NASA IXO Mirror Technology Development

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Mirror Technology Development Team

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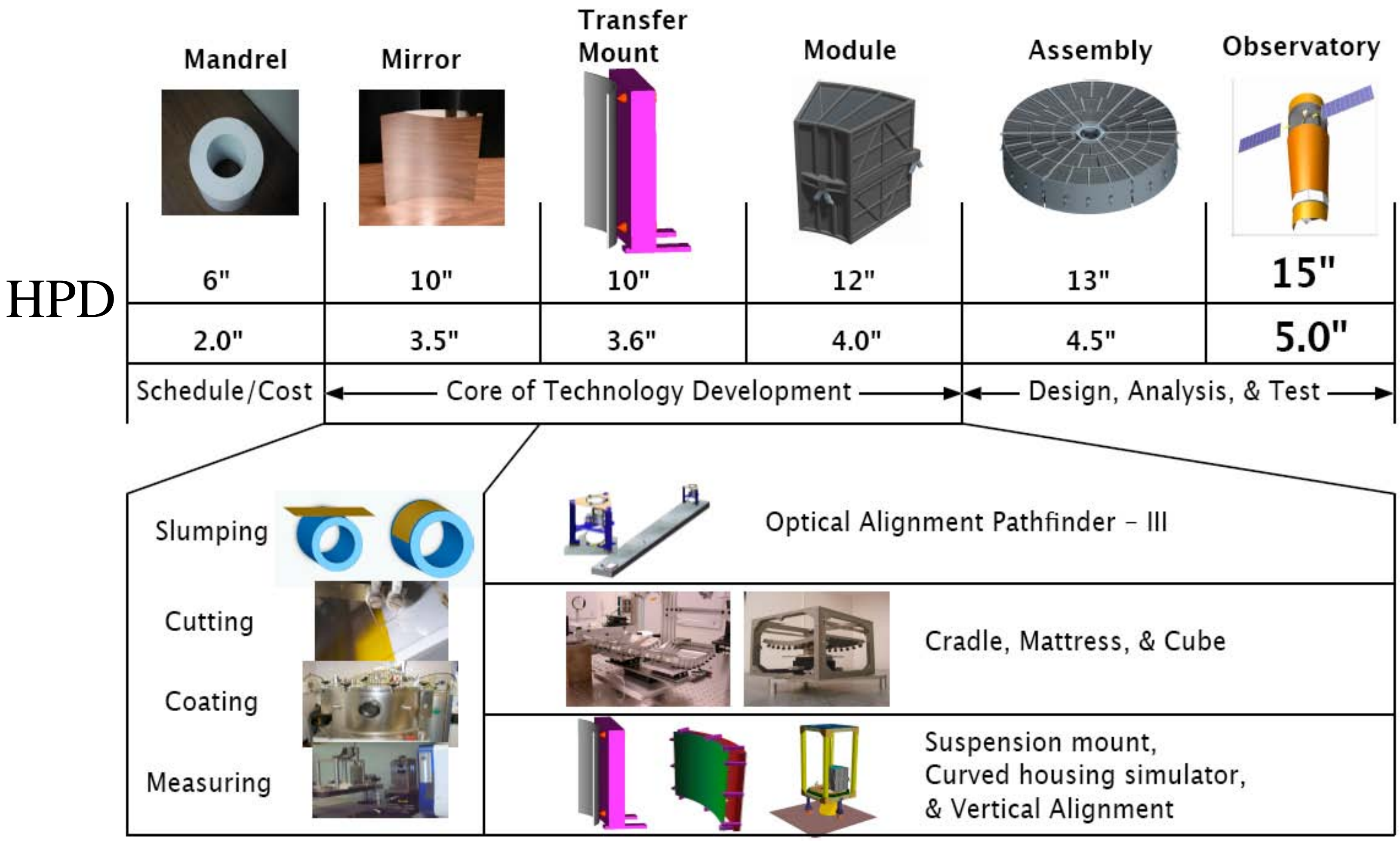
Summary of Presentation

- 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 meet requirements of 5” telescope
- Alignment and Integration
  - Excellent progress being made to meet 15” requirements
  - Major issues being identified and worked on to meet 5” requirements

Strategic Considerations

- **Wolter-I Design (Parabolic primary and Hyperbolic secondary)**
  - Arbitrarily good angular resolution possible
- **Segmented implementation**
  - Arbitrarily large effective area possible

Overview of Mirror Tech Development



Prescription and Definitions

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

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

Average radius: ρ_0

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

Average cone angle: θ_0

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

Average sag: s_0

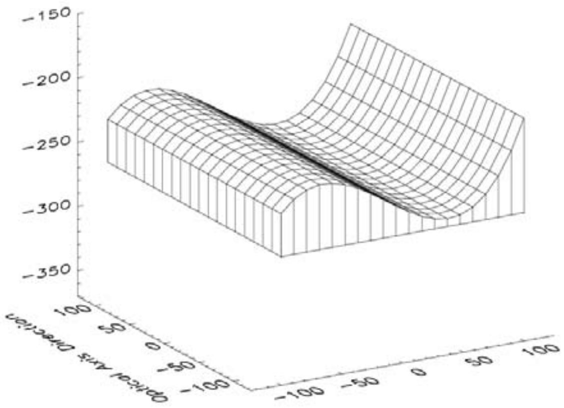
Sag variation: $\Delta s(\phi)$

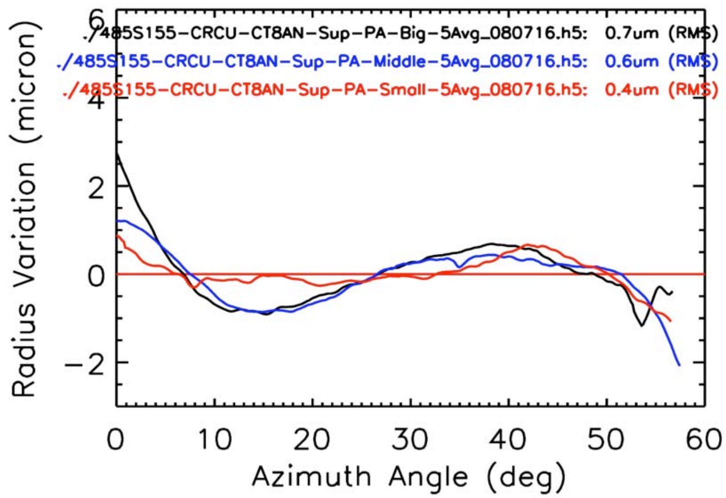
Remainder: $R(z,\phi)$

Mirror Segment Parameters

Mirror Parameter		Measurement Method
Radius	Average Radius: ρ_0	Hartmann test; Not yet adequately measured
	Radius Variation: $\Delta\rho(\phi)$	Interferometer and Transmission sphere
Cone Angle	Average Cone Angle: θ_0	Hartmann test; Not yet adequately measured
	Cone Angle Variation: $\Delta\theta(\phi)$	Derived from radius variation measurement
Sag	Average Sag: s_0	Interferometer and cylindrical null lens
	Sag Variation: $\Delta s(\phi)$	
Remainder	Low Spatial Frequency (200mm-20mm)	
	Middle Spatial Frequency (20mm-2mm)	
	High Spatial Frequency (2mm-0.002mm)	Interferometer: Zygo NewView 5000

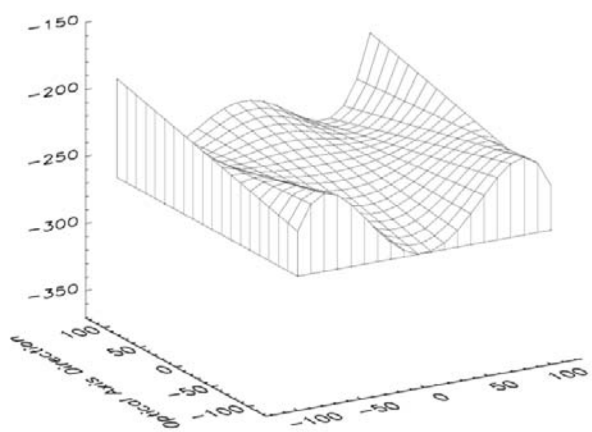
Radius Variation

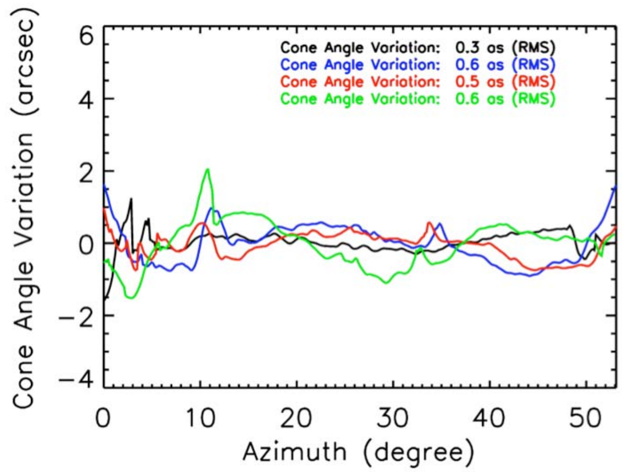




- Mirror segment has very small radius variation error; Its contribution (< 0.1”) to HPD is negligible
- Possible sources of error: (1) forming mandrel, (2) slumping process, (3) coating, and (4) metrology mount

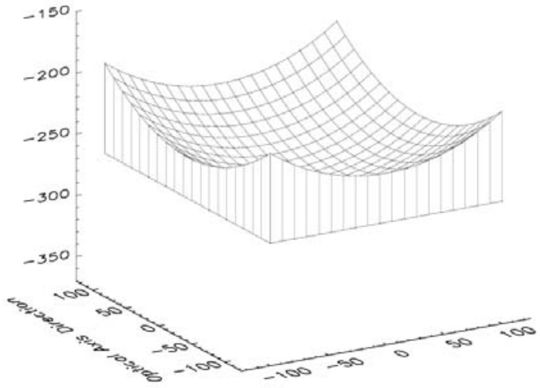
Cone Angle Variation





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

Average Sag Error



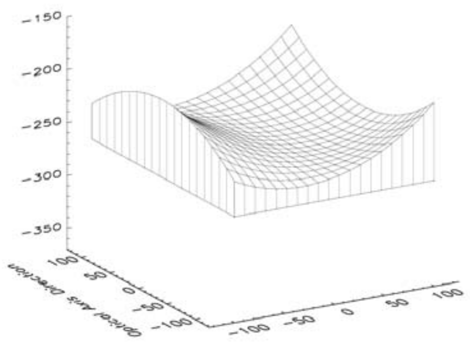
Measurement errors:

Systematic: ~0.25μm

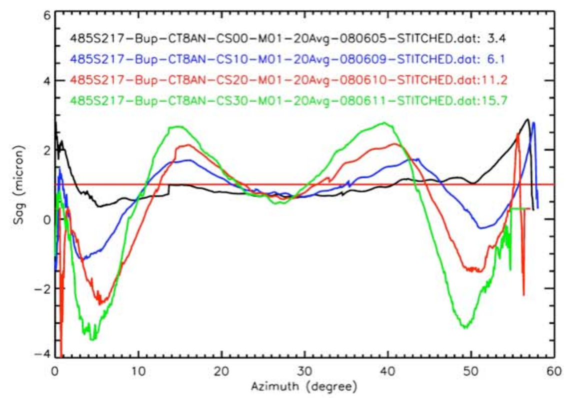
Random: ~0.10μm

- Different mounts (Cantor-tree and suspension mounts) give slightly different average sags
- Better understanding of metrology systematic error is needed before further progress can be made

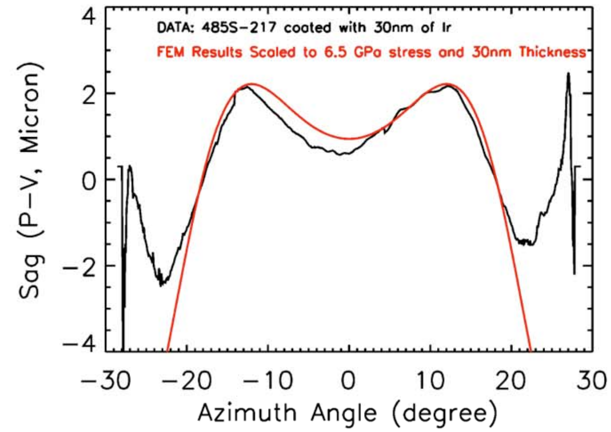
Sag Variation



Sag variation changes with Ir thickness

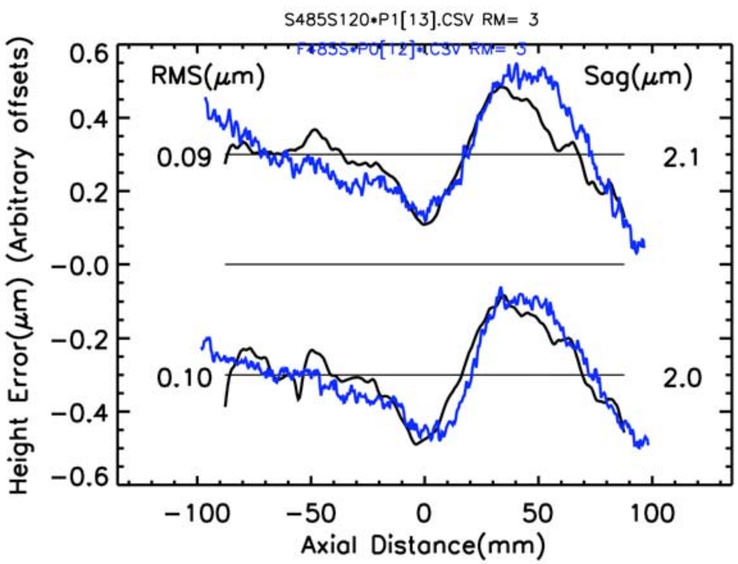


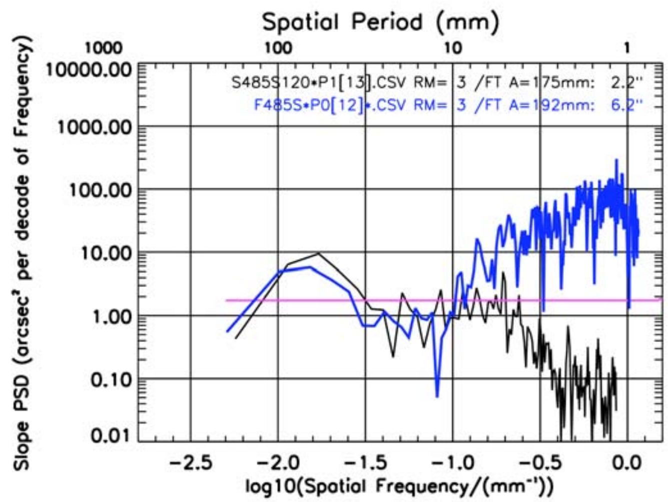
Measurement and FEM comparison



- 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 to 10</u>

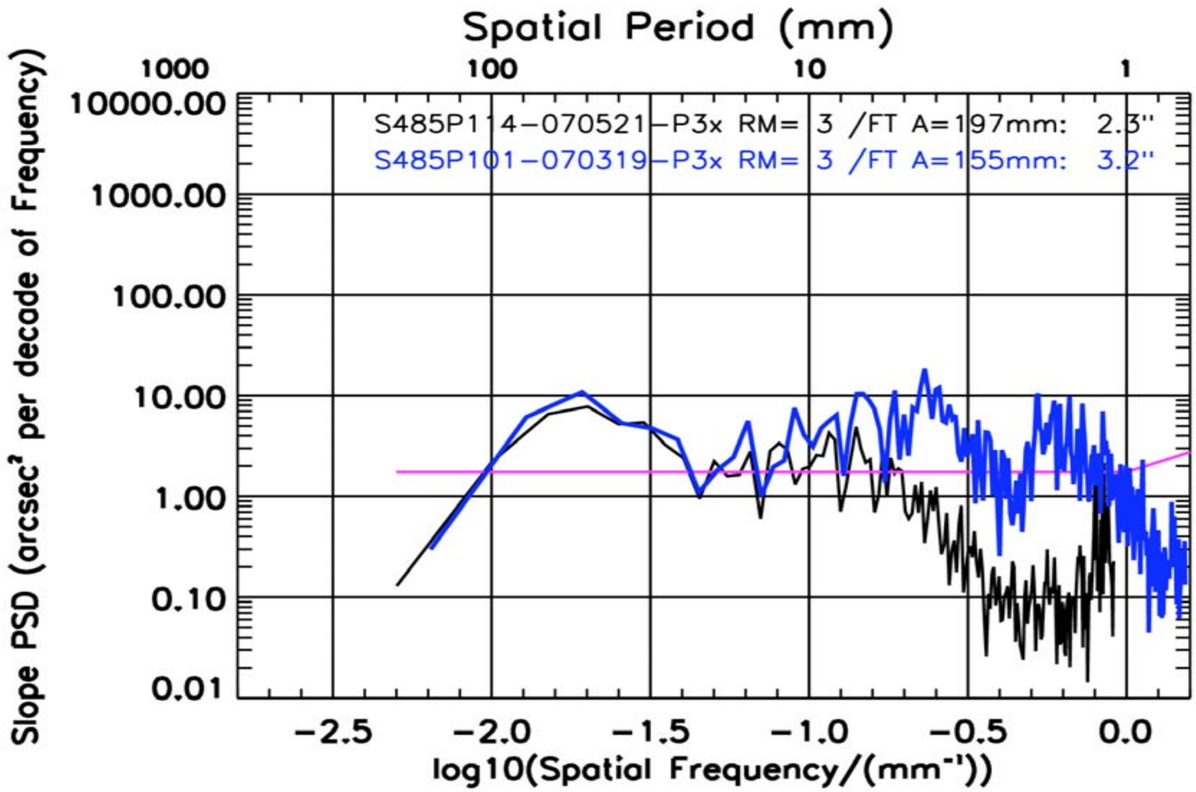
Remainder: Low Spatial Frequency





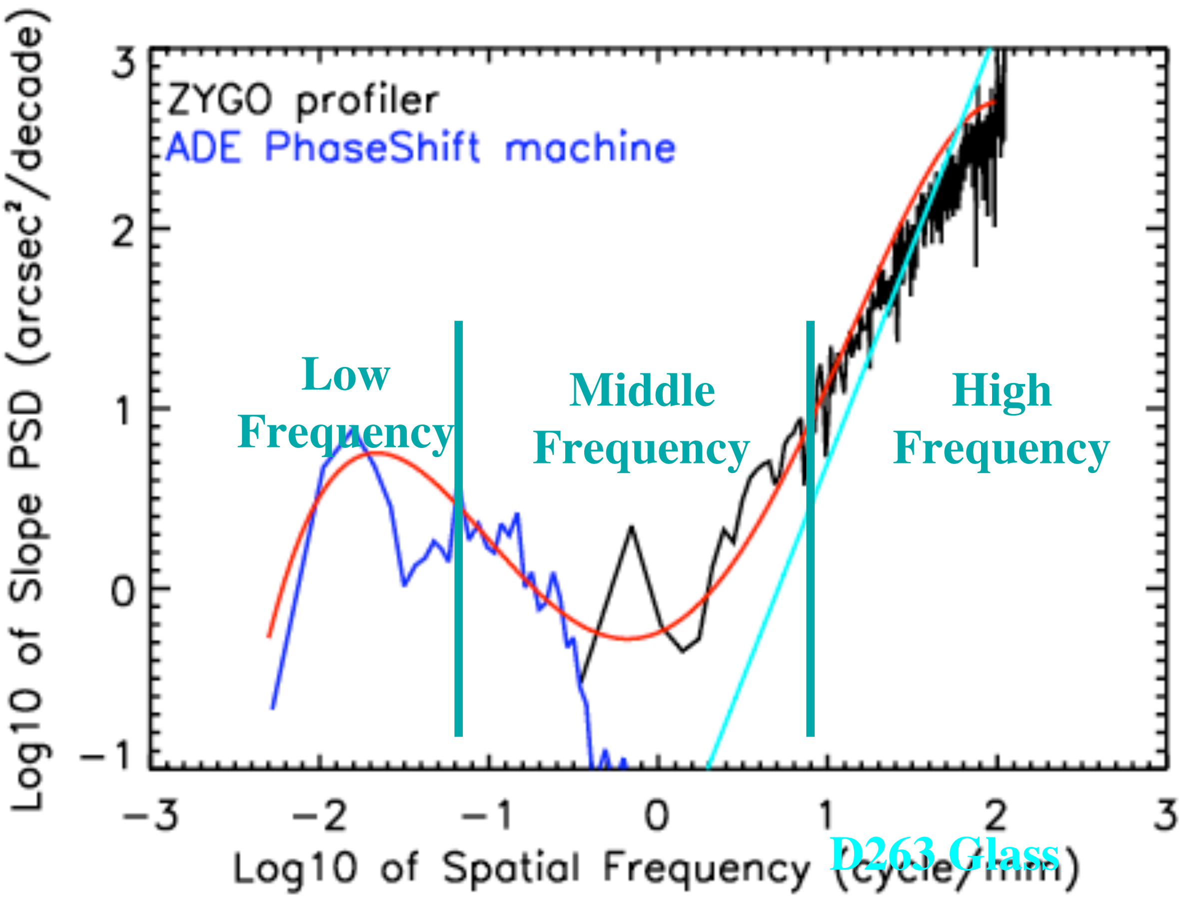
- Low spatial frequency figure is well understood
- Dominant source of error: <u>forming mandrel</u>; Better mandrels are needed to further reduce this error

Remainder: Middle Frequency



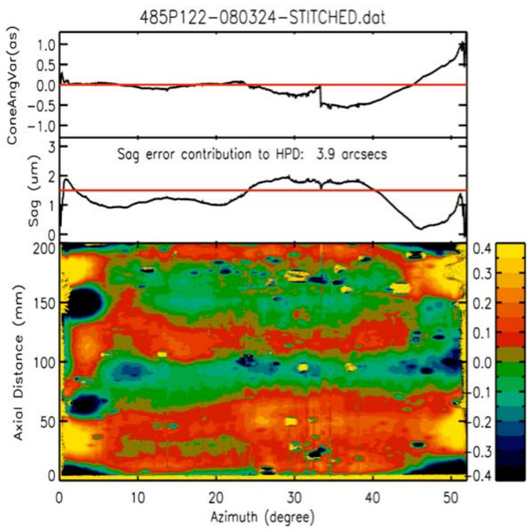
- Mid-frequency figure error is currently dominated by the slumping process
- Sources of error: (1) mandrel release layer, and (2) forming mandrel quality

Remainder: Complete Axial Figure

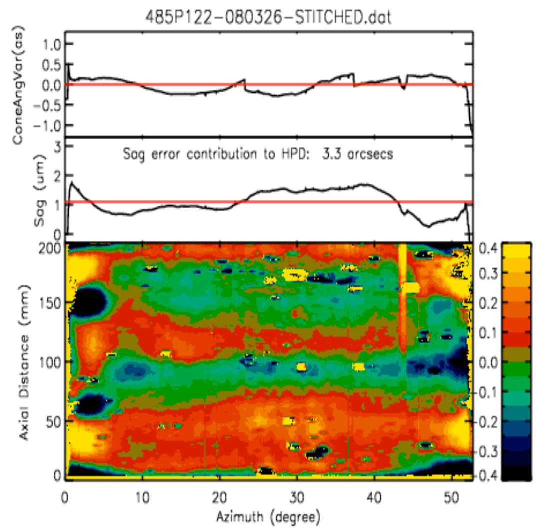


X-ray Performance Prediction
(Timo Saha)

Primary (Parabolic)



Secondary (Hyperbolic)



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

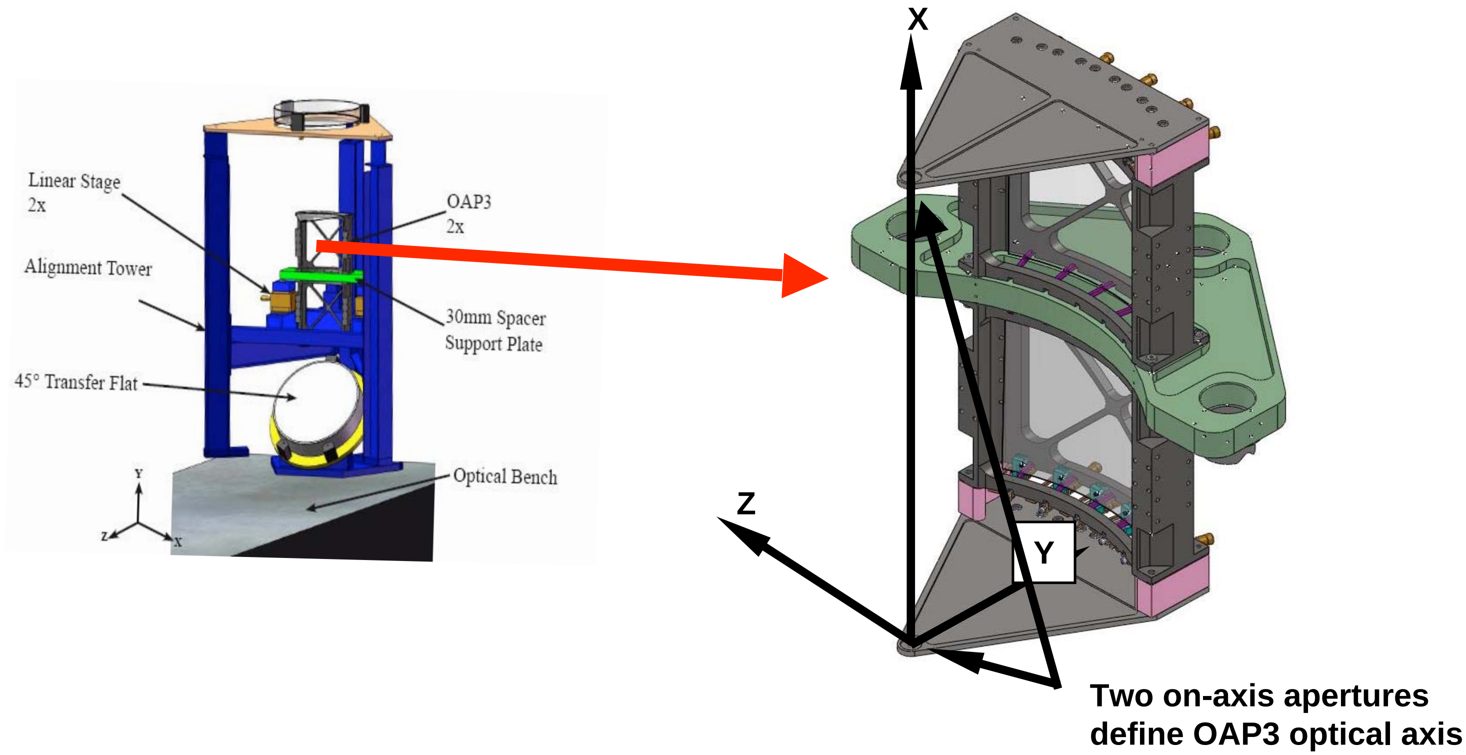
<u>80% EE Diameter:</u> 22 arcsec

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

Summary of Mirror Fabrication

Mirror Parameter		Now: Contribution to HPD (two reflection equivalent)	Now: Dominant Source of Error	Future: Difficulty of Mitigation	Future: 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**

Optical Alignment Pathfinder - III (OAP3) (Freeman et al.)



- Each mirror segment is actuated at ten points near the top and bottom edges under the monitoring of an optical beam
- When optimal figure and focus are reached, the mirror segment is bonded near these ten points

OAP3 Recent Results (Freeman et al.)

- Primary mirror aligned and bonded
- Secondary mirror aligned and one end bonded
  - second end to be bonded in next few days
- Alignment metrology (Hartmann test)
  - rms diameter =5.6 arcsecs; mainly from contribution of cone angle variation error
  - Requirement:
    - 7.4 arcsecs rms diameter for 15 arcsec telescope
    - 2.5 arcsecs rms diameter for 5 arcsec
- Caveat – preliminary result, not yet fully bonded, but from bonding experiments and primary mirror experience, do not expect significant change

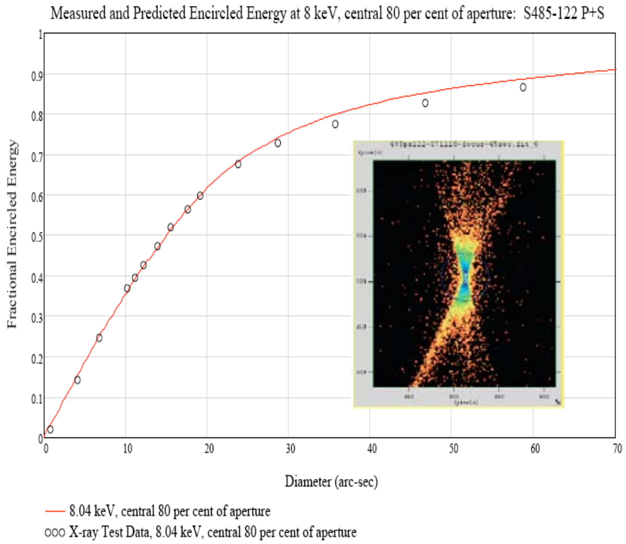
OAP3 Plan (Freeman et al.)

- Possible to meet 5 arcsec telescope budget for mirror alignment/mounting
- Repeat with newer (better) mirrors
- Results to date with aluminum housing – CTE mismatch between housing and mirrors causes thermal variations/errors
  - Build titanium alloy housing – reduce CTE difference by a factor of ~10
- Improve resolution and modify mirror attachment points of adjusters
  - Reduce introduction of small moments

Cradle, Mattress, and the Cube (Rohrbach et al.)

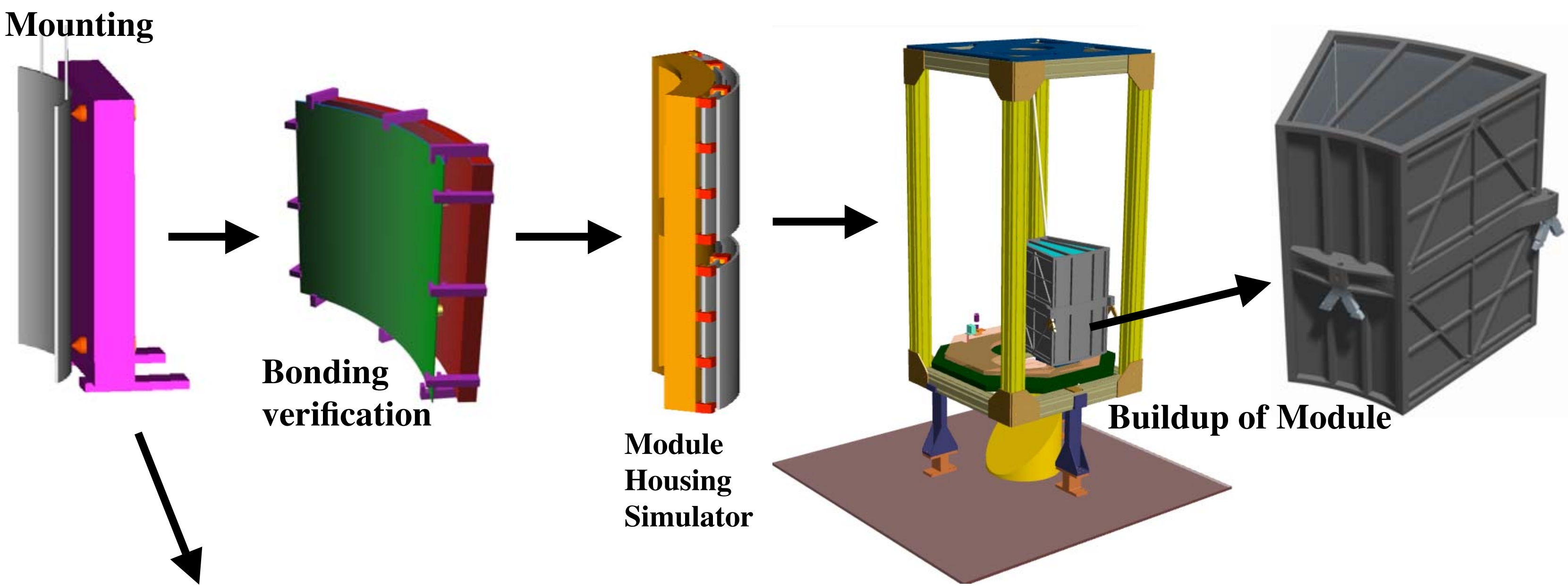
- Mirror segments are placed on a mattress (made of soft coils) to counter-balance gravity
- Heights of coils are adjusted to achieve good focus and good figure
- Mirror segments are permanently bonded to the Cube which simulates a permanent housing

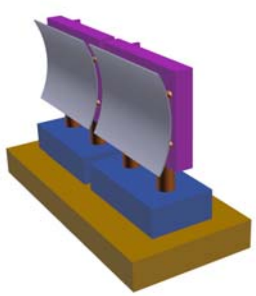
Status of Cradle/Mattress/Cube (Rohrbach et al.)



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

Suspension Mount and Vertical Alignment and Assembly (Chan et al.)



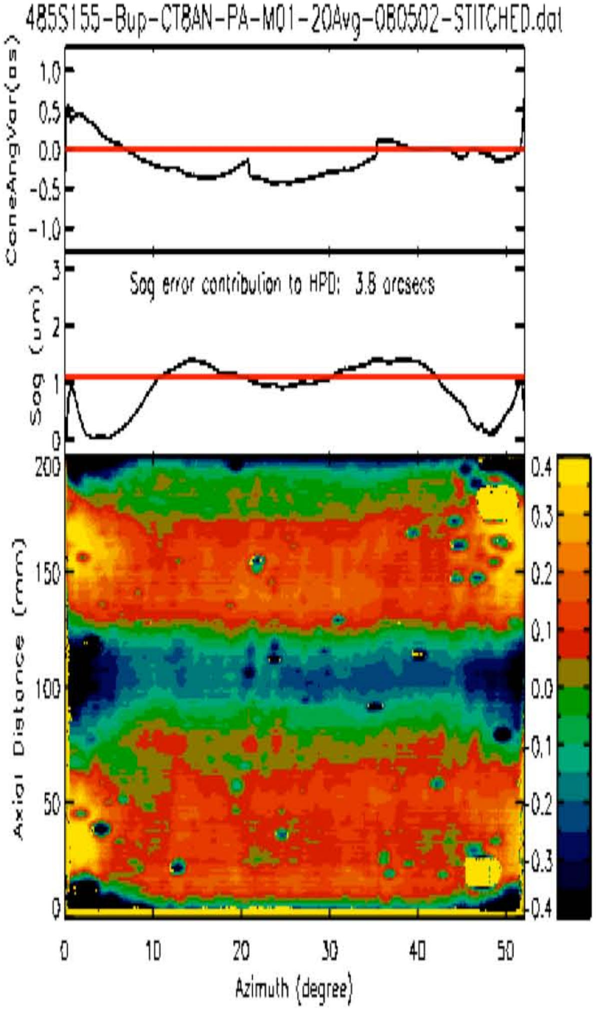


X-ray Test

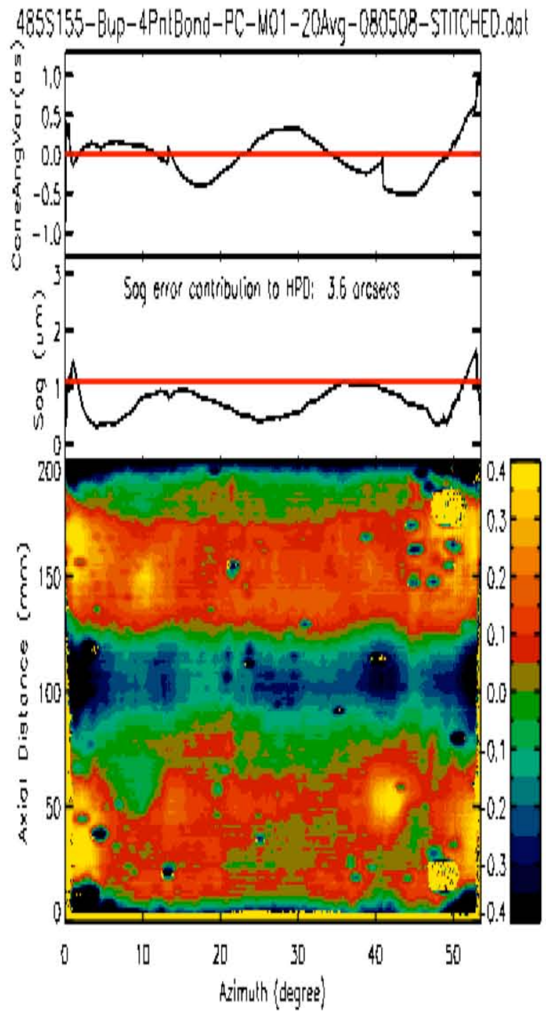
- Convert a mirror segment into a rigid body with acceptable distortion
- Maneuver the "rigid body" into alignment and bond to housing

Status of "Suspension Mount" (Chan et al.)

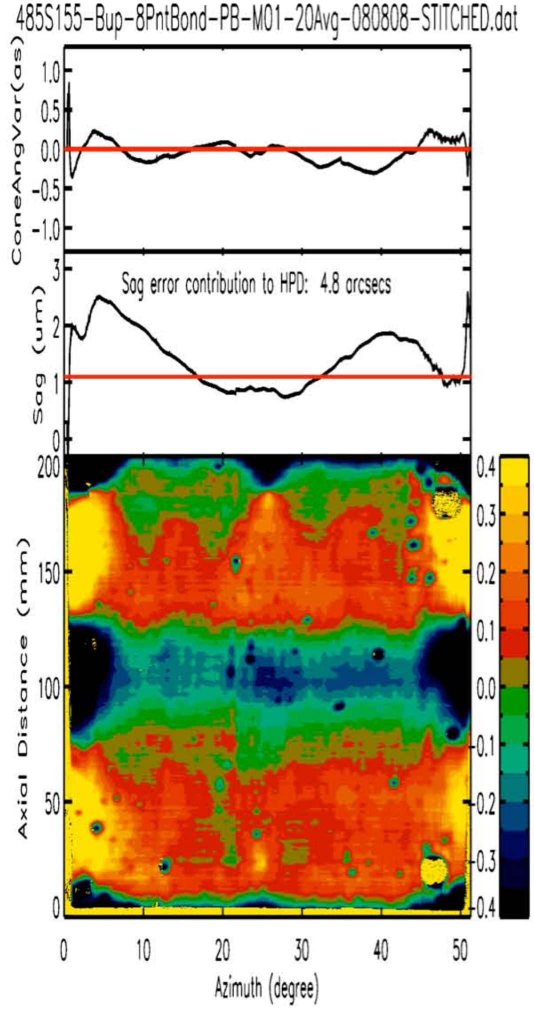
"Free Standing"



4-pt Constrained



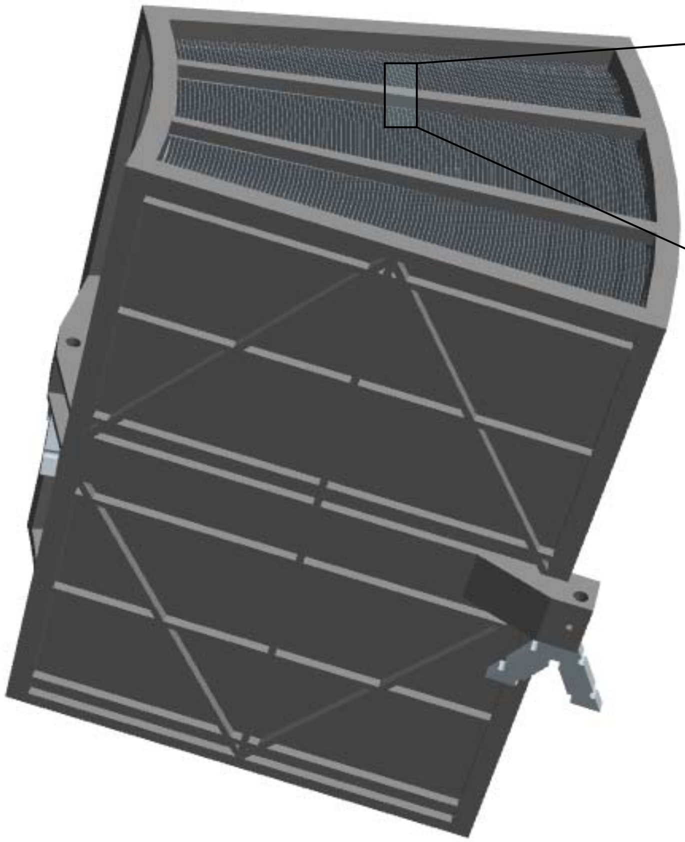
8-pt Constrained

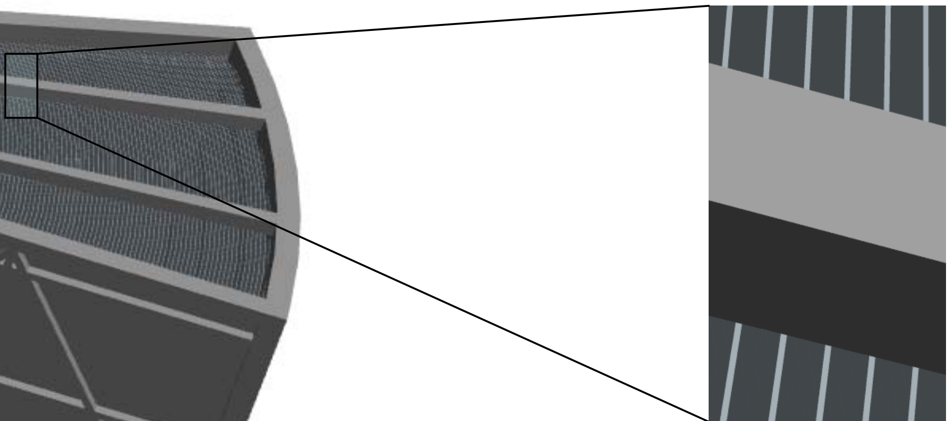


Status of "Suspension Mount" - cont. (Chan et al.)

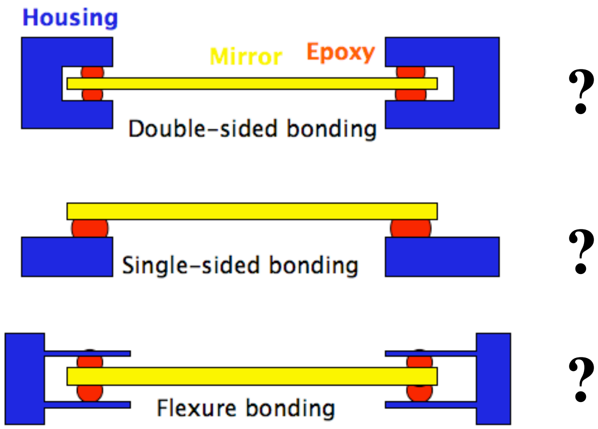
- Four point mounts have been demonstrated to be satisfactory: excellent repeatability and speed
- Eight point mounts are being experimented with; Initial results excellent
- X-ray test is set up, awaiting mirror segments
- Vertical mounting facility is being assembled
- Three ways of bonding are being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

An Extremely Important Detail: Bonding (McClelland et al.)



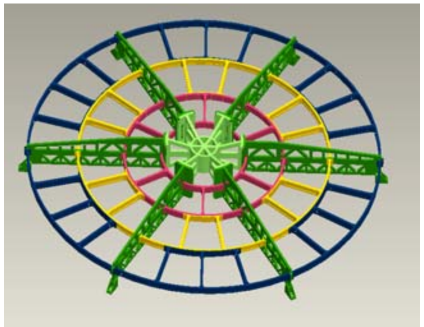


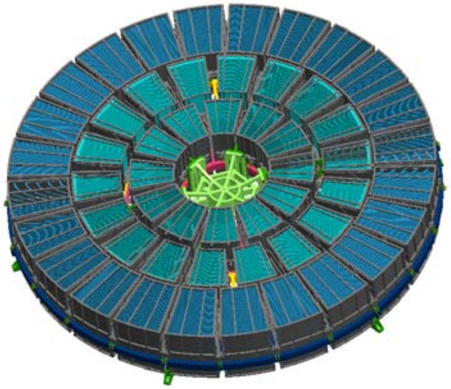
Three Ways of Bonding



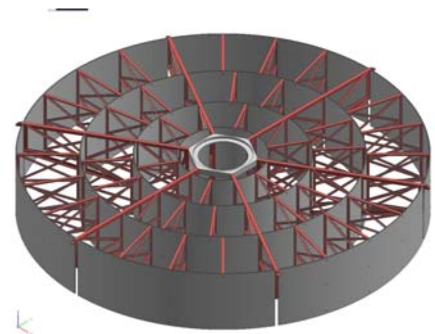
From Modules to Assembly
(McClelland and Byron)

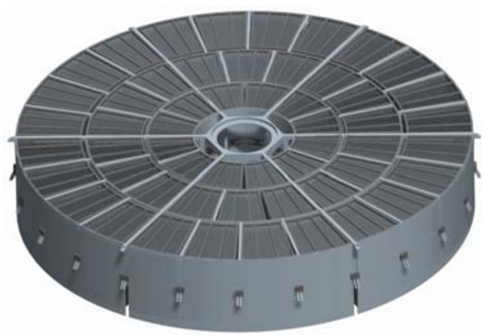
Option 1





Option 2





Outlook 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: making 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
  - Identify and prioritize issues
  - Devise and analyze potential solutions
  - Devise optimal test scenarios

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