JWST Optical Telescope Element
Center of Curvature Test

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NASA/GSFC

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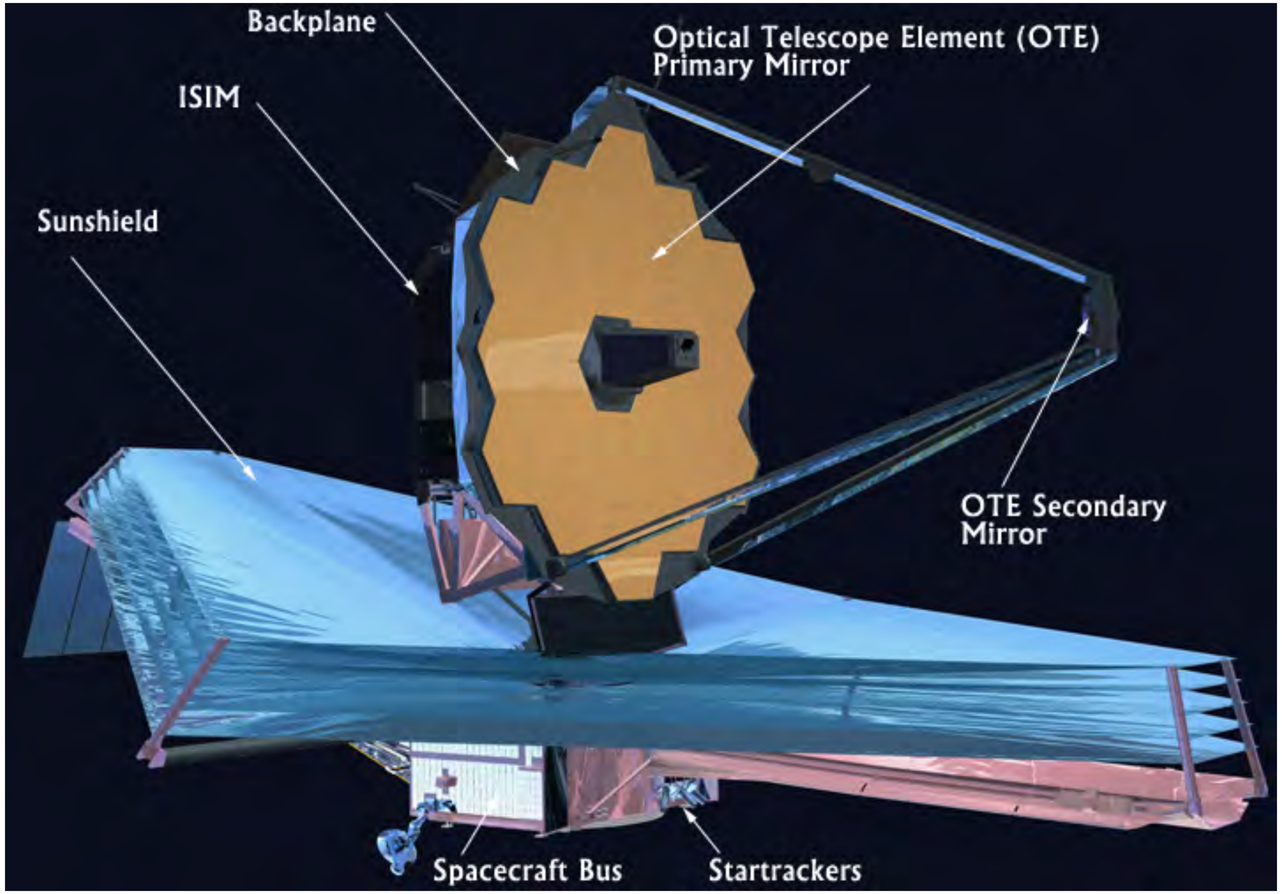
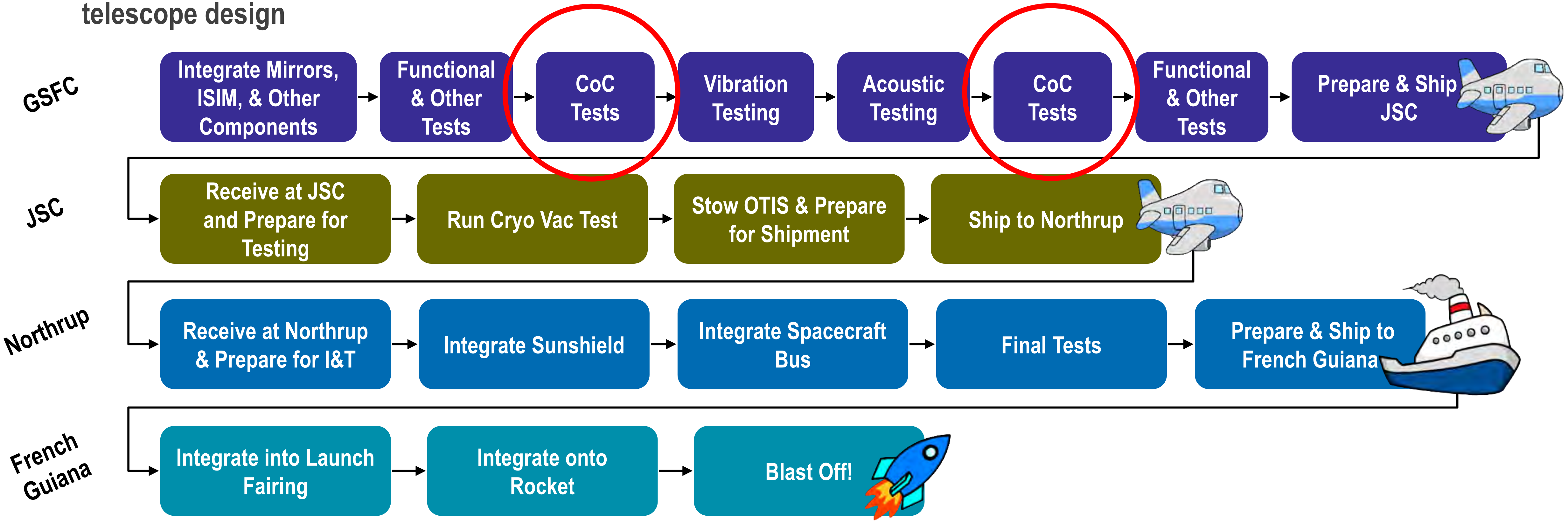
JWST Overview

- **James Webb Space Telescope (JWST) is a large infrared observing space telescope which will launch in 2020.**
- **The observatory is comprised of 4 major subsystems**
  – Optical Telescope Element (OTE)
  – Integrated Science Instrument Module (ISIM)
  – Sunshield
  – Spacecraft Bus
- **The OTE and ISIM are integrated together at Goddard Space Flight Center to form the OTIS assembly**



OTIS Integration & Test Summary

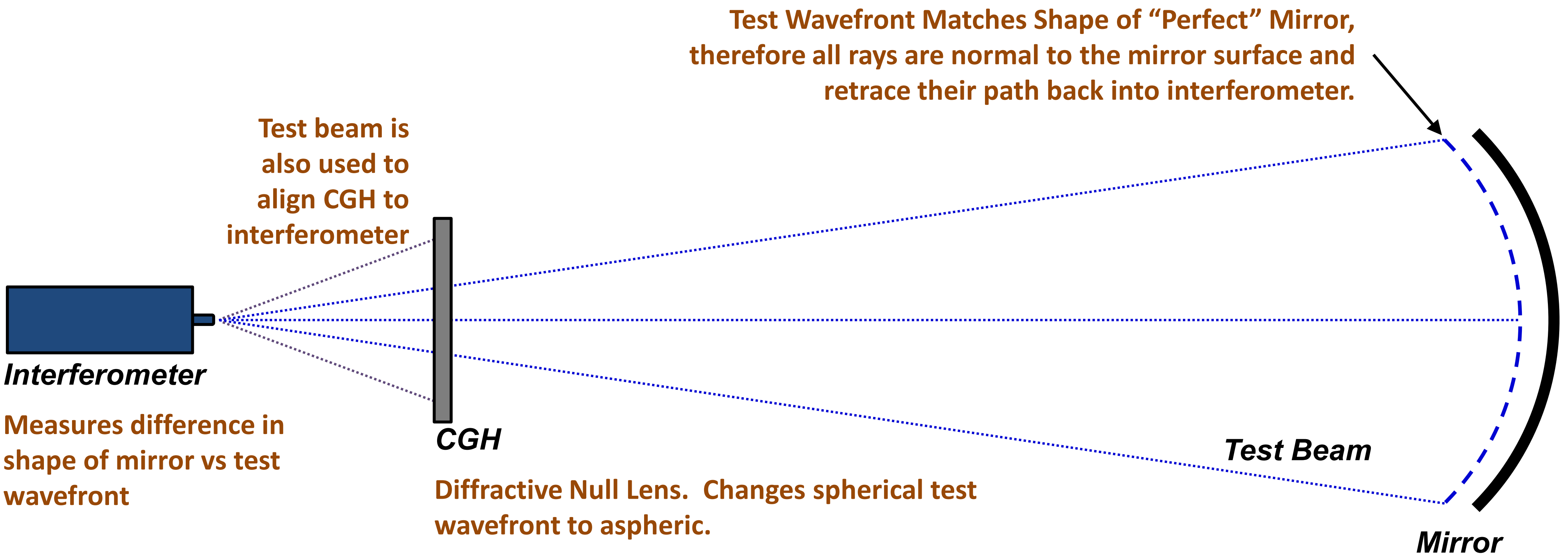
- The OTIS assembly was integrated at GSFC and then went through a series of vibration and acoustic tests to verify its launch worthiness.
- To verify that no detrimental changes occurred to the OTIS assembly from this environmental testing an optical Center of Curvature (CoC) test was conducted
- Help us in understanding potential anomalies identified during the OTIS cryo vac tests and will be helpful for future telescope design



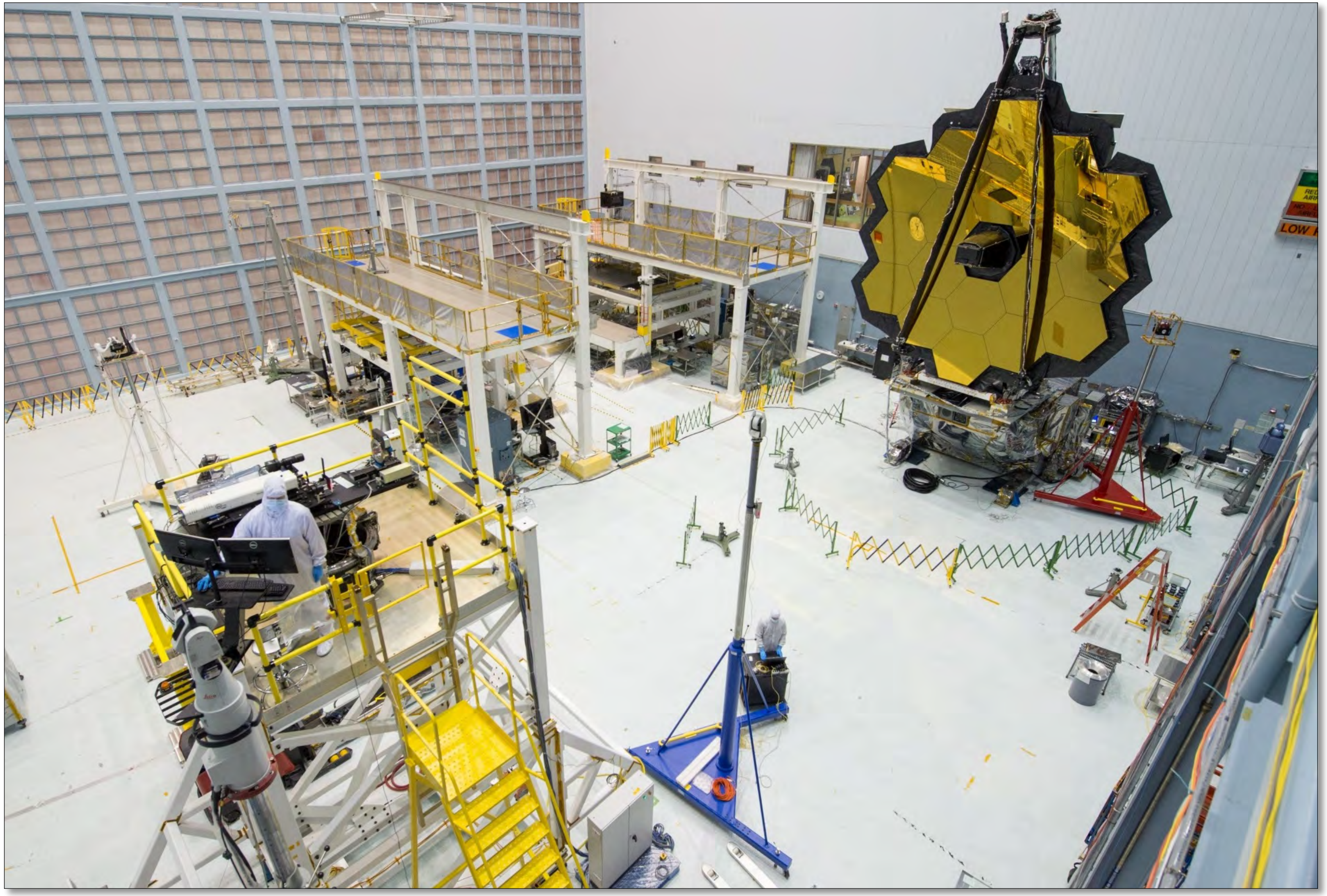
CoC Test Overview

- **CoC (Center of Curvature) test is a standard type of optical test used to measure the surface figure of mirrors using an interferometer.**
  - For the SSDIF CoC test we expanded on this basic center of curvature test methodology by using a high speed interferometer manufactured by 4D Technologies capable of taking more than 5,900 surface figure measurements every second.
- **We measured one mirror at a time (i.e. no phasing of mirrors)**
- **We performed two types of tests**
  - *Static Test:* measures the surface figure of the PM segments (one at a time) and looks for changes in the figure of the mirror. (resolution = 1520x1520)
  - *Dynamic Test:* takes up to 59,000 surface figure measurements over a 10 second period while applying a vibrational input force (stinger) to the OTIS backplane and then calculates changes to the phase and gain transfer functions. This is like having 40,000 one-axis accelerometers on each mirror segment. (resolution = 240x240)

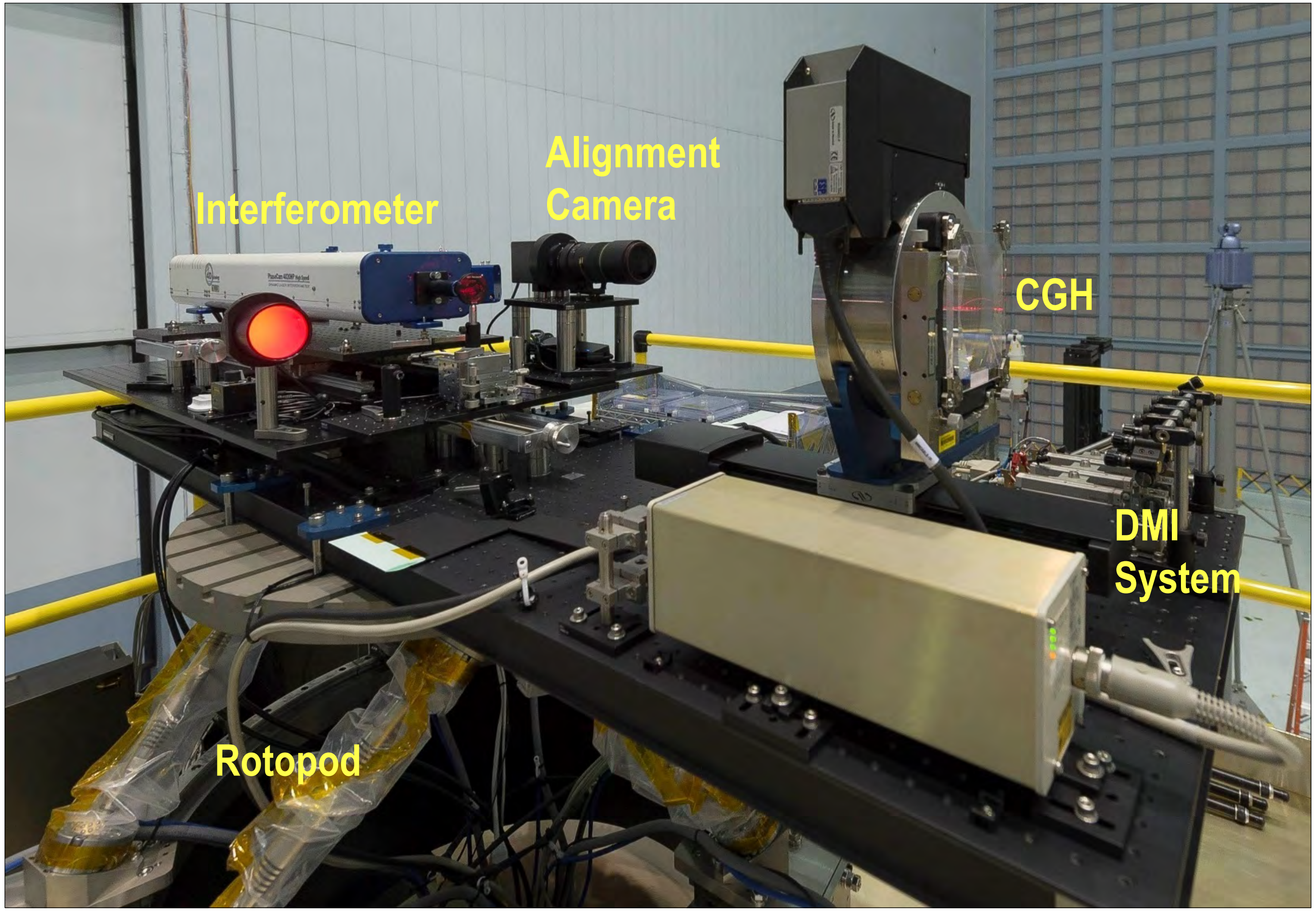
Basic Test Layout



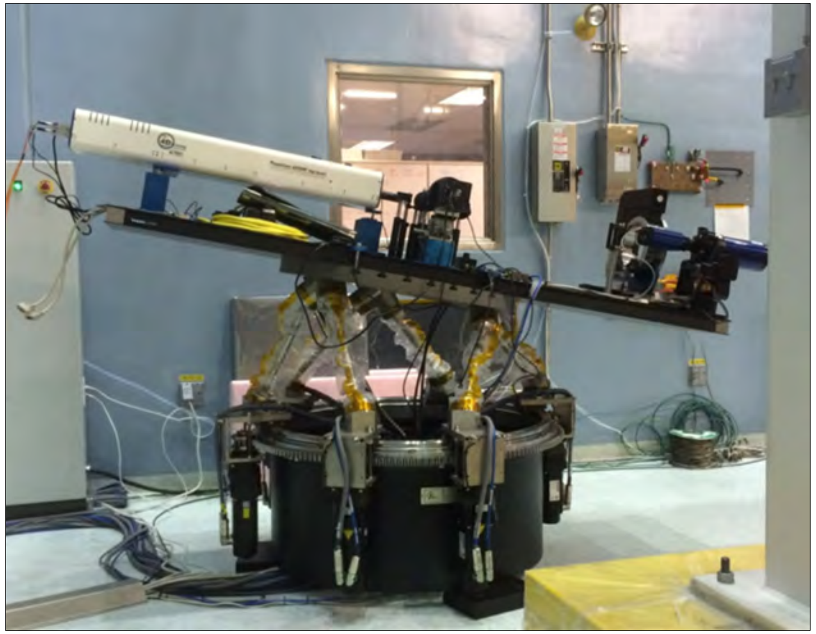
Picture of Actual Test Layout



Metrology Setup

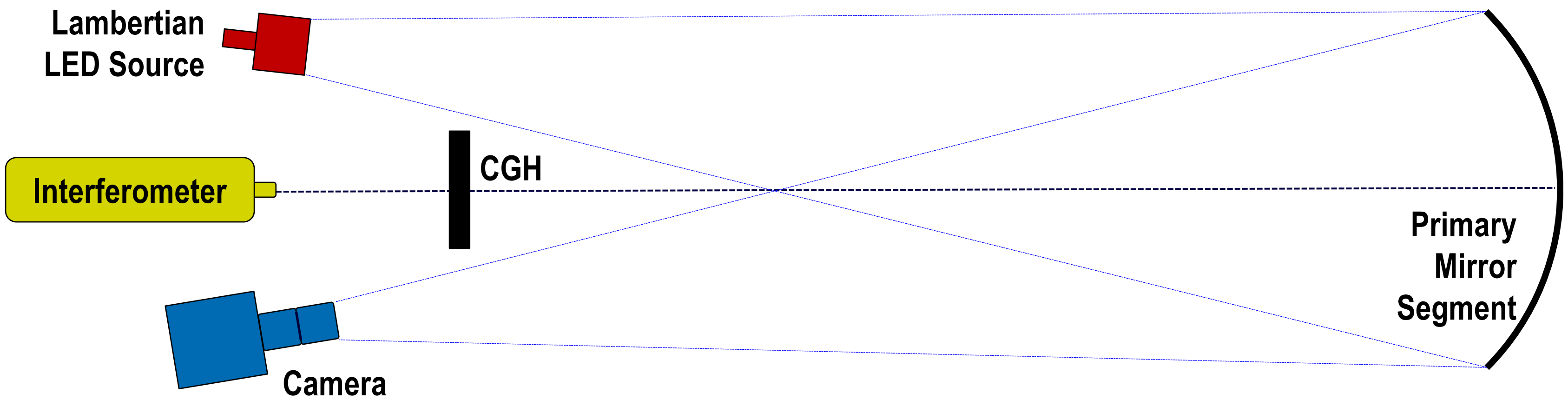


Rotopod



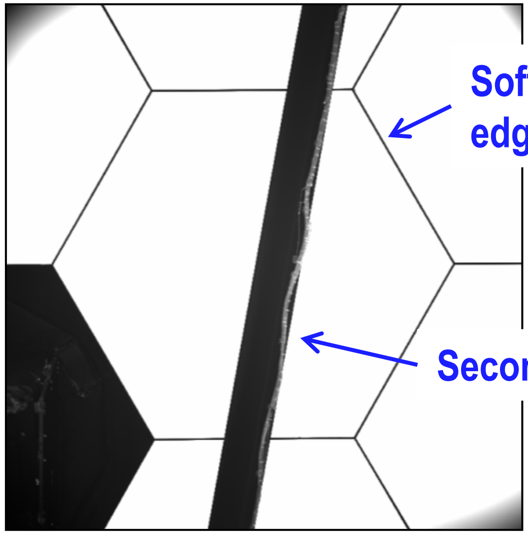
Alignment Camera System

- An newly developed alignment method was used to align the mirror under test to the CGH in 6 DoF.
  - Did not require adding fiducials to the sides of mirror segments (they are only 6-7 mm apart)
  - Used for matching alignment condition during pre and post environmental CoC testing
  - A camera system took two images
    - First image is of illuminated mirror
    - Second image is of 4 Laser spots projected from CGH onto mirror surface

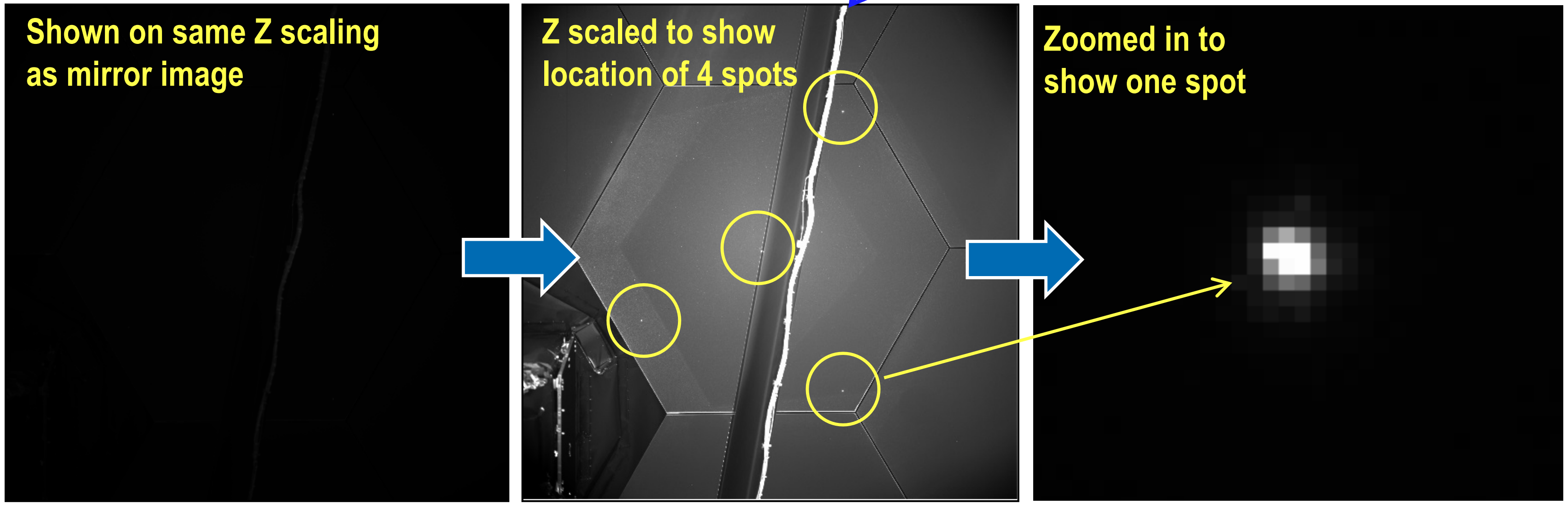


Alignment Camera Images

Mirror Image

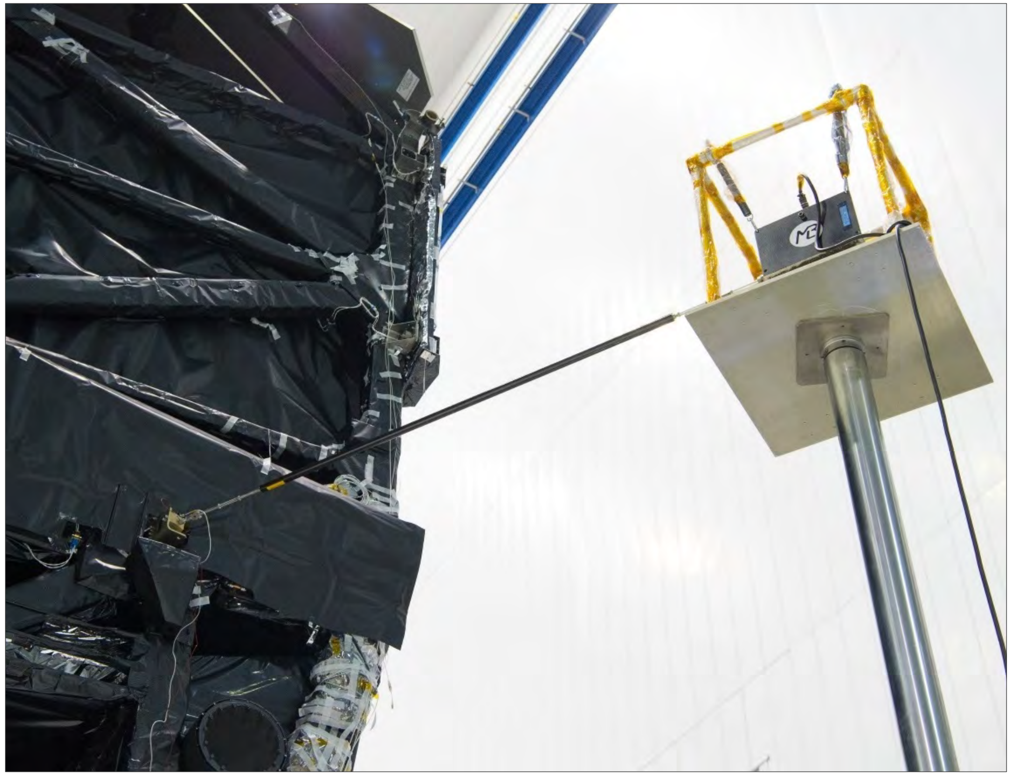


Spot Image



Dynamic Testing Shaker/Stinger

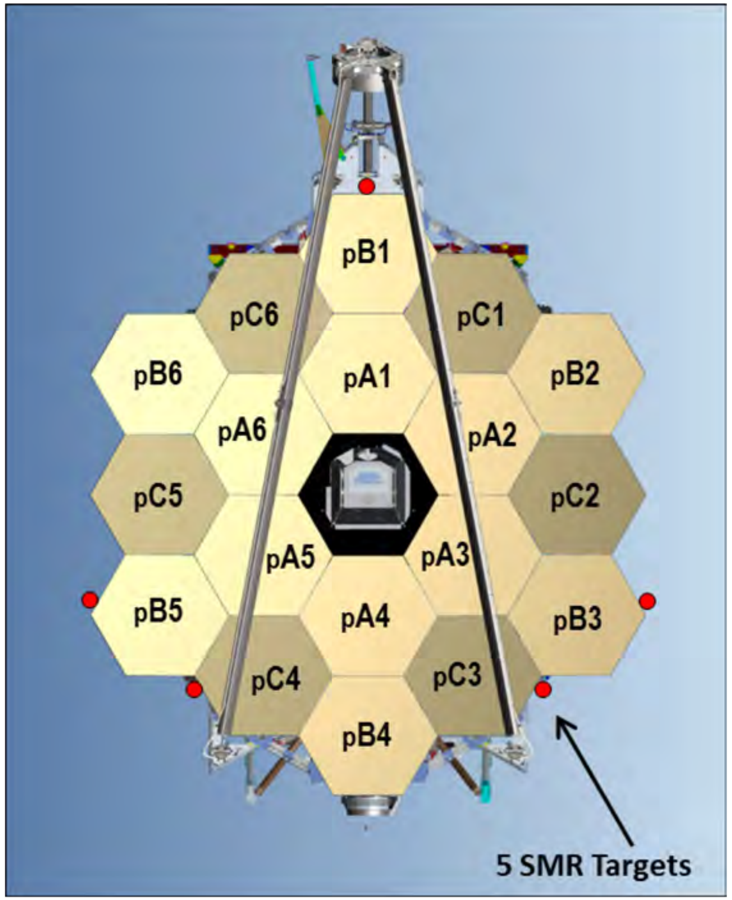
- A vibration shaker is used to apply a low level force into the composite backplane structure.
- Stinger (connection from shaker to mirror) is a graphite/epoxy rod to prevent sagging over the long distance
- A force gauge is attached between the stinger and backplane to capture input forces



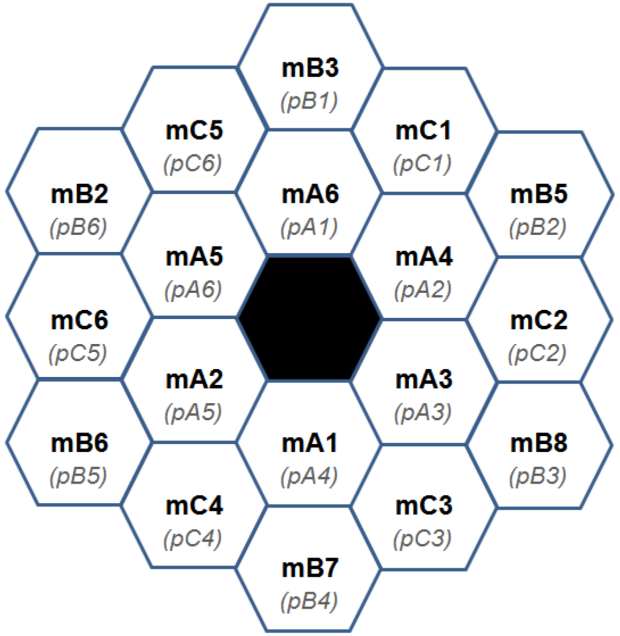
STATIC MEASUREMENT RESULTS

Mirror Nomenclature & Coordinate System

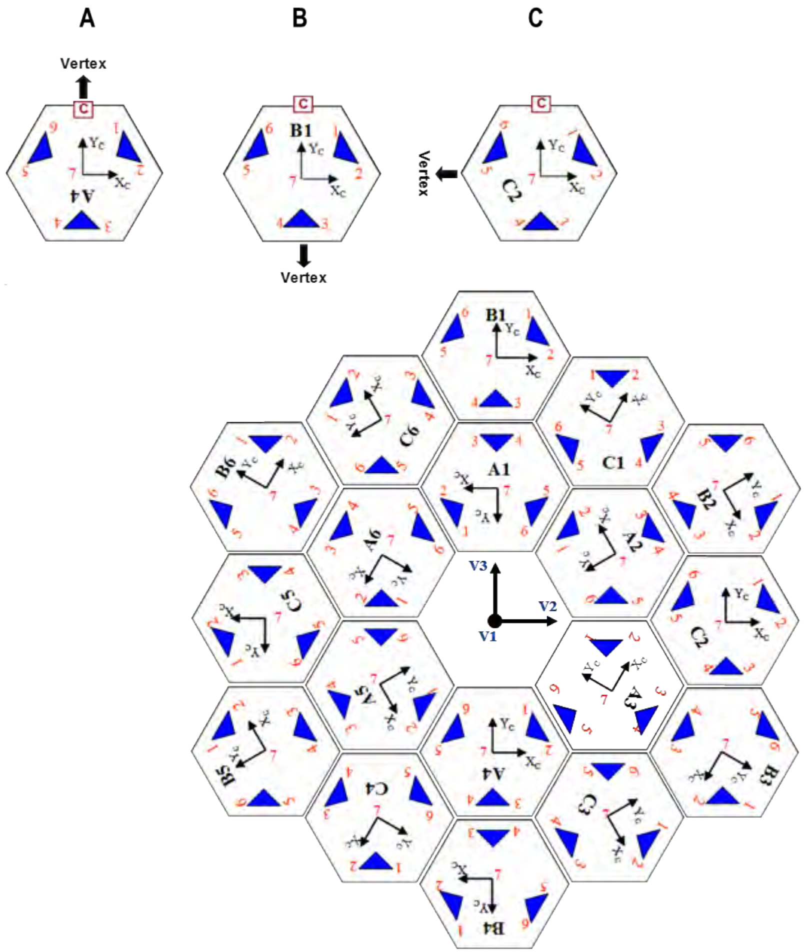
View as Tested



Position vs Mirror ID



Mirror Coordinate System



Composite Image of Surface Figure Changes

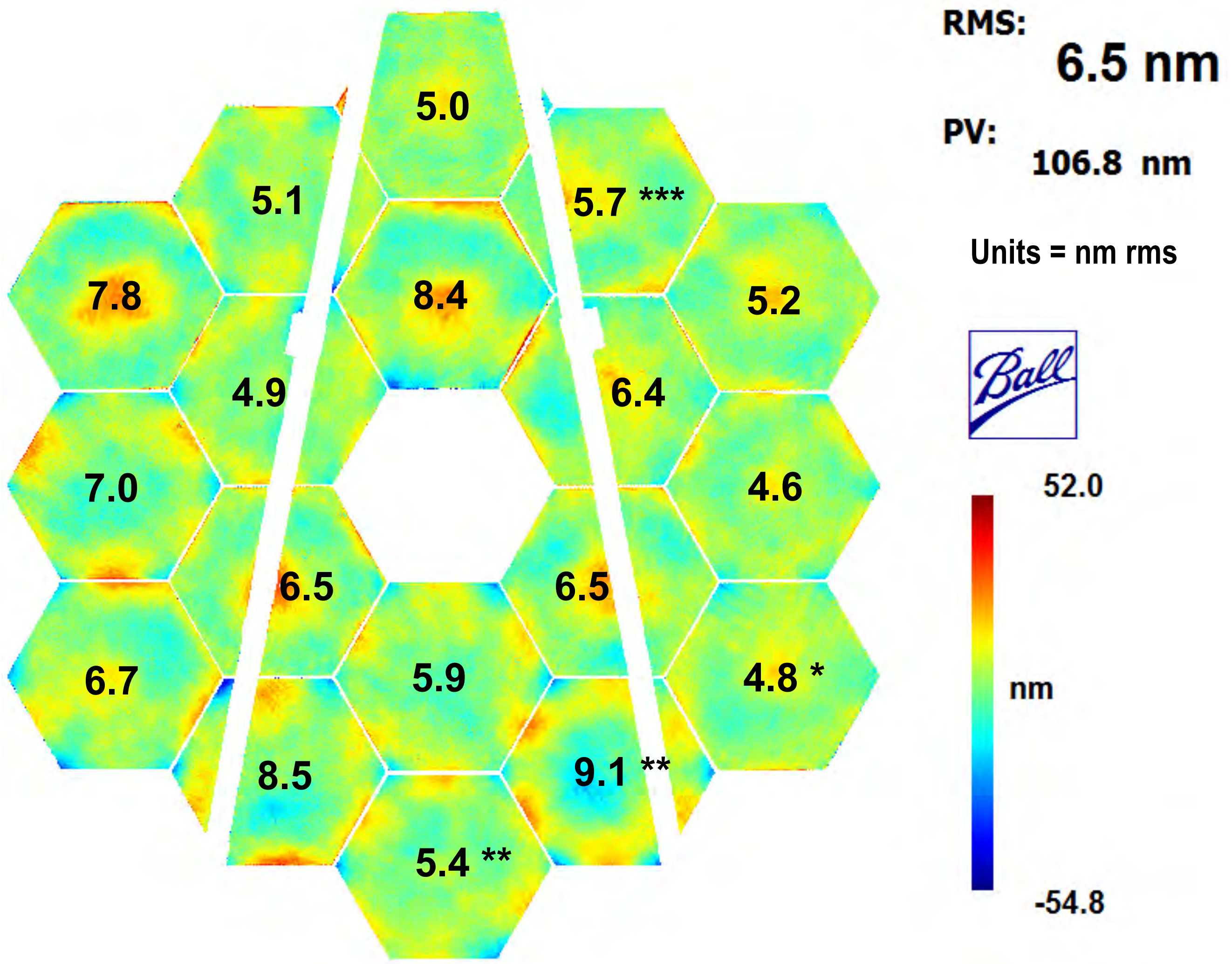
All Measured Changes were under our metrology uncertainty

Metrology Uncertainty	A	B	C
Figure	12	12	12

*   Measured 4 times
**   Measured 2 times
*** Modified Alignment Method

<u>Removed from Data</u>

Piston, Tilt, Power, Astigmatism

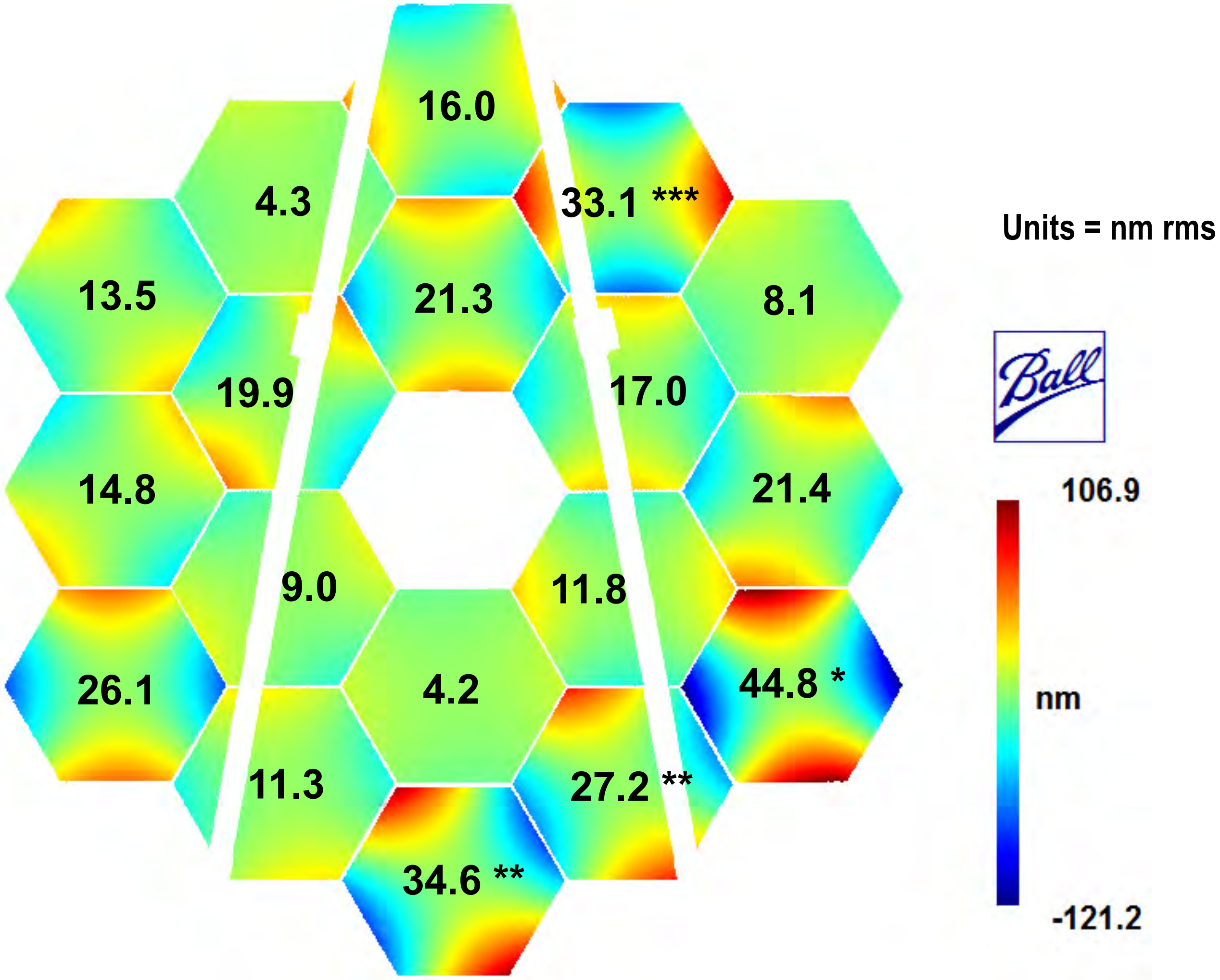


Composite Image of Astigmatism Changes

All Measured Changes were under our metrology uncertainty

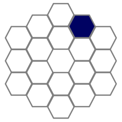
Metrology Uncertainty			
	A	B	C
Astig	26	53	45

*   Measured 4 times
**   Measured 2 times
***   Modified Alignment Method



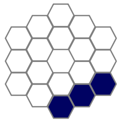
Additional Static Results Analyses

- **pC1 results looked a little high for astigmatism (33nm rms vs 45 uncertainty)**



  - This was probably due to an alternate method used to align mirror. The Secondary Mirror Support Struts interfered with our alignment features (projected CGH spots) and therefore we applied an approach of rotating the CGH 180˚ for alignment and then rotating back for the actual measurement. This added to astigmatism measurement error.

- **Lower right 3 mirrors (pB3, pC3, pB4) showed higher astigmatism levels than other segments**
  - Two potential error sources were looked at.

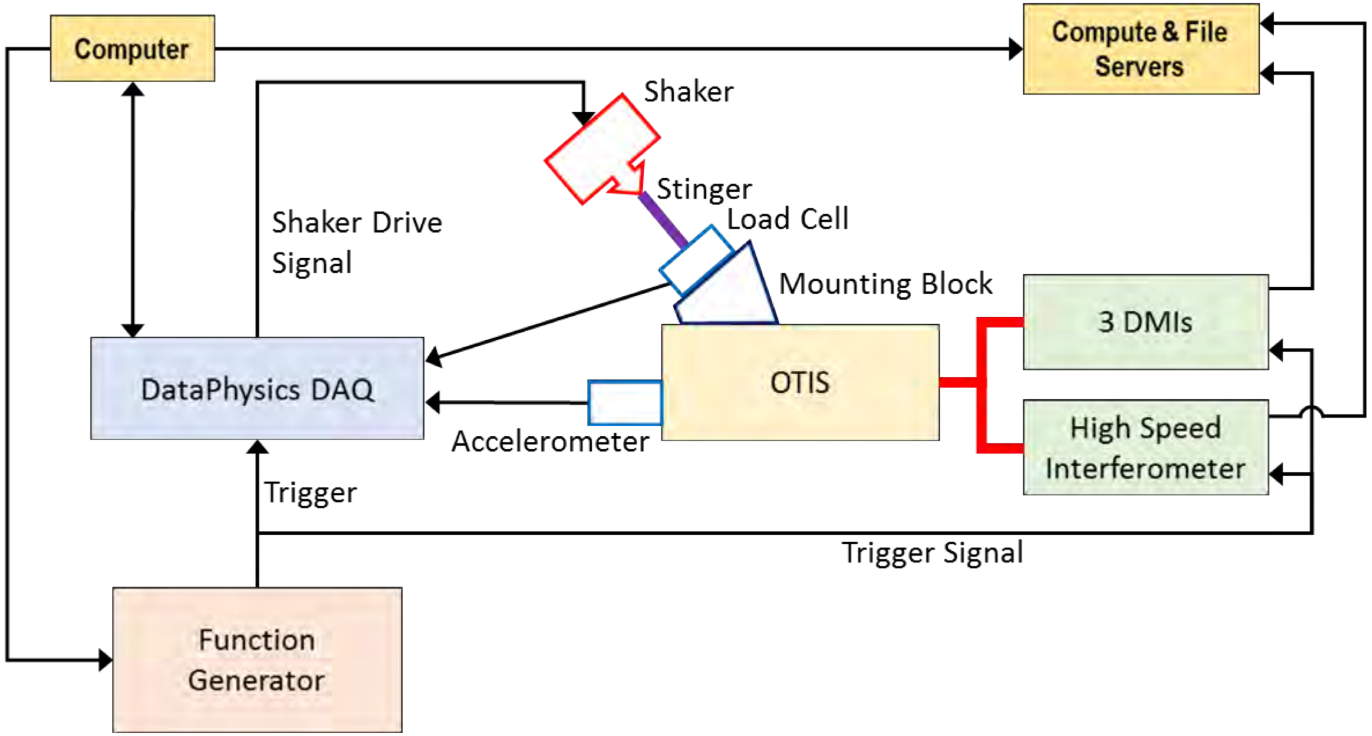


    - Heating from ISIM electronics unit was shown, through testing, not to be the source of the error.
    - Alignment camera system shown to be a “*potential”* source of error. Additional testing showed that additional uncertainties due to room lighting, illumination source power, camera & software settings needed to be accounted for in metrology uncertainty budget.

DYNAMIC MEASUREMENT RESULTS

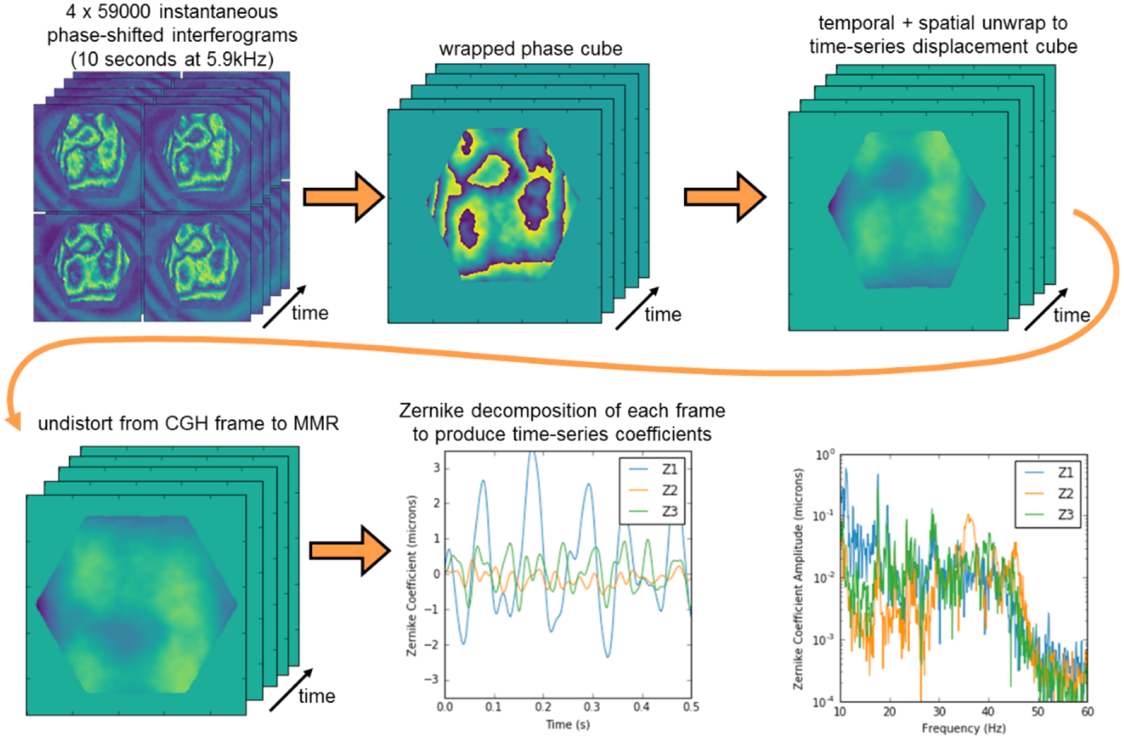
Dynamic Measurement Block Diagram

- The main goal of the dynamics CoC test is to acquire diagnostic survey data of the OTIS vibrational characteristics at low input levels
  - Background with no input stimulus,
  - Sine Sweep over 25-50 Hz or 10-50 Hz
  - Random input.
- The CoC dynamics test uses low level of forcing functions on order of 10 N or less. This force was a dynamic load applied to the OTIS composite structure while the HSI observed a PMSA

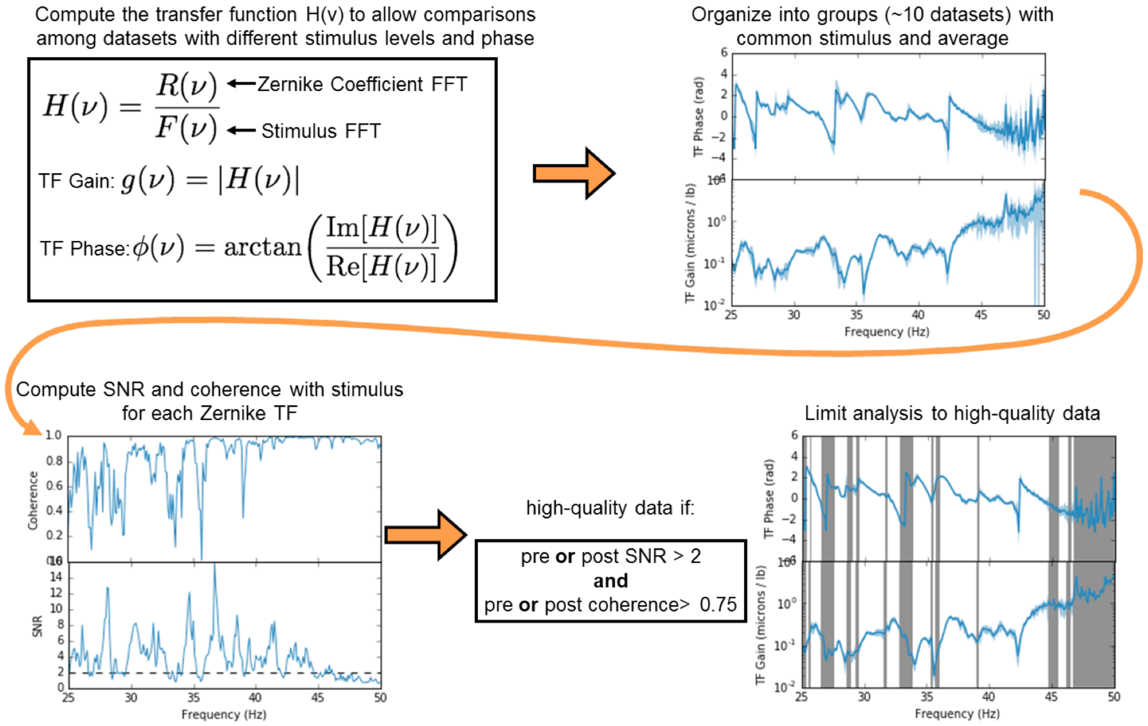


Dynamic Data Processing Flow

Processing Flow Chart
(for a single dataset)



Processing Flow Chart
(combining datasets)

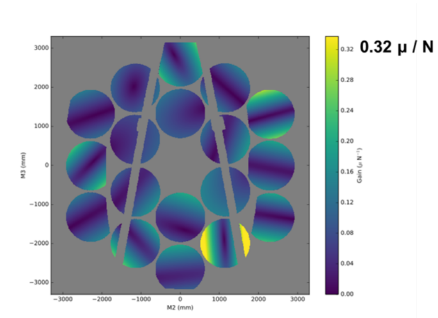


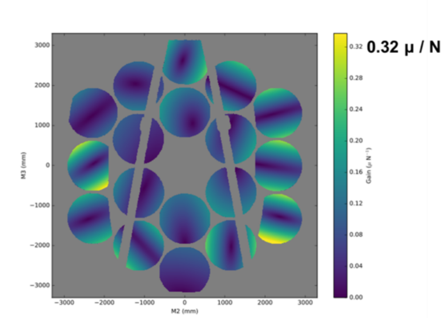
Example of Primary Mirror Response

Rigid Body (Z1-Z3) at 43.0Hz
Transfer Function Gain

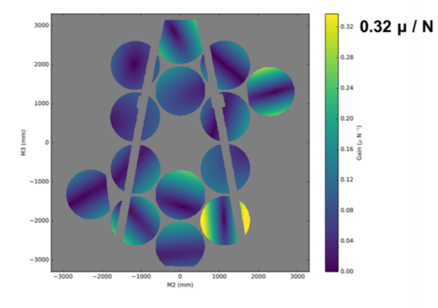
Preshake | Postshake

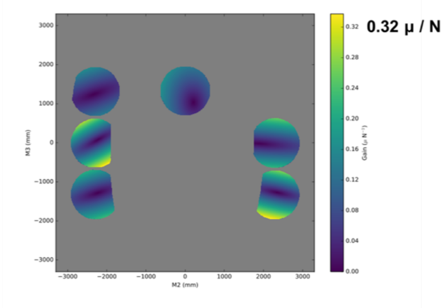
Nominal





Reproducibility

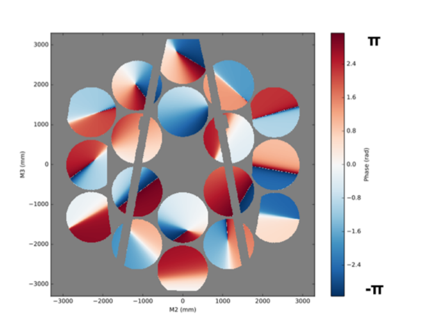


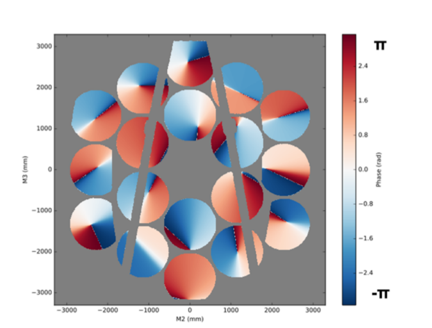


Rigid Body (Z1-Z3) at 43.0Hz
Transfer Function Phase

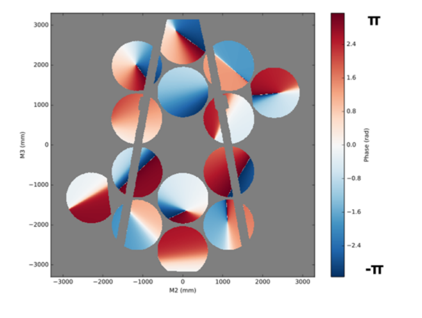
Preshake | Postshake

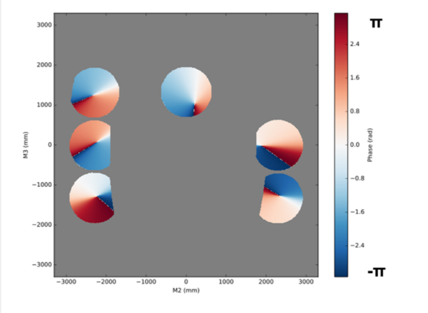
Nominal





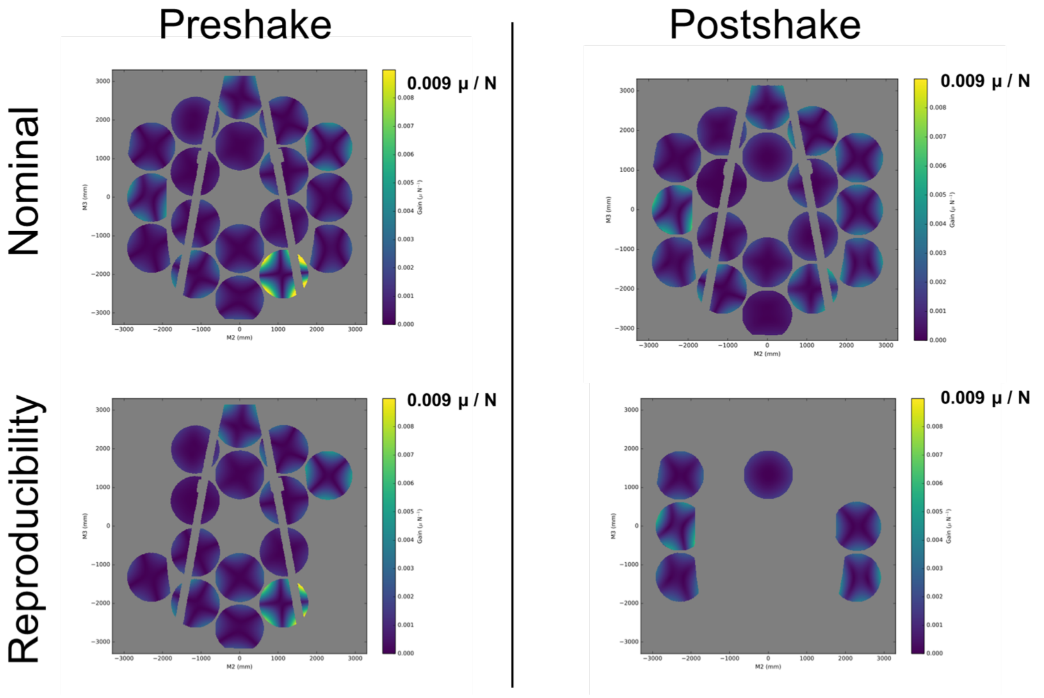
Reproducibility



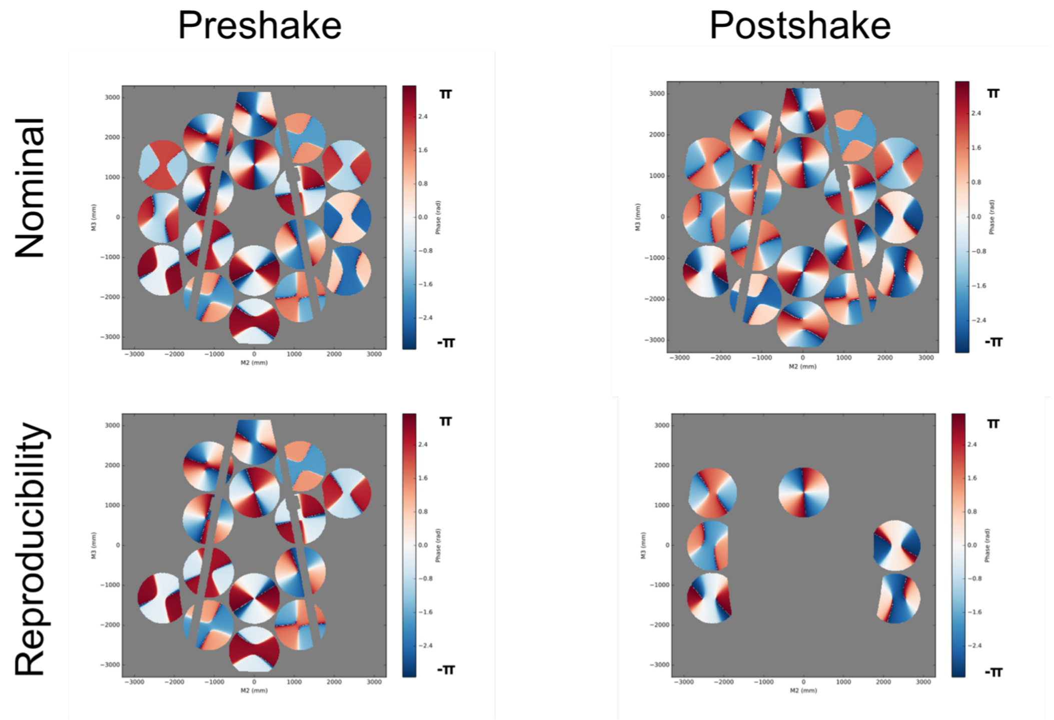


Example of Primary Mirror Response

Astigmatism (Z5-Z6) at 43.0Hz
Transfer Function Gain



Astigmatism (Z5-Z6) at 43.0Hz
Transfer Function Phase



Conclusion

- The Center of Curvature test was successful in verifying that no unacceptable changes occurred to the JWST telescope assembly as a result of vibro-acoustic testing.
- The static portion of the test provided excellent results given the enormity of the test.
- A newly developed alignment camera system worked well.
- The dynamics portion of the CoC test successfully measured the opto-mechnical modes of the telescope in low amplitude stimulation to nanometer precision.
- Informed about the health of the OTIS before shipping it to Johnson Space Center (JSC) for optical testing at cryogenic temperature.