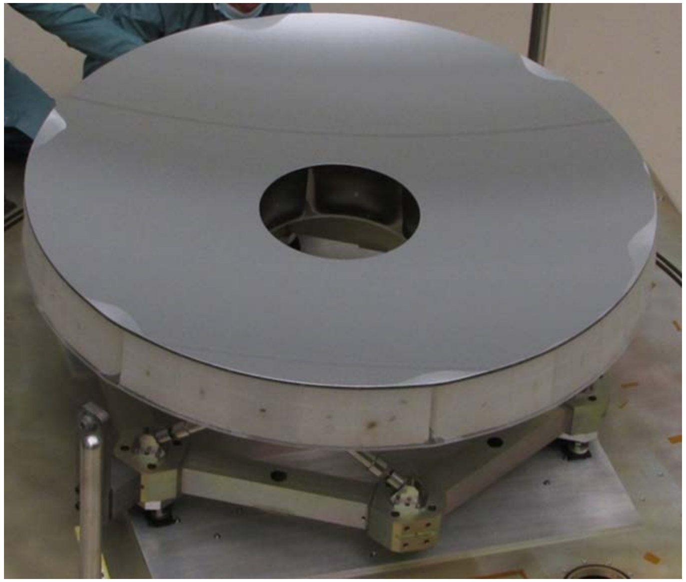
Cryogenic optical testing of space telescope mirrors



Ron Eng

Optics and Imaging Branch

NASA Marshall Space Flight Center

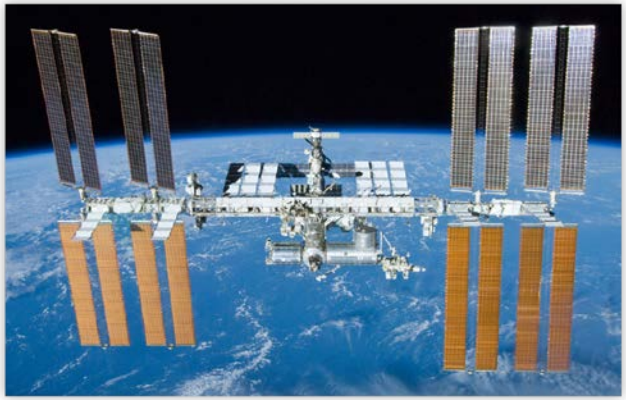
Instrumentation for Astronomical Space Science (IASS) workshop 2018

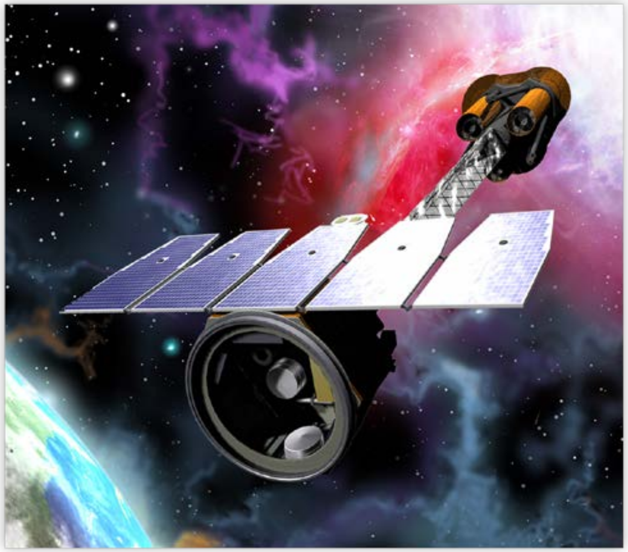
NASA Marshall Space Flight Center

Marshall Space Flight Center
Space Transportation, Propulsion Systems, Space Systems, and Science
Huntsville, Alabama

Space Transportation, Propulsion Systems

Space Systems and Science





X-ray cryogenic facility (XRCF)

Large test chamber:

- 7.3 x 22.9 m (O.D. x L) horizontal cylinder
- 6 x 18.3 m (I.D. x L) test volume
- 4.25 x 9.4 m (I.D. x L) Helium shroud
- < 22.5 m ROC without modification
- Up to 30 m ROC with modifications

Cryo shroud enclosure: 320º to 20º K

Refrigeration system: 2 gaseous helium refrigerators; each capable of ~1 kW at 20K.

Vacuum systems: 10^{-8} Torr

X-ray source: 527 m guide tube

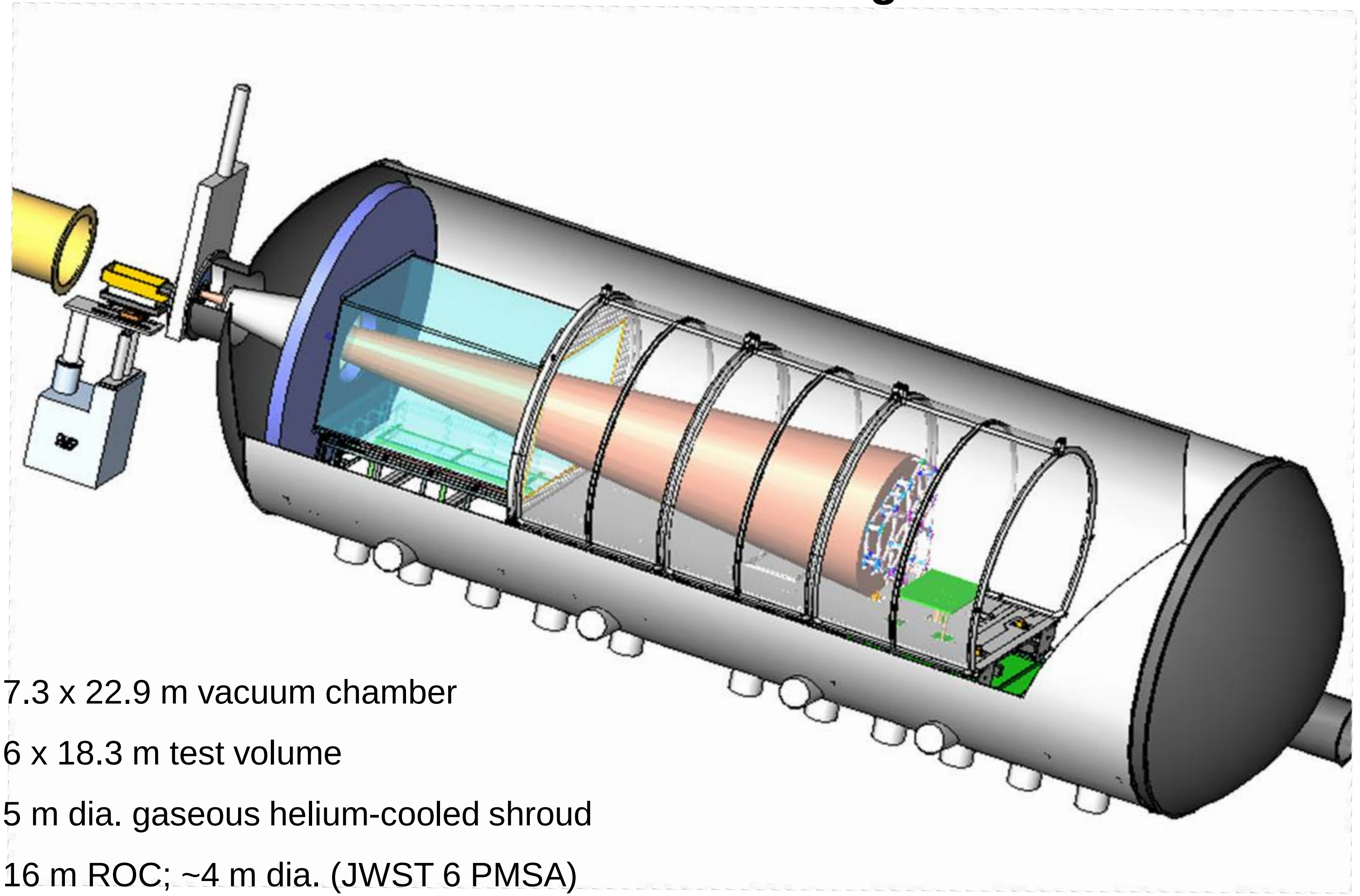
History

Testing grazing-incidence x-ray telescopes (Chandra, Solar X-ray Imager, Solar B) since 1992.

Cryogenic optical interferometric testing of normal incidence, visible & IR optics (NMSD, AMSD, JWST, AMTD) since 1999.

Chandra X-Ray Observatory

JWST PMSA test configuration



7.3 x 22.9 m vacuum chamber

6 x 18.3 m test volume

5 m dia. gaseous helium-cooled shroud

16 m ROC; ~4 m dia. (JWST 6 PMSA)

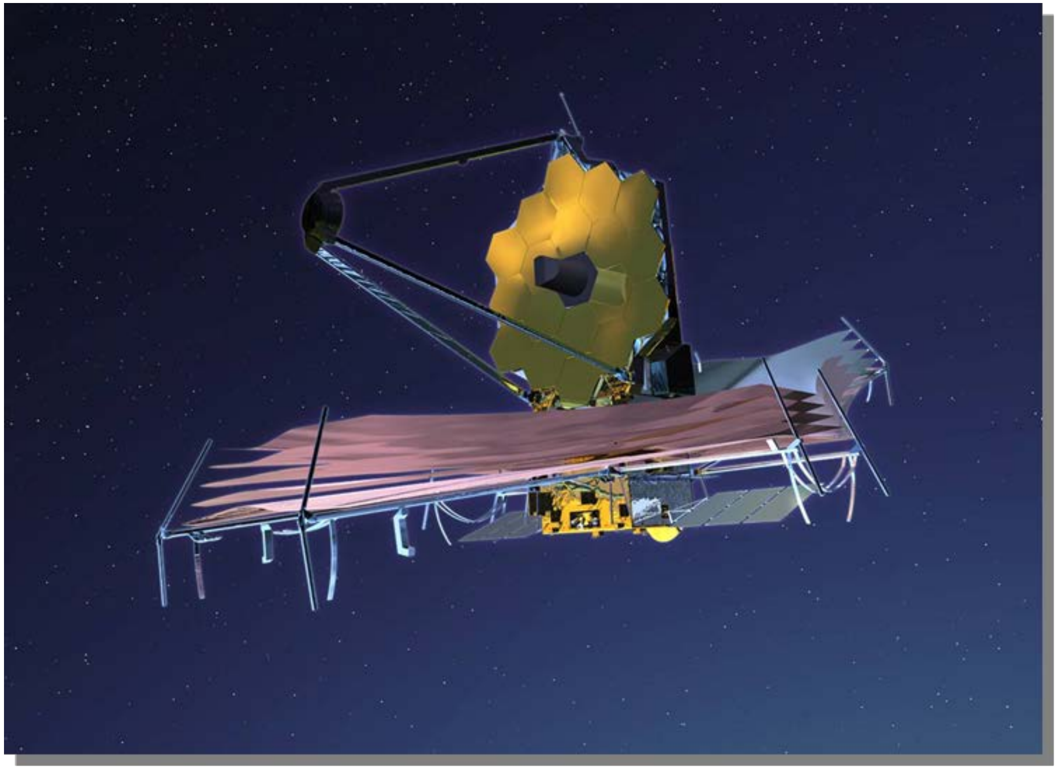
2 closed-loop helium cryogenic refrigeration systems <20 deg. K (2 KW capacity)

Existing structure prevents testing mirrors with ROC < 3.5 meters

A pressure tight enclosure (PTE) configuration to test mirror with short ROC < 3.5 meter

XRCF class 2K clean room

James Webb Space Telescope (JWST)



NASA, ESA, and CSA

2021 launch

0.6 – 30 microns (visible to mid IR)

4 scientific instruments

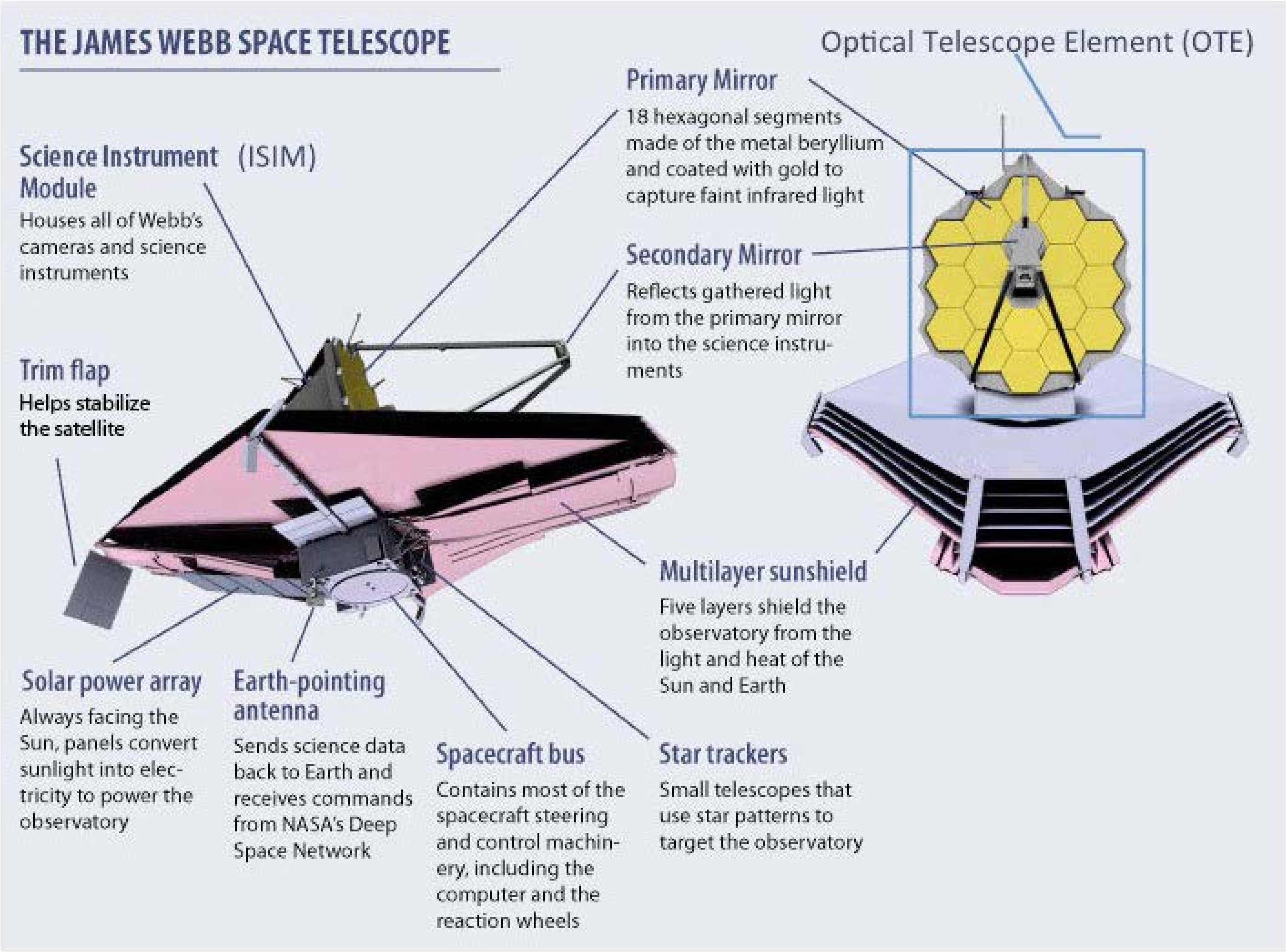
6.5m primary mirror

L2 orbit, 1,500,000 km

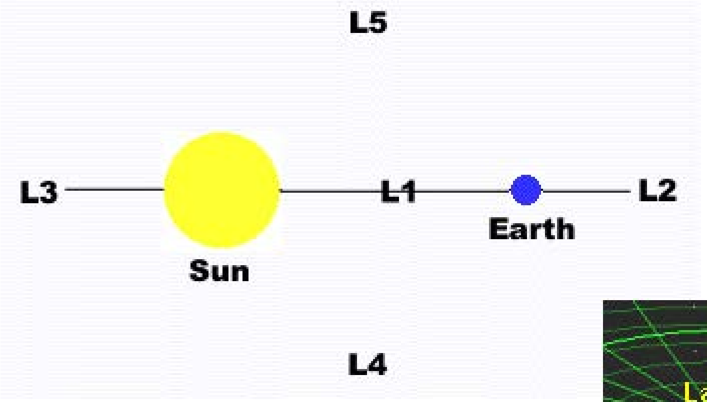
Science objectives: first light, formation of galaxies, birth of stars and planets, and origin of life

Technical challenges: deployable segmented telescope and structure, lightweight yet stable optics at 40 degrees Kelvin operational temperature.

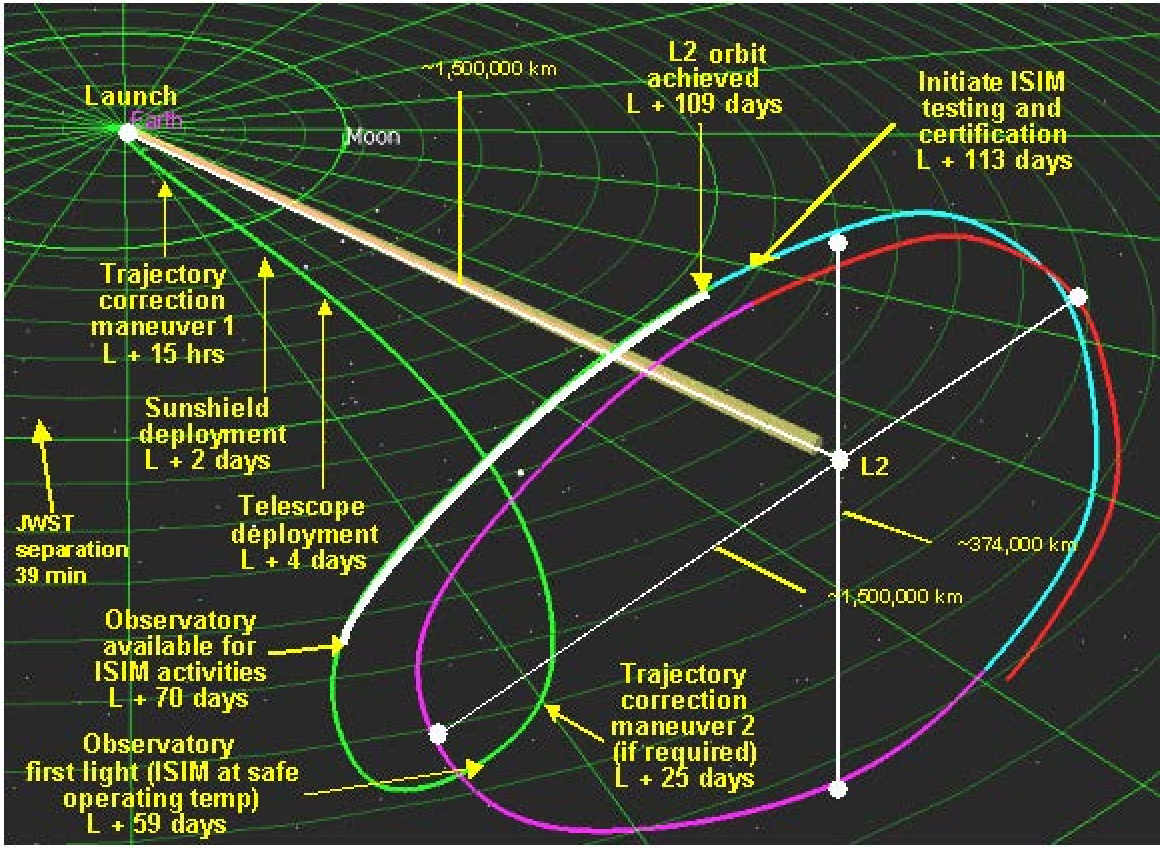
James Webb Space Telescope (JWST)



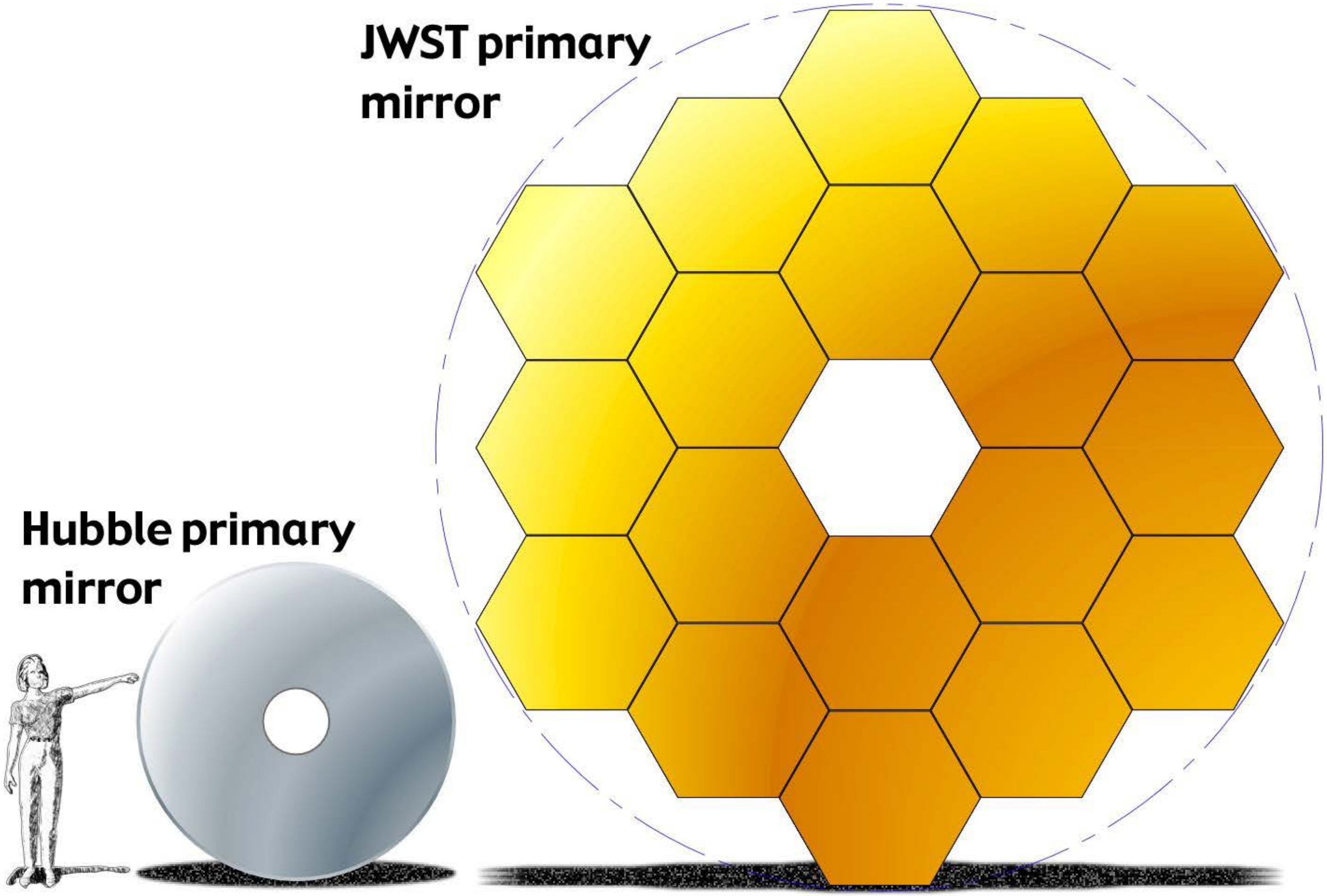
JWST orbit



- ~1,500,000 km from earth vs ~650 km for Hubble
- 30 to 60 deg. K operational temperature



HST & JWST primary mirror comparison



2.4 m dia.

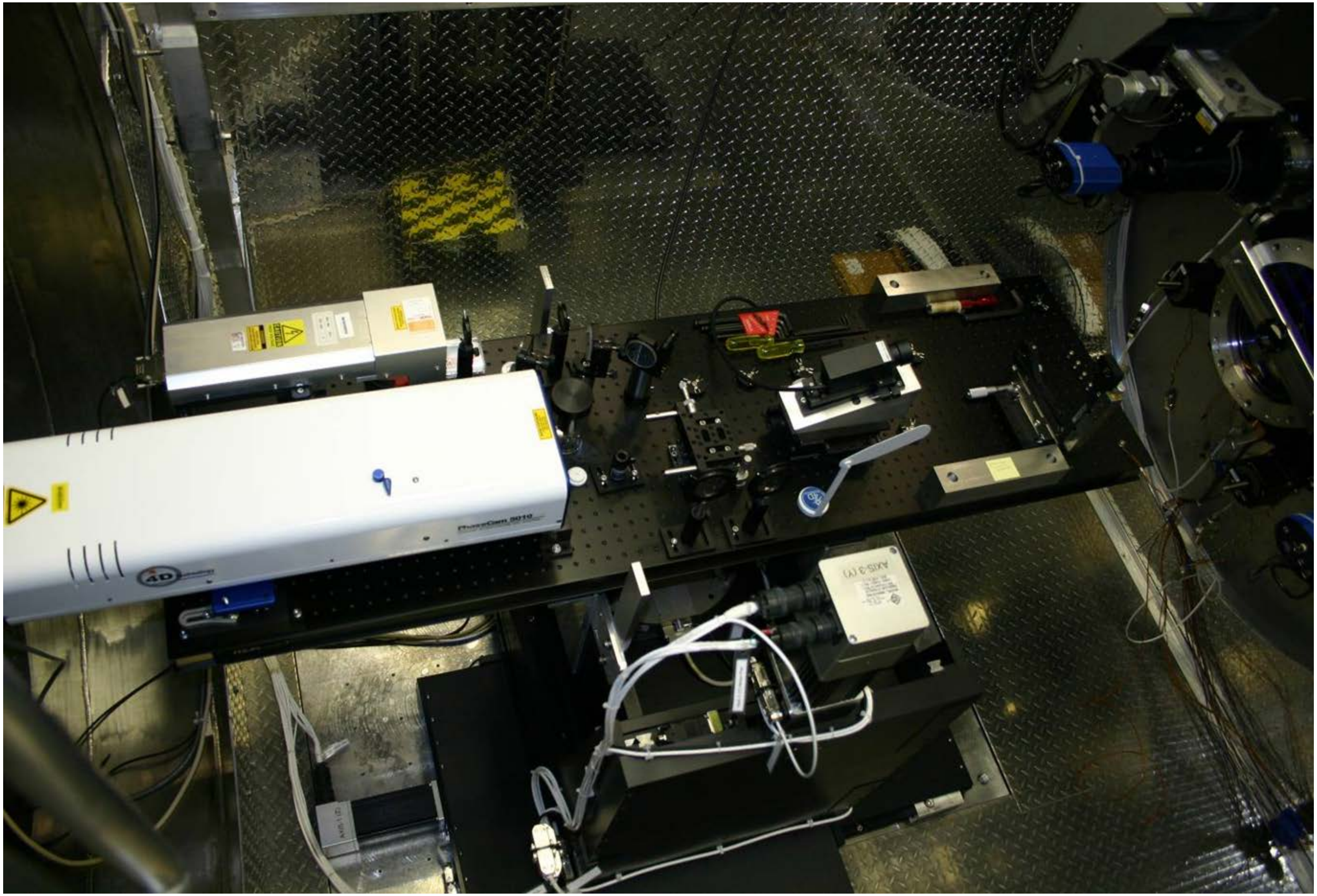
3.6 m^2

6.5 m (18 mirror segments)

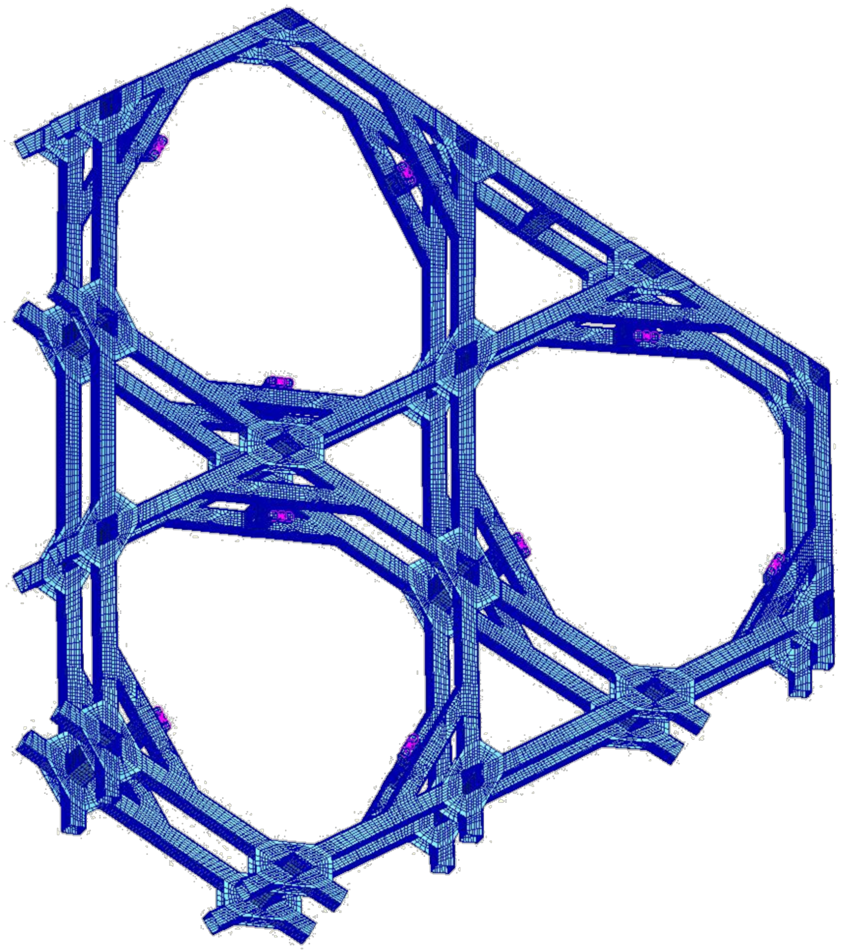
25 m^2

JWST primary mirror segment at XRCF

JWST mirror optical test instrument



Backplane stability test article (BSTA)



Design (ATK):
- Graphite Epoxy composite
- M55J/T300 laminate
- consist of tubes (1mm thick) and gussets (2.5mm thick)

Dimensions
- 2.8m x 2.5m (9.5 ft x 8.3 ft)

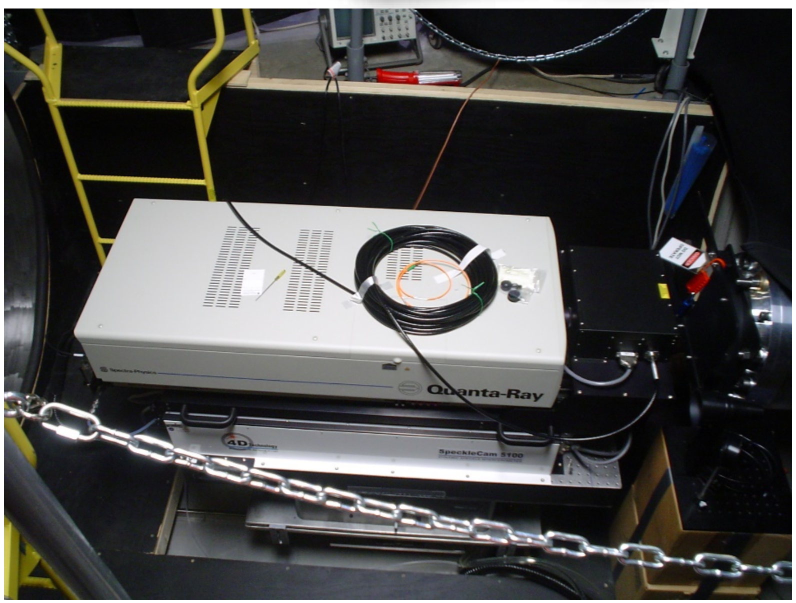
Mass
- 53 kg

Strength
- 2g, 1.25 S.F. yield

Thermal cycling
- 320 to 25 deg. K

BSTA delivered to MSFC for cryo testing

JWST mirror backplane test instrument



Simultaneous speckle pattern interferometer (4D)

Spectra-Physics Quanta-Ray PRO Nd:YAG 290-10, 1000mJ pulsed laser @532nm, 9ns pulse, 10Hz repetition rate

1000 x 1000 pixels, 9 microns pixel resolution

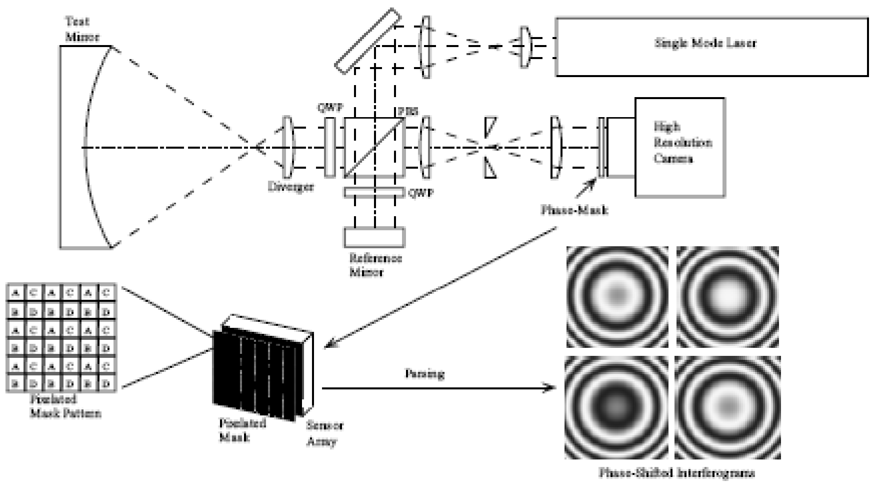
vibration insensitive with patented pixelated phase mask technology where a set of 4 pixels has discrete phase shift over entire array

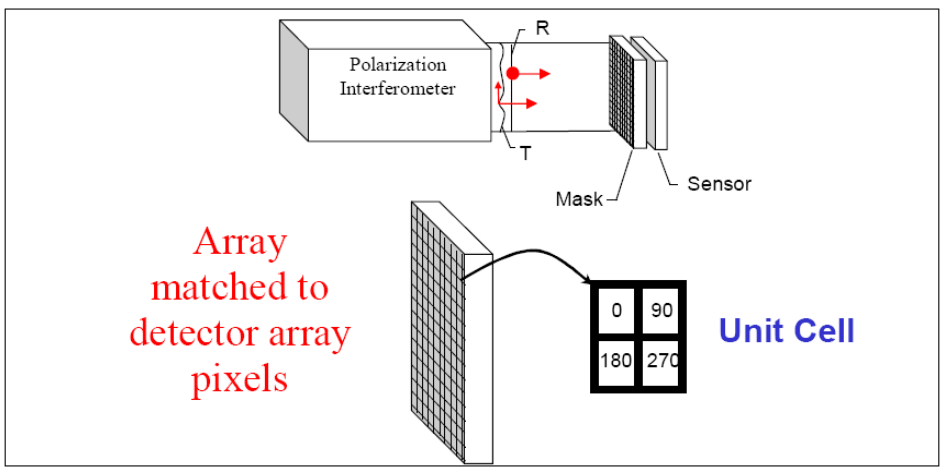
fast camera shutter speed

designed to measure large diffuse objects for change

5nm rms measurement repeatability

Simultaneous phase shifting interferometer



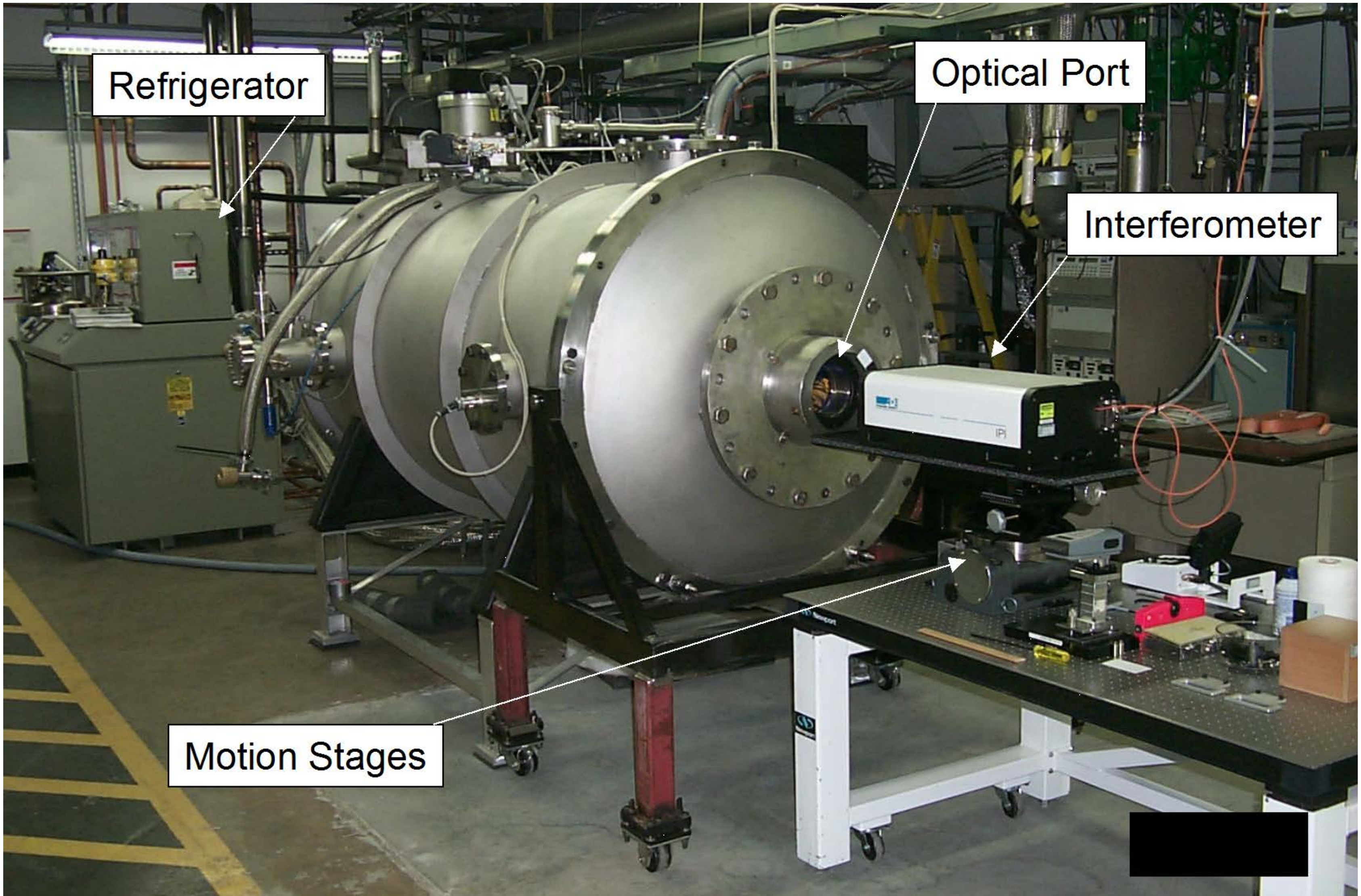


Micro-polarizer array camera sensor

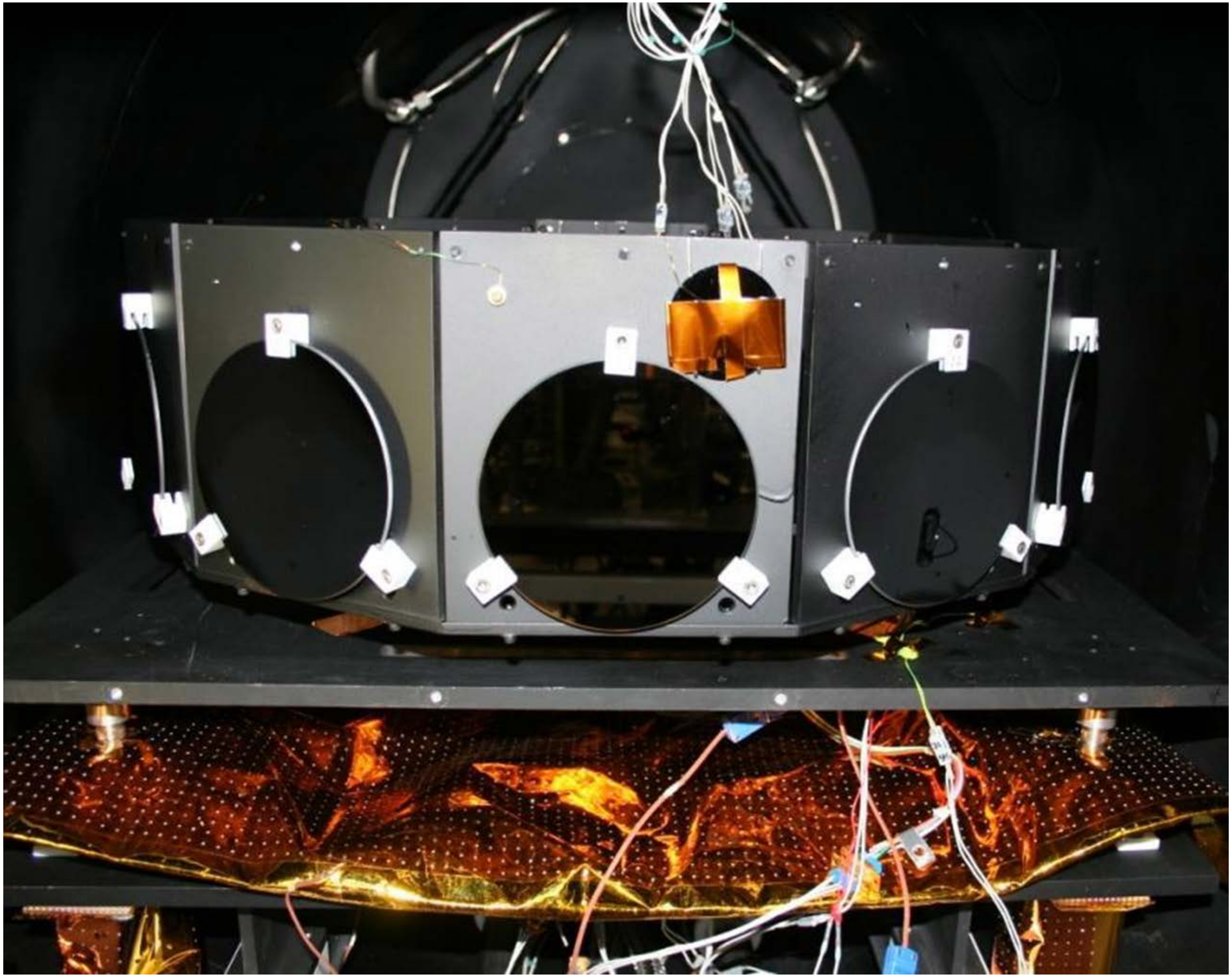
Spatial phase shifting overcomes previous single frame or temporal phase shifting interferometer technique

Overcomes vibration and air turbulence in long optical path test setup found in astronomical telescope metrology in vacuum test chamber

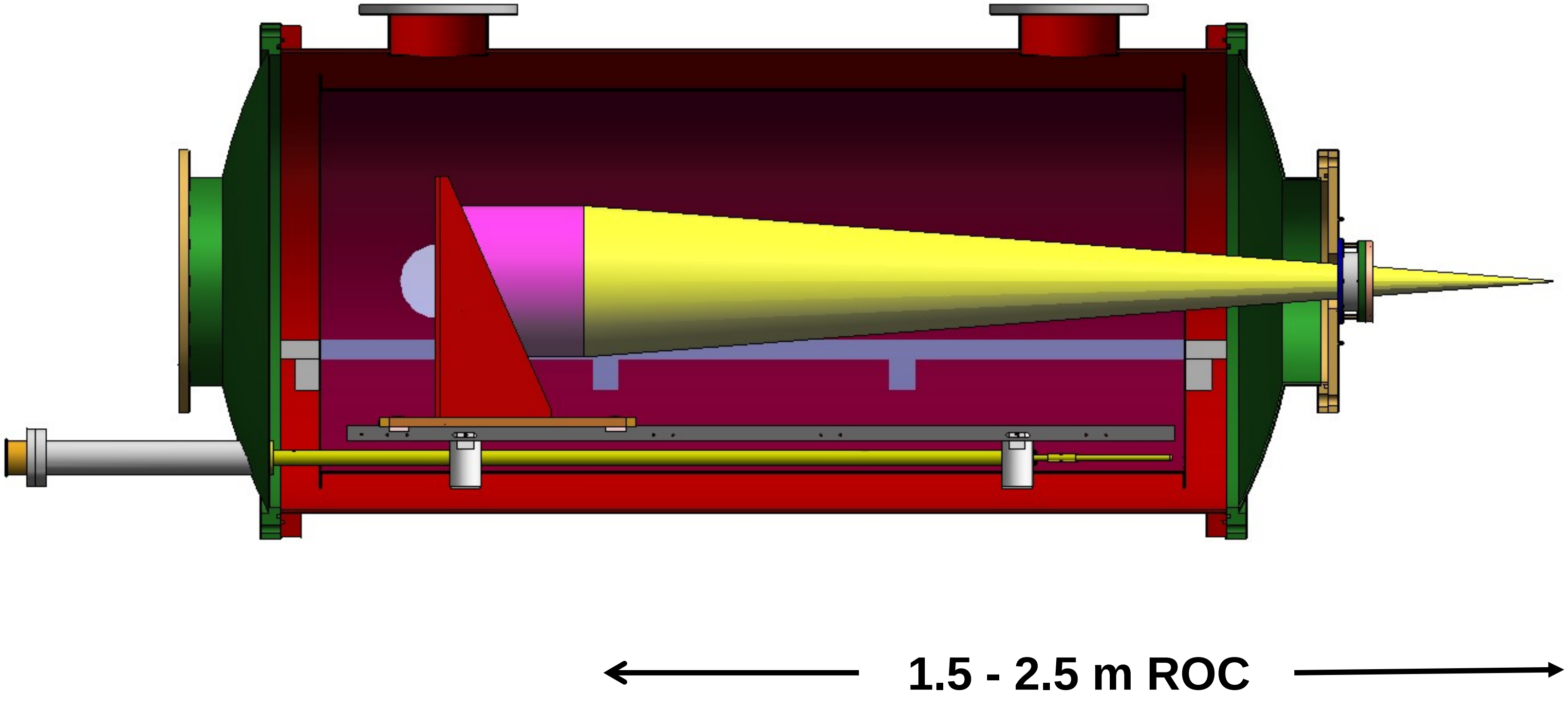
Small chamber for mirror characterization



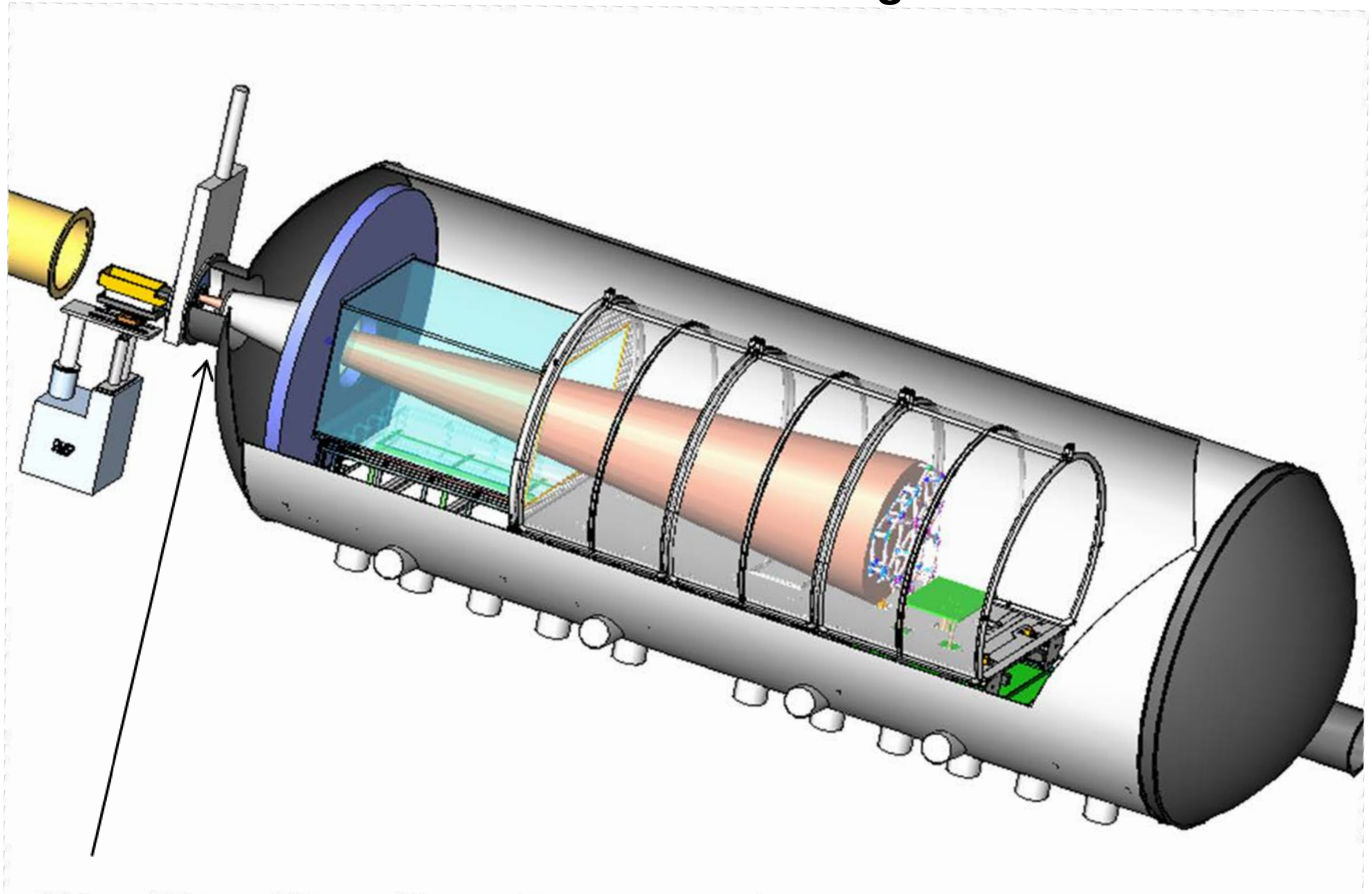
Cryo test of 12 SiC mirrors (~150 mm dia. each)



Test configuration for < 800 mm dia. mirror



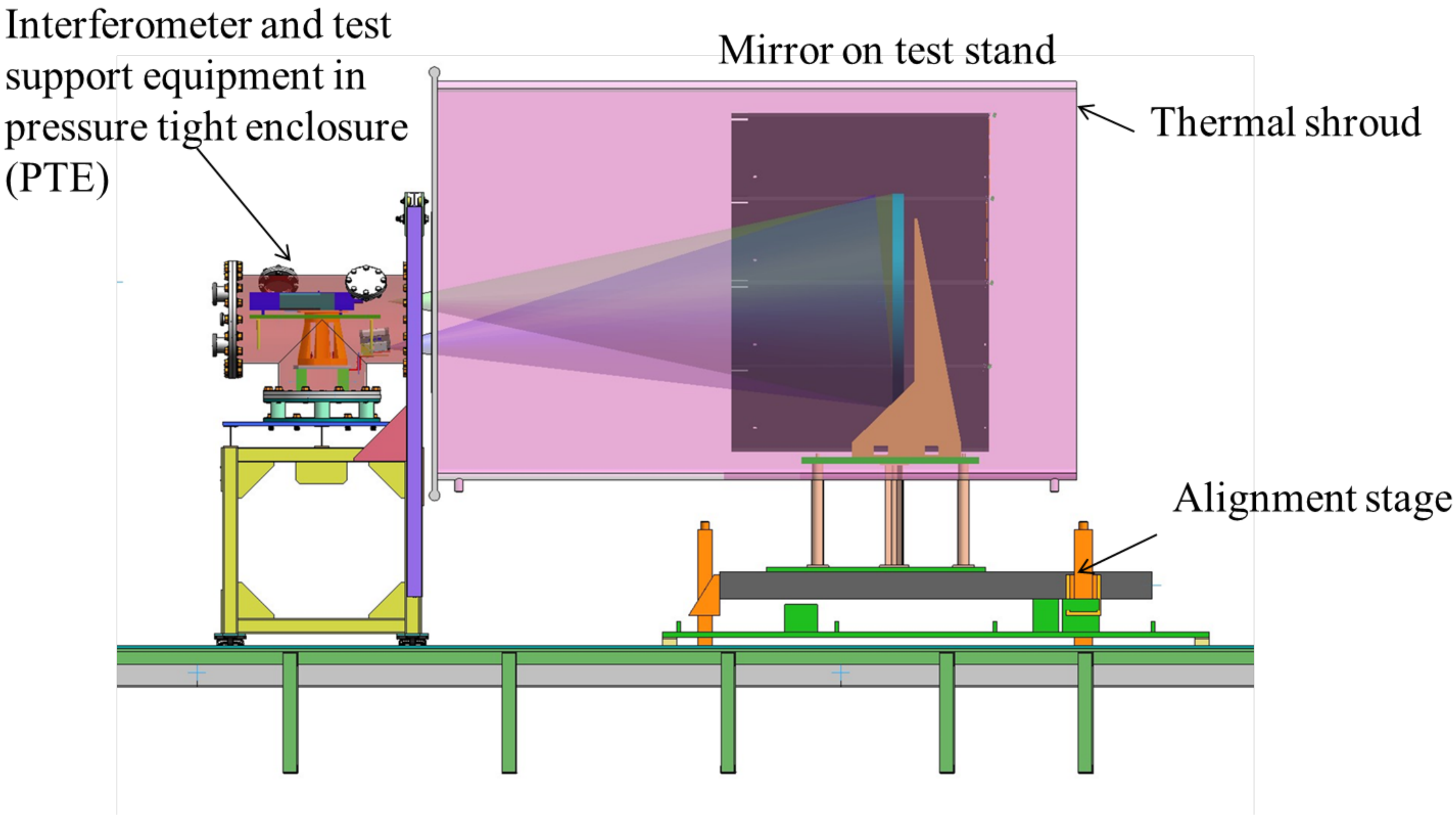
JWST PMSA test configuration



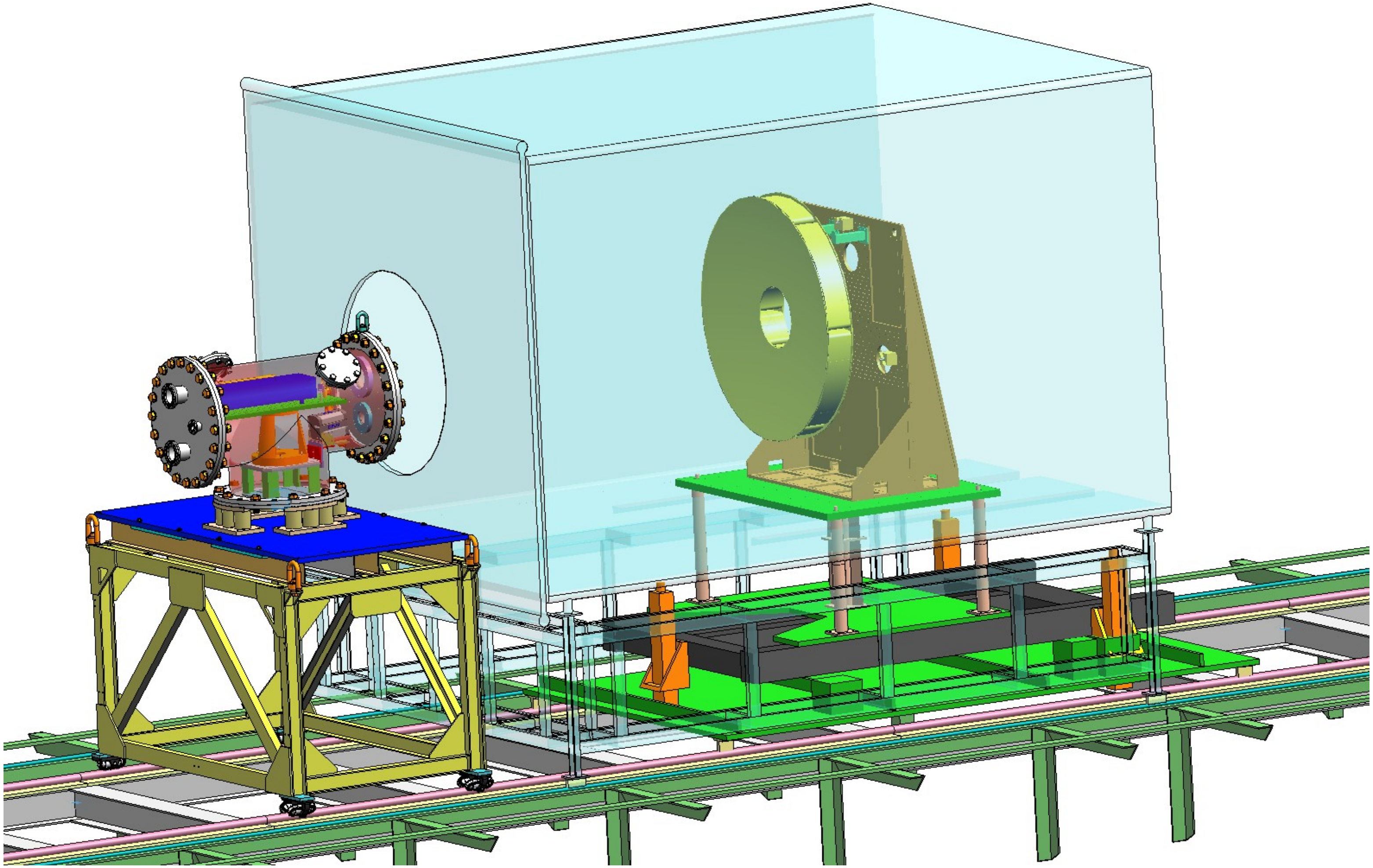
Existing structure prevents testing mirrors with ROC < 3.5 meters

A pressure tight enclosure (PTE) configuration to test mirror with short ROC < 3.5 meter

Test configuration for < 3.5 m radius of curvature mirror

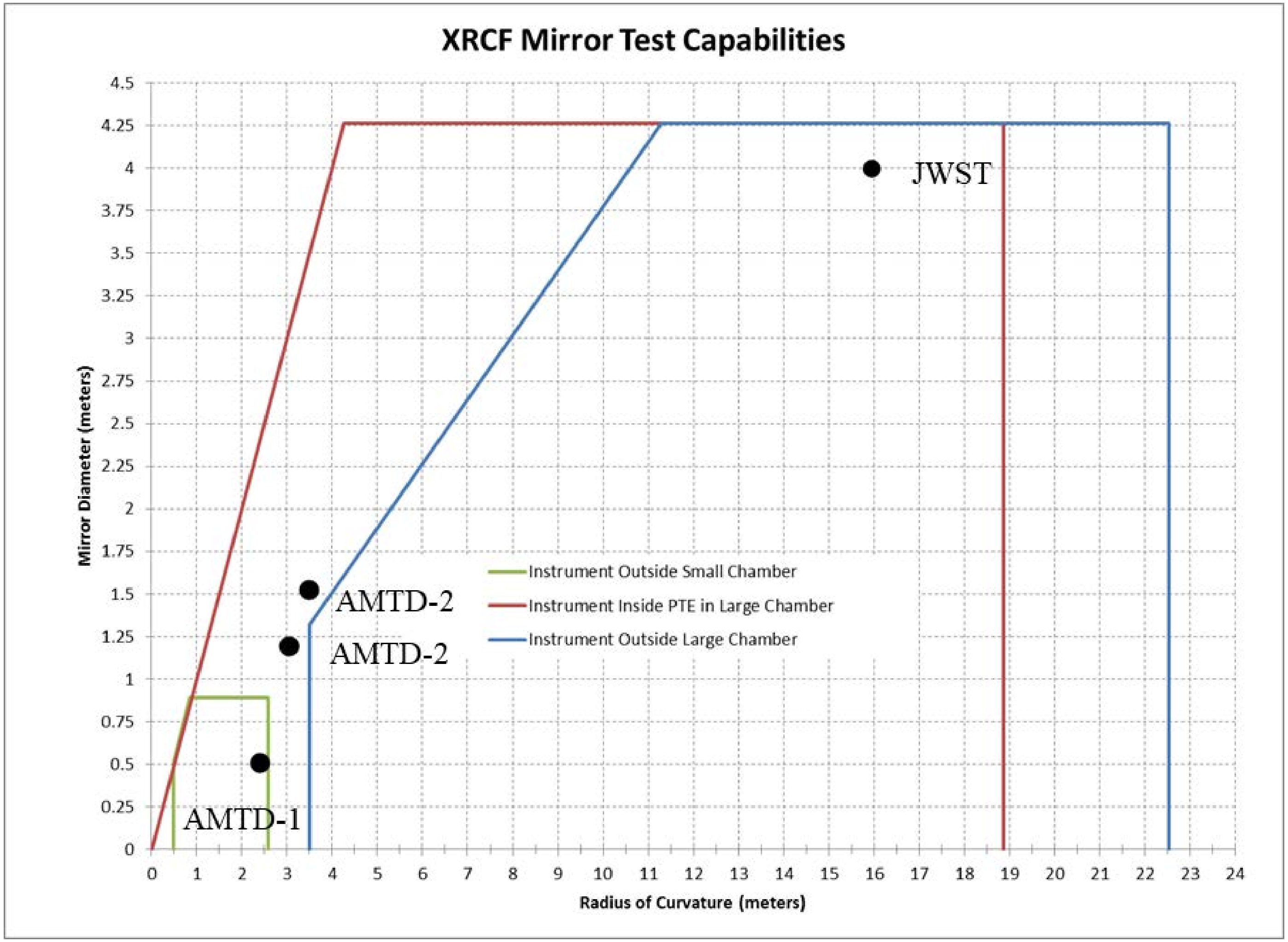


Test configuration for < 3.5 m radius of curvature mirror

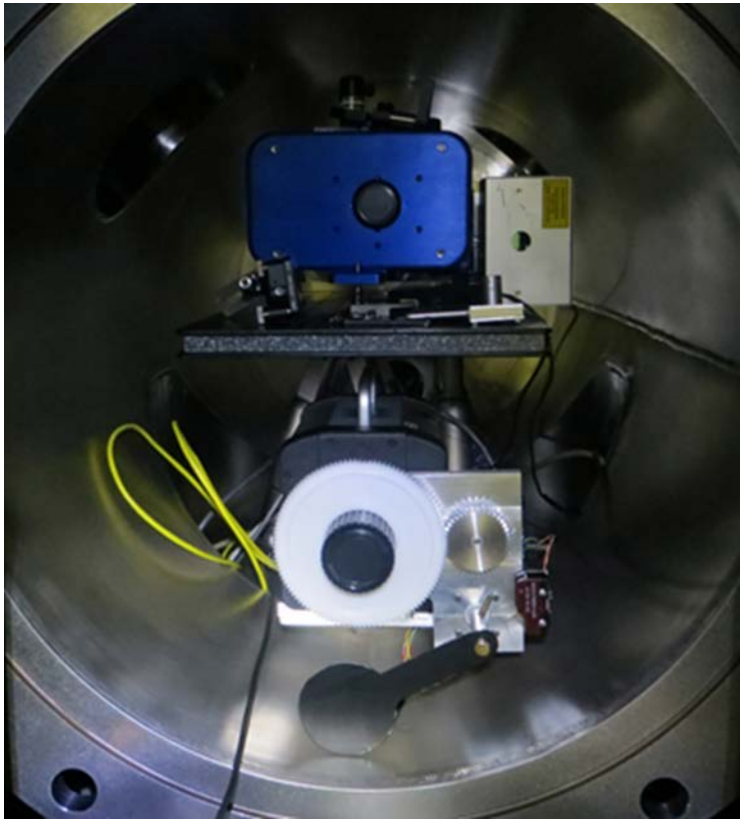


Test envelop for large and small chambers

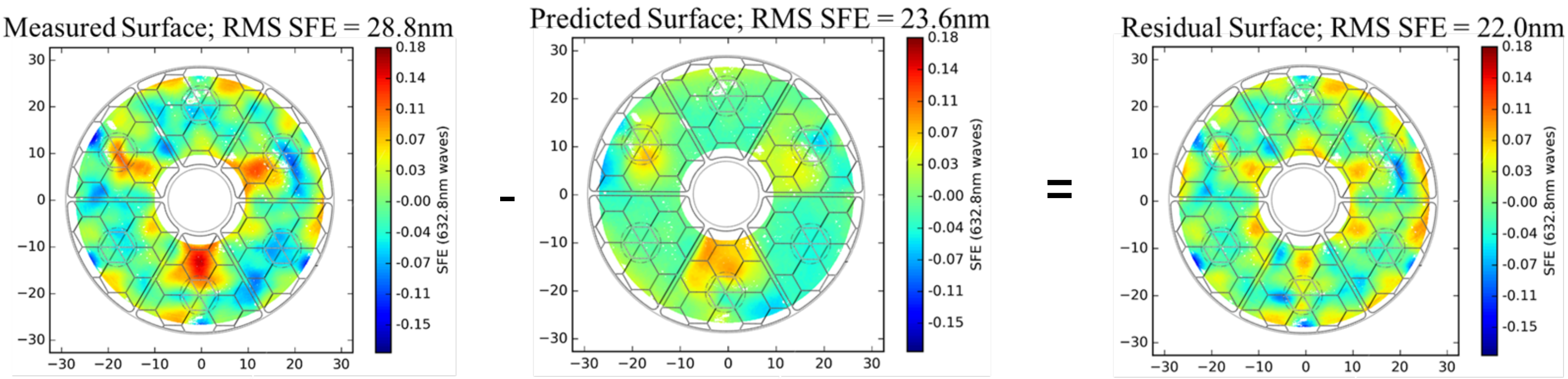
Chamber	Max Diameter	Max radius of curvature
Large	4.25 m	22.5 m
Small	0.8 m	2.5 m



Optical test equipment in pressure tight enclosure (PTE)



Thermal optical test surface figure error

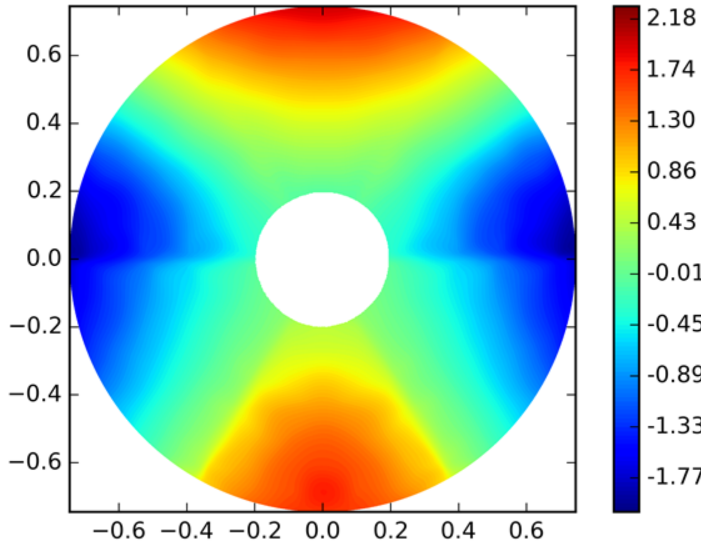


Predicted SFE uses:

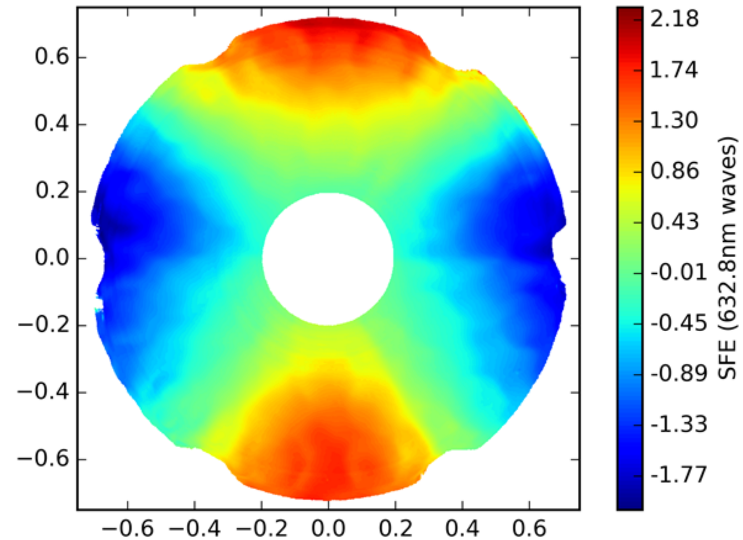
- as-built CTE distribution
- as-built shape from X-ray CT
- includes prying (due to aluminum frame) and all possible forces reacting between mount and bond pad

Residual SFE could be CTE inhomogeneity

Gravity sag (predicted vs measured)

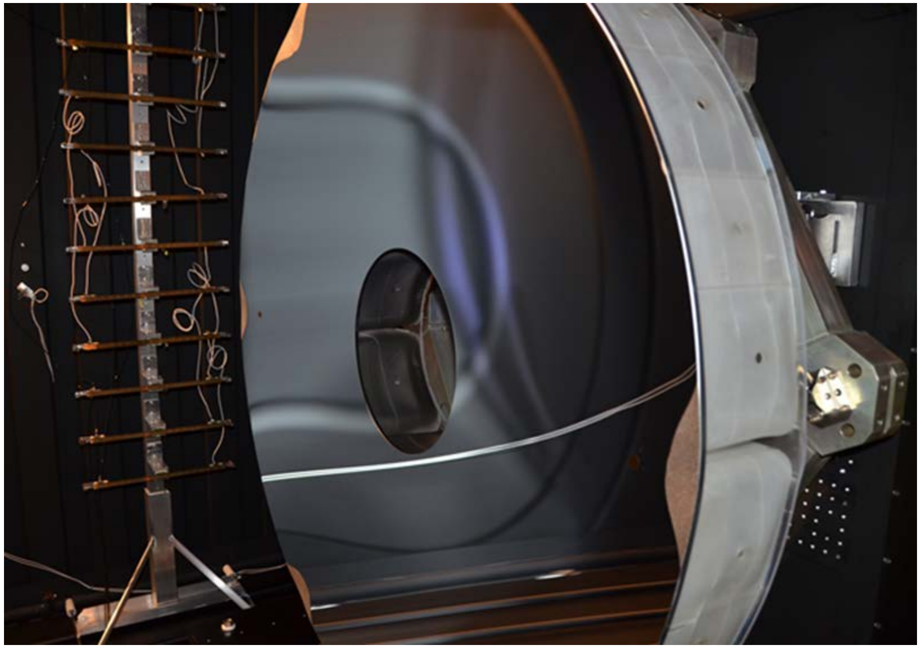


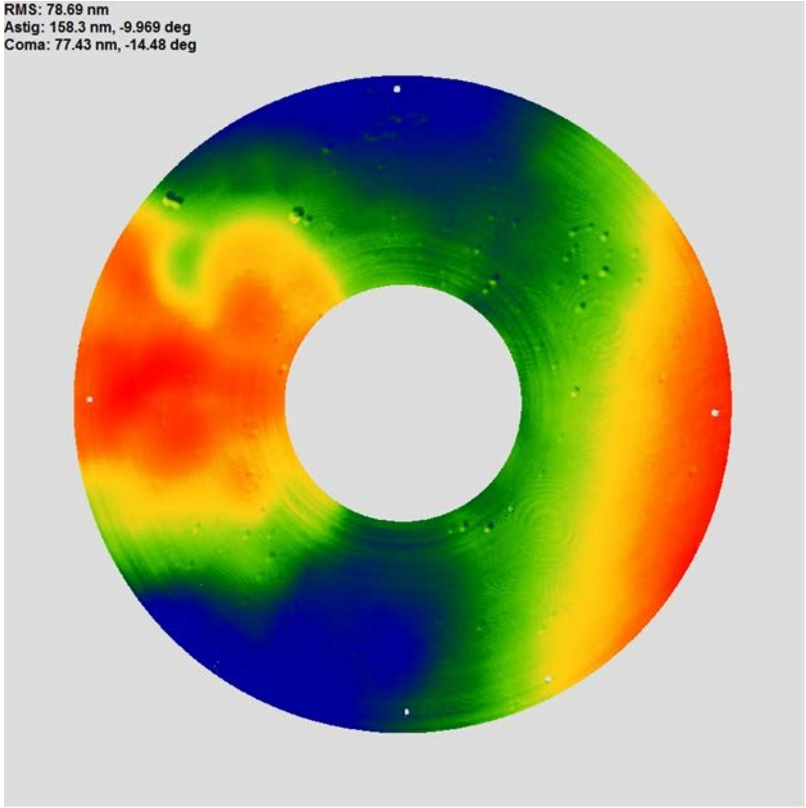
Predicted
580 nm rms



Measured
582.5 nm rms

Thermal gradient test





Future test plans

Current test facility modifications

- **Predictive thermal control**
- **Passive thermal**
- **Active thermal control**

- **Low CTE glass-ceramic mirrors**
- **Low CTE ceramic mirrors**
- **Low CTE metal mirrors**
- **Additive manufactured mirrors**

Acknowledgments

Phil Stahl: PI
Michael Effinger: program manager
Mark Baker, Bill Hogue, Jeffrey Kegley, Richard Siler, John Tucker, Ernest Wright: XRCF thermal-vac test support team
Thomas Brooks: thermal-mechanical analysis
Brent Knight, Frank Tsai: modal analysis
Alex McCool, Russel Parks: modal test
Ron Beshears, Dave Myers: X-ray computed tomography
Darrell Gaddy: thermal IR video
Brian Odom: MSFC historical photos

Thank you

Dr. Jeong-Yeol Han (KASI)

Ron Eng
ron.eng@nasa.gov
https://optics.nasa.gov