Status of the Advanced Mirror Technology Development (AMTD) Phase 2, 1.5m ULE® mirror [9575-21]

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Agenda

Motivation for developing new Corning ULE® mirror blank fabrication technology under the AMTD program

History of ULE® PM Blank Technology

- Description of existing technologies being leveraged for AMTD mirror blank construction

Overview of AMTD Mirror Blank fabrication technology

Summary of Phase 1 Accomplishments

Discussion and Status of Phase 2 Activities

Summary

Motivation

One architecture solution for the next generation Ultraviolet Optical Infrared (UVOIR) space borne astronomical observatory requires a passive monolithic primary mirror (PM) in the 4-8m size range

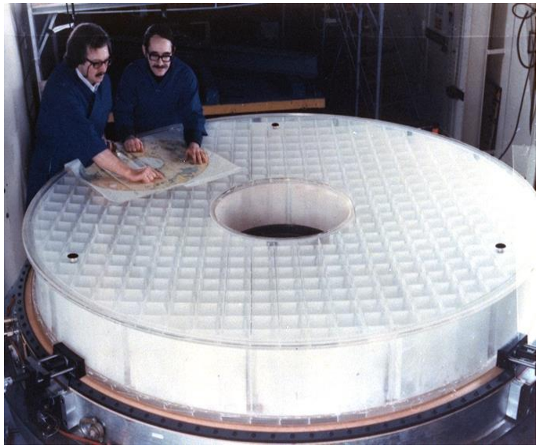
Current limitations regarding the fabrication of 4m+ class mirror

- 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

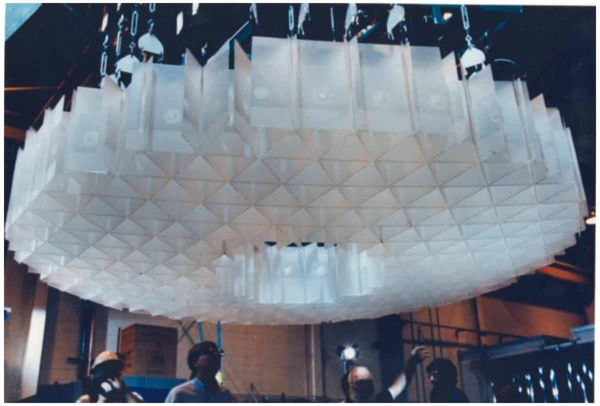
The AMTD program addresses these issues to reduce the cost and lead time for building a 4m class mirror blank

- Demonstrates the ability to polish and test the blank to UV quality
- Demonstrates the ability to scale new mirror fabrication processes to larger mirror sizes

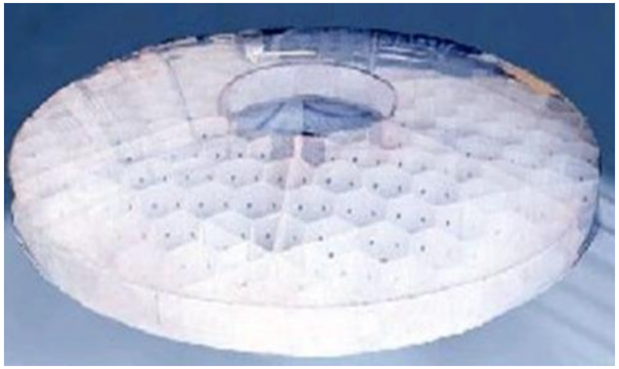
Large Lightweight ULE® Primary Mirrors at Harris



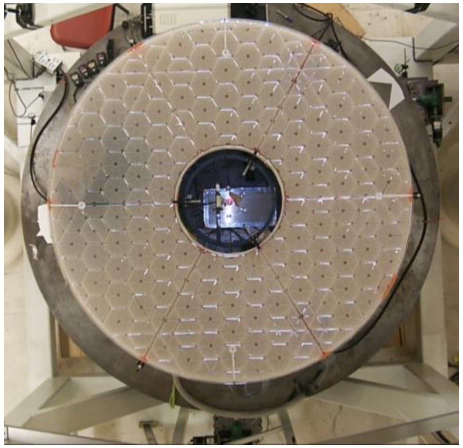
High Temperature Fusion – 1970's (Hubble Primary Mirror)



Frit Technology with Flame Welded Core – 1980's



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

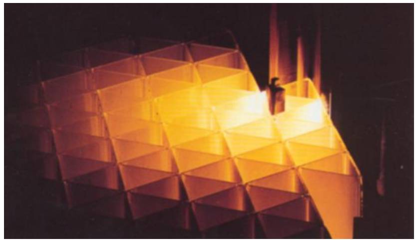
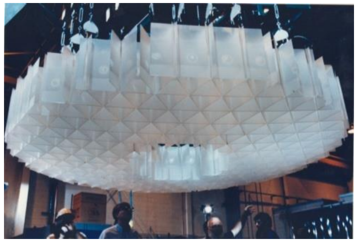


Primary Mirror – Low Temperature Fusion – 2000's

Key Lightweight Technologies Implemented for Large PMs

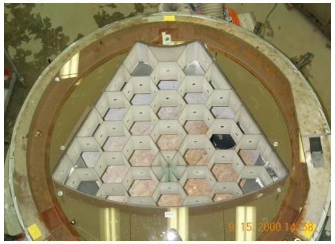
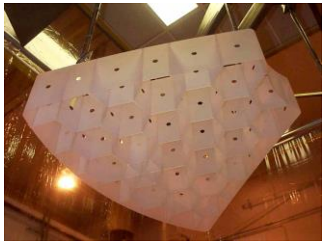
Lightweight Fused Core

- 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

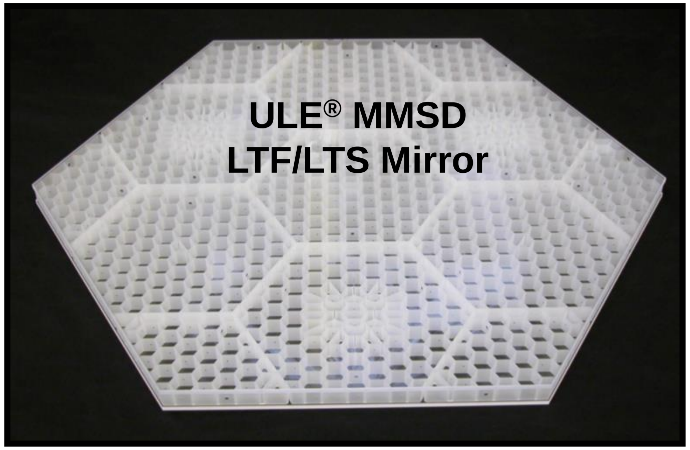
Abrasive Water Jet Core

- Lightweight core cut directly from a pre-shaped 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


Leveraged Mirror Blank Manufacturing Technologies

- **Low Temperature Fusion (LTF)**
- **Low Temperature Slumping (LTS)**
  - The LTS processes reduces blank manufacturing costs by enabling plates and cores to be shined as plano parts in preparation for LTF process
- **Abrasive Waterjet (AWJ)**
- **Segmented mirror cores**
- **These technologies have been demonstrated and qualified to a Technology Readiness level of 6**
  - Initial demonstration on the AMSD Program
  - TRL advancement on MMSD program
- **AMSD/MMSD style mirrors are active and geared towards segmented PMs**
- **The AMTD technology is directed at large passive monolithic PMs**



Overview of AMTD Mirror Blank Construction Technology

AMTD builds upon AMSD/MMSD LTF/LTS mirror technology with the introduction of the concept of a stacked core

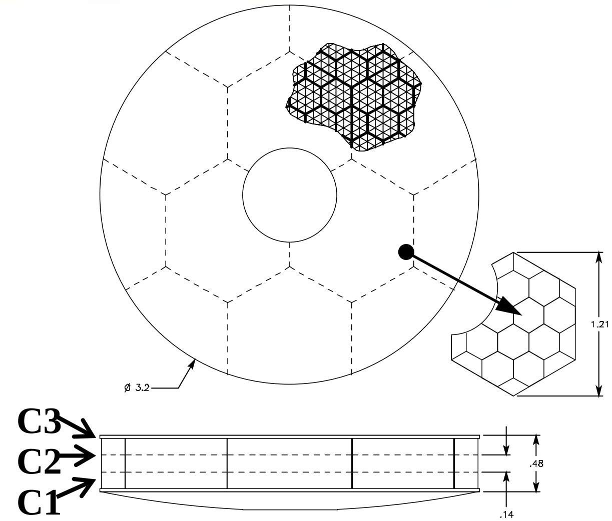
- The stacked core approach enables the use of standard ULE® boules without the need for the expensive and time consuming process of stack sealing of boules to achieve overall core depth

AMTD is Developing Technologies for Near Term Large Lightweight Primary Mirrors

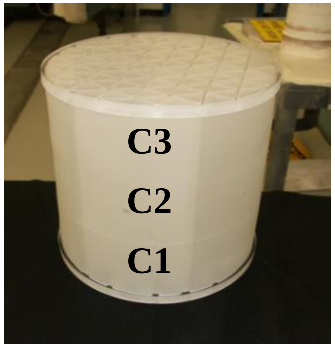
HARRIS

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 fabrication

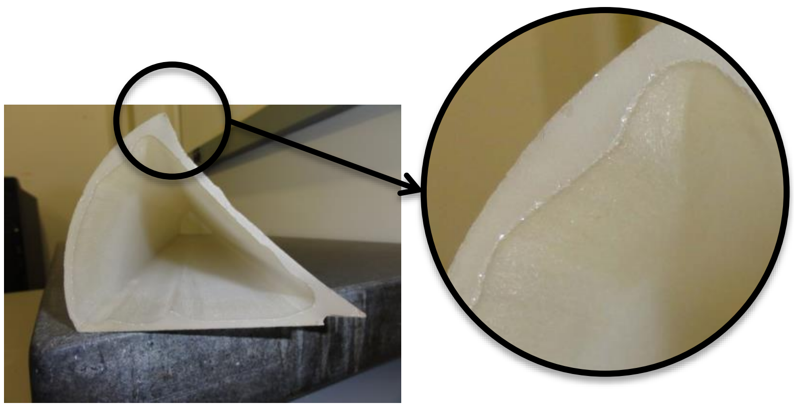


4m PM Conceptual Layout



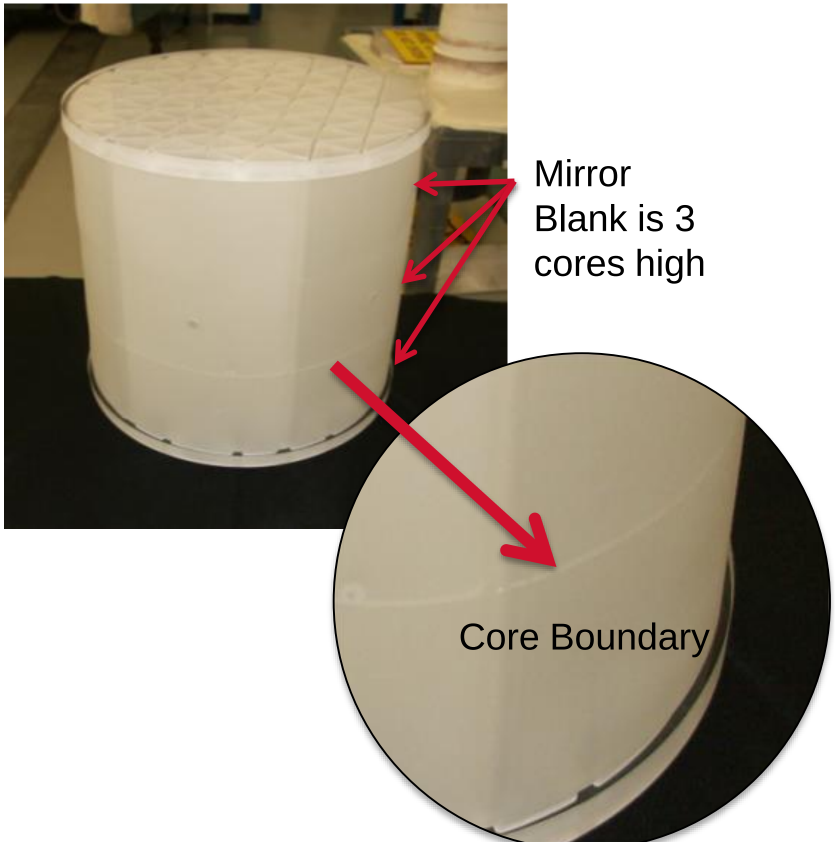
Deep AWJ Cutting

- 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



Phase 1 Stacked Core Mirror Demo

0.4m Demonstration part fabricated



Single Mirror Core
(Note large cell size)

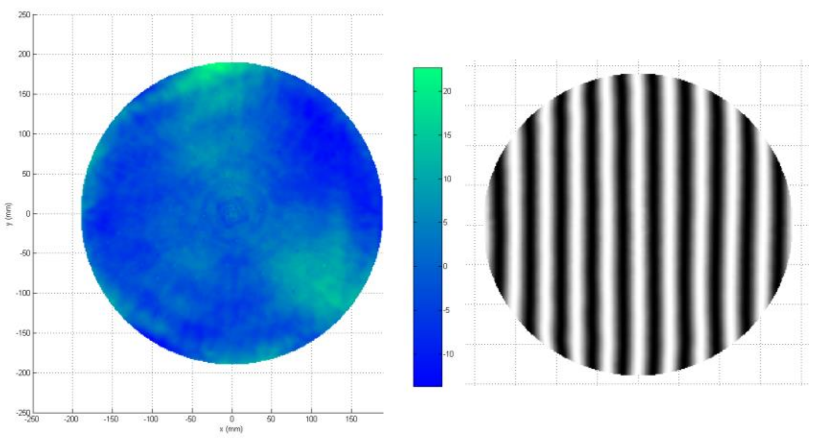
- The individual core segment surfaces are polished and AWJ just like traditional LTF mirrors
- During Low Temperature Fusion (LTF), the faceplates **<u>and</u>** the 3 core layers are fused together (Co-Fired)
- After LTF, blank underwent LTS to a radius of ~2.5m and was then polished

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

AMTD Phase 2: 1.5m LTF/LTS Segmented Stacked Core ULE® Mirror

The AMTD Phase 2 work being performed at Harris serves to build upon the successful Phase 1 demonstration to demonstrate the ability to scale the technology to larger mirror sizes

The 0.4m Phase 1 Demo mirror design was essentially a cored section of a 4m PM design

In Phase 2, Harris has developed and begun the fabrication of a 1.5m design

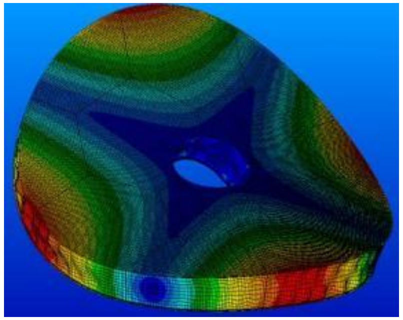
- Design has a segmented stacked core and a global mirror stiffness that approximates that of a 4m point design
- Mirror serves to demonstrate segmented stacked cores and the lateral scalability of the Phase 1 technology to large mirrors, with respect to dynamic performance and the ability to LTS the plano blank
  - AMSD/MMSD style mirror blanks are in a state of pure bending during LTS
  - The AMTD phase 1 mirror blank was in a state of pure shear during LTS
  - A 4m+ mirror will have a combined state of stress during LTS and the 1.5m deign developed reflects this

Dynamic Considerations

4m Dynamic Performance

- 3 layer core
  - 35 kg/m^2
  - 137 Hz First Free-Free Mode
- 4 layer core
  - 43 kg/m^2
  - 150 Hz First Free-Free Mode

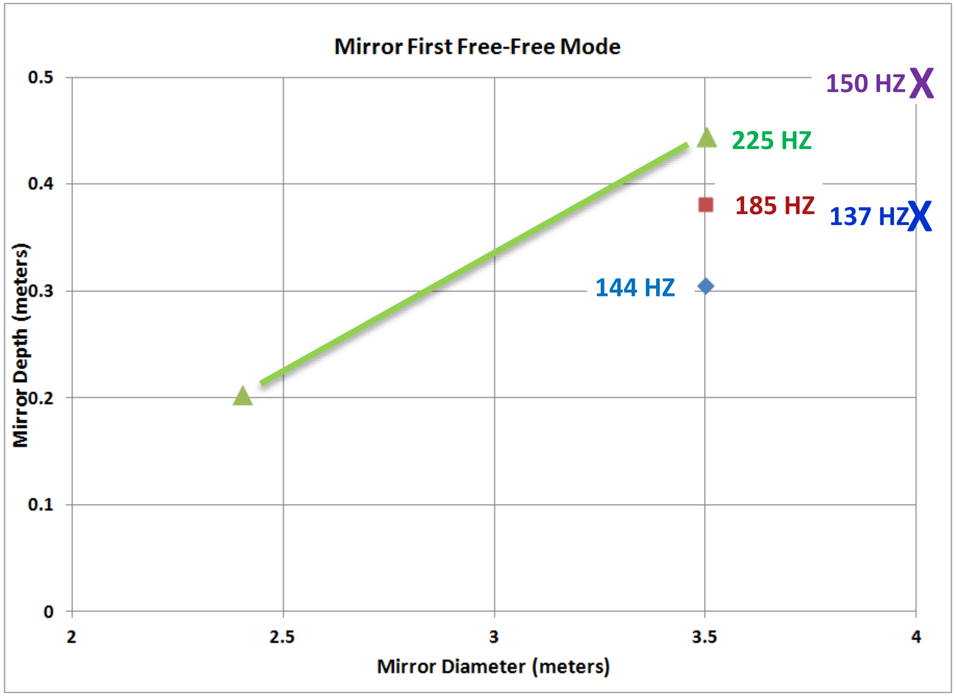
- Limited leverage at this scale to increase first mode frequency
- Active Dynamic Control measures likely needed at system level



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

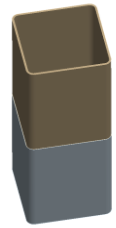
- At large sizes, the mirror dynamics may not be the biggest problem
- A system approach is recommended
- Harris active dynamic control is at TRL8

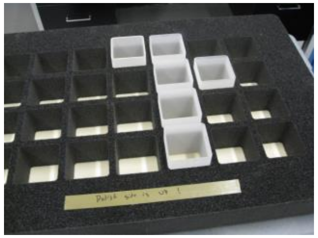
Phase 2 Accomplishments

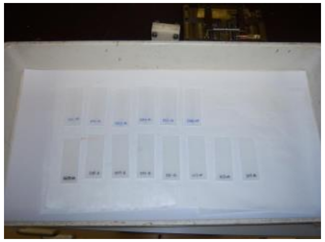
Developed A-basis allowable for strength of core-core LTF bonds by testing 70 MOR samples

- Strength found to be ~17.5MPa which is ~50% higher than typical core-plate LTF Bonds

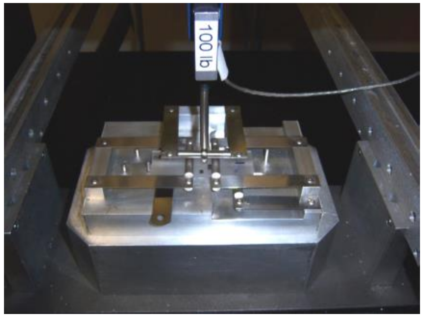
This data was used for designing the 1.5m mirror core to ensure adequate strength in a launch environment







AWJ LTF Boxes from which MOR samples (right image) are fabricated



MOR Sample in Test Fixture

Phase 2 Accomplishments (con't)

Investigated several other 4m PM point designs and performed trades on the benefits of having pocket-milled face sheets versus uniform thickness facesheets

- Based on current understandings of UVOIR requirements, it was determined that pocket-milling is not required to meet performance requirements

Slumping behavior of a 4m point design that had uniform thickness facesheets was assessed by performing non-linear visco-elastic modelling in the Abaqus finite element package (from Dassault Systèmes)

- Results from this analysis were used to develop the 1.5m design that could be used to demonstrate the lateral scalability of the LTS process

Phase 2 Accomplishments (con't)

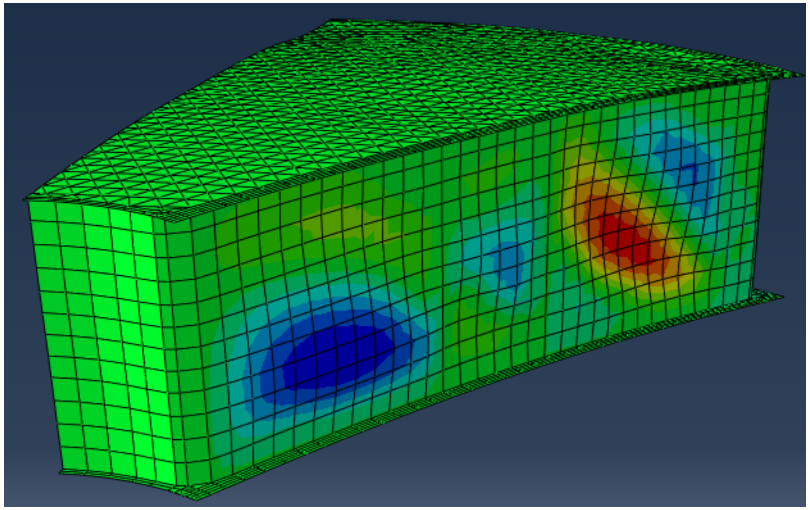
A 1.5m blank design has been developed that meets strength requirements and stiffness requirements to demonstrate lateral scalability

Non-linear Visco-elastic FEM analyses were performed in finalizing the design

- To ensure that adjacent core segment stacks would not come into contact during the LTS process
- Contact between core segments would cause an unacceptable stress concentration
- Analyses predict changes in facesheet and core thicknesses
  - As slumped geometry predictions incorporated into linear FEMs to assess strength performance under a launch load environment and to finalize nominal core strut thickness geometry

LTS Blank Geometry from Abaqus Viscoelastic FEM (30° Symmetric Model)

The contours indicate the areas at the core segment boundary that are bowing (red in, blue out towards the adjacent segment)



Phase 2 Fabrication Status

Harris acquired 3 pieces of ULE® glass for the mirror plates from Corning

- Two of the plates have gone through processing to prepare them for the LTF process.
- The third piece of glass will be used as a loading body during the LTF

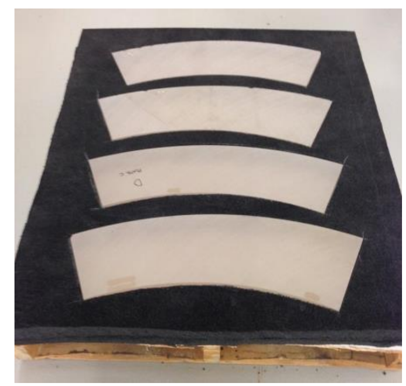
Plate preparation started with an AWJ step to reduce the plates in diameter to be slightly oversized from what is required for the finished Plano Blank.

- Four large pieces of residual glass were generated during this AWJ process for each plate.
- Half of the residuals were send to Ormond for use in AWJ technology development

Three core boules have been sliced in half and are being processed in preparation for AWJ

- 4 ½ of the slices are required to yield the 18 individual core segments that will make up the 1.5m mirror core

An AMTD mirror plates (face sheets) being rounded in AWJ



Residual glass sent to Ormond (right)

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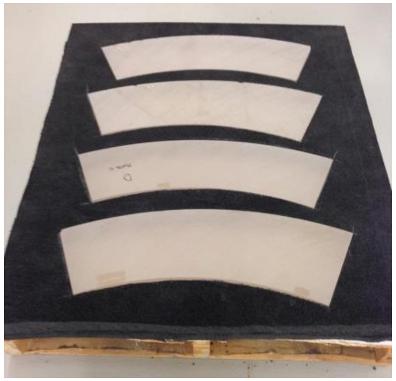

Residual glass sent to Ormond (right)

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

- The mirror blanks can be lower cost by leveraging the ability to accomplish parallel work on multiple, lower cost waterjet robots and saving the time and energy required to create very thick core solids that are subsequently cut to create the lightweight core

Harris has demonstrated the ability to fabricate and process a lightweight, stacked core mirror and control the spatial frequency figure errors needed to produce a lightweight, UV quality mirror

Summary

During Phase II NASA and Harris continues this development by building and process a 1.5m stacked core mirror

- Future work Phase II and Phase III includes
  - Optical testing at ambient and 250K to demonstrate performance and correlate FEMs
  - Environmental testing will be completed to understand the performance in a launch and flight environment

All work performed under NASA contract number NNM12AA02C

- COTR: Michael R. Effinger

Summary

Related Papers at this conference

- Thermal optical metrology development for large lightweight UV to IR mirrors and future space observatory missions (9575-6)
- Beyond JWST: a technology path to the next great UVOIR space telescope (9602-2)
- SLS launched missions concept studies for LUVOIR Mission (9602-5)
- Overview and accomplishments of advanced mirror technology development phase 2 (AMTD-2) project (9602-7)
- Technology development for the Advanced Technology Large Aperture Space Telescope (ATLAST) as a candidate large UV-Optical-Infrared (LUVOIR) surveyor (9602-8)
- Advanced Mirror Technology Development (AMTD) thermal trade studies (9577-2)
- AMTD: Advanced mirror technology development in mechanical stability (9577-3)