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

Gary W. Matthews, Charles S. Kirk, Steve P. Maffett and Calvin E. Abplanalp
Exelis Inc.

H. Philip Stahl, Michael R. Effinger
NASA Marshall Space Flight Center

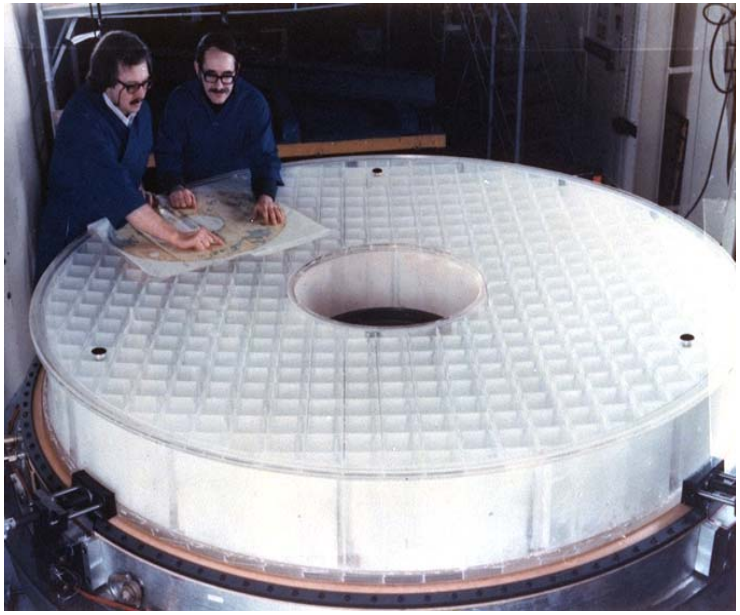
Work completed under NASA contract number NNM12AA02C

# Advanced UVOIR Mirror Technology Development (AMTD) Program

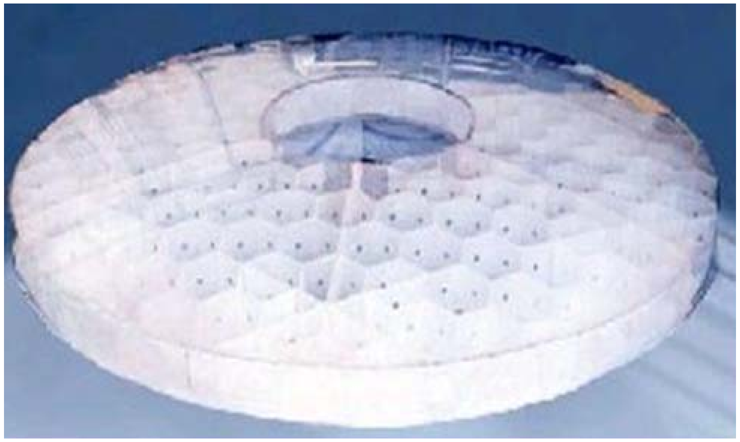
- Develop mirror blank technology applicable to building a cost effective, large (4m-8m class), passive, monolithic mirror capable of imaging in the UV spectrum
  - 0.43m demonstration mirror fabricated
  - 5.5nm RMS overall surface figure demonstrated
- Current limitations regarding a 4m class mirror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

NASA EXELIS

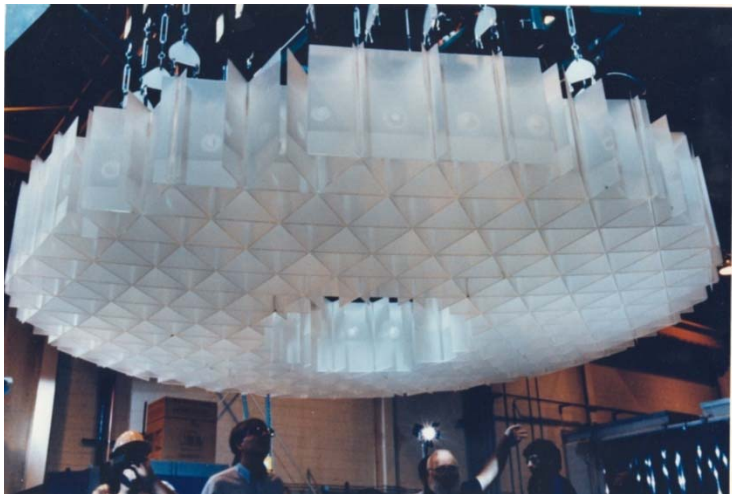
# Large Lightweight ULE® Primary Mirrors at Exelis



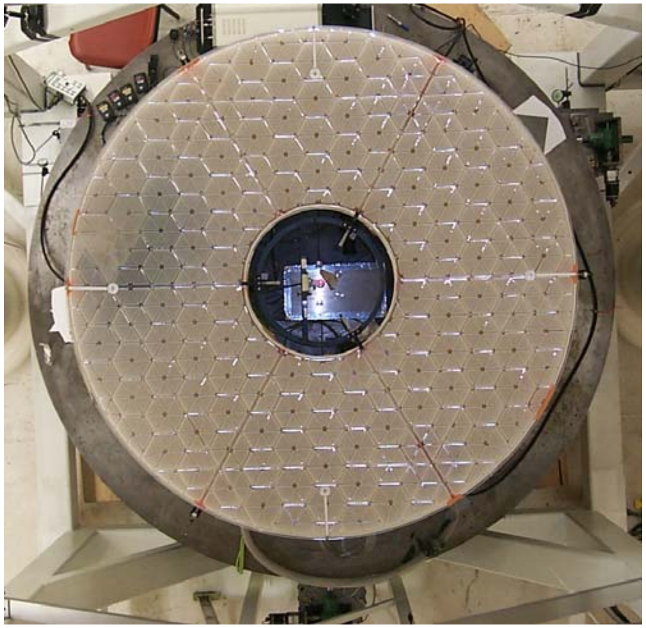
High Temperature Fusion – 1970's
(Hubble Primary Mirror)



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



Frit Technology with Flame Welded Core – 1980's



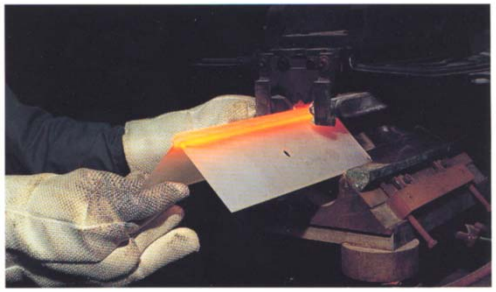
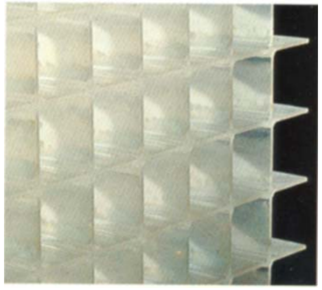
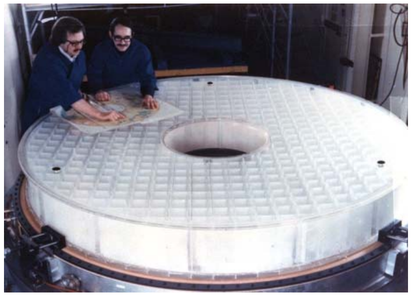
Primary Mirror – Low Temp Fusion – 2000's

EXELIS

# Key Lightweight Technologies Implemented for Large PMs

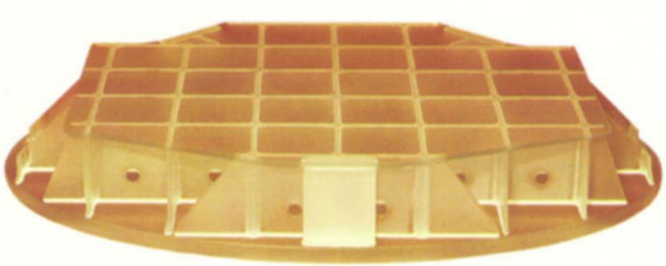
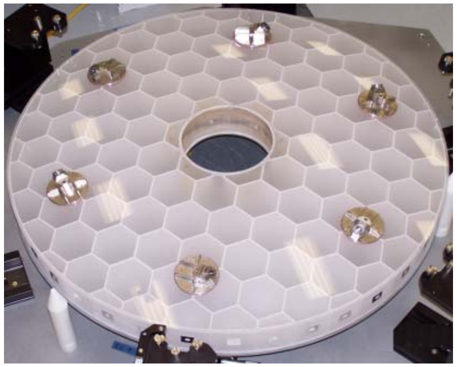
## High Temp Fusion and Slumping

- Posts and struts flame welded into square cell core, faying surfaces ground plano
- Plano faceplates high temp fused to core, assembly slumped over firebrick form
- Light weighting limited by core buckling at high temp

## Frit Bonding

- Frit is a powdered glass that devitrifies into a glass ceramic at a temp below softening point of ULE® and adheres strongly to core and faceplates
- Enables much lighter weight near net shape mirrors (very little distortion during firing)

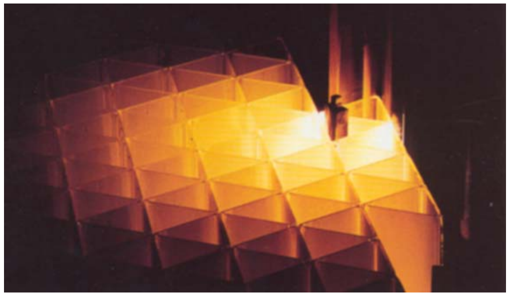
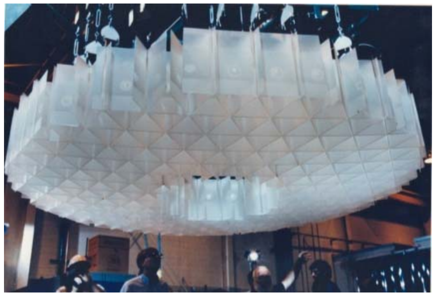



NASA EXELIS

# Key Lightweight Technologies Implemented for Large PMs

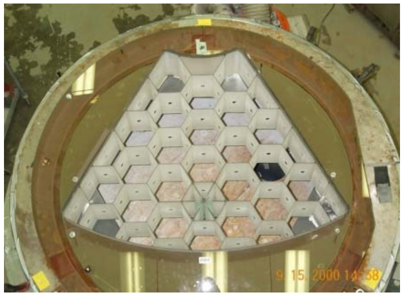
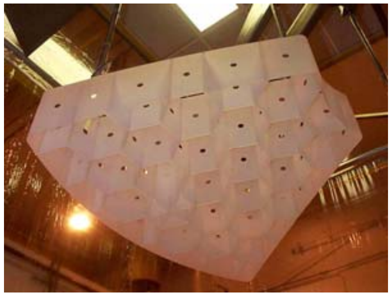
## Lightweight Fused Core

- Thin plates fused into triangles then fused into core, faying surfaces ground spherical
- Frit slurry applied to interfaces, faceplates added, and assy fired
- Light weighting and design options limited by need to machine LW core faying surfaces

## Abrasive Water Jet Core

- Lightweight core cut directly from a preshaped glass solid
- Enables lighter weight cores, opens up design space, improves reliability, reduces risk, cost & schedule
- Cores can then be Frit bonded or Low Temperature Fused to faceplates

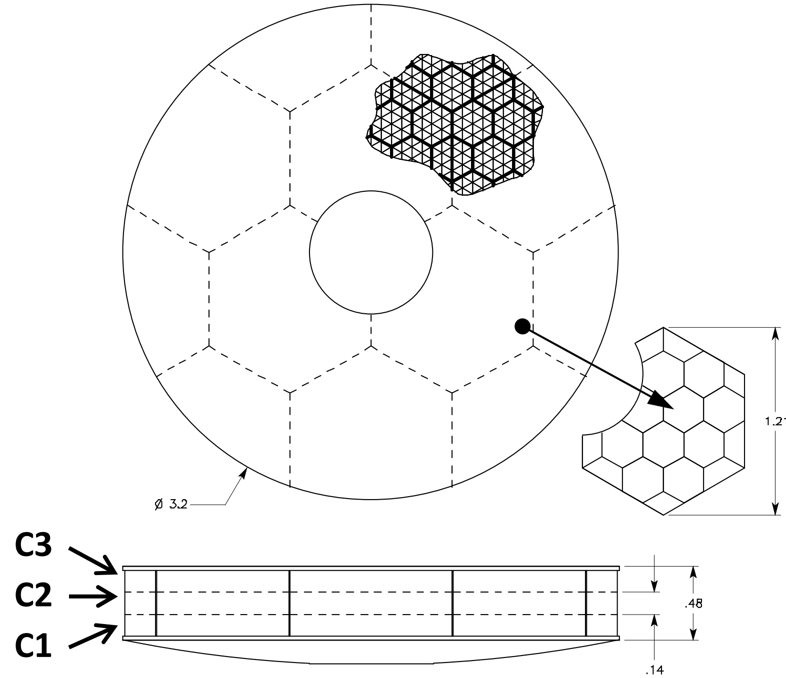




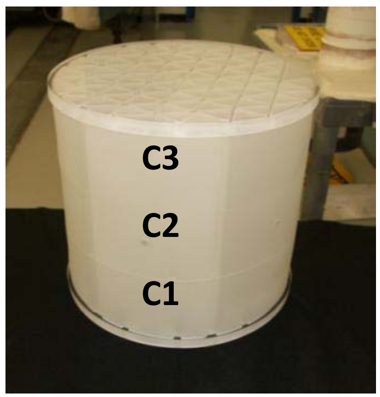

EXELIS

# AMTD is Developing Technologies for Near Term Large Lightweight Primary Mirrors

## Stacked core

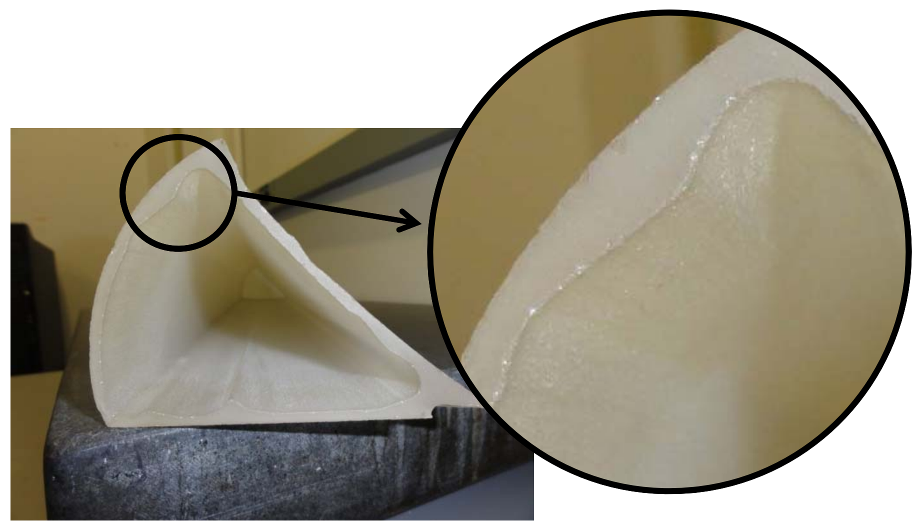
- Core segments are fabricated from standard thickness boules, then stacked & fused during blank assembly to achieve a deep core
- Eliminates need for stack sealing of boules and deep AWJ cutting of cores
- Enables  lighter weight cores and reduces cost & schedule for blank fab




## Deep AWJ Cutting

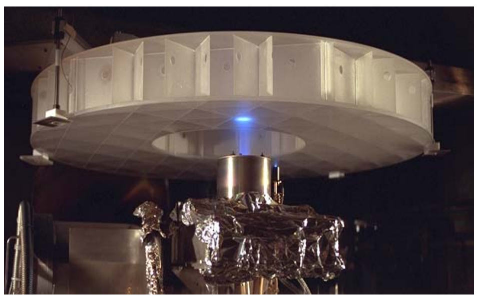
- Extend AWJ cutting depth for LW cores from current 300mm (11.6 in) up to 480mm (19 in) depending on mirror stiffness
- More difficult to control exit surface parameters

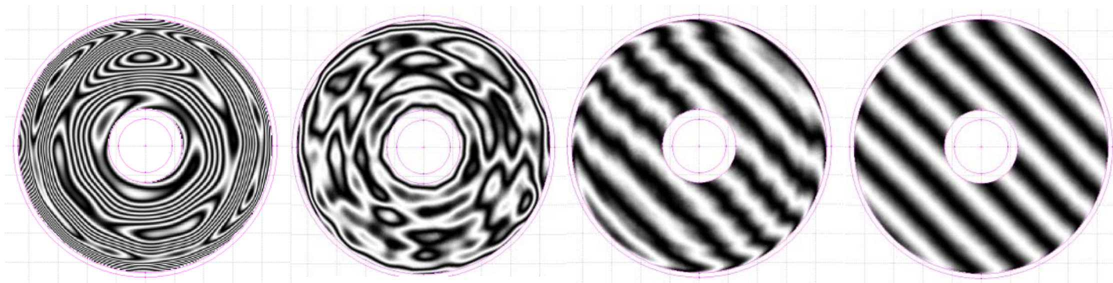


# Key Lightweight Technologies Implemented for Large PMs

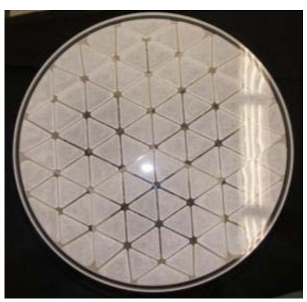
## Ion Figuring

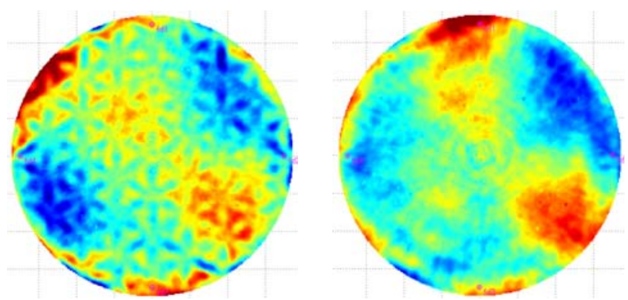
- Ion figuring provides deterministic figure correction by using a directed ion beam to physically sputter material from a mirror surface
- Ion addresses both low and mid-spatial figure errors
- Enables lighter weight mirrors by allowing more flexible faceplates to be precisely finished using noncontact means (e.g. polishing quilting is removed)
- Deterministic method that greatly reduces cost and schedule





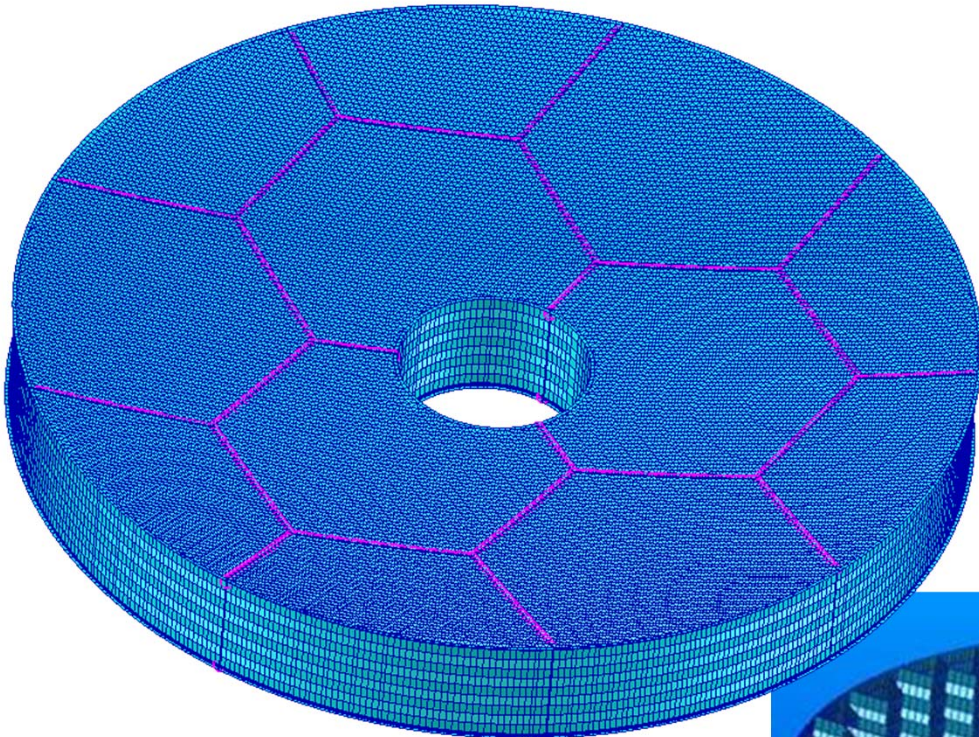
1.1m LW PM, 3 ion & test iterations over 3 wks, 6.3 nm RMS surf





30 mm dia (B) pocket quilting corrected, 5.5nm RMS surf

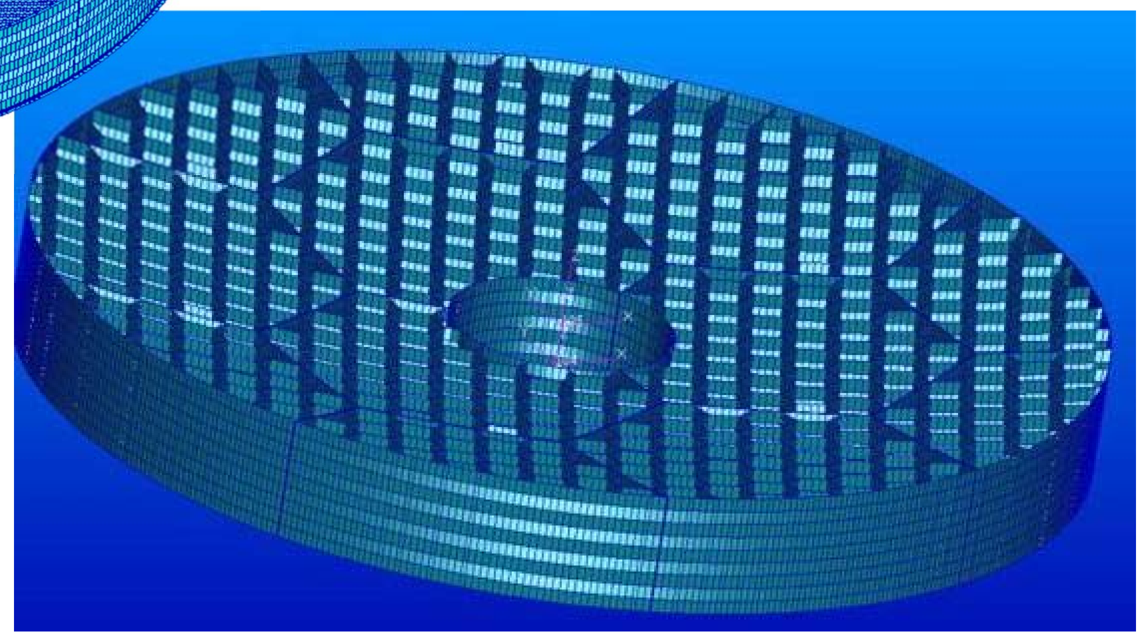
# 4m Mirror Concept



**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**



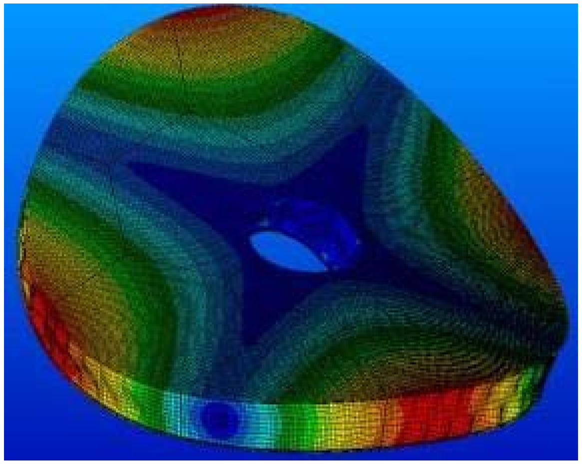
EXELIS

# 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



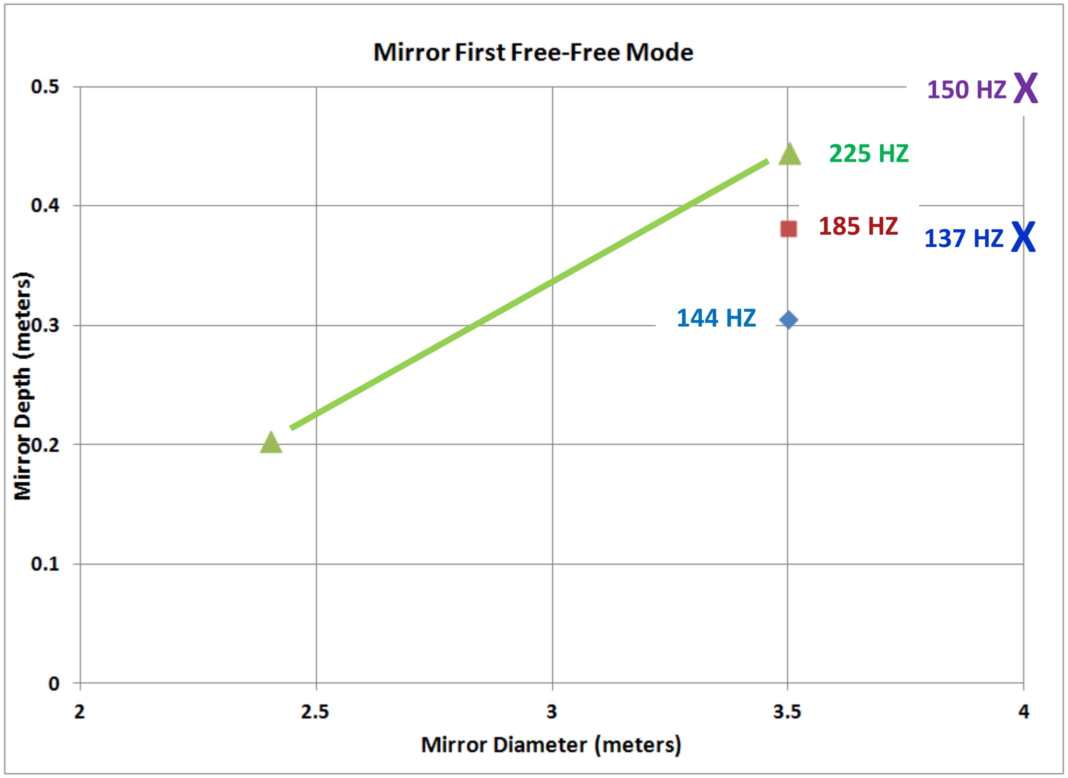
First Mode

## *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*

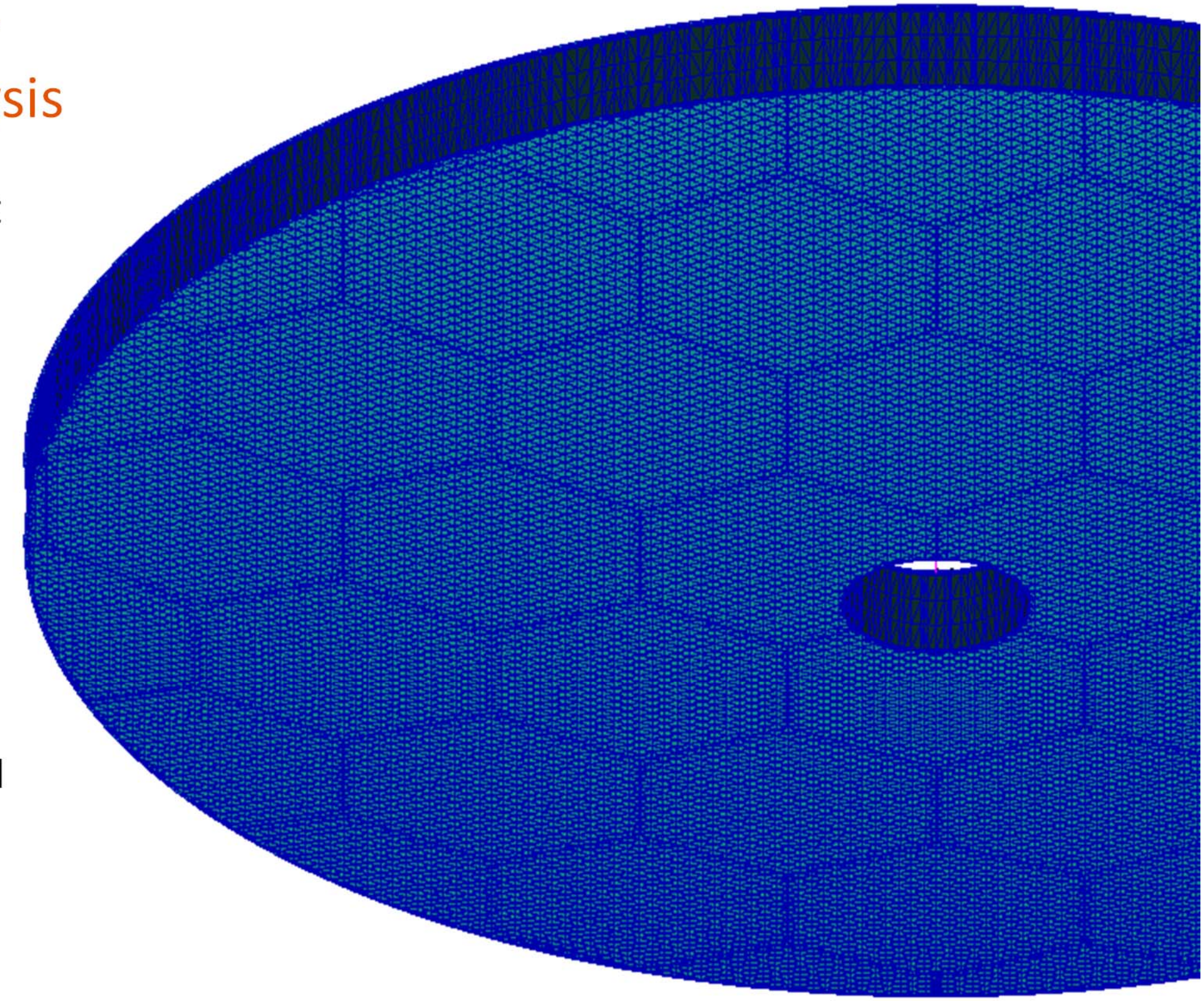
- *At large sizes, the mirror dynamics may not be the biggest problem*
- *A system approach is recommended*
- *Exelis active dynamic control is at TRL8*




EXELIS

# AMTD 8m Mirror Design and Analysis

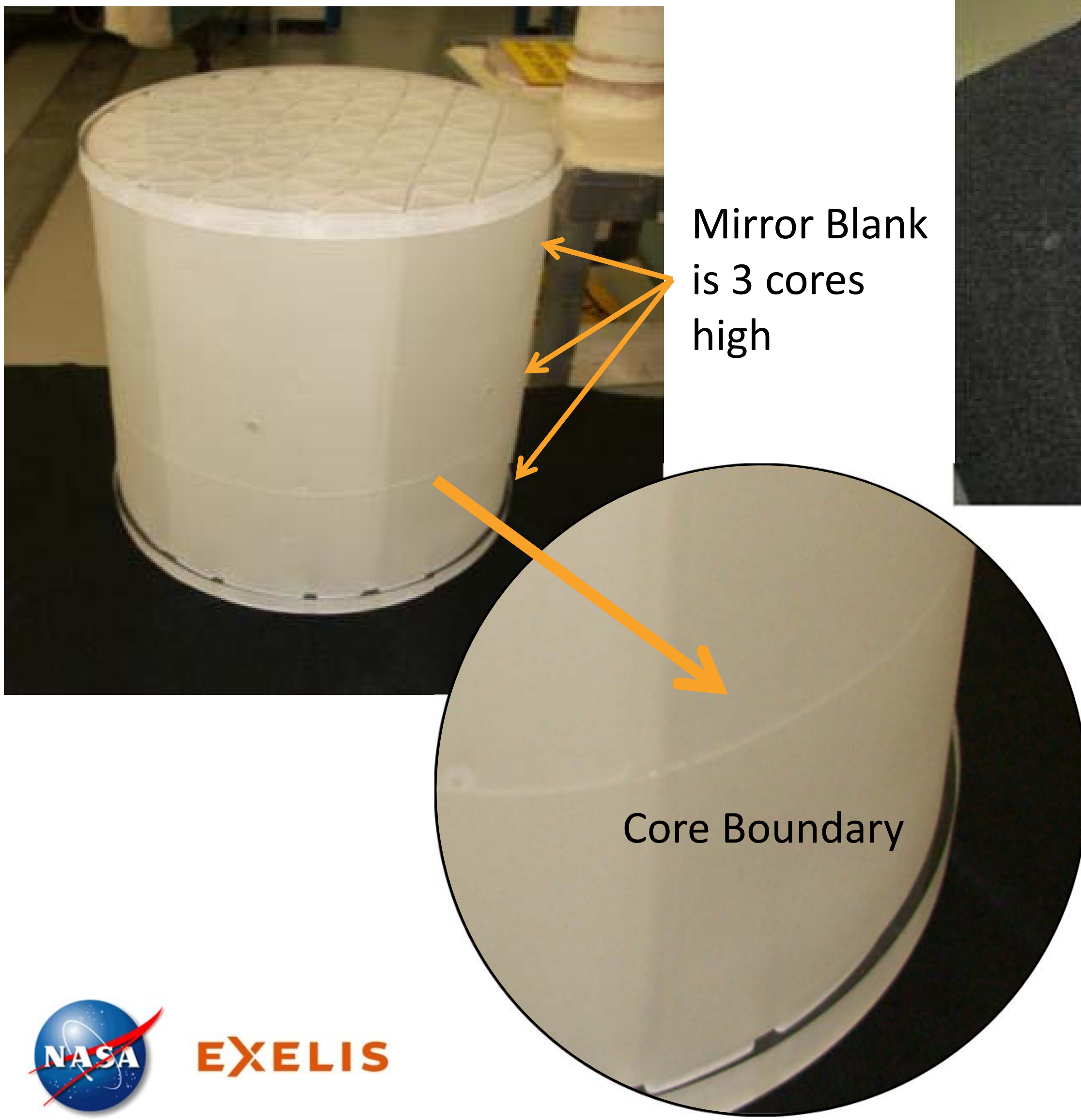
- Stacked core and Pocket milled facesheet design
- 24.2m RoC (f#1.5)
- The 8 meter mirror modeled to assess performance
  - Model includes light-weighted face plates joined to a light-weighted core.
  - 5% additional mass added to light-weighted sections to account for corner radii.
- Total mass was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



NASA EXELIS

# Stacked Core Mirror Demonstration

0.4m Demonstration part fabricated




Single Mirror Core
(Note large cell size)

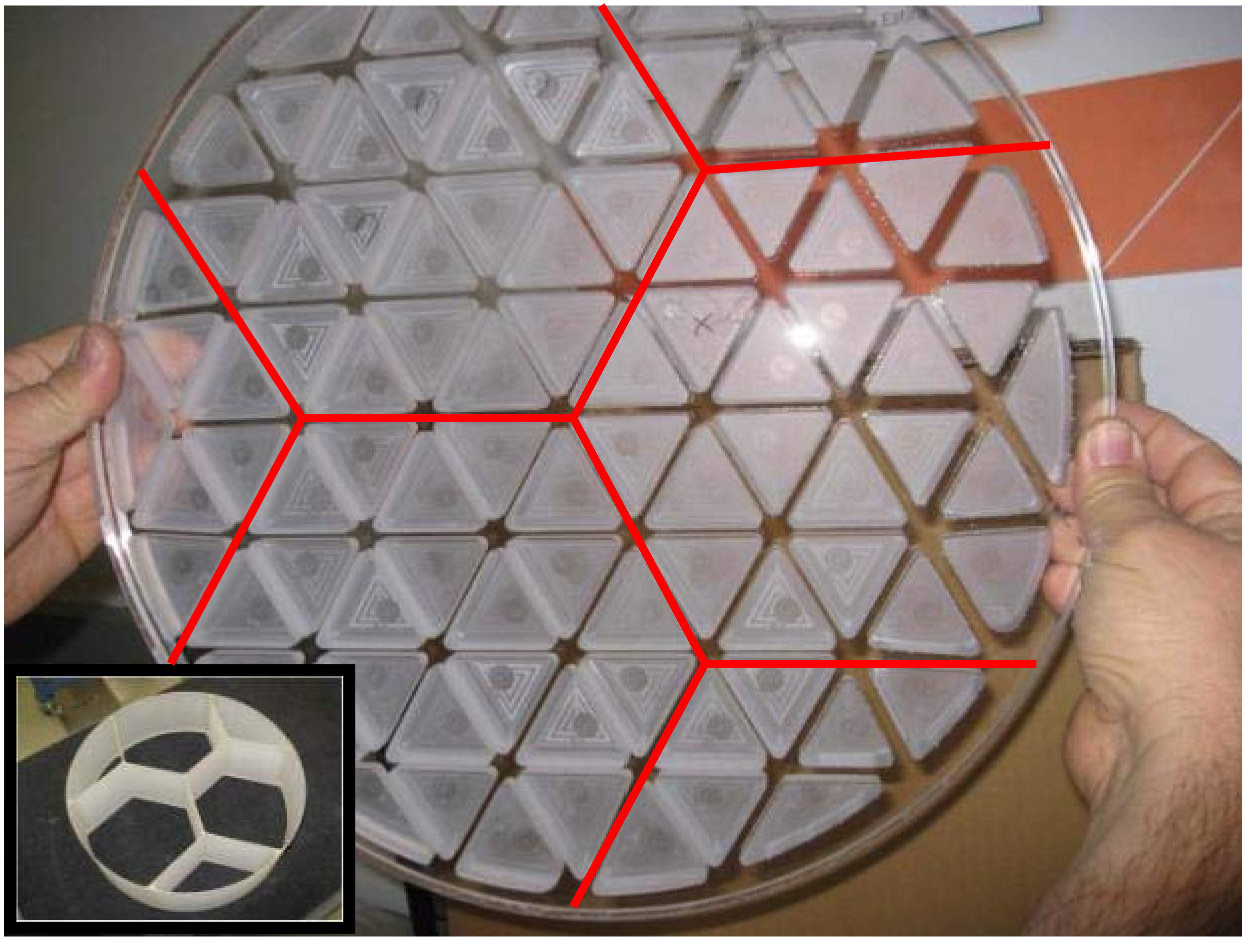
- The individual core segment surfaces are polished and AWJ just like traditional LTF mirrors
- During Low Temperature Fusion (LTF), the faceplates **and** the core segments are fused together (Co-Fired)

NASA EXELIS

# 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

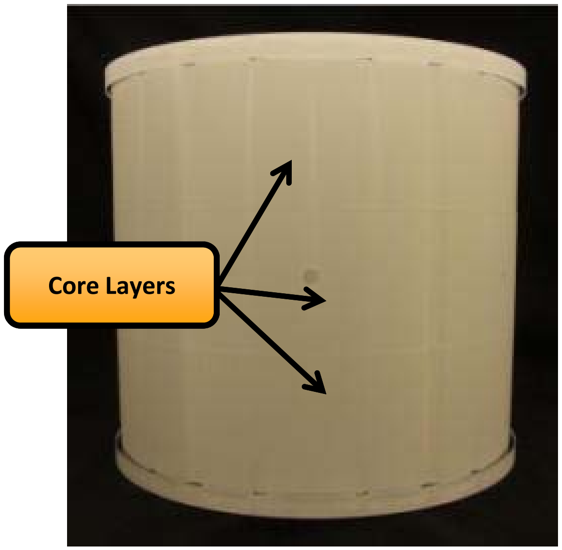
Pocket Milled Facesheet



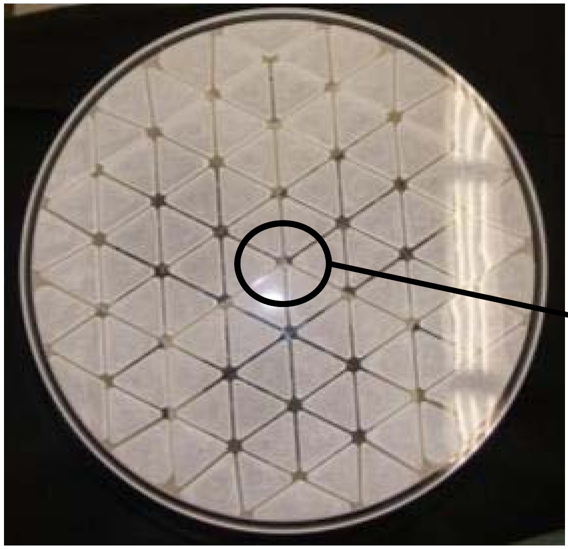
Pocket Milled Facesheet
Core cells locations shown in red
(Core shown for reference)

# Demonstration Blank Low Temperature Fusion

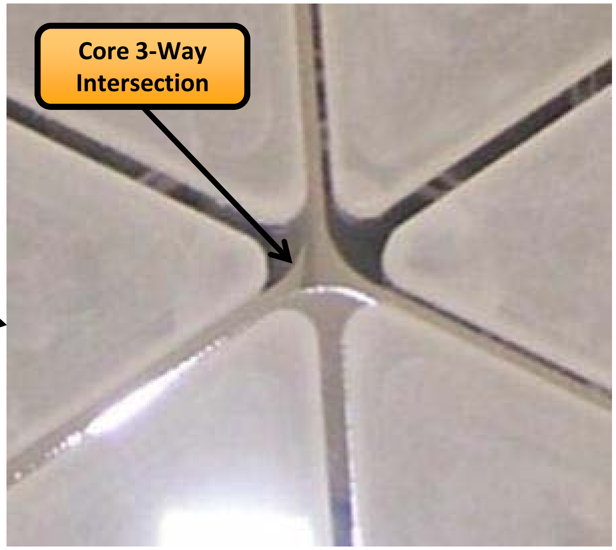
***First-Ever Layered Core Demonstrator Successfully Fused***




**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***

# 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

NASA EXELIS

# Processing Quality

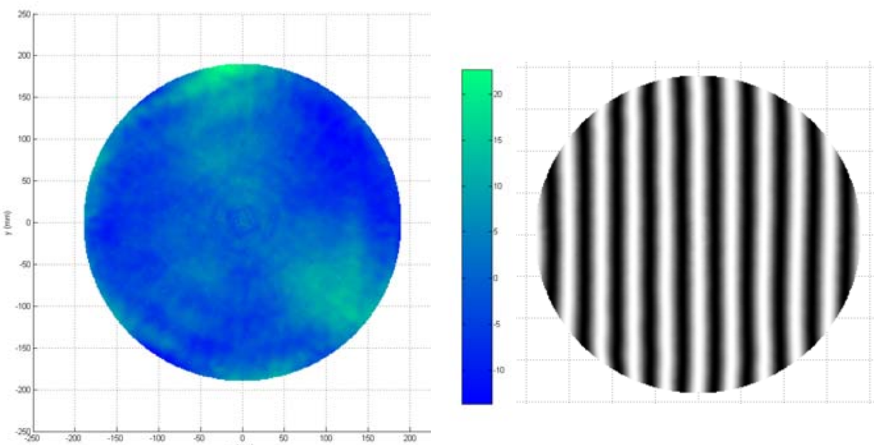
Processing completed to demonstrate that UV quality (5nm RMS) could be achieved

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

# 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

All work performed under NASA contract number NNM12AA02C

- COTR: Michael R. Effinger

Related Papers at this conference

- Thermal testing of a stacked core mirror for UV applications (8837-10)
- Cryogenic optical performance of a lightweighted mirror assembly for future space astronomical telescopes: optical test results and thermal optical model (8837-11)