NASA IXO Mirror Technology Development

Rob Petre
NASA IXO Deputy Project Scientist
X-ray Astrophysics Laboratory
NASA Goddard Space Flight Center

Mirror Technology Development Team

J. Bolognese, G. Byron[3], K.W. Chan[1], D.A. Content, T.J. Hadjimichael[2], Charles He[2], M. Hill, M. Hong[3], L. Kolos, J.P. Lehan[1], L. Lozipone[3], J.M. Mazzarella[3],R. McClelland[3], D.T. Nguyen, L. Olsen[3], S.M. Rohrbach, R. Petre, D. Robinson, R. Russell[3], T.T. Saha, M. Sharpe[3], T. Wallace, **W.W. Zhang**

NASA Goddard Space Flight Center

[1] ***University of Maryland, Baltimore County***

[2] ***Ball Aerospace and Technologies Corp.***

[3] ***Stinger Ghaffarian Technologies, Inc.***

M.V. Gubarev, W.D. Jones, S.L. O'Dell

NASA Marshall Space Flight Center

D. Caldwell, W. Davis, M. Freeman, W. Podgorski, P.B. Reid, S. Romaine

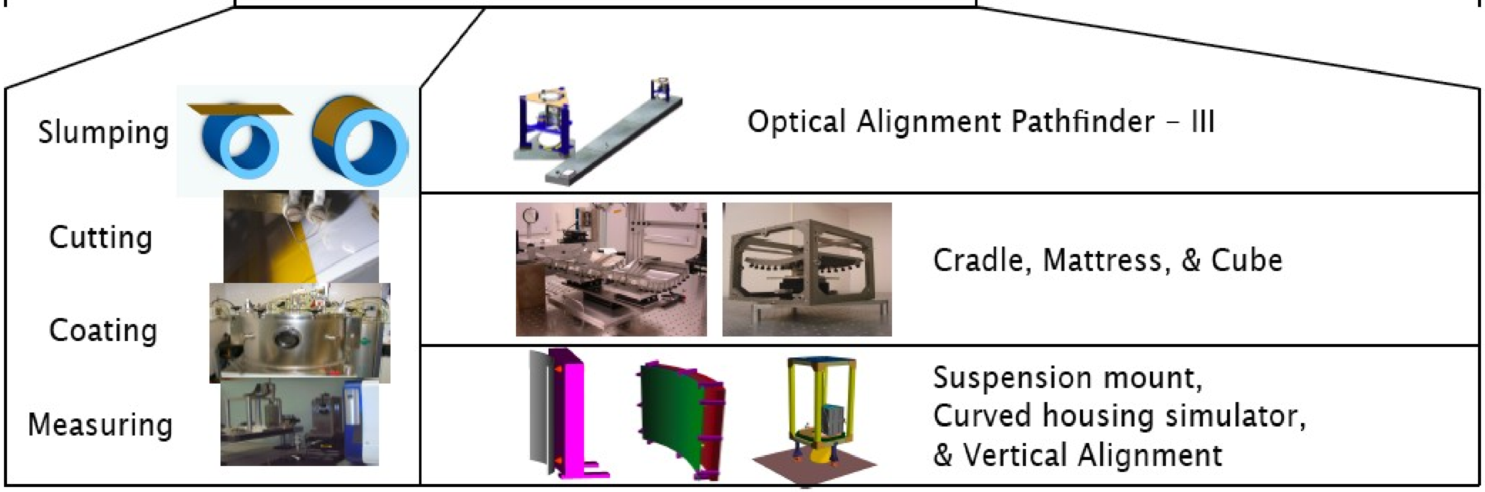
Smithsonian Astrophysical Observatory

Summary

- Mirror segment fabrication
  - Fully meet requirements of 15” telescope
  - Major errors identified: (1) Ir coating stress, (2) mandrel quality, and (3) mid-frequency error caused by the slumping process
  - Well on the way to meeting requirements for 5” telescope
- Alignment and Integration
  - Excellent progress being made toward meeting 15” requirements
  - Major issues being identified and worked on to meet 5” requirements
- Flight mirror assembly concept
  - Highly modular design
  - All high precision alignments within module

Overview of Mirror Tech Development

	Mandrel	Mirror	Transfer Mount	Module	Assembly	Observatory
HPD	6"	10"	10"	12"	13"	15"
	2.0"	3.5"	3.6"	4.0"	4.5"	5.0"
	Schedule/Cost	← Core of Technology Development →			← Design, Analysis, & Test →	



Prescription and Definitions

$$\rho(z,\phi) = \rho_0 + \Delta\rho(\phi) + z \cdot \tan[\theta_0 + \Delta\theta(\phi)] - \left(\frac{2z}{L}\right)^2 [s_0 + \Delta s(\phi)] + R(z,\phi)$$

$$0 \le \phi \le \phi_{max}, \quad -\frac{L}{2} \le z \le \frac{L}{2}$$

Average radius: ρ_0

Radius variation: $\Delta\rho(\phi)$

Average cone angle: θ_0

Cone angle variation: $\Delta\theta(\phi)$

Average sag: s_0

Sag variation: $\Delta s(\phi)$

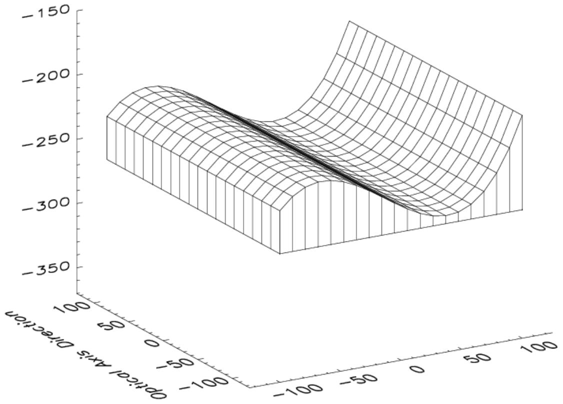
Remainder: $R(z,\phi)$

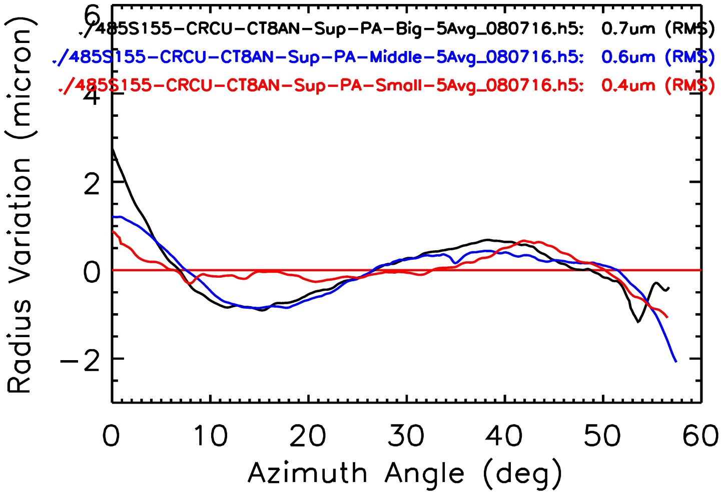
Mirror Segment Parameters

Mirror Parameter		Measurement Method*
Radius	Average Radius: ρ_0	Hartmann test
	Radius Variation: $\Delta\rho(f)$	Interferometer and Transmission sphere
Cone Angle	Average Cone Angle: θ_0	Hartmann test
	Cone Angle Variation: $\Delta\theta(f)$	Derived from radius variation measurement
Sag	Average Sag: s_0	Interferometer and cylindrical null lens
	Sag Variation: $\Delta s(f)$	
Remainder	Low Spatial Frequency (200mm-20mm)	
	Middle Spatial Frequency (20mm-2mm)	
	High Spatial Frequency (2mm-0.002mm)	Interferometer: Zygo NewView 5000

***An essential part of technology development is demonstrating a metrology approach for each term**

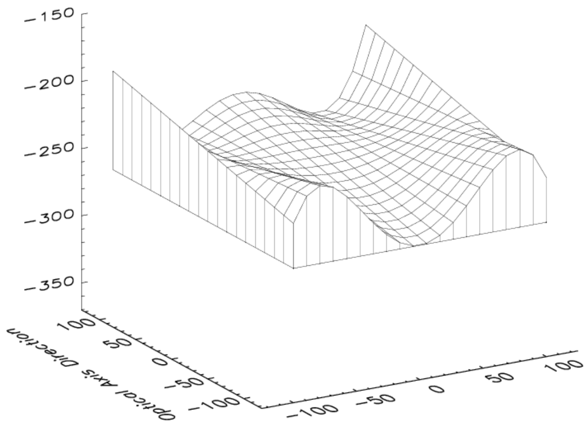
Radius Variation

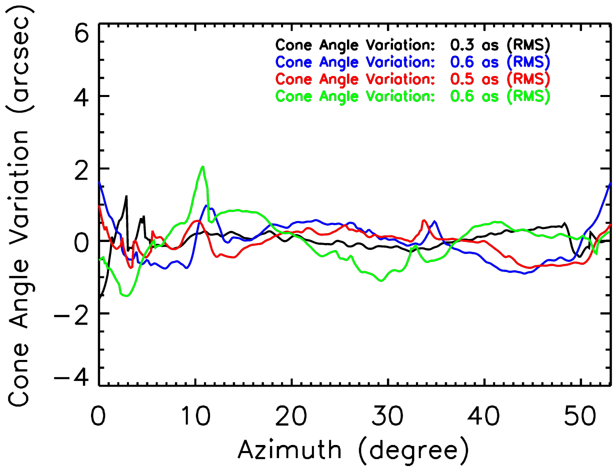




- Mirror segment has a very small radius variation error; Its contribution (< 0.1”) to HPD is negligible
- Possible sources of error: (1) forming mandrel, (2) slumping process, (3) coating, and (4) metrology mount

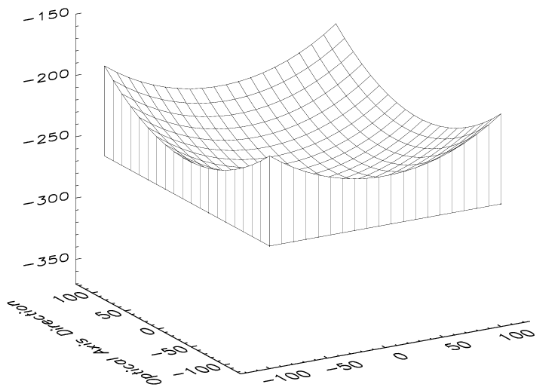
Cone Angle Variation





- Current cone angle variation error contributes ~2” to HPD, meeting requirements for a 15” system (but not for a 5” system)
- Possible Sources of error: (1) forming mandrel, (2) slumping process, (3) coating, and (4) metrology mount

Average Sag Error



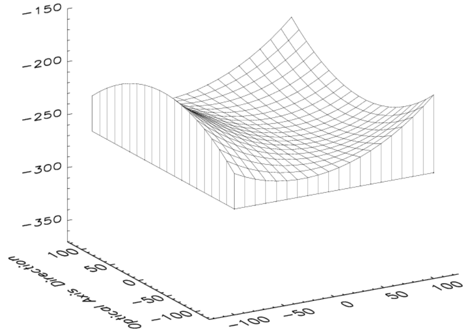
Measurement errors:

Systematic: ~0.25μm

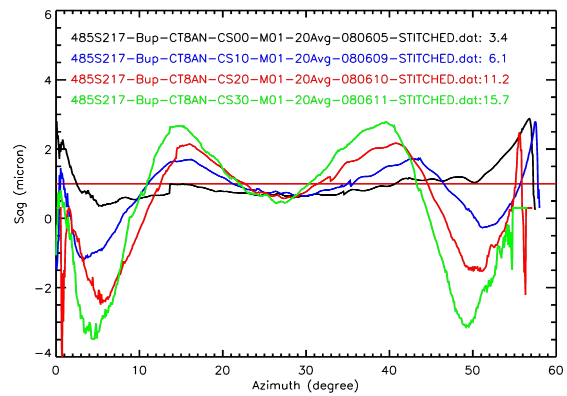
Random: ~0.10μm

- Different mounting approaches give slightly different average sags
- Better understanding of metrology systematic error is needed before further progress can be made

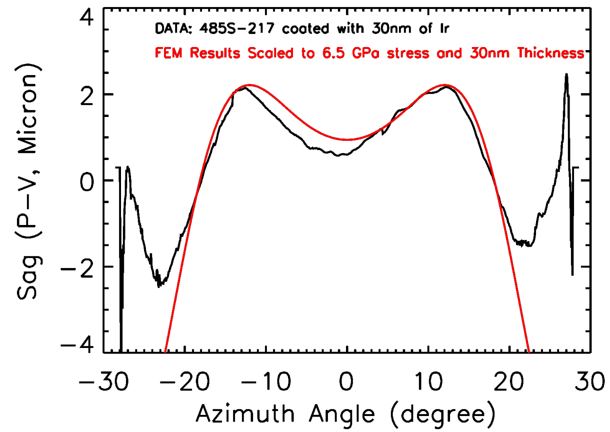
Sag Variation



Sag variation changes with Ir thickness

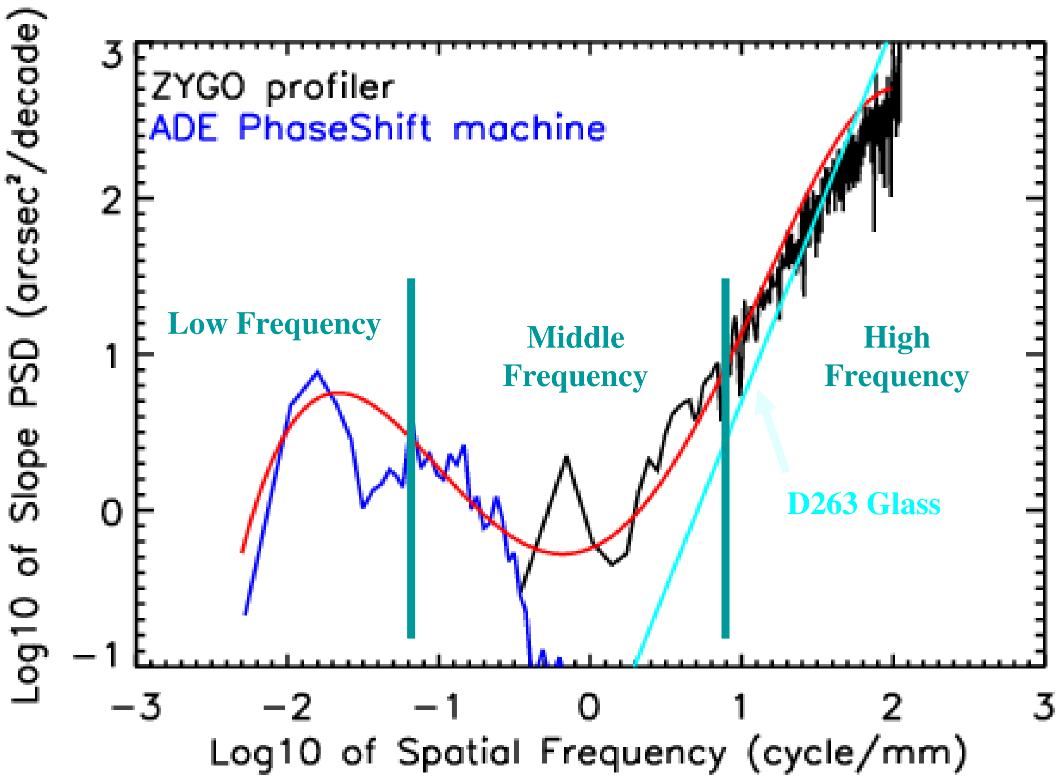


Measurement and FEM comparison



- It's all but certain that most, if not all, sag variation error has been caused by Ir coating stress. Other sources, including gravity, mount stress, contribute at much lower levels.
- This error is easy to fix: <u>reduction of coating stress by a factor of 5-10</u>
- This is a source for concern if multilayers are applied

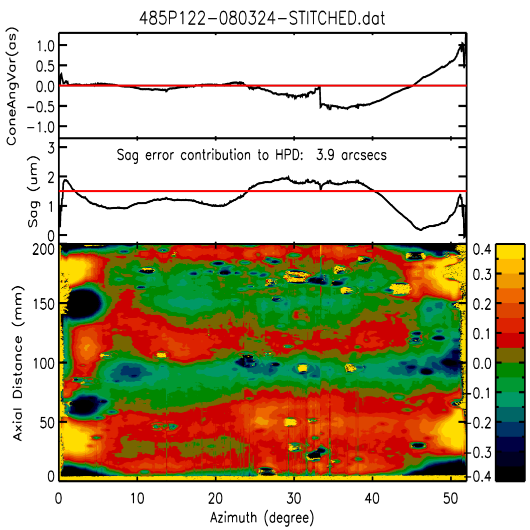
Axial Figure Residuals



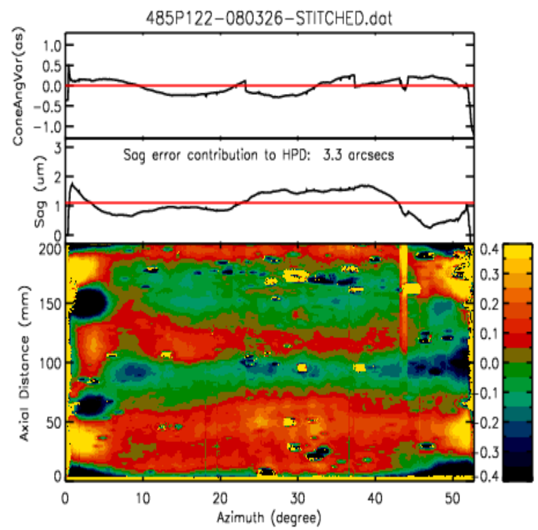
Low frequency errors from mandrel figure errors
Mid frequency errors from slumping
High frequency profile matches raw material

X-ray Performance Prediction

Primary (Parabolic)



Secondary (Hyperbolic)



Combined HPD <u>(50% EE Diameter):</u> 10 arcsec

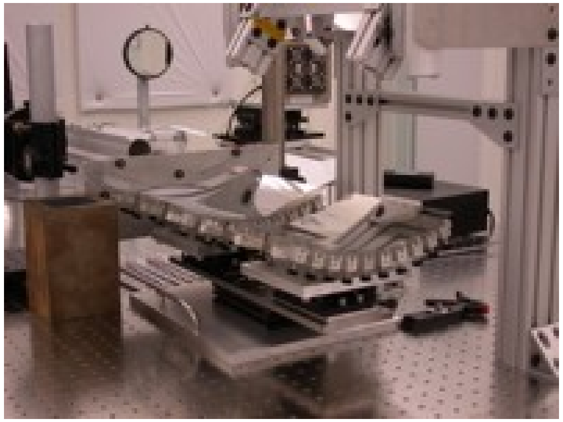
<u>80% EE Diameter:</u> 22 arcsec

<u>90% EE Diameter:</u> 38 arcsec

Summary of Mirror Fabrication

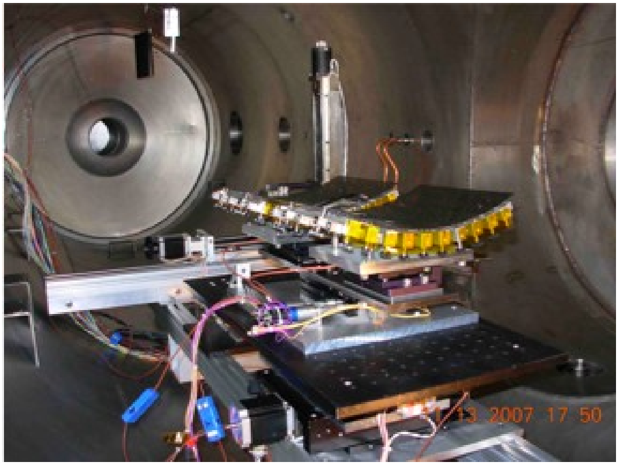
Mirror Parameter		Now		Future	
		Contribution to HPD (two reflection equivalent)	Dominant Source of Error	Difficulty of Mitigation	Expected Contribution after Mitigation
Radius	Average radius	0.0	NA	NA	0.0
	Radius variation	0.0	Mandrel or thermal or coating stress	Easy	0.0
Cone Angle	Average cone angle	0.0	NA	NA	0.0
	Cone angle variation	2.0	Measurement uncertainty	Moderate	1.0
Sag	Average sag	3.0	Measurement uncertainty	Moderate	1.0
	Sag variation	3.0	Coating stress	Easy	0.5
Axial Figure	Low frequency figure (200mm-20mm)	6.0	Forming mandrel	Easy	2.0
	Middle frequency figure (20mm-2mm)	6.0	Slumping process	Hard (?)	2.0
	High frequency figure (2mm-0.002mm)	1.5	Glass sheet quality	Easy	1.5
HPD (arcsec)		10			3.5

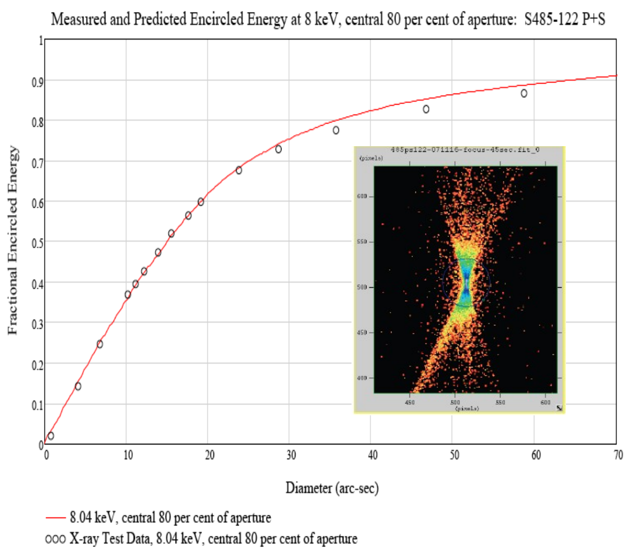
Alignment & Mounting: Cradle, Mattress, & Cube



- Mirror segments are placed on a "mattress" (made of soft coils) to counter-balance gravity
- Heights of coils are adjusted to achieve good focus and good figure
- Mirror segments are permanently bonded to the "Cube" which simulates a permanent housing

Status of Cradle/Mattress/Cube



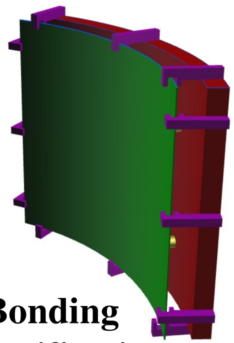


- Reasonably good figure and focus quality can be achieved quickly and repeatably
- Good x-ray test result achieved, demonstrating the validity of optical metrology; Figure distortion dominates X-ray image quality
- More X-ray tests in both temporary and permanent configurations are forthcoming

Suspension Mount and Vertical Alignment and Assembly

Mounting

QuickTime□ and a decompressor are needed to see this picture.



Bonding verification

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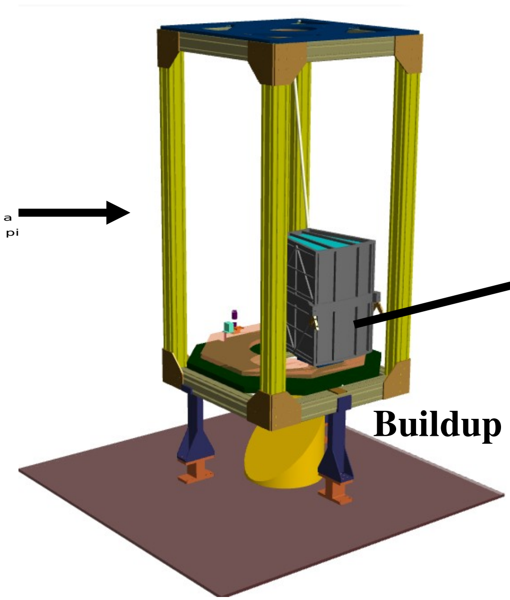
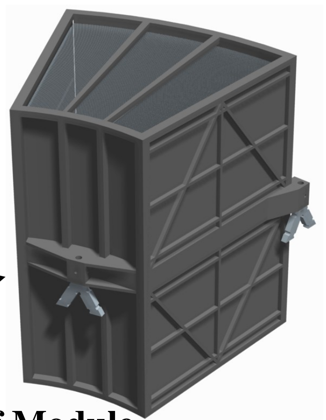
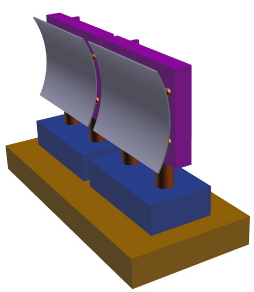


Module Housing Simulator



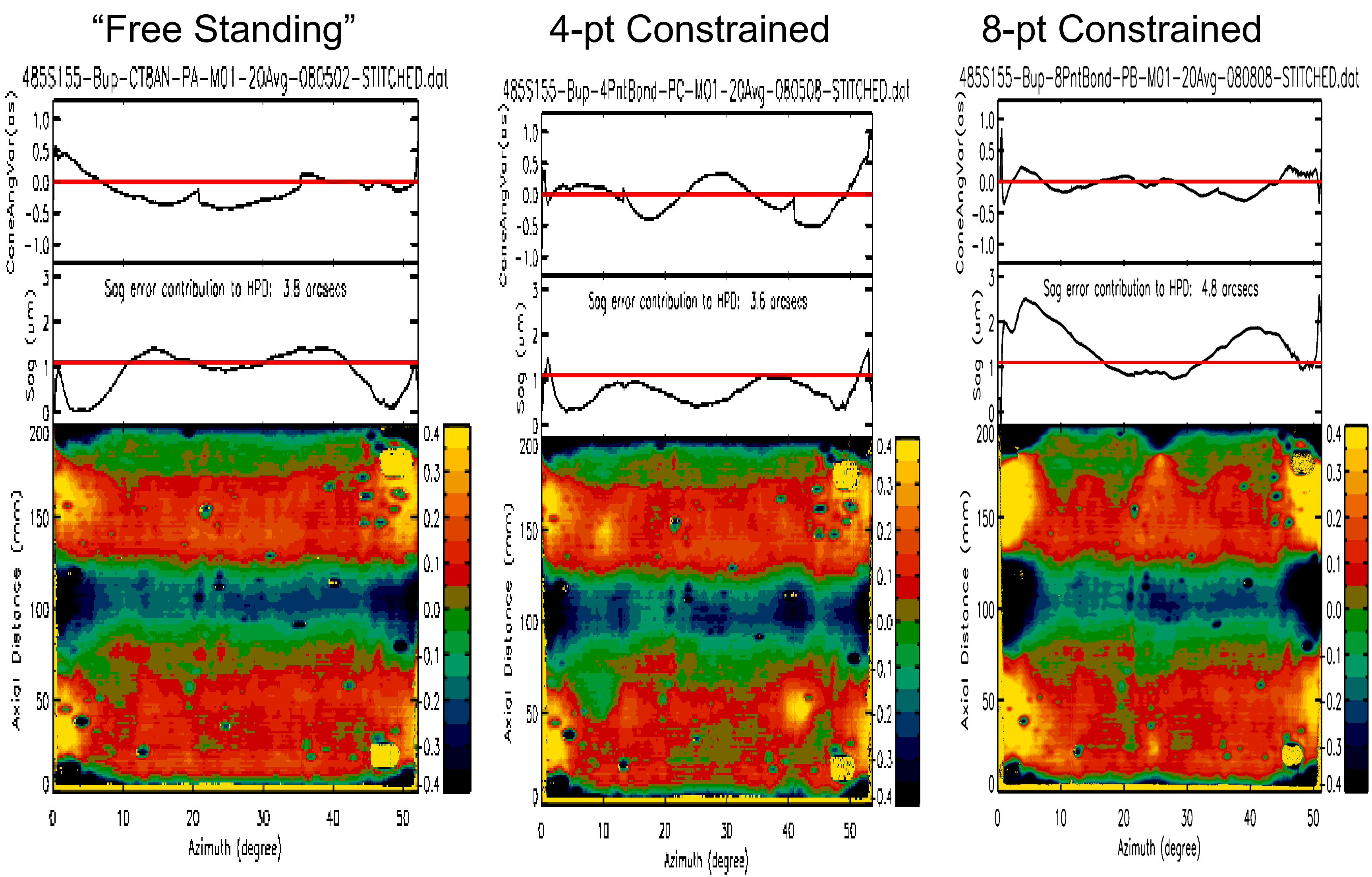
Buildup of Module



X-ray Test

- Convert a mirror segment into a rigid body with acceptable distortion
- Maneuver the “rigid body” into alignment and bond to housing

Status of “Suspension Mount”

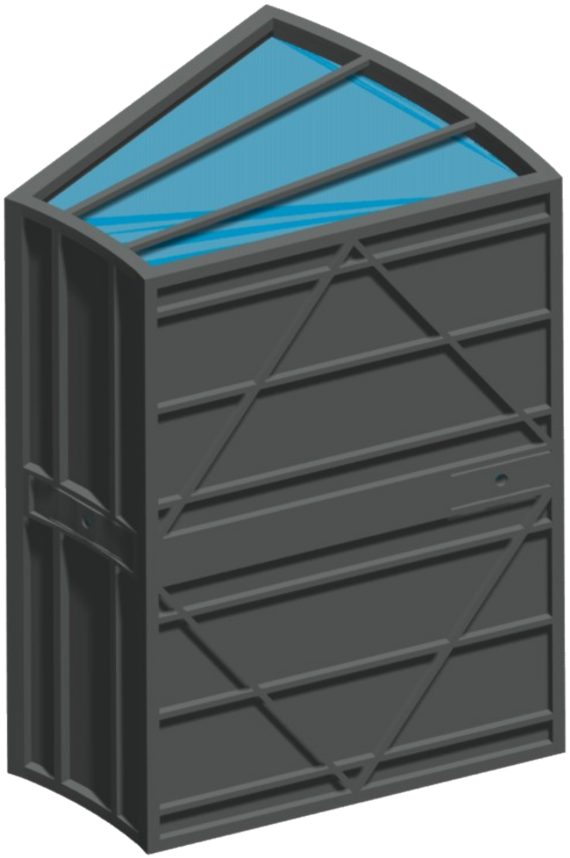


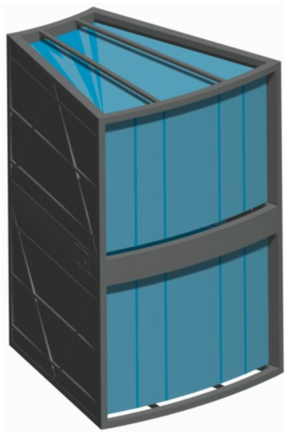
Status of "Suspension Mount"

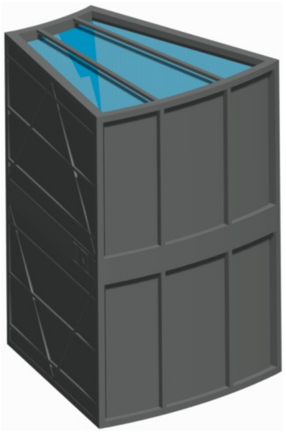
- Four point mounts have been demonstrated to be satisfactory: excellent repeatability and speed
- Eight point mounts are being experimented with; Initial results excellent
- X-ray test is set up, awaiting mirror segments
- Vertical mounting facility is being assembled
- Three ways of bonding are being investigated: experimentation and finite element analysis

FMA Module Design

- Closed out on four sides for structural stiffness, FOD protection, and thermal control.
- Mirrors installed from back
- Material TBD - match glass CTE as closely as possible

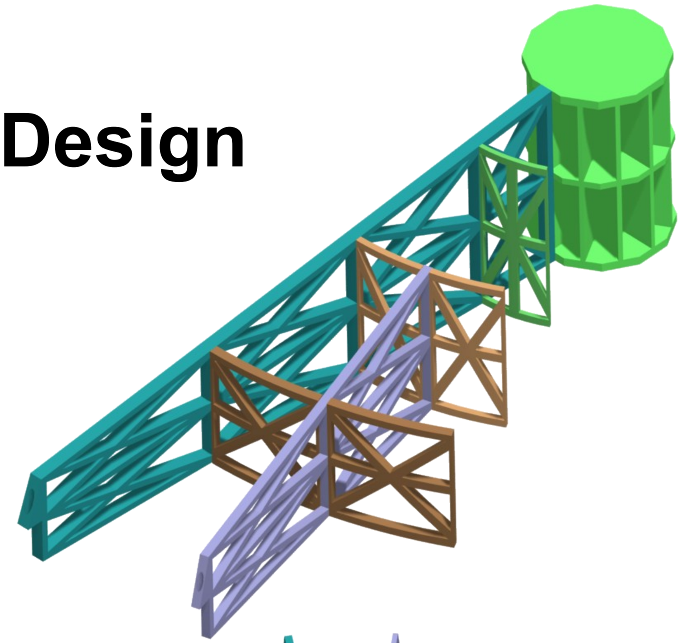


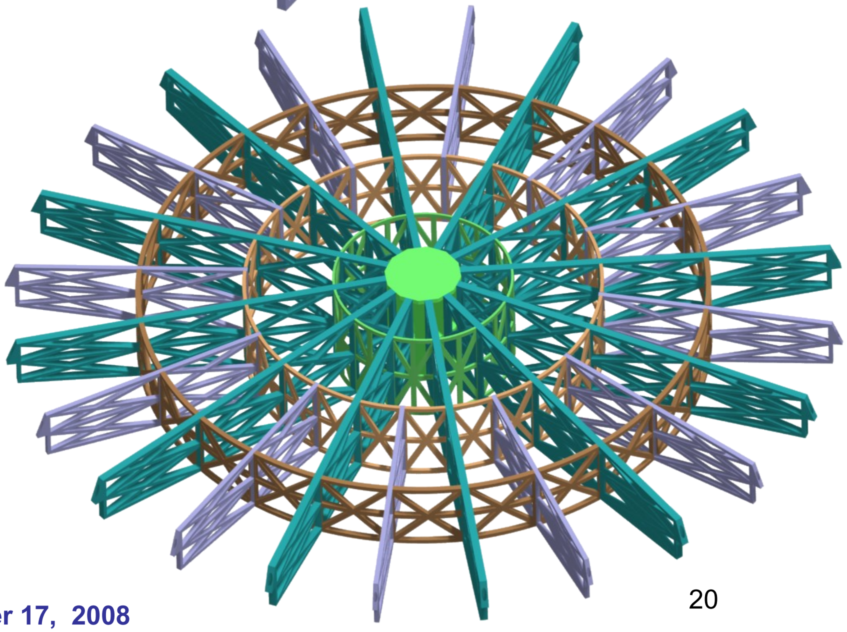




FMA Structural Design

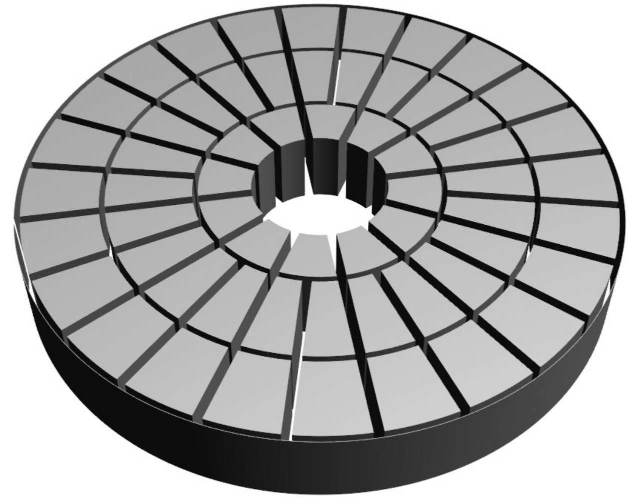
- All optical alignment within modules: structure only needs to provide rigid mount
- Machined truss structure
- Only 6-7 unique parts
- Similar to ELC shuttle carrier design
- Mass 520 kg before any optimization

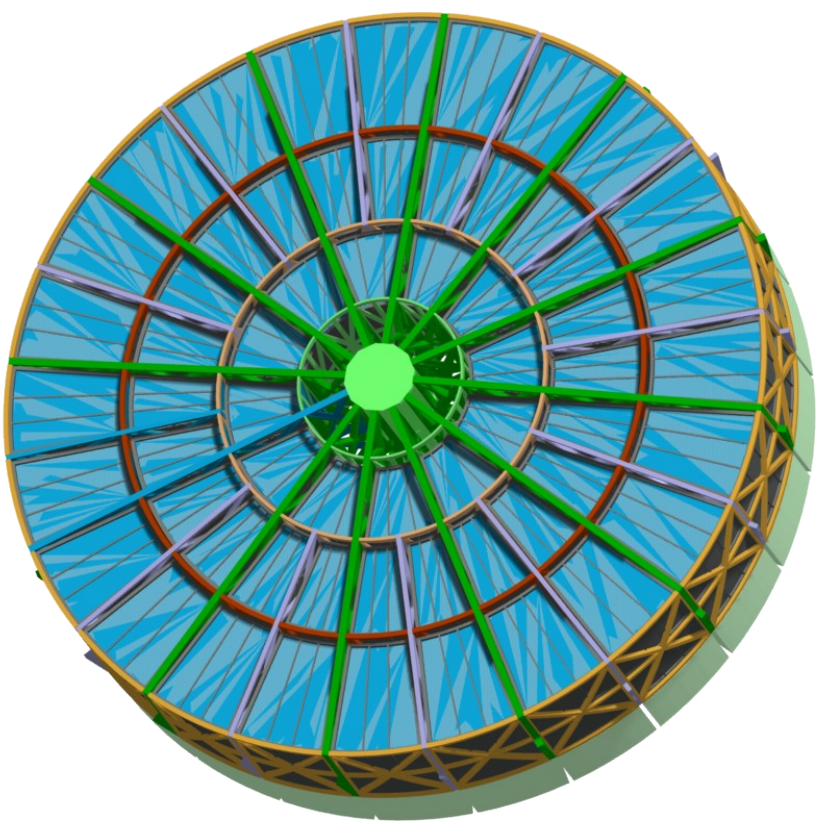


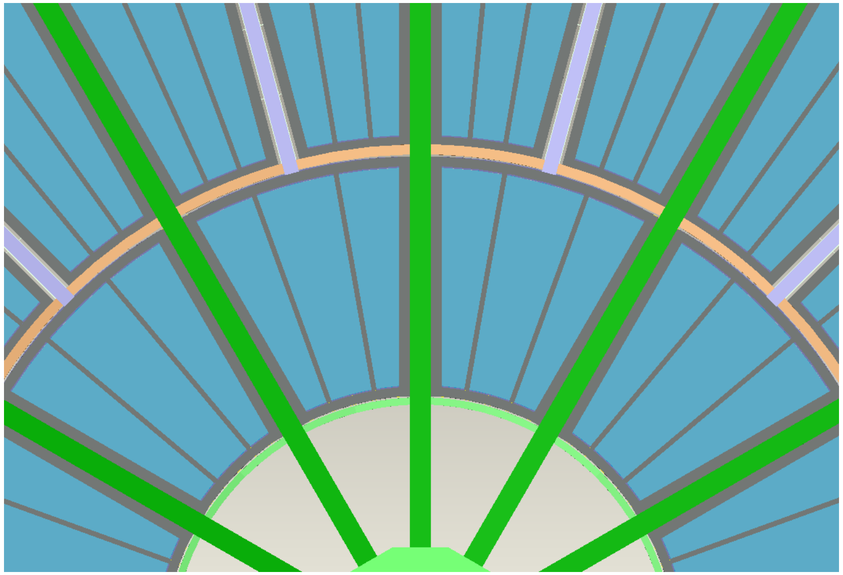


FMA Module Layout

- **Module size constrained by glass size (<35 cm)**
- **12/24/24 layout optimizes module packing**







NuSTAR - A Mirror production demonstration

- GSFC is supplying 3000+ slumped glass substrates for NuSTAR by December 2009
- Production facility completed in August 2008
- Facility provides a demonstration of mass production of IXO mirrors

Plan for Next Year(s)

(Detailed Roadmap in Development)

- **Mandrel Fabrication**
  - Obtain at least one mandrel that is close to 2” HPD to enable the fabrication of 5” mirror segments: MSFC, GSFC, or industry
- **Mirror Fabrication**
  - Reduce coating stress to bring down individual mirror segments’ performance to better than 10”
  - Further reduce mid-frequency error: make mirror segments almost as good as the mandrel: ~6” HPD
  - Use 2” mandrels to make 3.5” mirror segments
- **Mirror Module Alignment and Build-up**
  - X-ray test individual pairs of mirrors
    - Achieve better than 10” HPD
    - Achieve repeatable temporary and permanent bonding of individual mirror pairs
  - Finalize methods of permanently bonding mirrors in module housing
    - Combine experiments and finite element analysis
  - Complete module design and begin the build-up of a prototype module with at least 2 pairs of mirrors
    - Perform X-ray and environment tests
- **Mirror Assembly Design and Analysis**
  - Optimize mass
  - Finite element analysis
  - Thermal analysis to verify requirements
  - Devise optimal test scenarios
- **Mirror Production Approach**
  - Refine production and mandrel procurement plan
  - Refine technology transfer plan