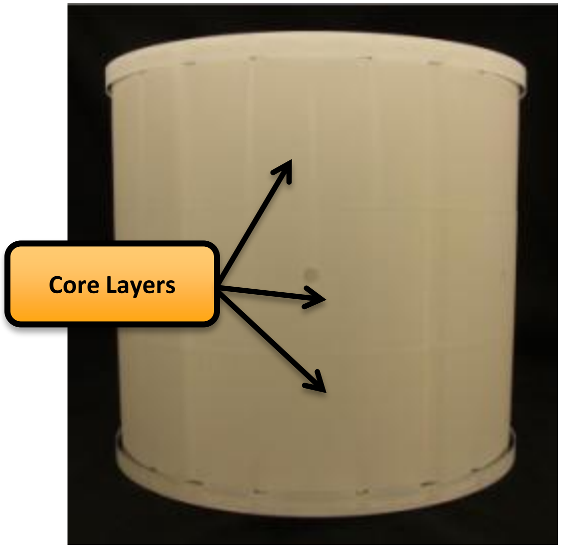
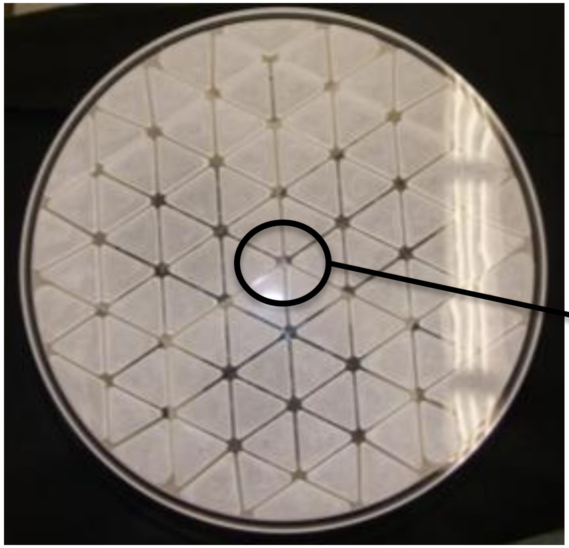
Demonstration Blank Low Temperature Fusion

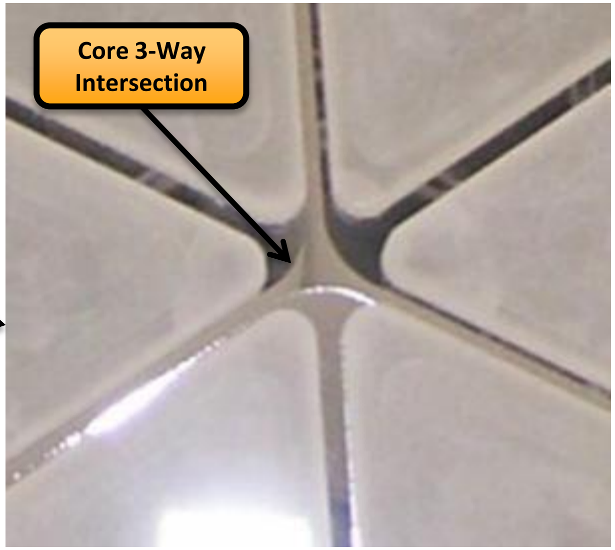
First-Ever Layered Core Demonstrator Successfully Fused



Post-Fusion Side View
3 Core Layers and Vent Hole Visible



Post-Fusion Top View
Pocket Milled Faceplate



Top View Enlargement
Core-To-Faceplate LTF Bond Visible

- LTF joint strengths in the core-to-core joints (2,500 psi) are consistent with faceplate-to-core strengths (1,940 psi)
- Highest stresses are at the faceplate-to-core interface so the core-to-core strengths are fully acceptable

Validates Reduced Cost Approach for Manufacturing Deep Mirror Cores

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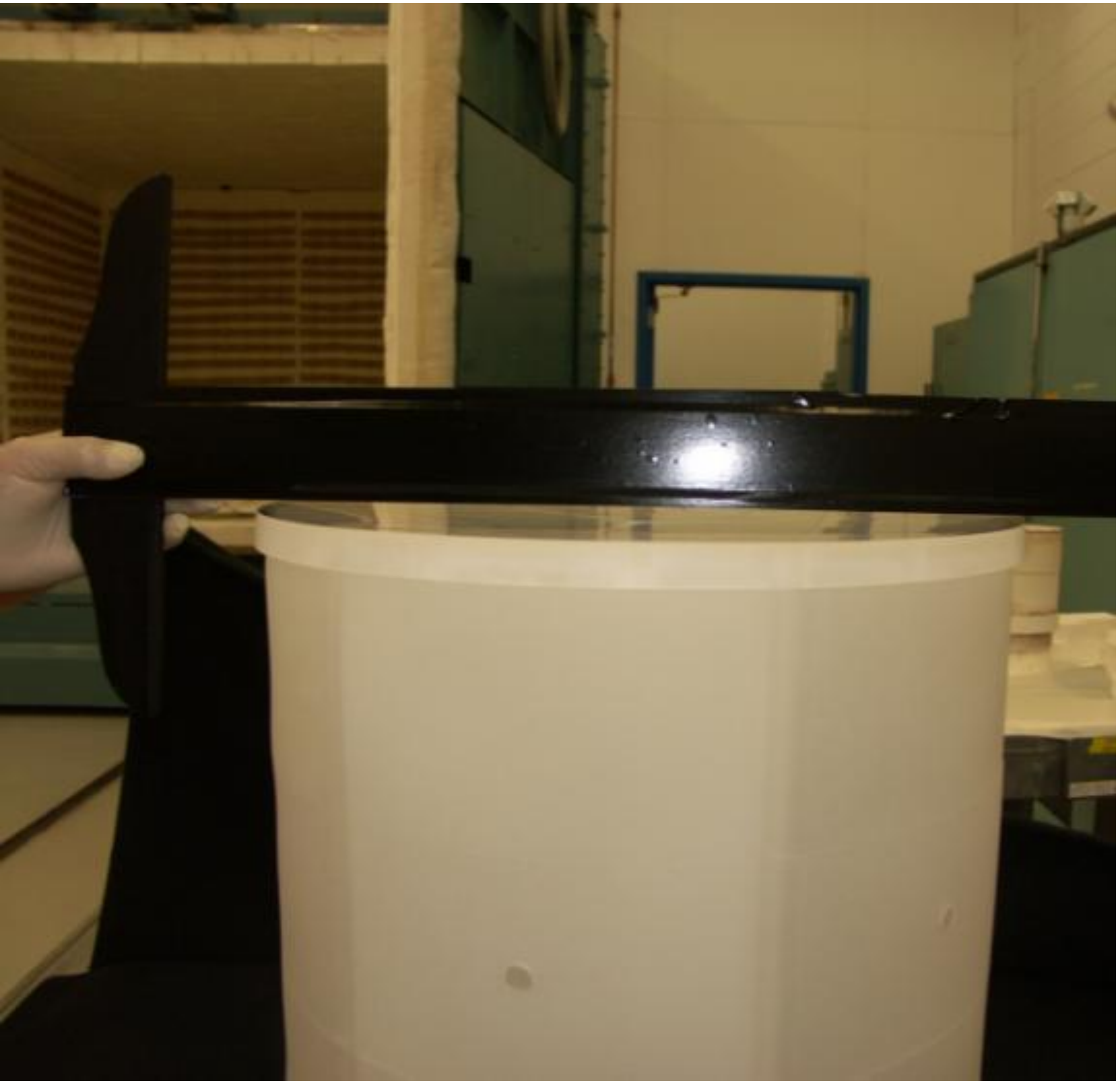
Low Temperature Slumping Incorporated into Development



- Low Temperature Slumping (LTS) demonstrated on AMSD/MMSD active mirror programs
- Incorporated into this development to reduce blank part processing costs
- Part successfully slumped to a very fast 100 inch (2.4m) Radius of Curvature (RoC)
  - Thermal testing at MSFC completed
- Minor but acceptable deformation of some of the core walls

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Processing Quality

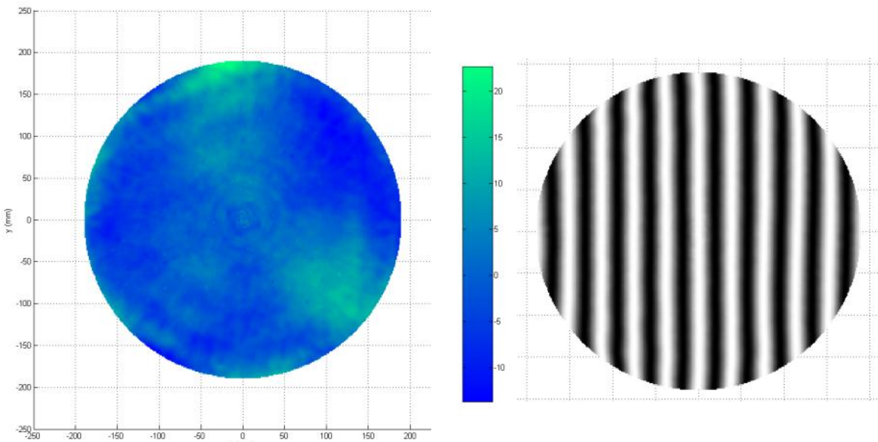
Processing completed to demonstrate that UV quality (5nm RMS) could be achieved

Multiple orientation test minimized test errors and analytical backouts

- Some minimal trefoil did not cancel out during testing

Mirror was cryo tested at MSFC

- Reference 8837-11

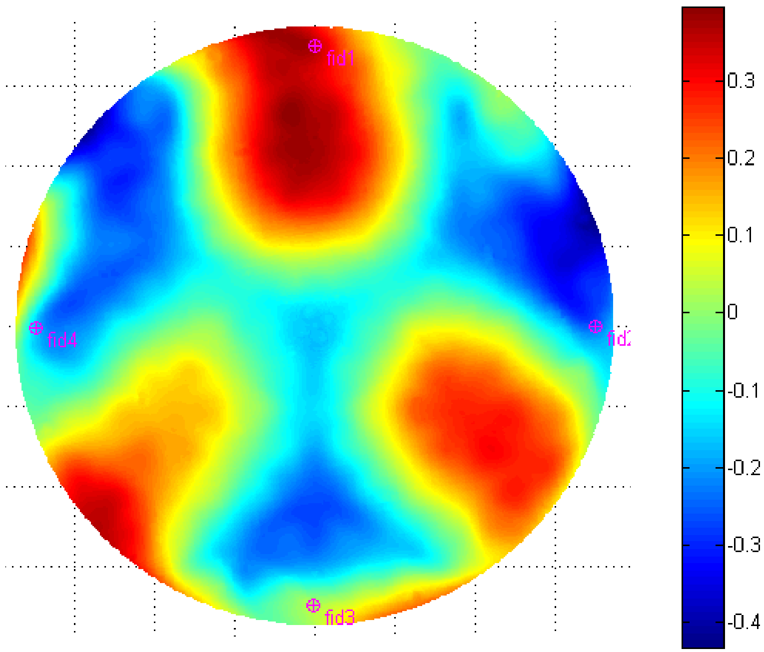


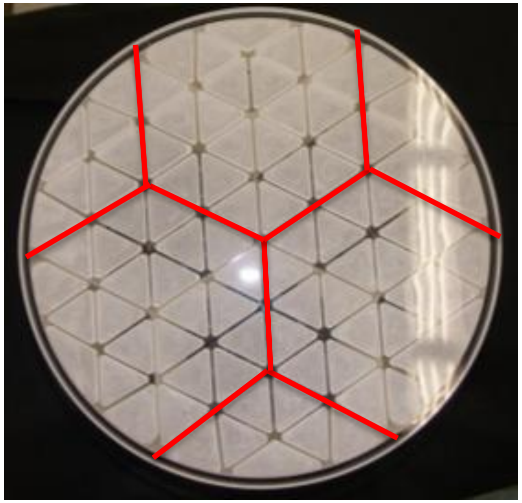
Final Optical Test – 5.5nm RMS

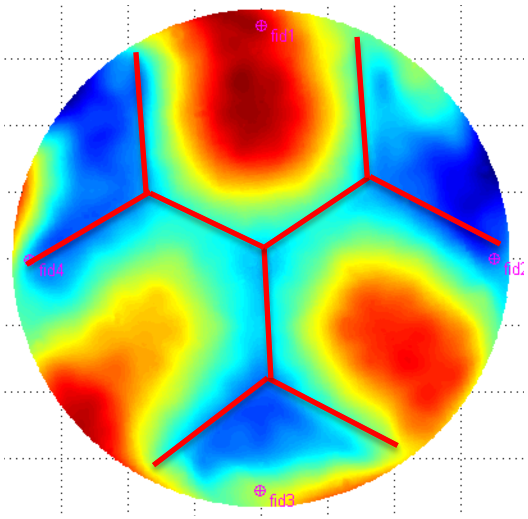
Demo Part in V-Block for Horizontal Testing

First Light Test

117nm RMS – 524nm P-V
Power Removed







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

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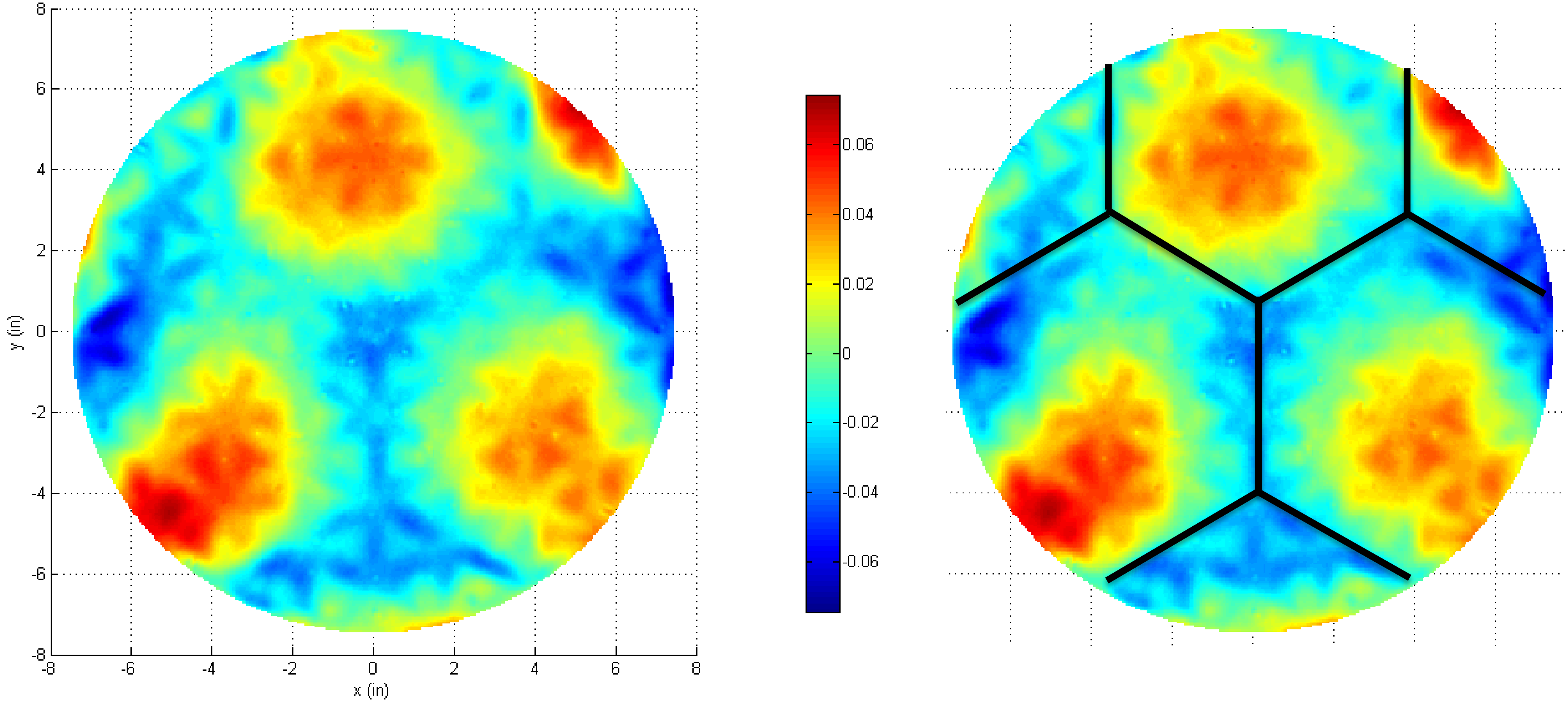
Post Ion Figuring #1

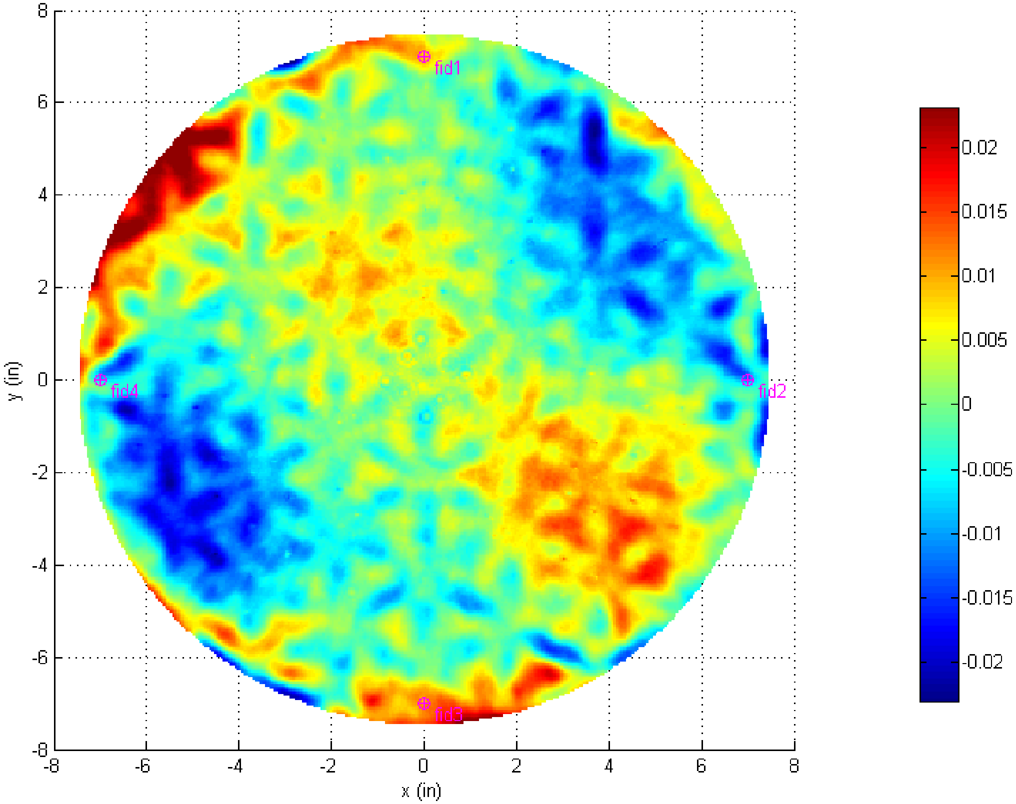
16nm RMS – 87nm P-V
Power Removed

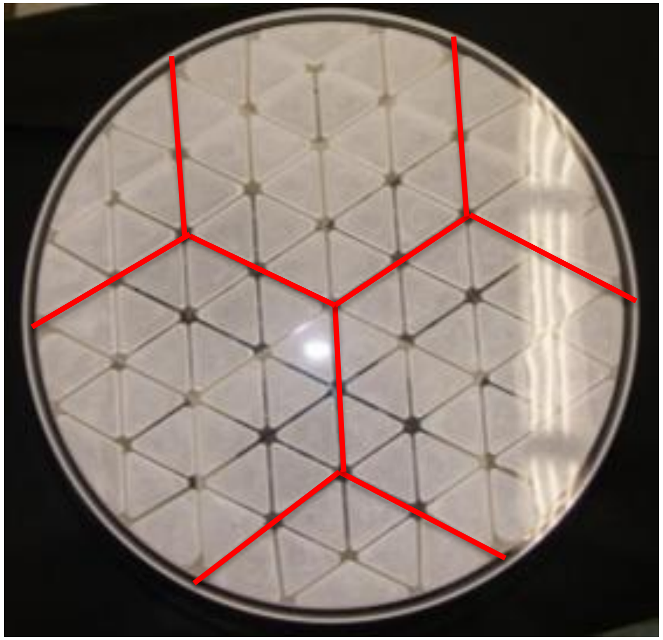


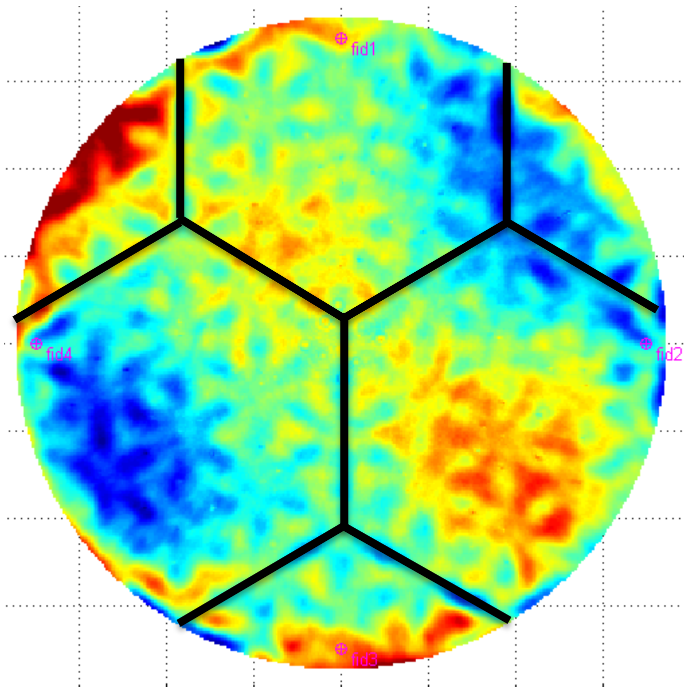
- First ion cycle greatly reduced the global figure error by 86%.
- Some cell quilting still visible

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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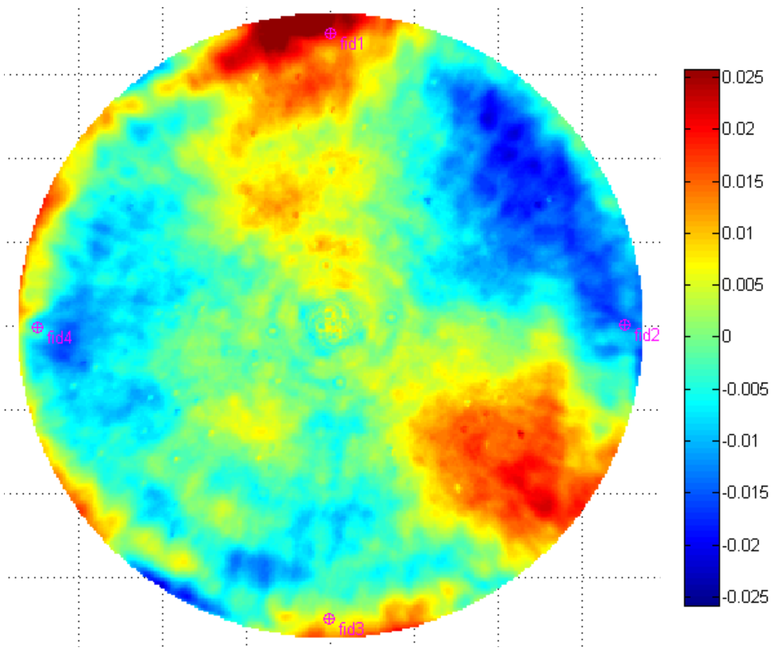
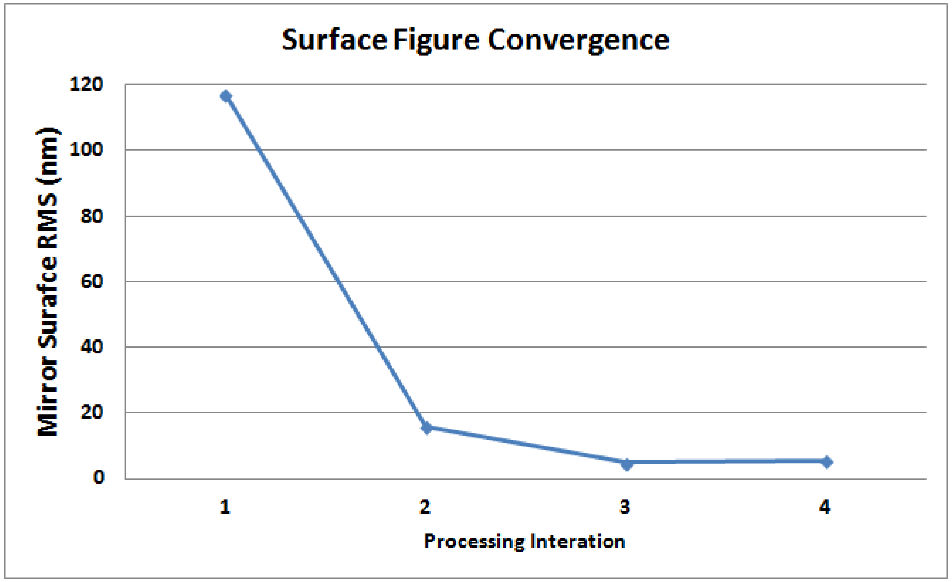
Post Ion Figuring #3

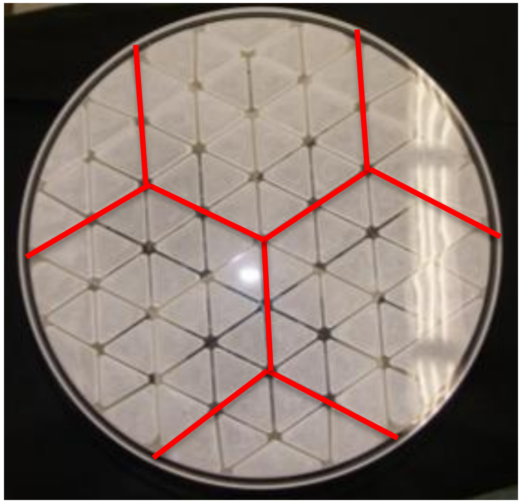
5.4nm RMS – 37nm P-V
Power Removed

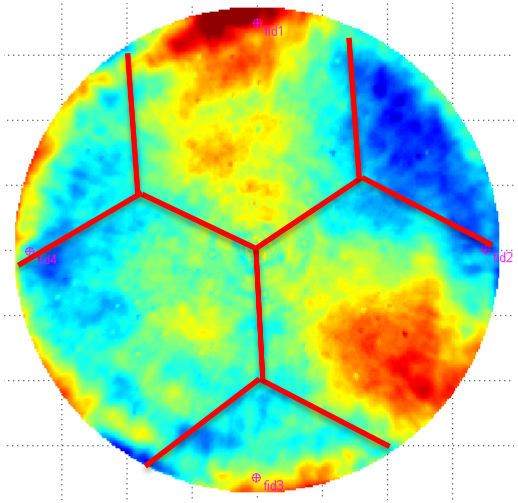


- Final ion figuring run focused on pocket quilting errors
- Mount repeatability limits overall surface quality



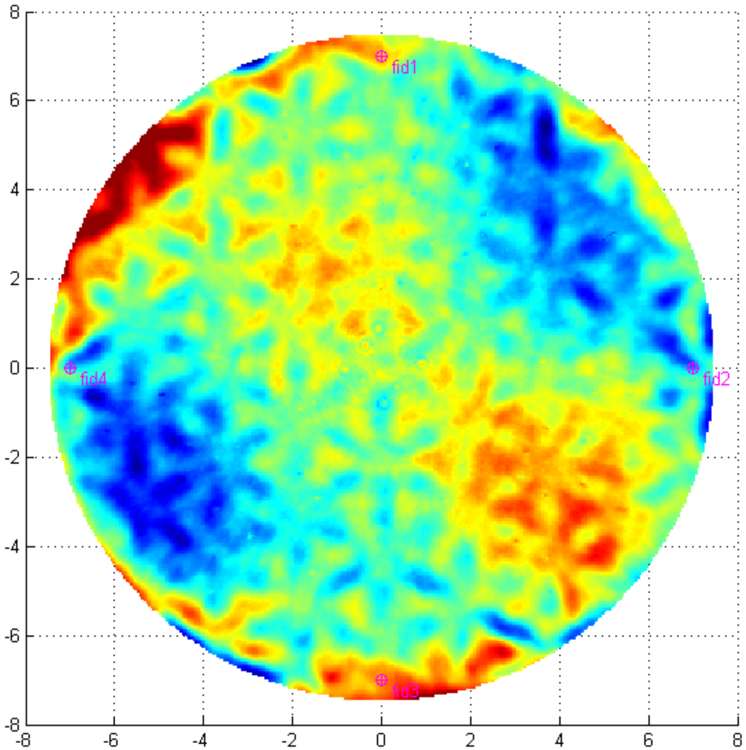
- Rapid convergence to final surface quality
- Deterministic processes reduce schedule time



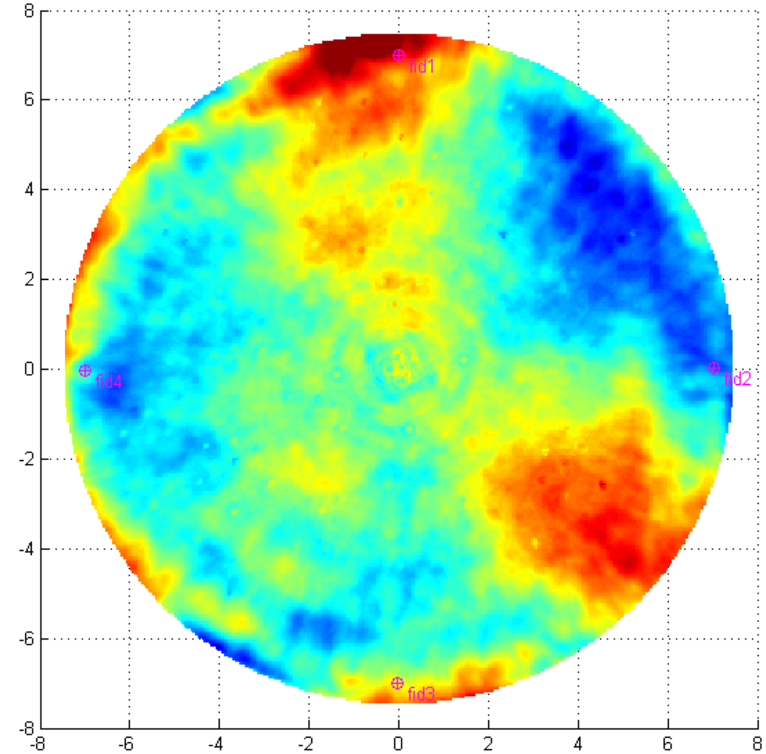


AMTD PSD Testing Summary

- 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

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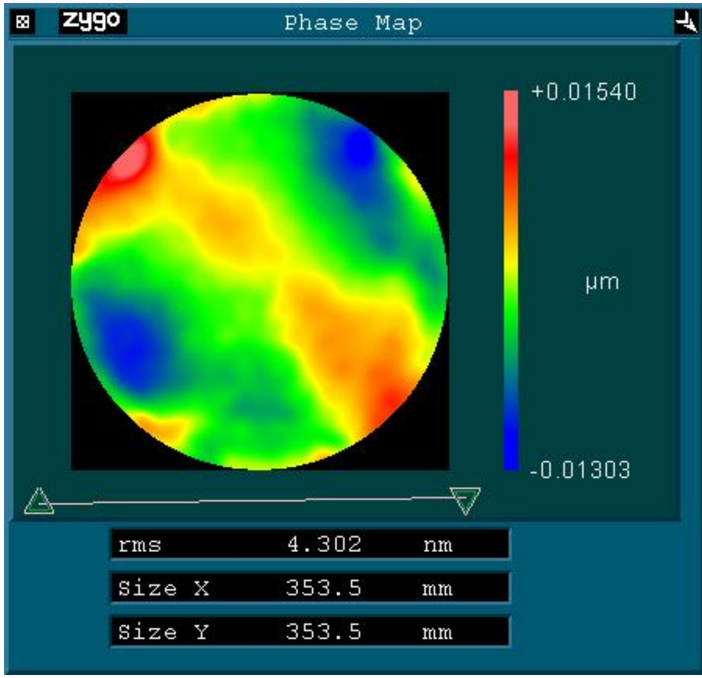
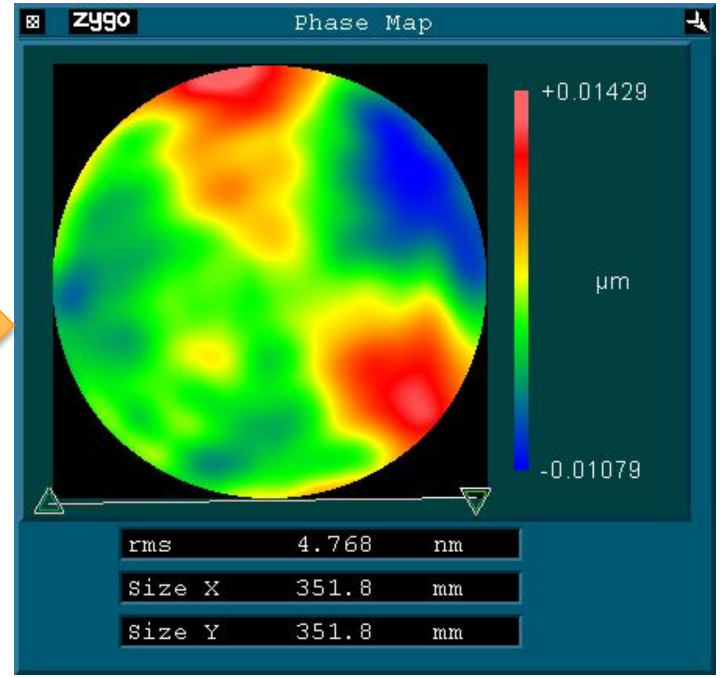
50mm FFT Low Pass Filter (Final Ion Iteration)

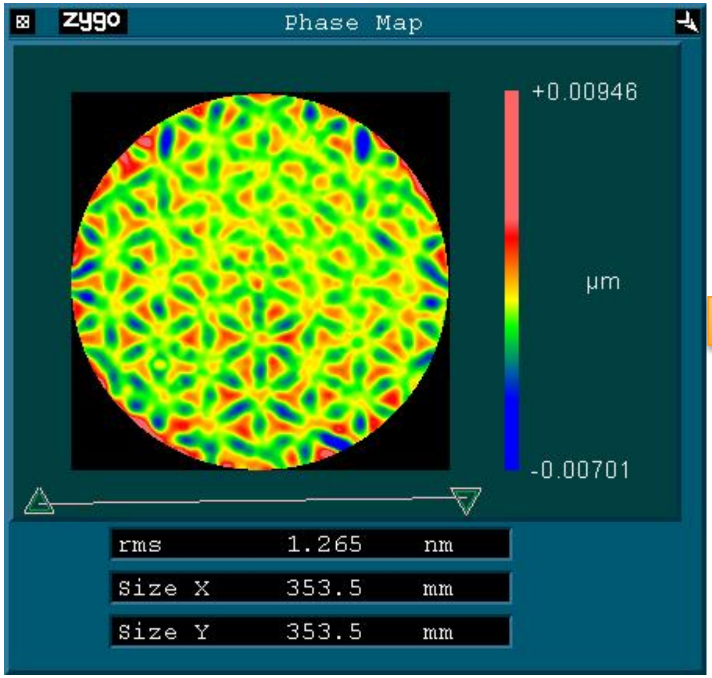




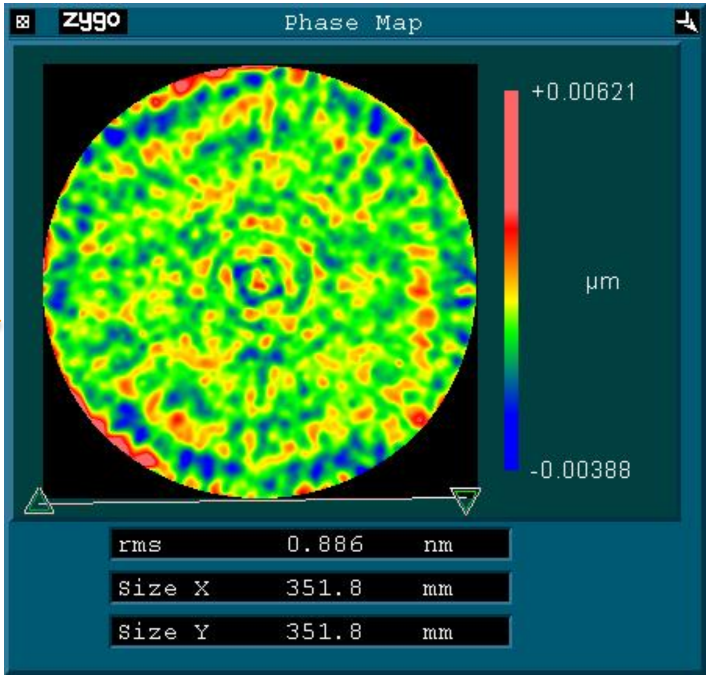
- Low order figure error has reached the current metrology reproducibility limit in the current configuration leading to no improvement in figure errors with spatial periods longer than 50mm
- Low order figure error present in the measurement after ion figuring is driven by mount reproducibility
- Metrology 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

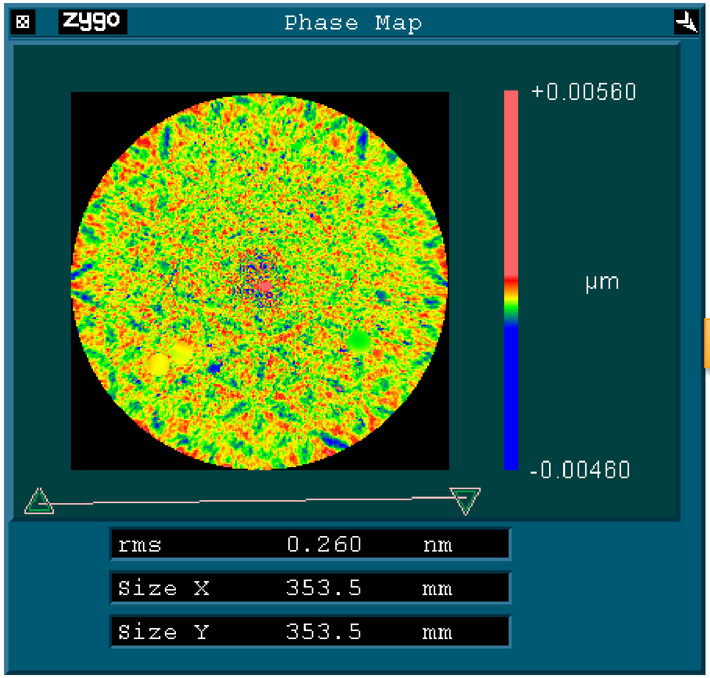


> The quilting period appears at ~20-30mm spatial periods before final ion figuring

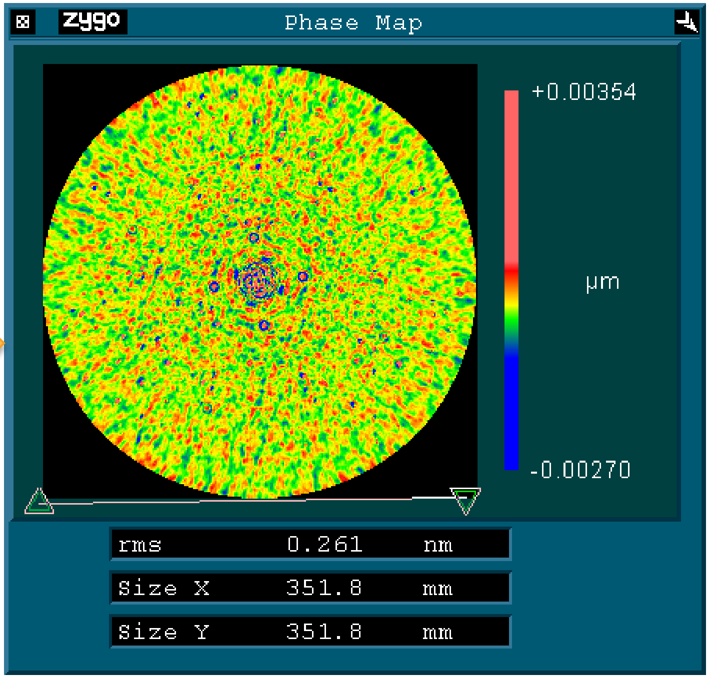
> Ion figuring improved the rms in the 50-10mm spatial period band eliminating most of the quilting structure

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

Summary

To date, the stacked core approach shows great promise to reduce the cost and schedule for building large, 4m-8m, closed back, mirror blanks

- Lower cost using the ability to accomplish parallel work on multiple, lower cost waterjet robots
- Eliminates the high cost of stack sealing boules and traditional deep core cutting

Exelis has demonstrated the ability to fabricate and process a lightweight, stacked core mirror

- Mid/High Spatial Frequency Figure Errors were controlled
- Demonstrated the ability to ion figure processing quilting in a pocket milled facesheet to obtain a very high precision mirror
- Global surface figure limited by mount repeatability

All work performed under NASA contract number NNM12AA02C

- COTR: Michael R. Effinger