Alignment and Bonding of Silicon Mirrors for High-Resolution X-ray Optics

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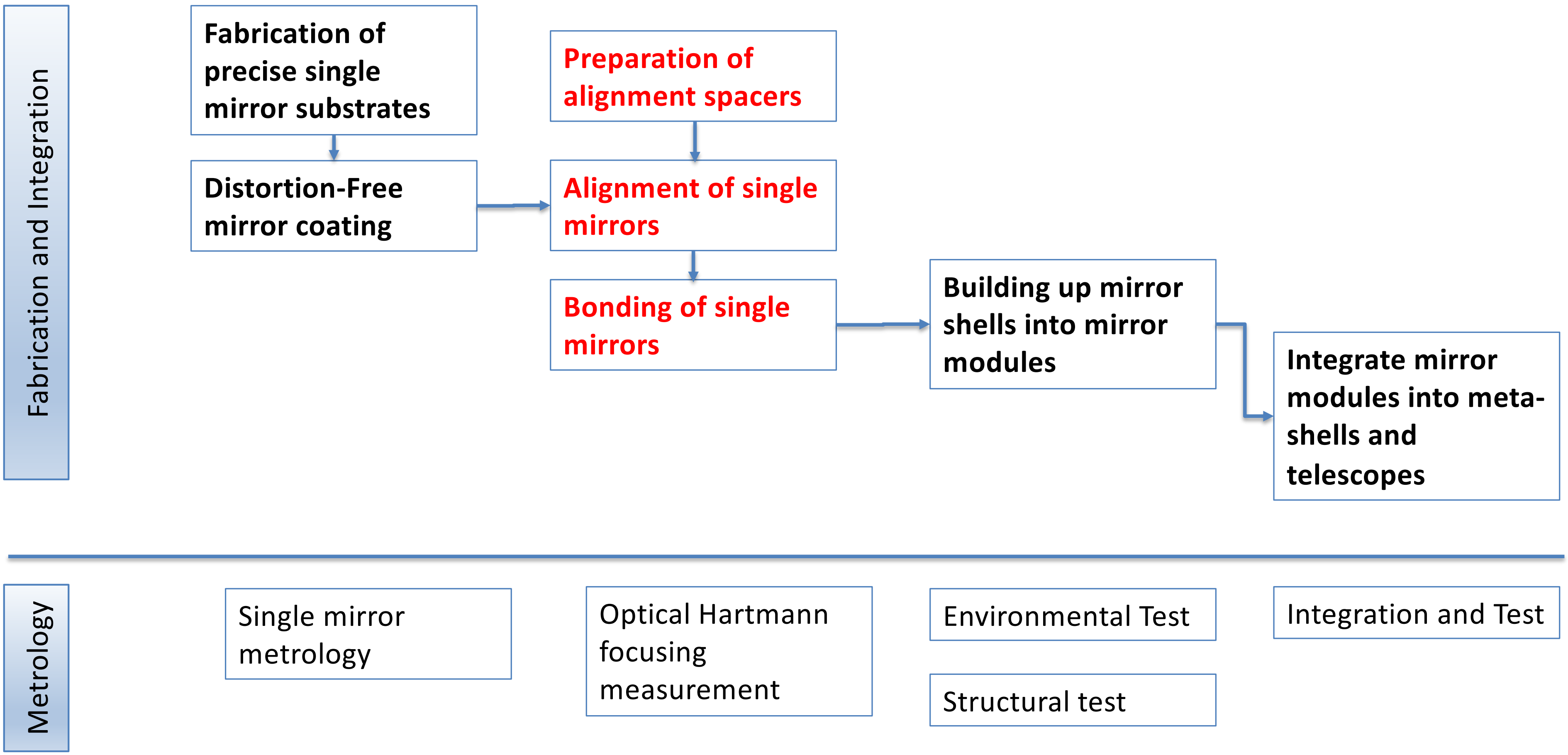
Building An X-Ray Telescope

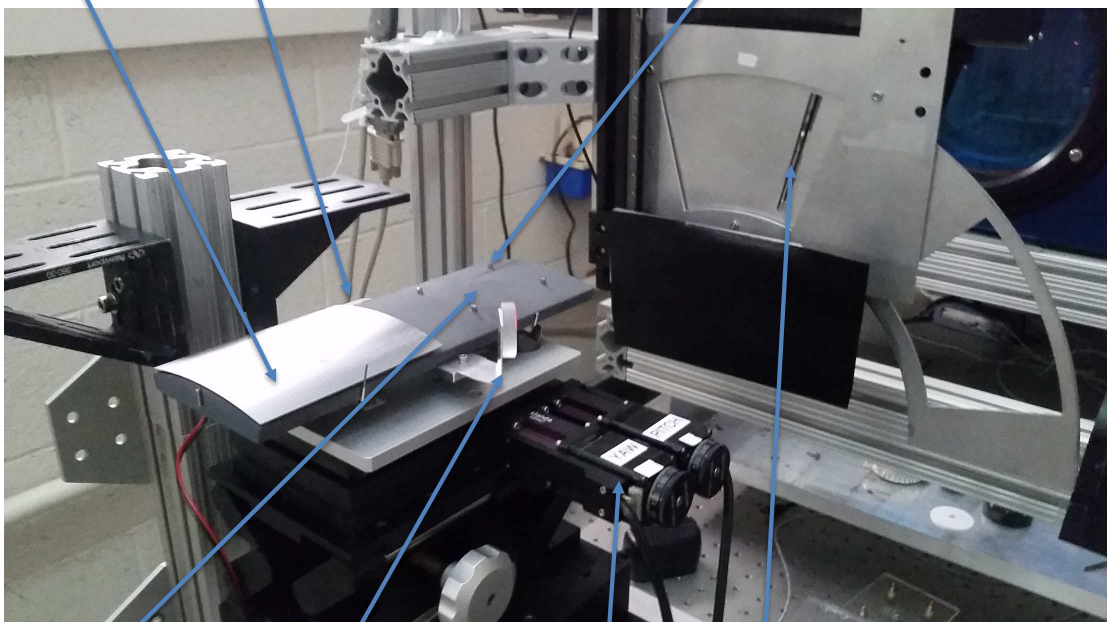


Alignment and Bonding

How to align and bond sub-arcsecond silicon mirrors?

- **Description of the alignment and bonding process**
- **Technical challenges and advances in aligning and bonding precise silicon mirrors**
  - Precise mirror placement
  - Measurement of focusing
  - Method of spacer adjustment
  - Bonding distortion and displacement
  - Co-alignment and bonding of subsequent mirrors
- **Recent result**
- **Summary and Near-term Work**

The Alignment and Bonding Process – Part 1



1. **Place mirror on spacers/support**
   - 4-point mount
   - Silicon spacers with approximate pre-set heights
   - Acoustic or mechanical agitator
2. **Measure the focusing quality**
   - Optical parallel beam to provide full illumination
   - Sub-aperture Hartmann measurements

The Alignment and Bonding Process – Part 2

3. Apply the spacer correction

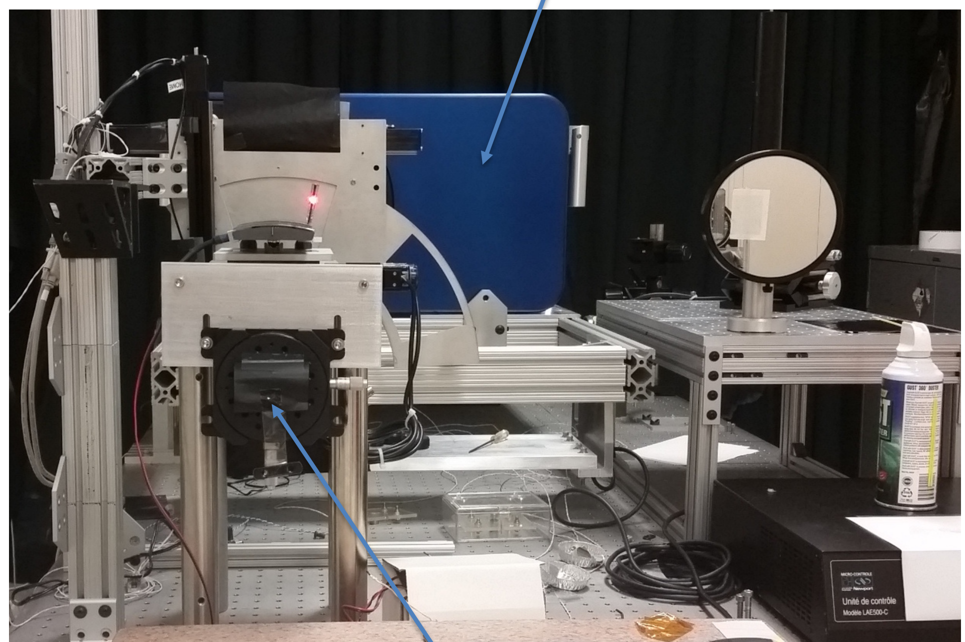
- Derive the amount of correction needed
- Remove the mirror and apply spacer correction: currently polishing

4. Bond in the mirror

- Remove the mirror and apply adhesive onto the spacer
- Replace the mirror and shake it into place
- Epoxy is cured in room temperature

5. Repeat for mirrors in the secondary stage and for the next shell

- Image of the double-reflection is used
- For mirrors in the next shell, mirrors from existing shells are blocked
- Co-locate mirror image to the same spot on the focal plane



Technical Issue 1. Precise Mirror Placement

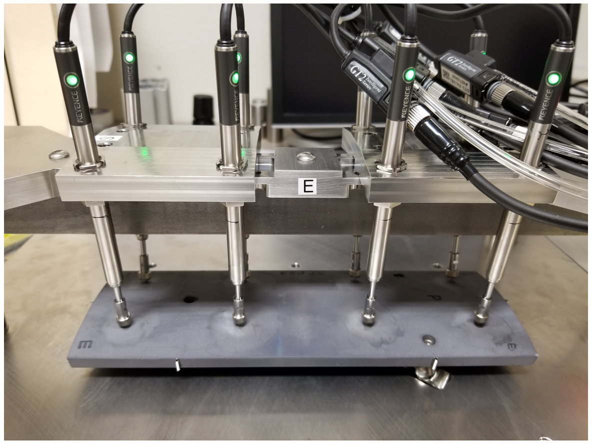
How to orient and position a mirror precise and consistently?

1. Precise mirror placement

- 4-point mount for cylinder-like segmented mirrors (Roll and axial translation degrees of freedom not precisely constrained)
- Initial spacer heights were set approximately with radius gauges
- Mirror was "shaken" into place
- Repeatability < 0.3"

Top surface of each spacer has a tip-top "crown" (dome shape, cone shape) to ensure only a single point is in contact with the mirror

- Initial spacer dimension to set the mirror position
- A few μm in mirror translation is sufficient for 1"
- Radius gauge is capable of 0.1 μm



- Either with a mechanical vibrator, or acoustic agitator
- Dependent of mirror weight

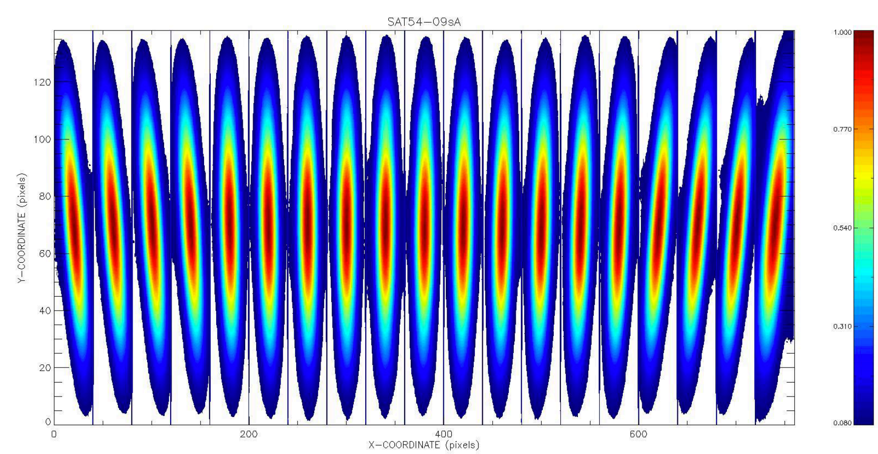
Technical Issue 2. Focus Measurement

How to determine the goodness of mirror orientation?

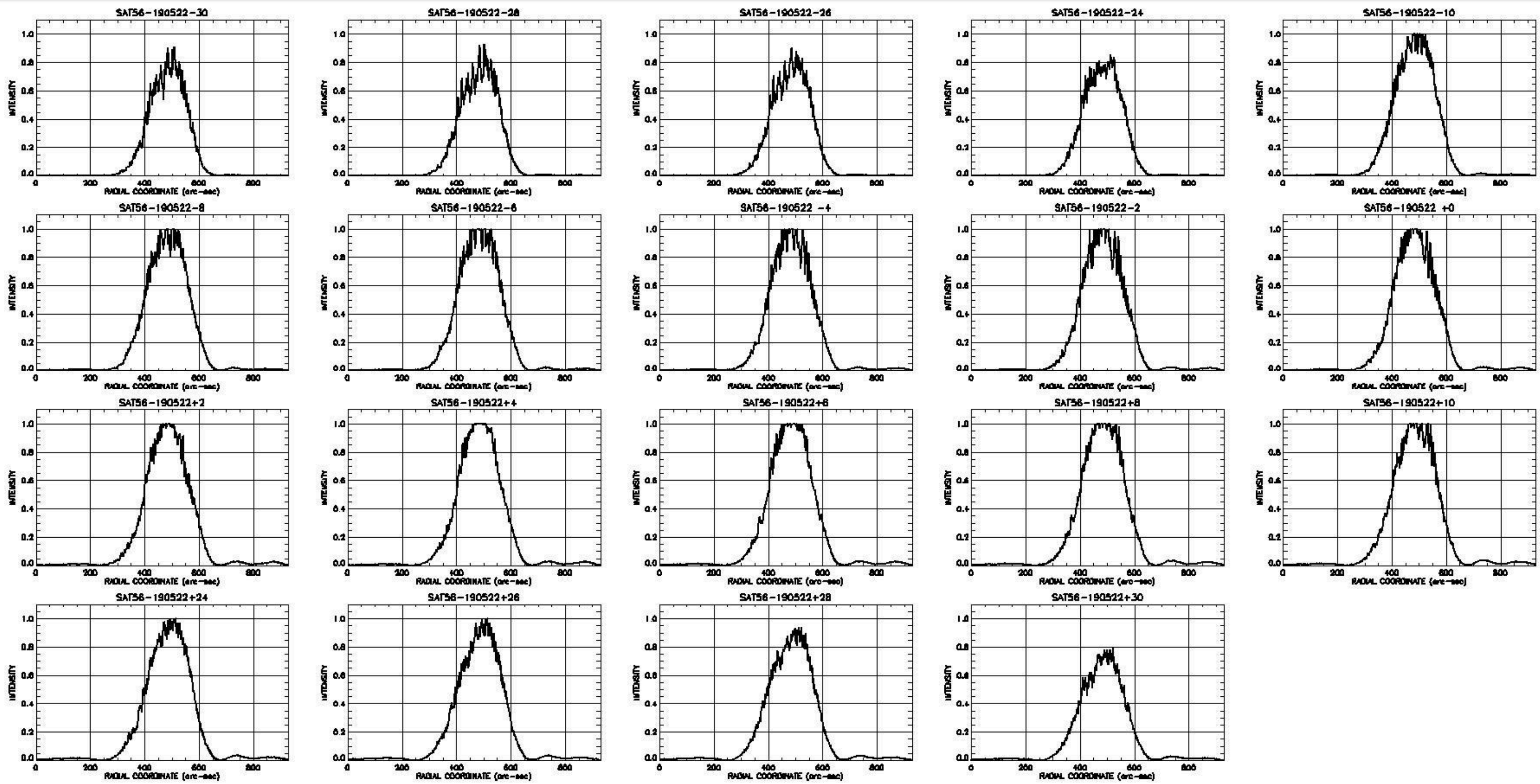
2. Determination of Focus Error

- Optical parallel beam to provide full illumination at grazing incidence
- Sub-aperture “Hartmann” measurements to determine image centroids
- Diffraction
- Repeatability ≈ 0.3”

- An off-axis paraboloidal mirror to provide the parallel light beam
- Blue light is used to minimize diffraction
- Large difference between mirror in the primary and the secondary stages
- Sub-aperture slit also produces diffraction the transverse direction



Detailed Image Profiles

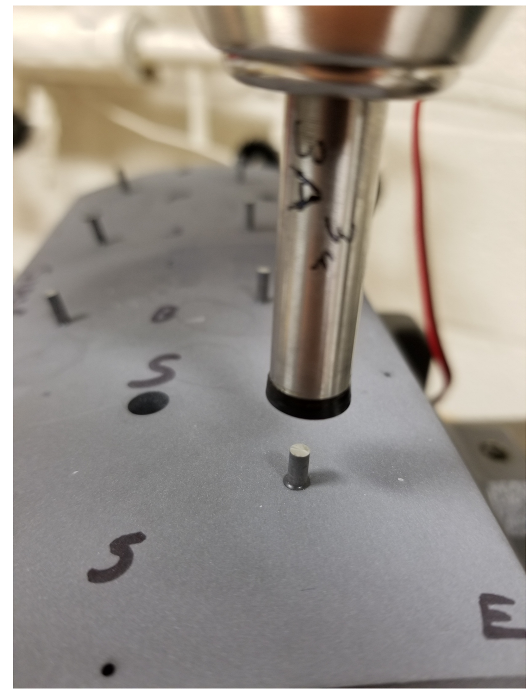


Technical Issues. 3. Spacer Height Correction

How to accurately, and efficiently, modify the spacer height?

3. Modification of Spacers

- Current method: polishing
- Height requirements for supporting spacers ≈ 0.1 μm for < 1″ alignment
- Precision 0.1 μm



- Post-polish rough check by radius gauge to ~ 0.1 μm
- Detailed centroid distribution from optical Hartmann measurements

Technical Issues. 4. Bonding of Mirror

How to bond/fix the mirror reliably?

4. Bonding mirror with epoxy

- Currently completed manually, in the process of mechanization
- Critical parameters
  - Size of epoxy bead
  - Viscosity of epoxy
  - Mass of mirror
- Mirror is agitated into (already set) orientation
- Mirror distortion due to epoxy curing

Mechanization is needed for reliability (precision of mirror placement, precision of epoxy bead, etc.)

Distortion depends on: Size of epoxy beads (diameter of spacer), stiffness of mirror

Technical Issues. 5. Alignment and Bond Subsequent Mirrors

How to co-align subsequent mirrors?

5. Align subsequent mirrors

- Primary and Secondary stage alignment of mirrors in the same shell is determined by focusing of the combined image
- Co-alignment of mirrors in subsequent shells is independent of previous alignment, as long as subsequent bonding does not distort the existing module (That is, the exact same procedure can be carried out again.)

- Translational alignment error between the primary and secondary stage is negligible
- Only 1 of the orientational alignment errors for Primary and Secondary stage is set independently
- The other is determined by the focusing of the combined image

- Independence of mirror alignment in subsequent shells also implies no stack-up error.
- Light from existing stack is blocked in alignment of current shell

Results from Aligned Mirrors - Full Illumination in X-ray

SMD12_190524_178_Frown_FullImage
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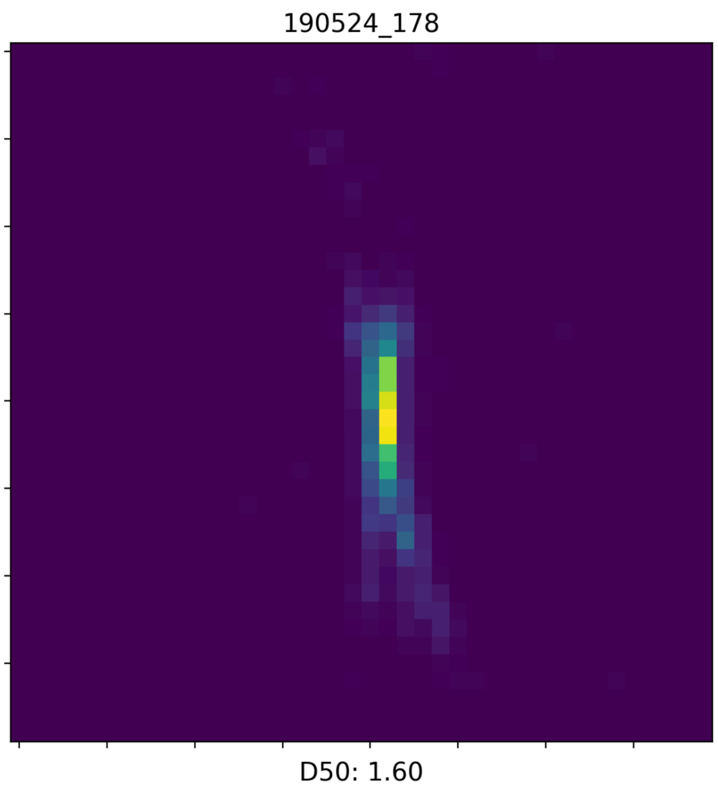
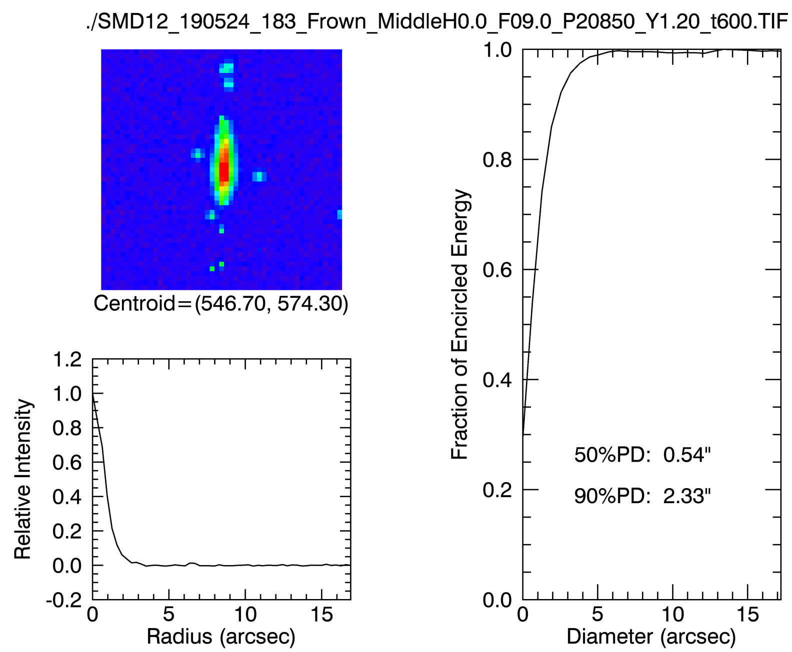


- ❖ HPD = 1.6”
- ❖ Individual sector is good: < 1”



SUMMARY: ALIGNMENT AND BONDING OF SILICON MIRRORS

- **Precise placement of silicon mirrors**
  - Sub-arcsecond mirror placement is achieved on 4-point mount
  - Friction is overcome with acoustic or mechanical agitation
  - Repeatability is better than 0.3”
- **Measurement of focusing**
  - Focusing is measured by sub-aperture Hartmann test in an optical beam
  - Pitch and yaw errors can be derived from the distribution of centroids of diffracted sub-aperture images
- **Fine correction of spacer heights**
  - Relative translational (X and Y) errors are negligible by initial radius measurements
  - Pitch and yaw errors can be corrected by adjusting spacer heights
  - Current method of refinement: polishing
- **Bonding of mirrors**
  - Bonding with epoxy
  - Placement with epoxy is dependent on epoxy viscosity, size of the epoxy beads, and mass of the mirror
  - Distortion due to epoxy curing is minimized by minimizing the size of the epoxy bead
  - Long-term stability of epoxy bonding is being investigated
- **Alignment and bonding of mirrors in subsequent shells**
  - Co-alignment of mirrors in the subsequent shell is independent of the mirrors in the existing module
- **Current result**
  - Current result of a single pair has resolution approaching 1”.

Work plan for the next year

- **To build a multi-shell module**
  - To test co-alignment to comparable precision at 1”
  - To test spacer correction with existing mirrors in an integrated module
- **To improve single pair precision to better than 1”**
- **To test long term stability of integrated mirrors**
- **Environmental tests**
  - Vibration and shock tests
  - Thermal-vacuum test
  - Acoustic test