Performance of the Center-of-Curvature Optical Assembly during Cryogenic Testing of the James Webb Space Telescope

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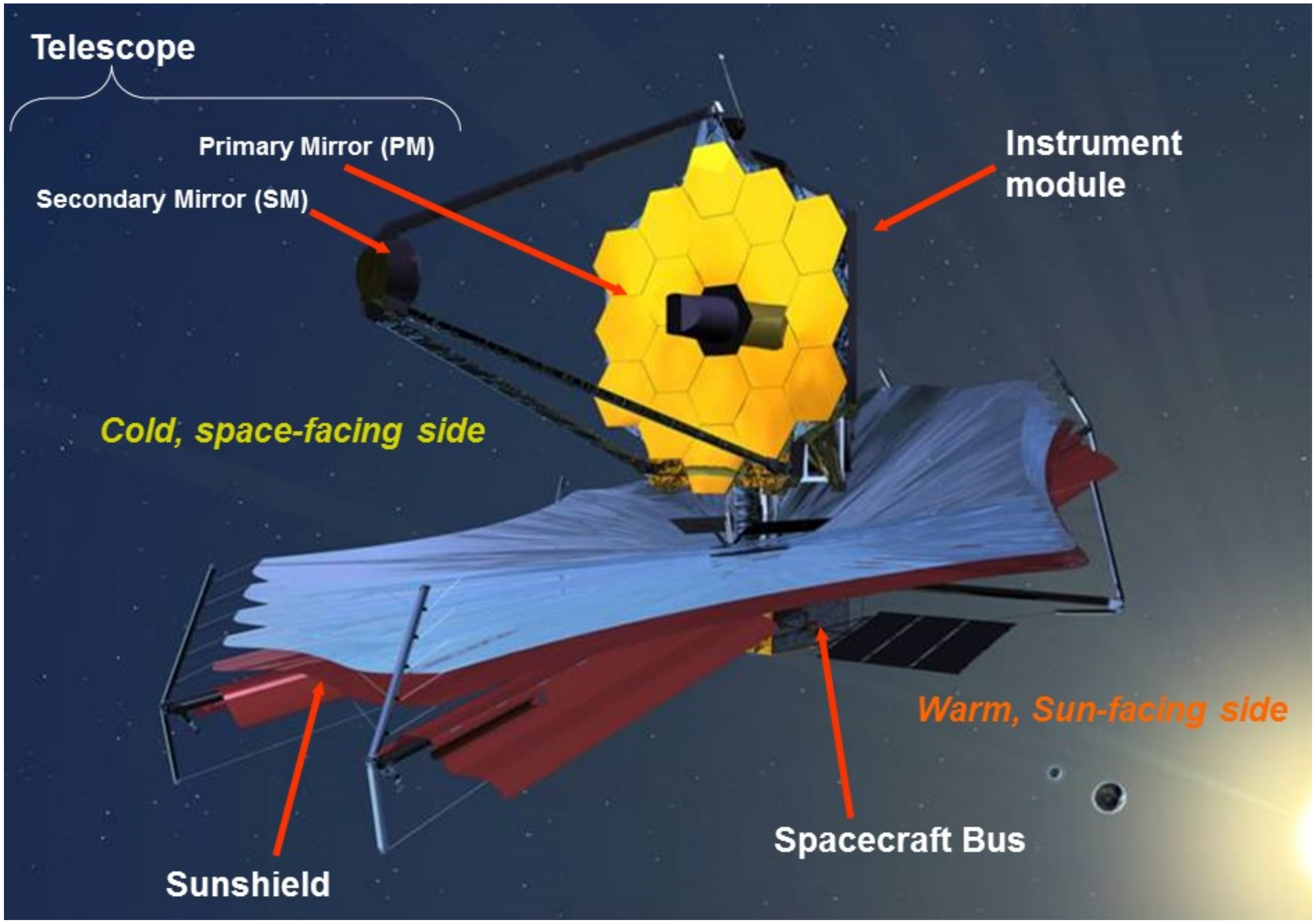
The James Webb Space Telescope (JWST)

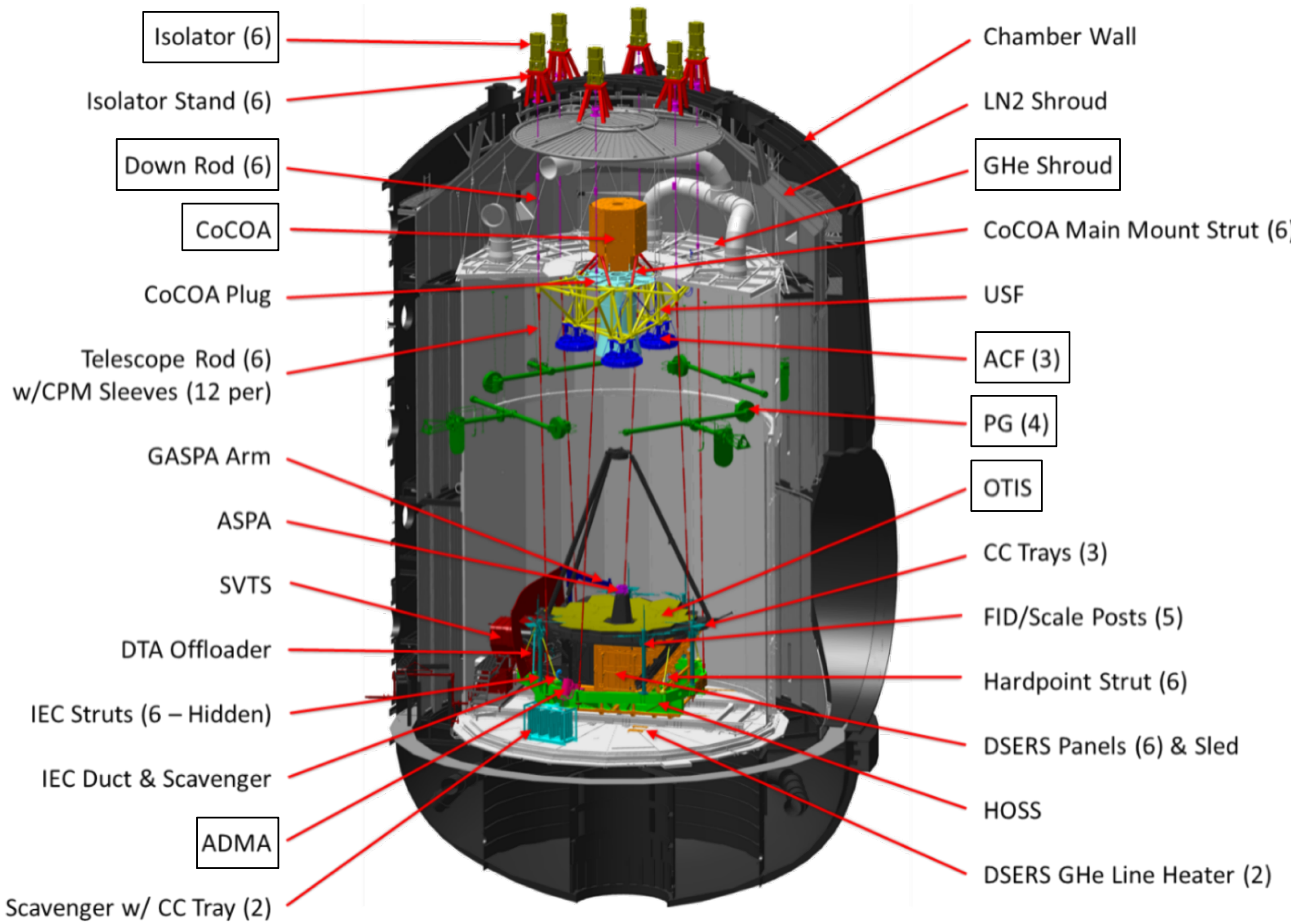


- Near & mid IR
- 3-mirror anastigmat
- Orbit around L2
- NASA, ESA, & CSA

- 6.6 m diameter PM
- 18 segments
- Beryllium w/ gold coating
- 6-DOF & ROC each seg
- 32-59 K operational temp

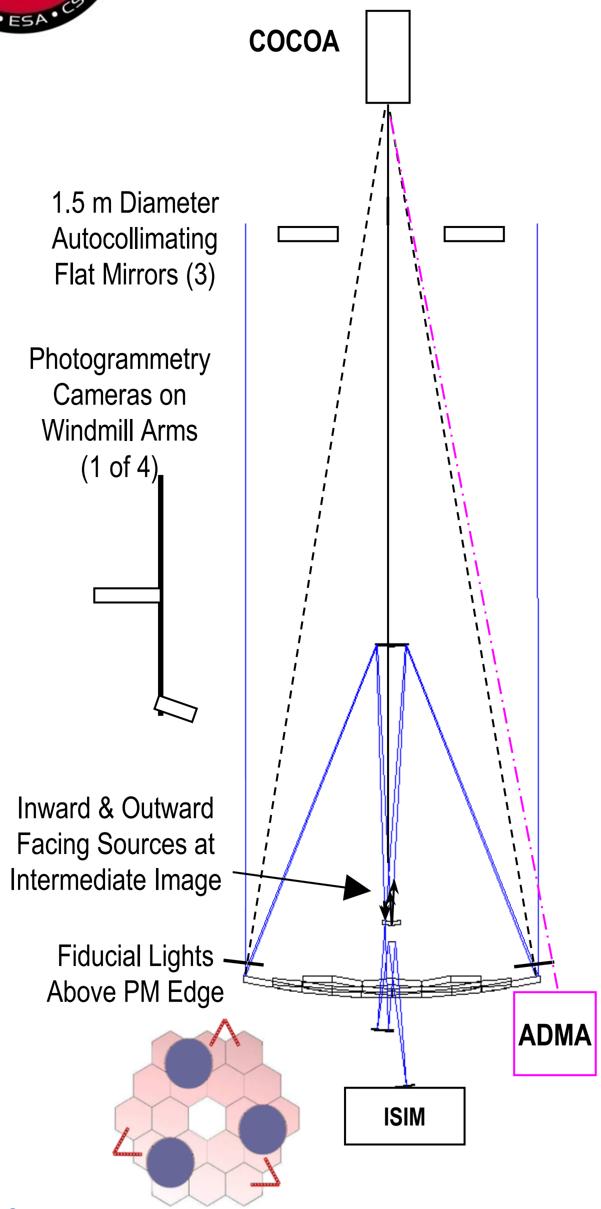
JWST Cryogenic Test Overview

Chamber A at JSC



JWST in Chamber A at JSC

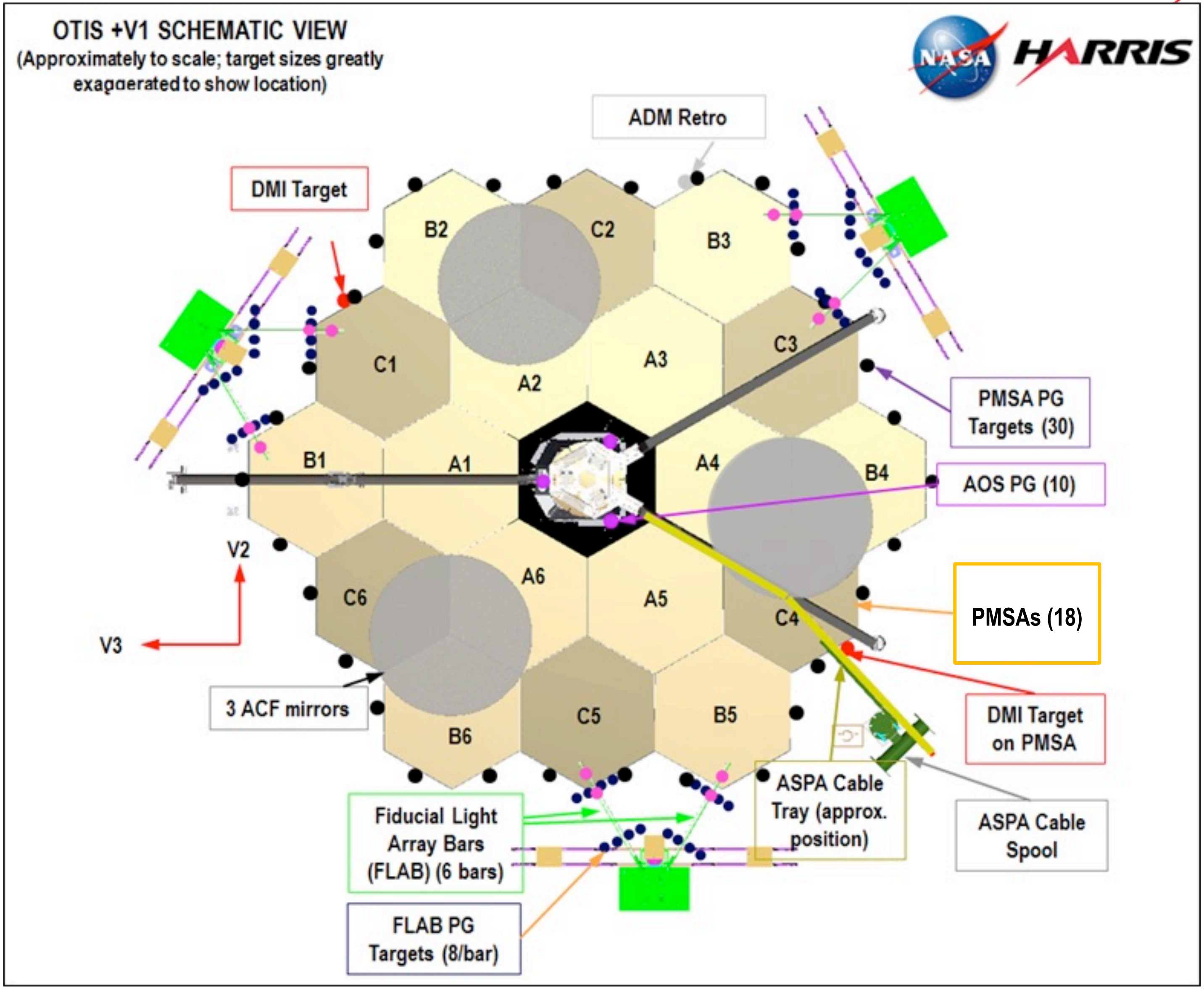
Optical Layout for JWST Cryogenic Test



PM Alignment & Measurement

- **Photogrammetry (PG) for global positioning.**
- **Center-of-curvature optical assembly (COCOA) for PM alignment & wavefront error (WFE) measurment.**
  - Alignment cameras for initial capture.
  - Multi-wavelength interferometer (MWIF) & reflective null for final alignment & PM WFE measurement.
  - Computer-generated-hologram (CGH) for interferometer/null WFE calibration.
  - Displacement measuring interferometers (DMIs) to monitor axial change during thermal distortion test.
- **Fiducial lights around PM for initial alignment.**
- **Absolute distance meter assembly (ADMA) for axial distance/ROC.**

PM Layout for JWST Cryogenic Test

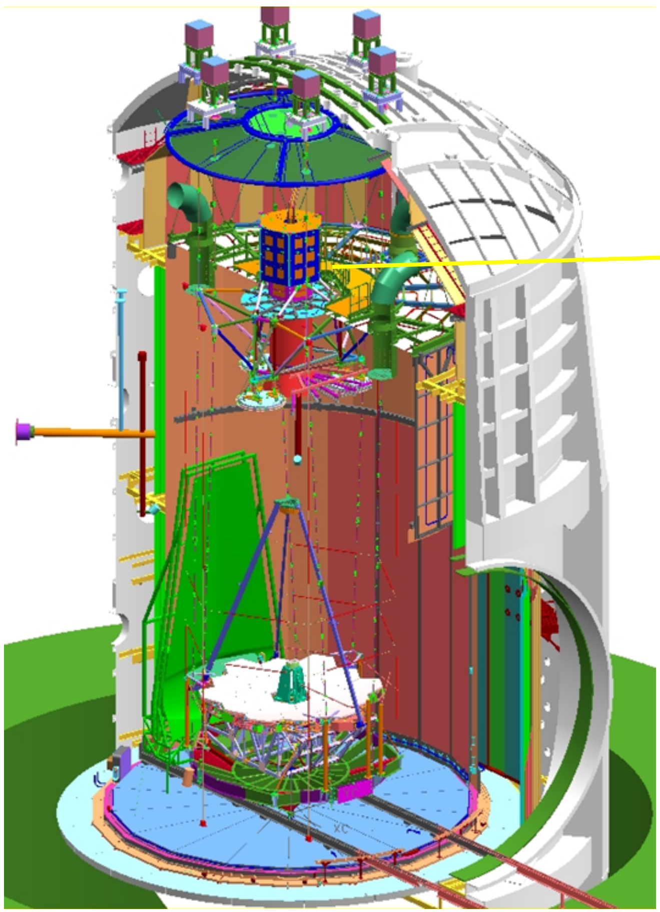


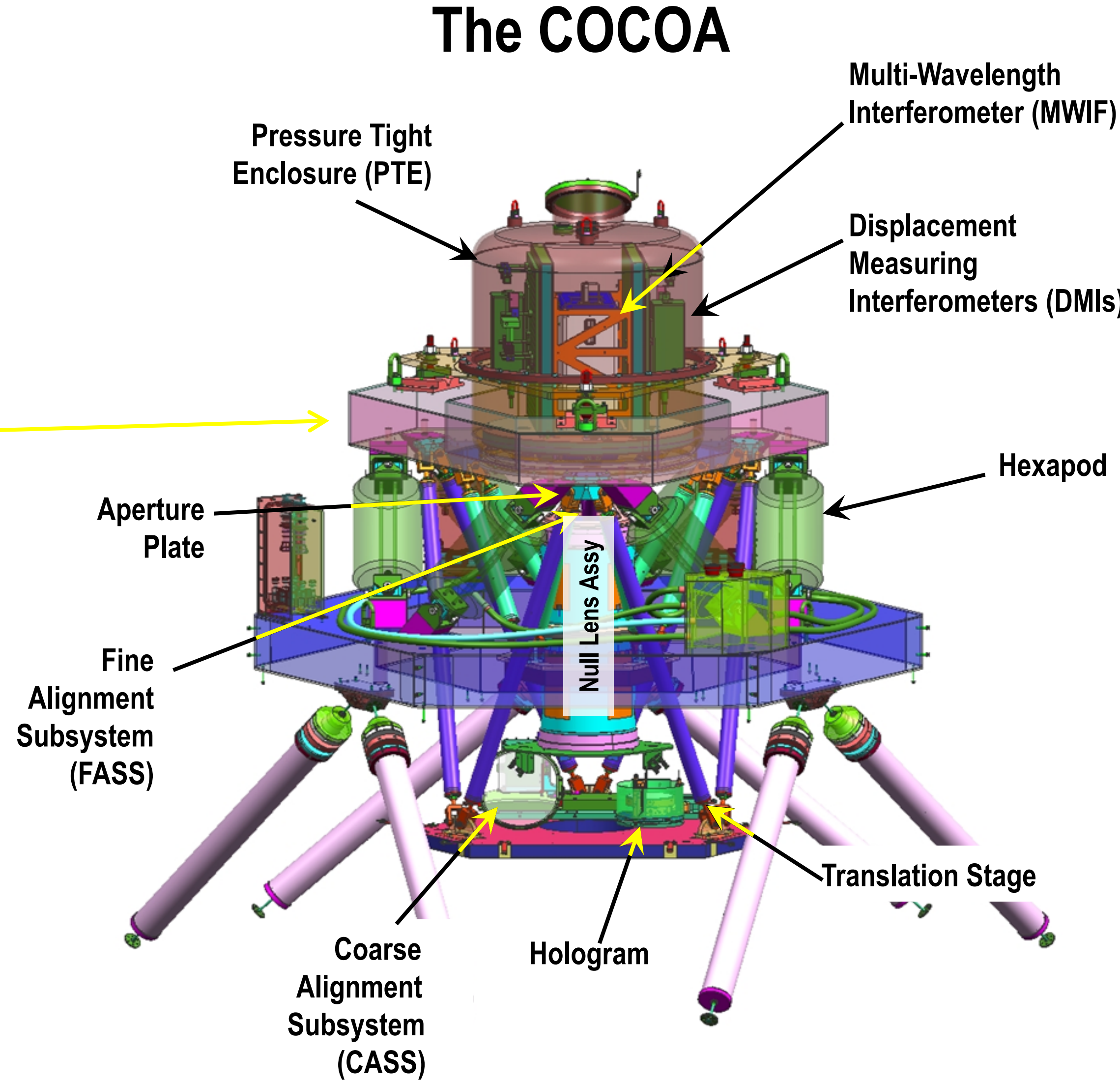
PM Alignment & WFE Measurement Overview

- **Objectives:**
  - Align PM Segment Assemblies (PMSAs) into a phased PM, with proper ROC & conic constant, and align phased PM globally to fixed Aft Optical System (AOS).
  - Measure phased PM WFE, ROC, conic constant, & collecting area in 1g test environment.
  - Realign & measure WFE as required to support other testing, such as PM Thermal Distortion Figure Drift Tests and Pass-and-a-Half testing.

- **Phased PM measurement results used to:**
  - Compare measured 1g PM WFE to prediction.
  - Estimate 0g PM WFE.
  - Check measured 1g PM ROC & conic constant deltas from nominal to expected uncertainties.
  - Determine PM collecting area and compare to prediction.

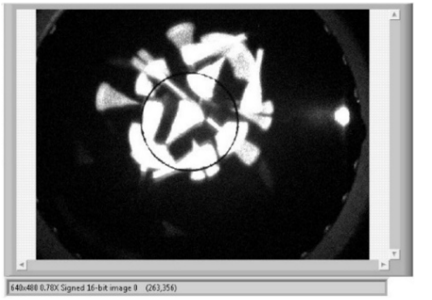
The Center-of-Curvature Optical Assembly



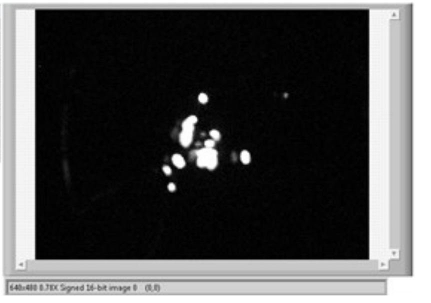


PM Alignment Sequence

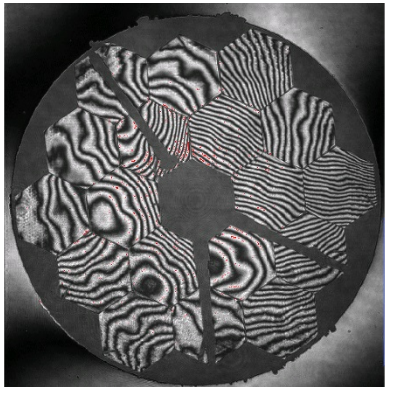
1. **Align outer PMSAs to AOS using PM.**
   – Only outer PMSAs capable of holding PG targets.
2. **Align COCOA to outer PMSAs.**
3. **Align PMSAs in tilt using Coarse Alignment Subsystem.**
   – To within range of Fine Alignment Subsystem.



4. **Align PMSAs in tilt using Fine Alignment Subsystem.**
   – To within range of interferometer (i.e. get fringes).



5. **Align & phase PMSAs using Multi-Wavelength Interferometer.**
   – Correct PMSA piston errors progressively via step-down process through incremental "synthetic wavelengths" from 15 mm to 17 um.
   – Align PMSAs in tilt, radial decenter, clocking, & ROC to minimize total PM WFE.
   – Adjust COCOA in decenter to minimize PM tilt and pointing to minimize PM coma. Maintain axial distance with ADMA.



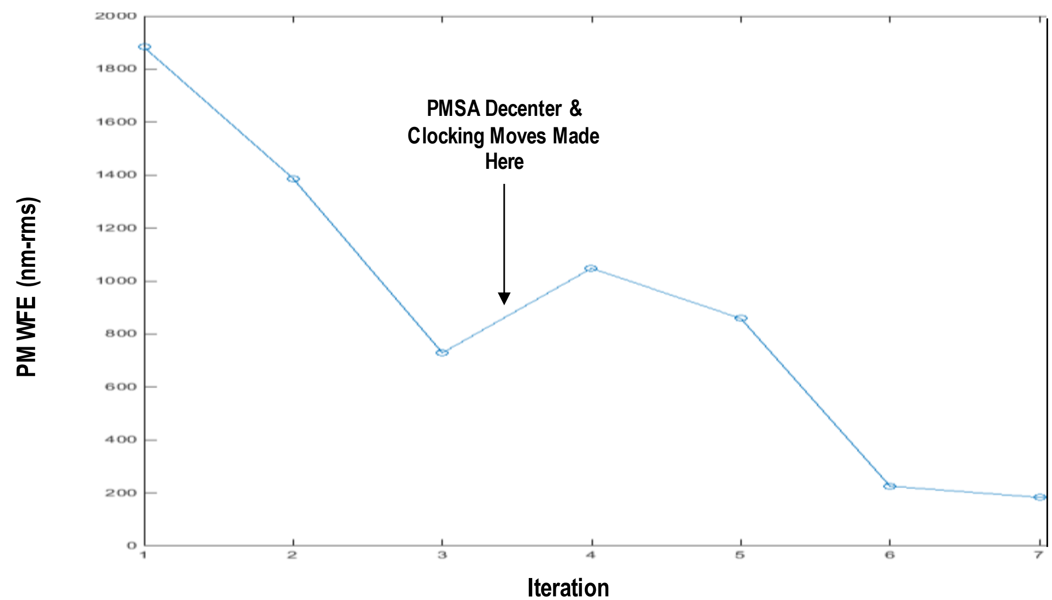
6. **Iterate as required.**

PMSA Alignment Results

Excellent final PMSA alignment & phasing results:

- **Piston: 118 nm-PV** (34 nm-RMS), meeting requirement of ≤150 nm-PV
- **Tilt: ≤83 nrad**
- **Decenter: ≤816 um**
- **Clocking: ≤683 urad**
- **Power/ROC: ≤10 nm-PV**

Good PM WFE convergence:



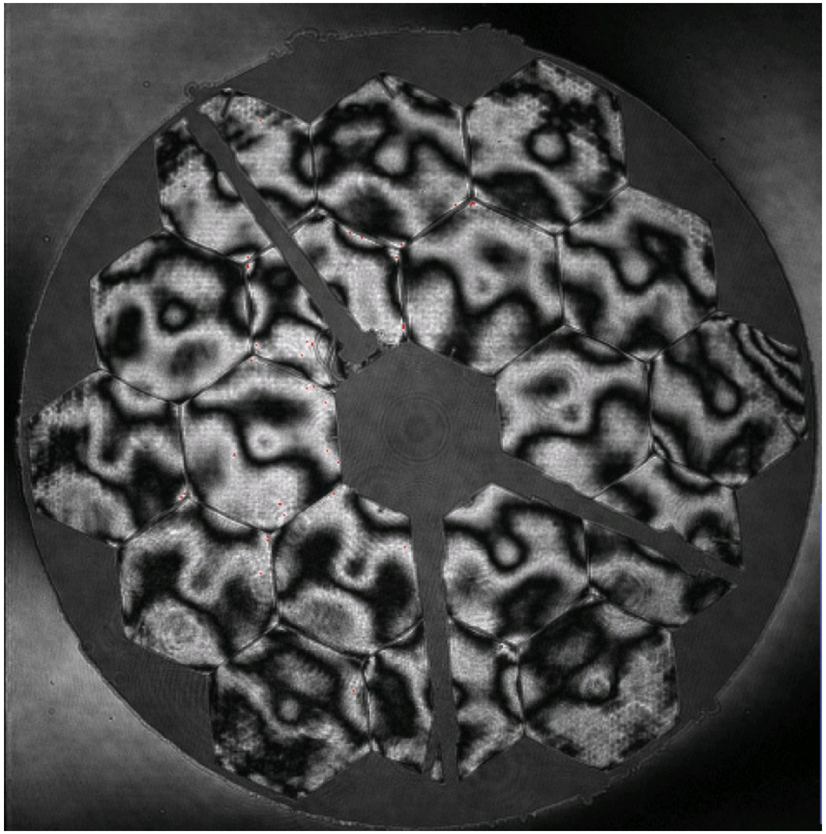
PM Global Alignment Results

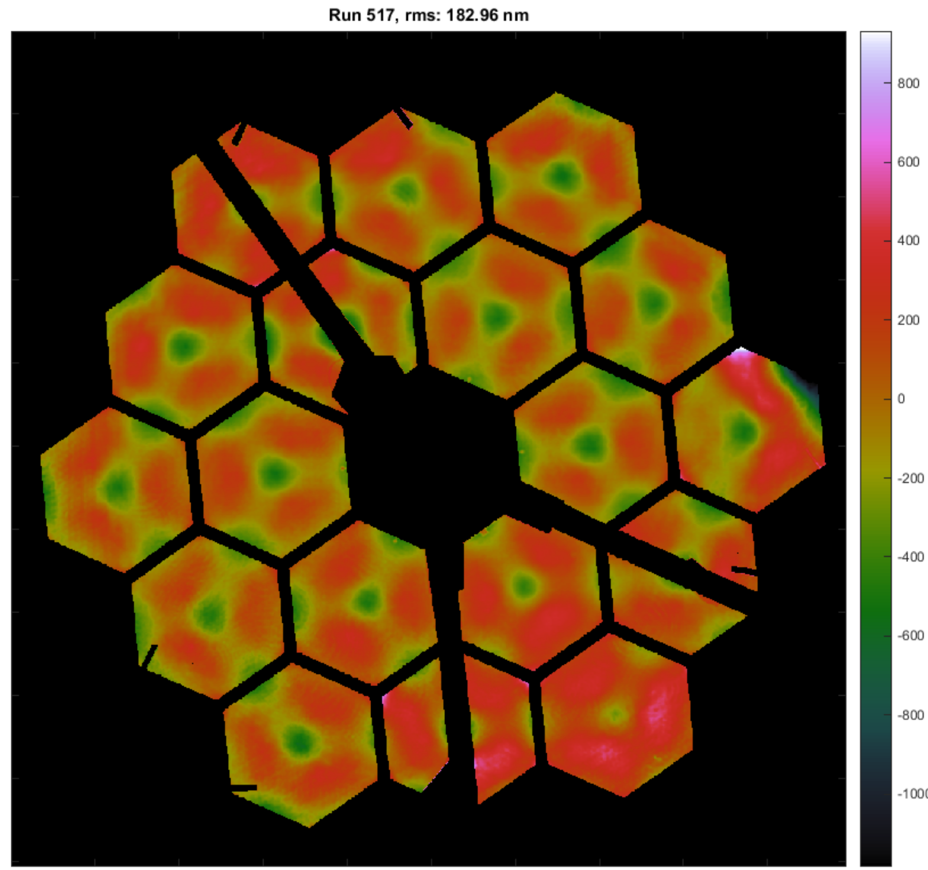
PM global alignment results from PG after final PMSA alignment & phasing:

	Measured	Tolerance
Piston (mm)	-0.016	±0.084
Decenter (mm)	0.451	±0.030
Clocking (mrad)	-0.036	±0.697
Tilt (mrad)	0.065	±0.079

- **During alignment of PMSAs using COCOA, PM was inadvertently misaligned in global decenter.**
  - Cause determined to be error in settings within code used for calculations of PMSA & COCOA alignment moves from measured PM WFE.
  - Error led to incorrect COCOA pointing, resulting in global decenter of PMSAs/PM to realign to COCOA.
  - Could have corrected misalignment. But team determined that alignment was acceptable, since amount of misalignment was known.
  - And ability to globally align PM to within all tolerances demonstrated during late cool-down.

Final PM WFE Measurement Results





- Excellent PM WFE achieved, with low segment-level astigmatism.
- 183 nm-rms achieved close to theoretical minimum of 158 nm-rms.
- Unusual, uncorrectable deformation noticed on PMSA at far right.
  - Determined to be from hang-up of PMSA PG target on edge closeout – not flight issue.

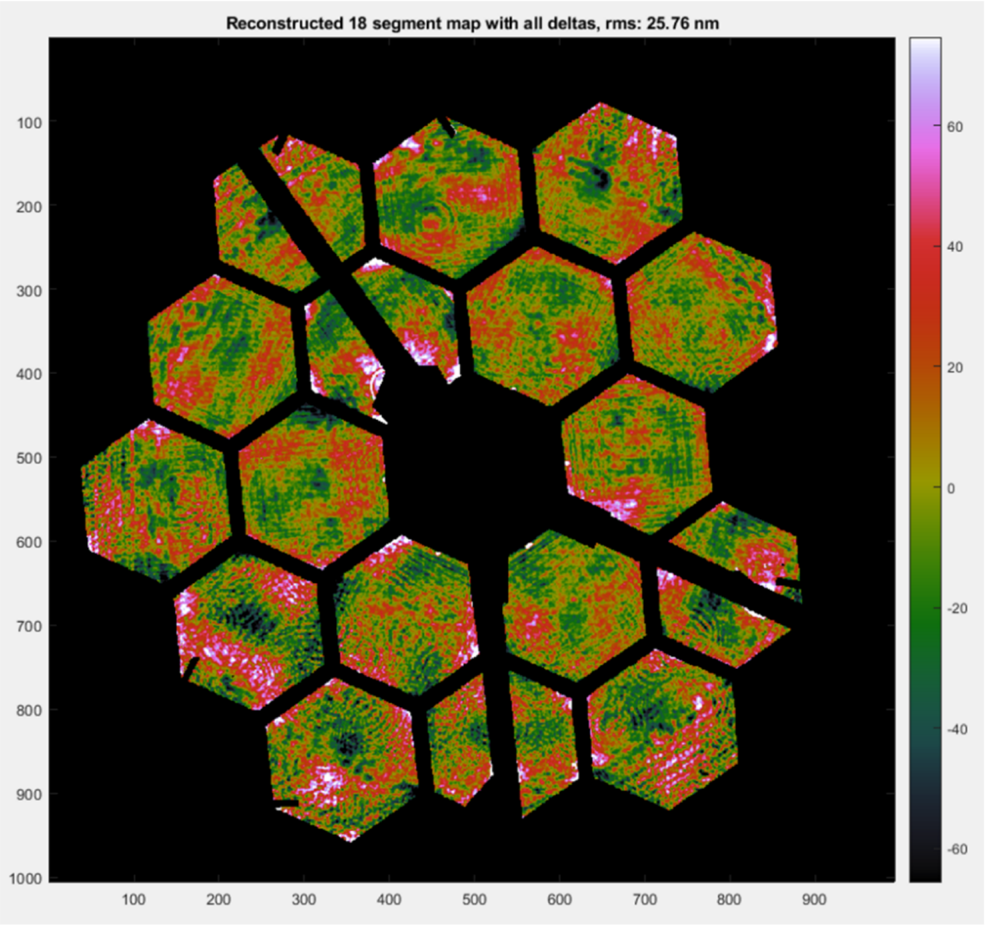
Final PM ROC & Conic and Collecting Area Measurement Results

- **PM ROC & conic results both met requirements.**
- **See Poster 10698-136, "*Setting the James Webb Space Telescope primary mirror radius-of-curvature and conic constant during cryogenic testing*", by Joseph Cosentino for further details.**

Parameter	Measured Value	Delta from Nominal	Estimated Uncertainty	Required Uncertainty
ROC (mm)	15,879.209	-0.013	±0.350	±0.400
Conic	-0.996692	-32 ppm	±21 ppm	±200 ppm

- **Predicted PM collecting area, as viewed from center-of-curvature, was 25.054 m^2 with an uncertainty of +4.3% / -4.2%.**
- **Measured area of 25.411 m^2 matched predicted area to 1.4%, well within prediction uncertainty and below measurement uncertainty requirement of ≤5%.**

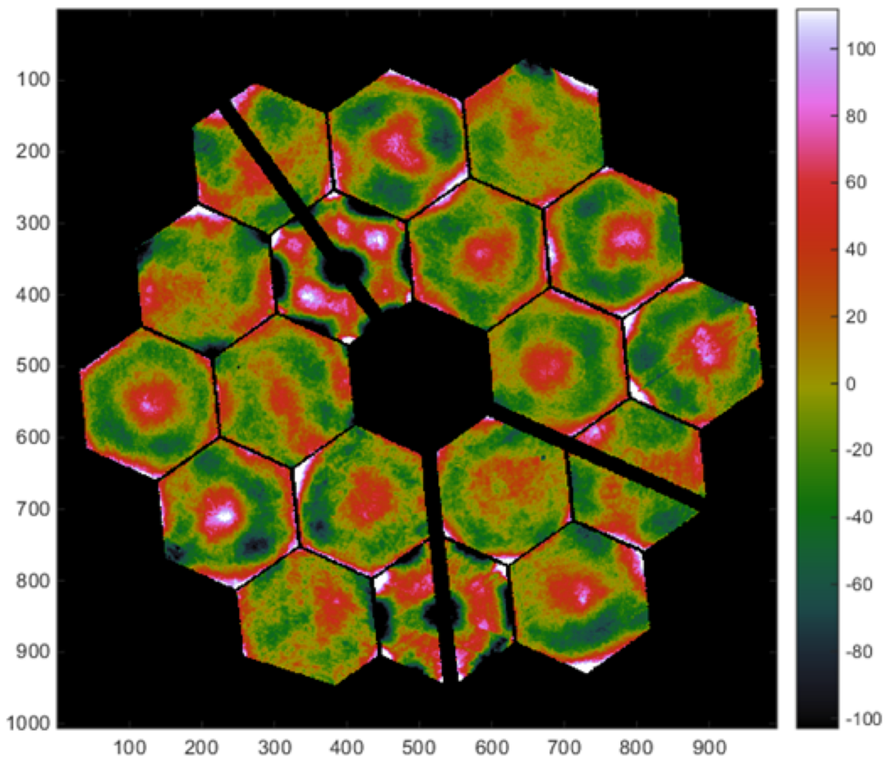
Measured-minus-Predicted PM 1g WFE



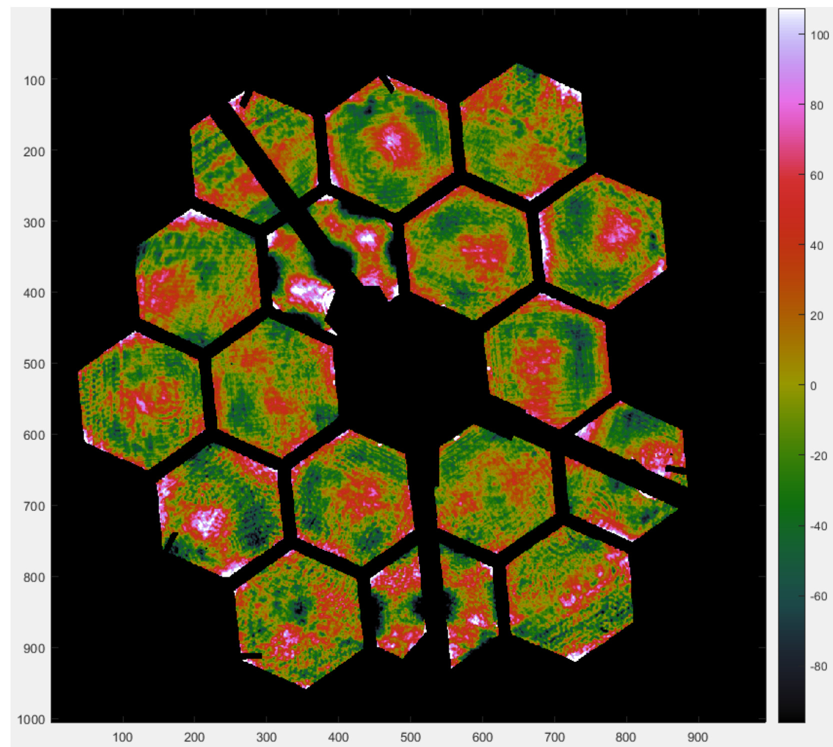
Result of 25.8 nm-rms within estimated prediction/measurement/registration uncertainty of 26 nm-rms. One PMSA not shown due to deformation discussed above.

Estimated vs Predicted 0g PM WFE

Prediction
39 nm-rms



Estimate
37 nm-rms



Prediction from 0g WFE of each PMSA from cryogenic acceptance testing.
Estimate from removal of 1g deformations from JWST cryogenic test measurement.
Excellent visual & magnitude correlation.

Summary & Conclusions

- **All test objectives accomplished.**
  - Aligned PMSAs into phased PM, with proper ROC & conic constant.
  - Measured phased PM WFE, ROC, conic constant, & collecting area.
  - Aligned PM globally to AOS.
  - Aligned PM sufficiently for all other testing.

- **All test requirements met.**
  - Measured 1g PM WFE matched prediction to within tolerance.
  - Estimated 0g PM WFE, with excellent correlation to prediction.
  - Measured PM ROC & conic constant within required uncertainties.
  - Measured PM collecting area matched prediction to within tolerance.