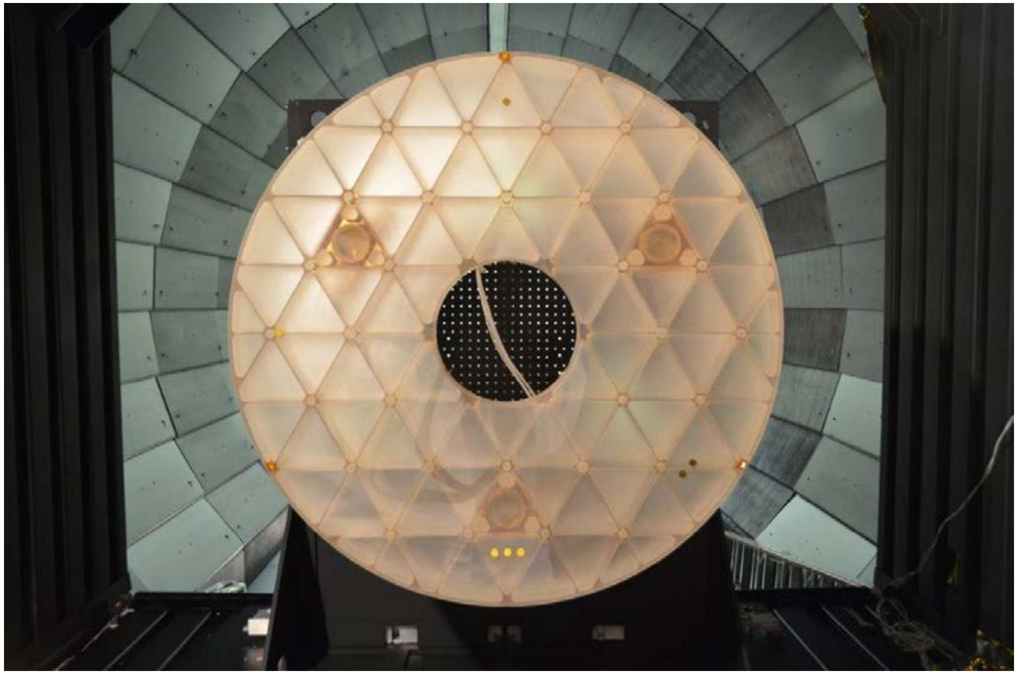
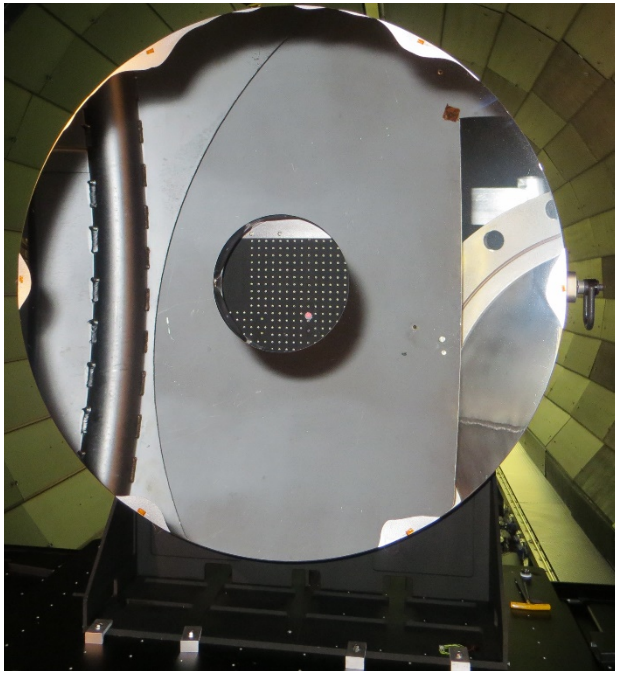
Large space telescope development programs





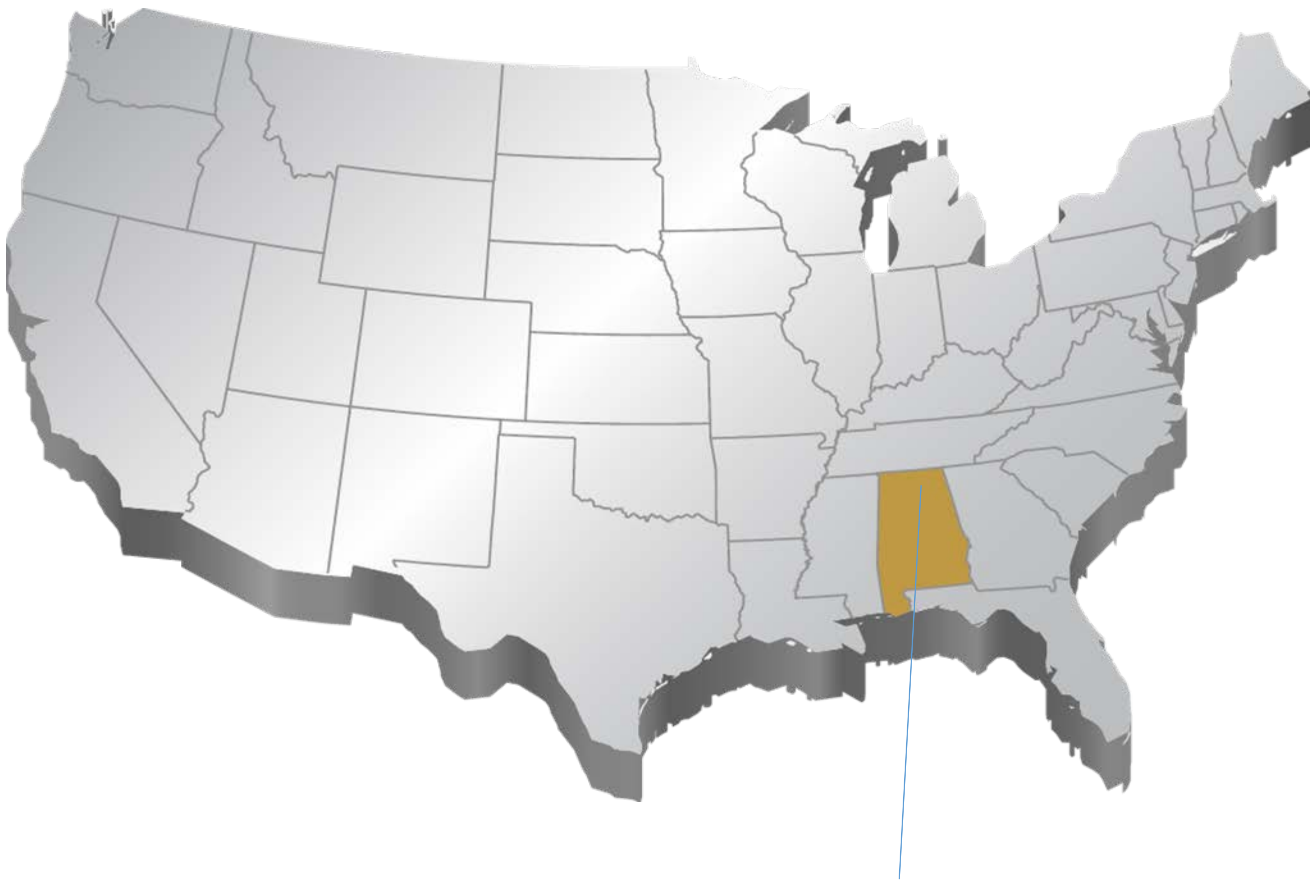
Ron Eng

Optics and Imaging Branch

NASA Marshall Space Flight Center

1st Silicon Carbide International workshop

NASA Marshall Space Flight Center

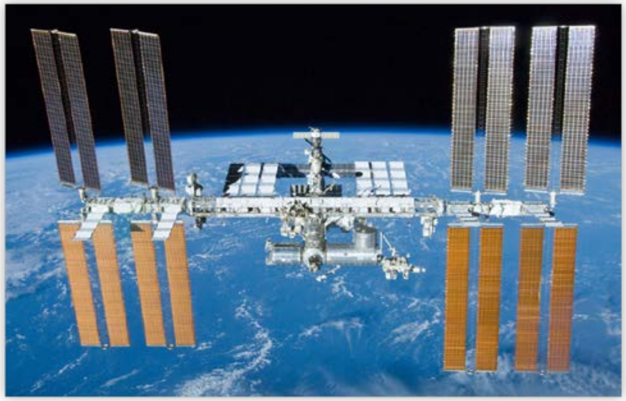


Marshall Space Flight Center
Space Transportation, Propulsion Systems, Space Systems, and Science
Huntsville, Alabama

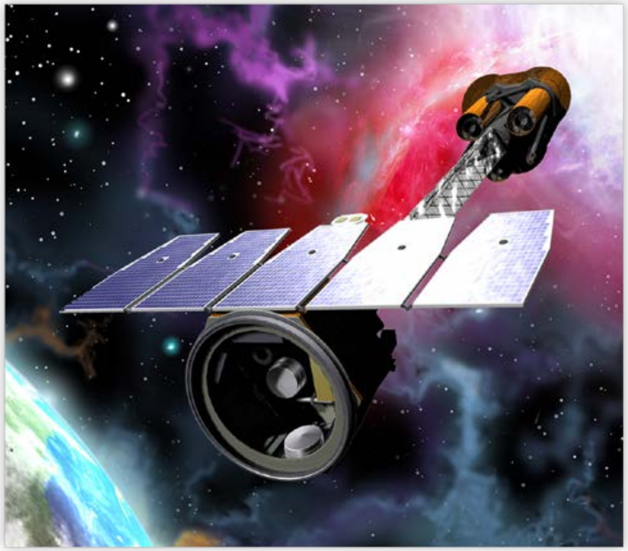
Space Transportation, Propulsion Systems

Space Systems and Science

High Energy Astronomy Observatories (1977-1981)



International Space Station (1998-present)

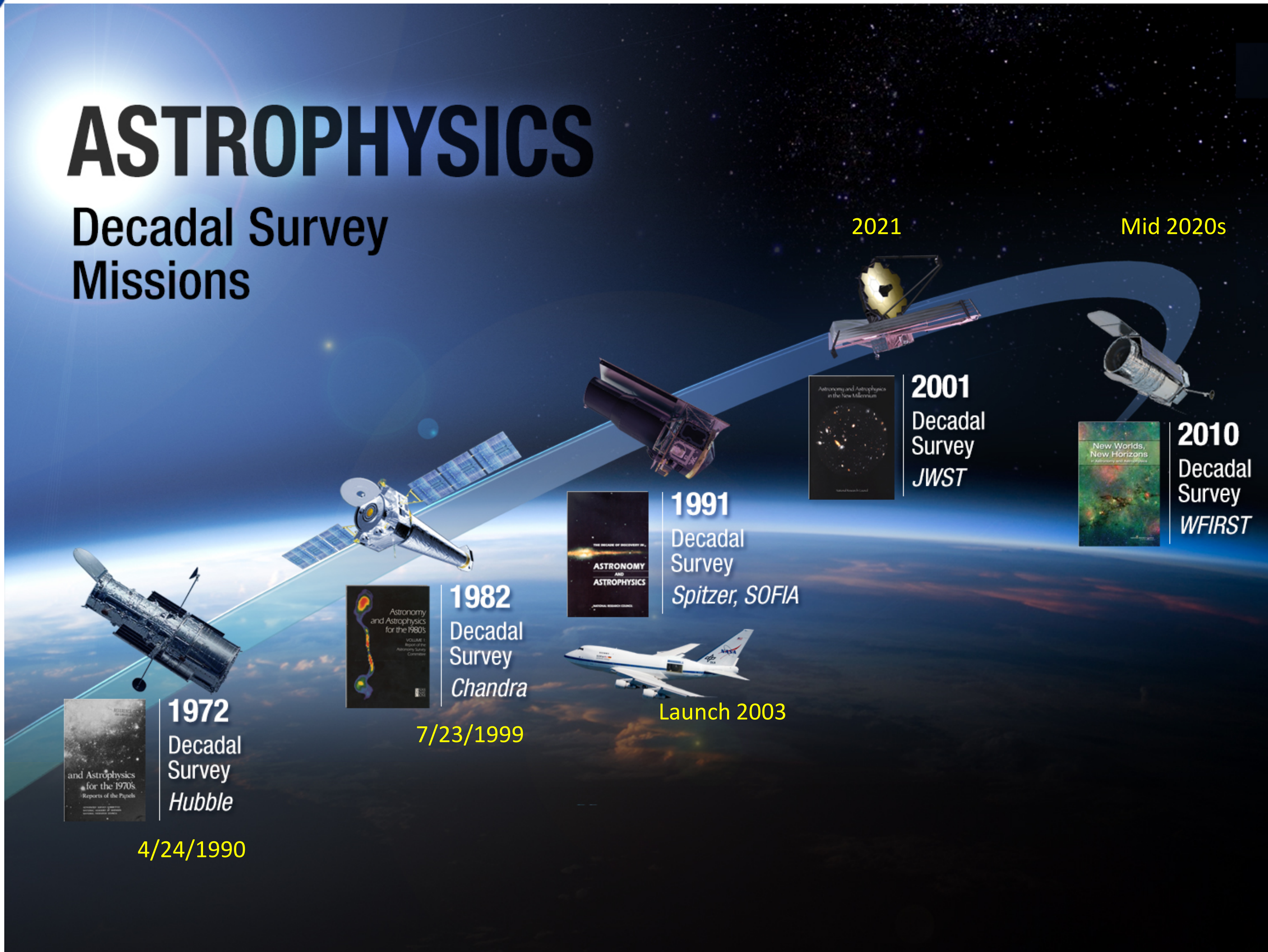


Imaging X-ray Polarimetry Explorer (IXPE) Under development

Chandra X-Ray Observatory (1999-present)

Hubble Space Telescope (1990-present)

Current and planned astrophysics missions


ASTROPHYSICS
Decadal Survey
Missions
1972
Decadal
Survey
Hubble
4/24/1990
1982
Decadal
Survey
Chandra
7/23/1999
1991
Decadal
Survey
Spitzer, SOFIA
Launch 2003
2021
2001
Decadal
Survey
JWST
Mid 2020s
2010
Decadal
Survey
WFIRST

Detecting exoplanet

Imaging exoplanet (a planet orbiting a sun-like star) is a tremendous technological challenge, since the Earth is 10 billion times fainter than the sun. The Cassini wide-angle camera used Saturn as an external occulter to block the sun.

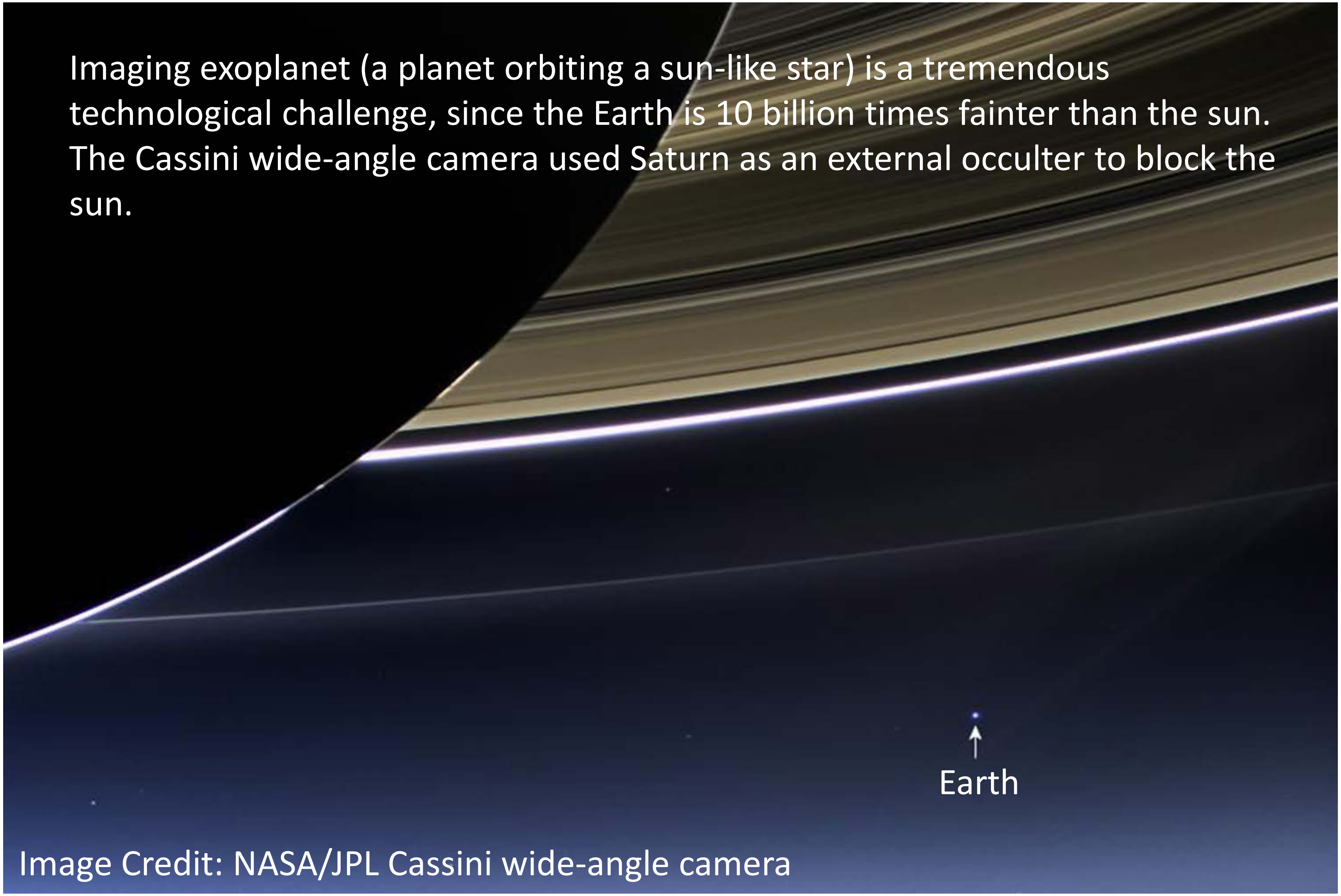
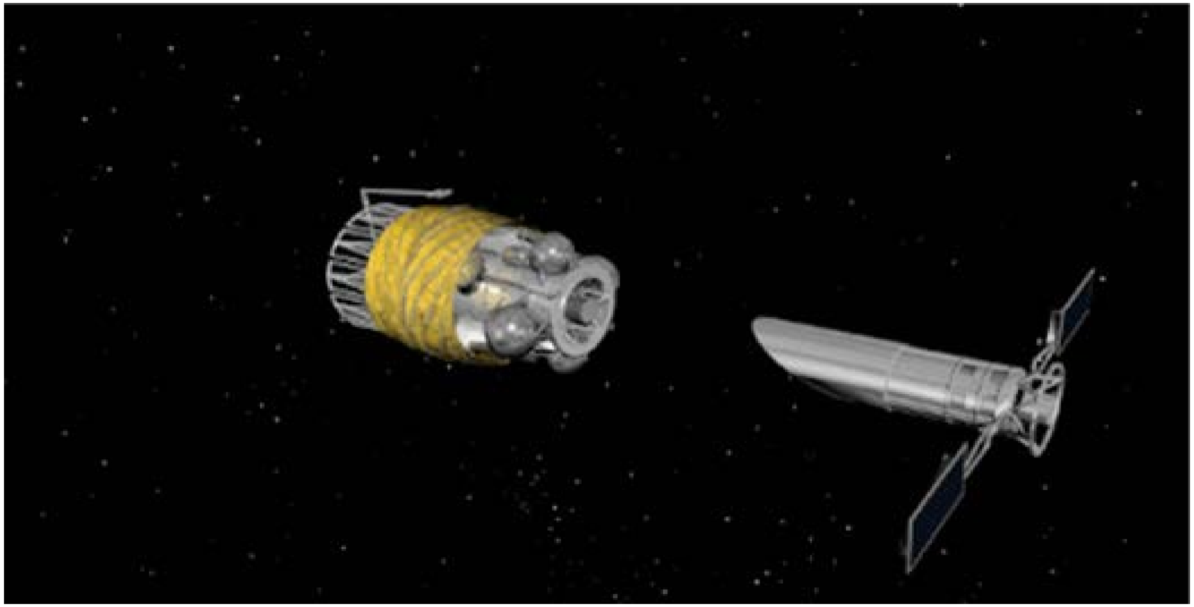
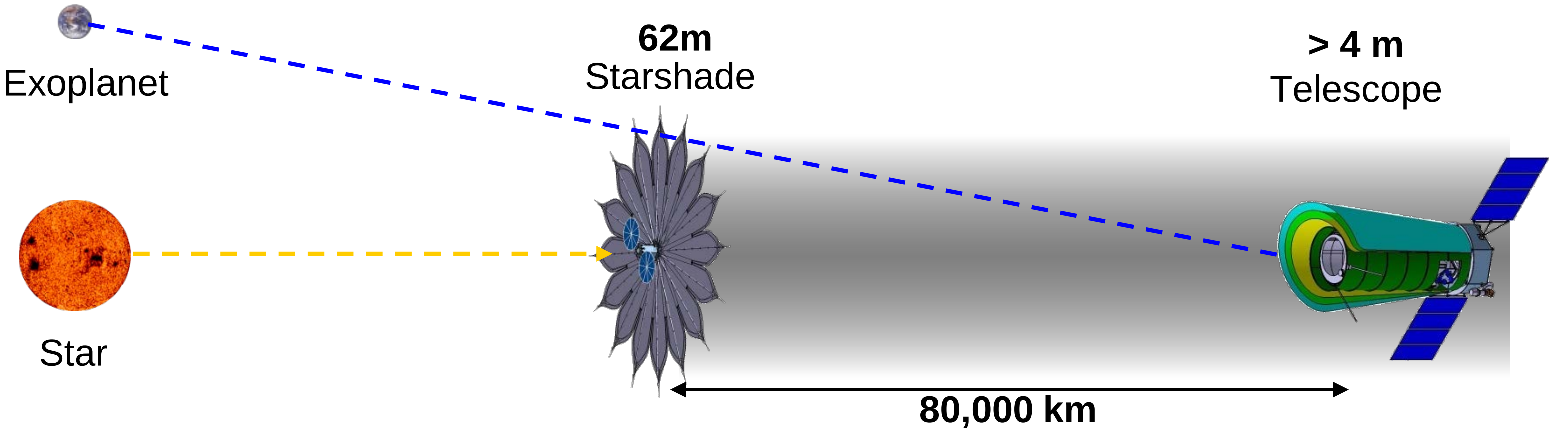


Image Credit: NASA/JPL Cassini wide-angle camera

Direct imaging technique with external starshade





Chandra X-Ray Observatory

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

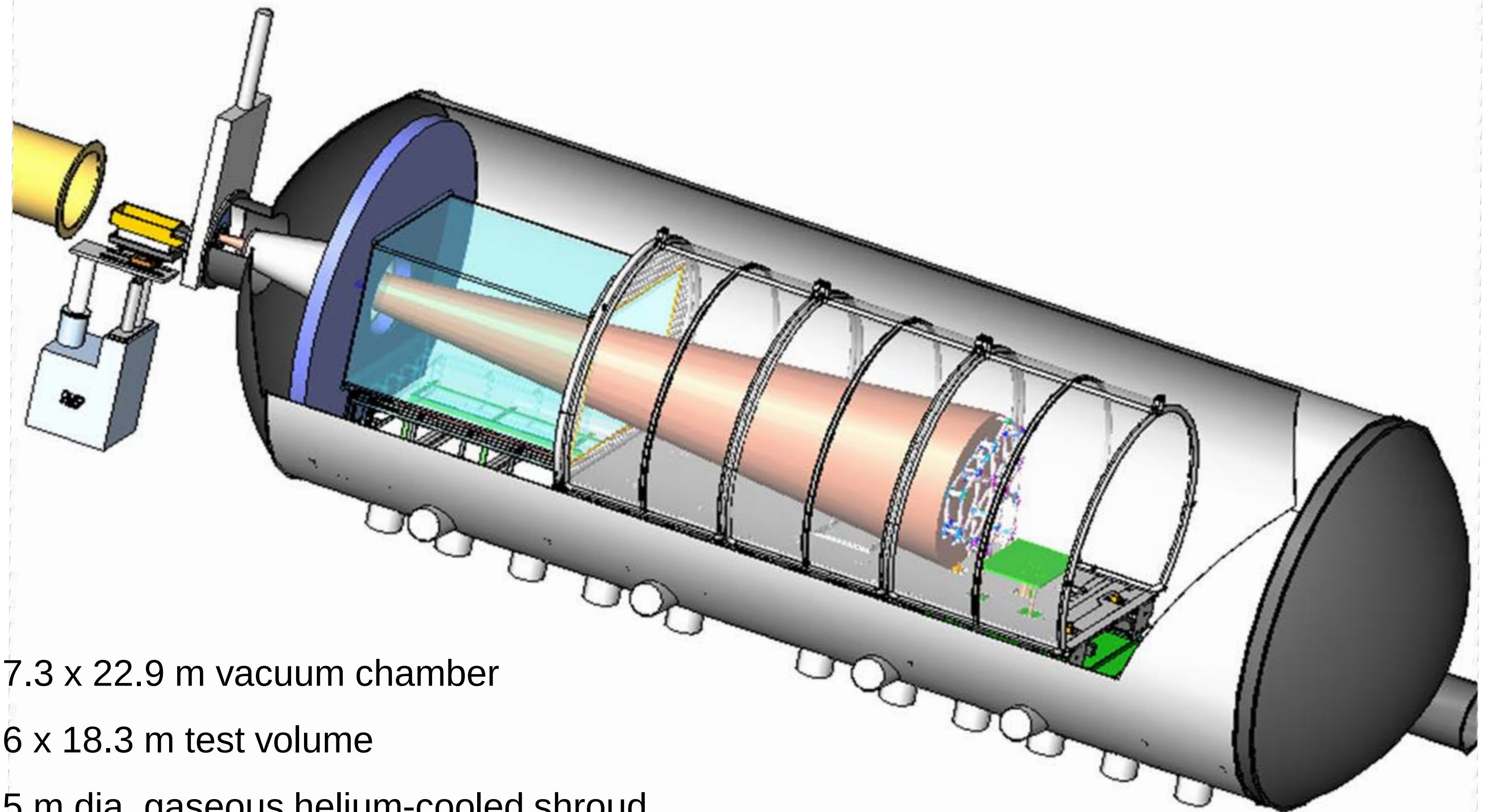
X-ray source: 527 m guide tube

History

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

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

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)

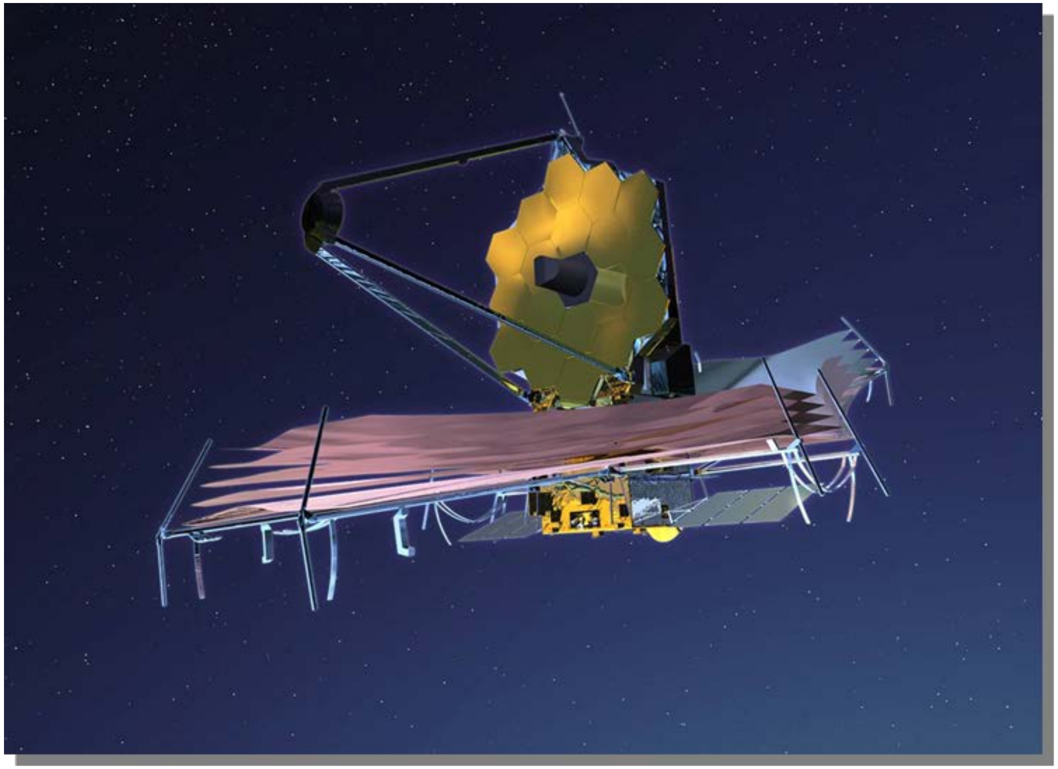
2 closed-loop helium cryogenic refrigeration systems <20 deg. K (2 KW capacity)

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

Planned launch date 3/30/2021

0.6 – 30 microns (visible to mid IR)

4 scientific instruments

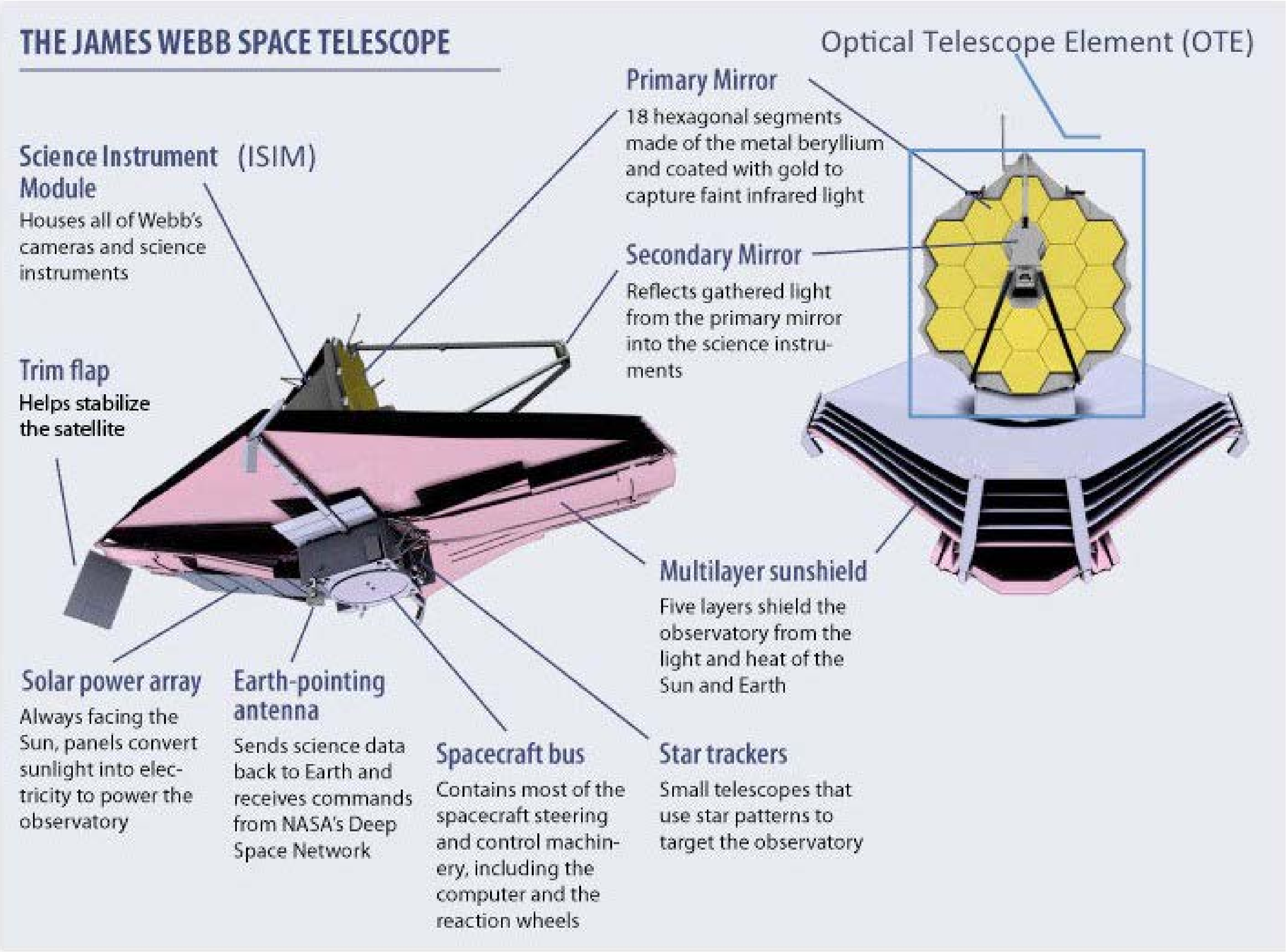
6.5m primary mirror

L2 orbit, 1,500,000 km

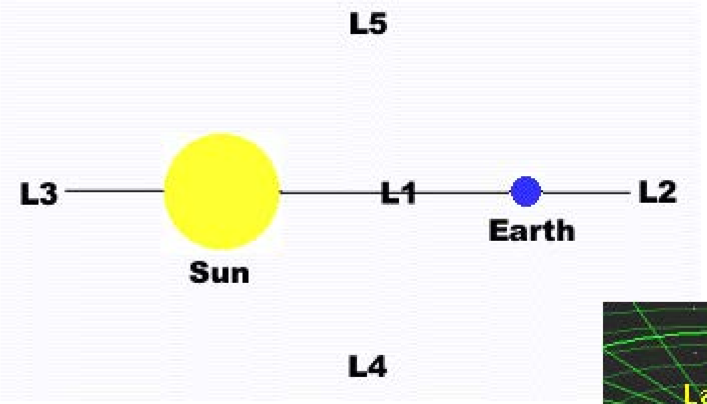
Science objectives: first light, formation of galaxies, birth of stars and planets, and origin of life.

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

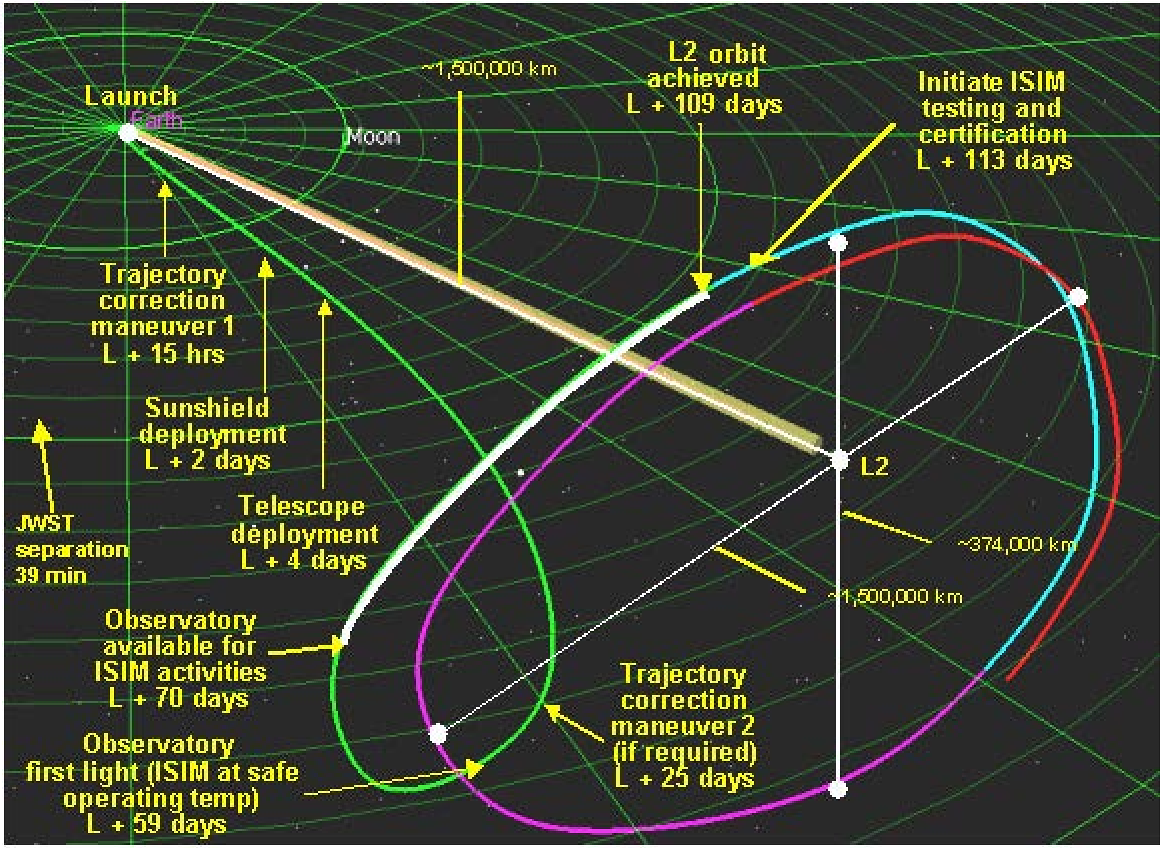
James Webb Space Telescope (JWST)



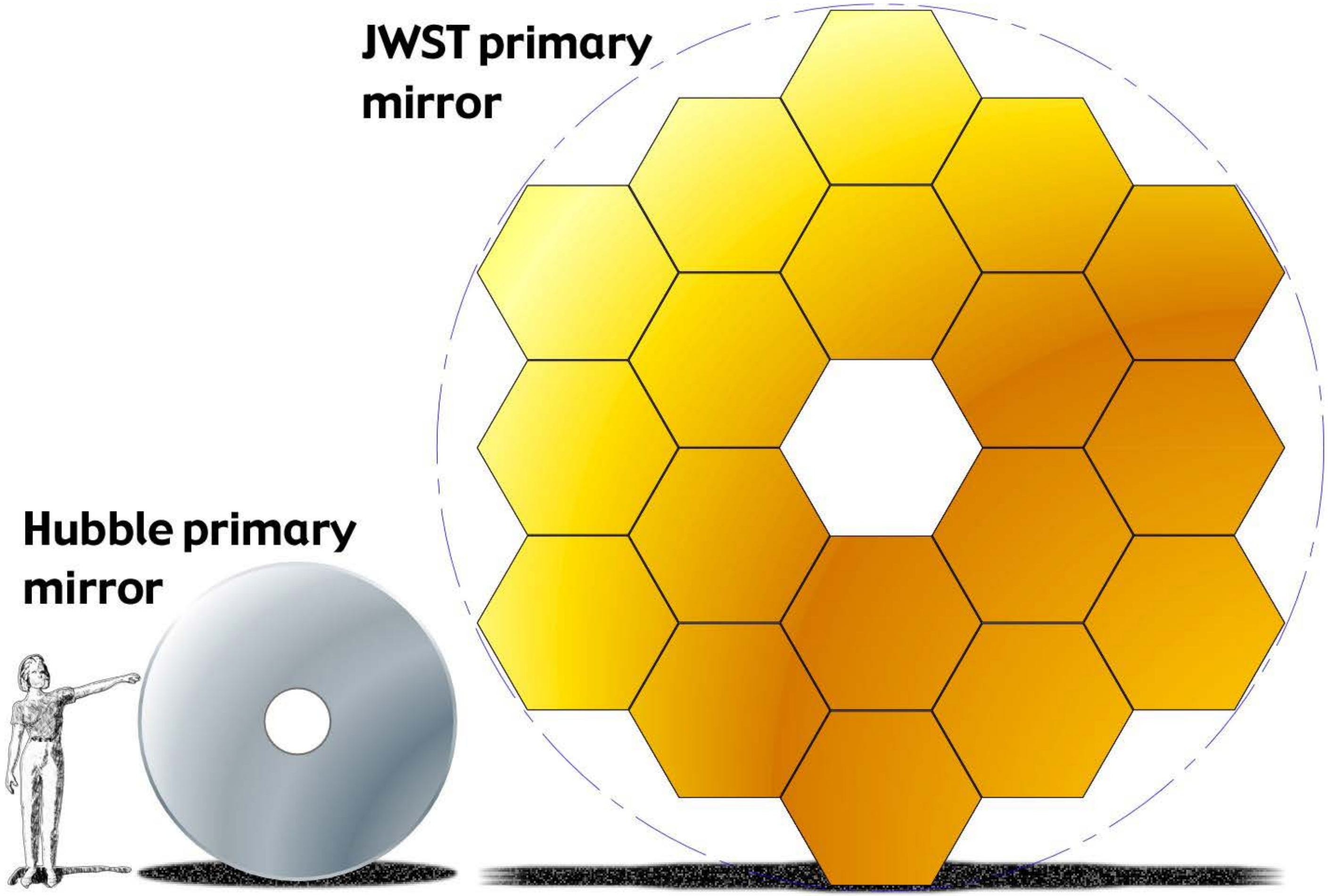
JWST orbit



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



HST & JWST primary mirror comparison



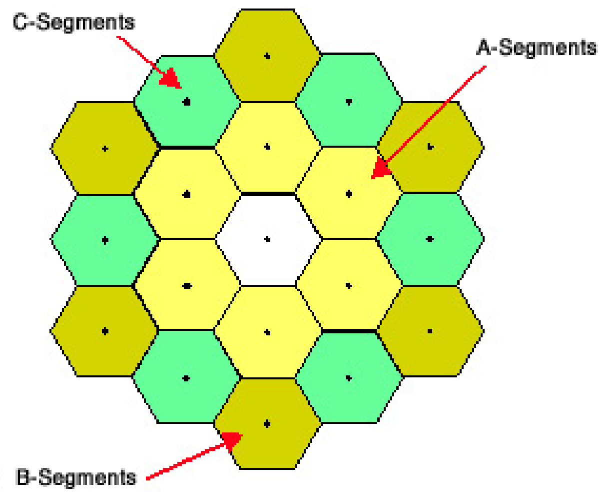
2.4 m dia.

3.6 m^2

6.5 m (18 mirror segments)

25 m^2

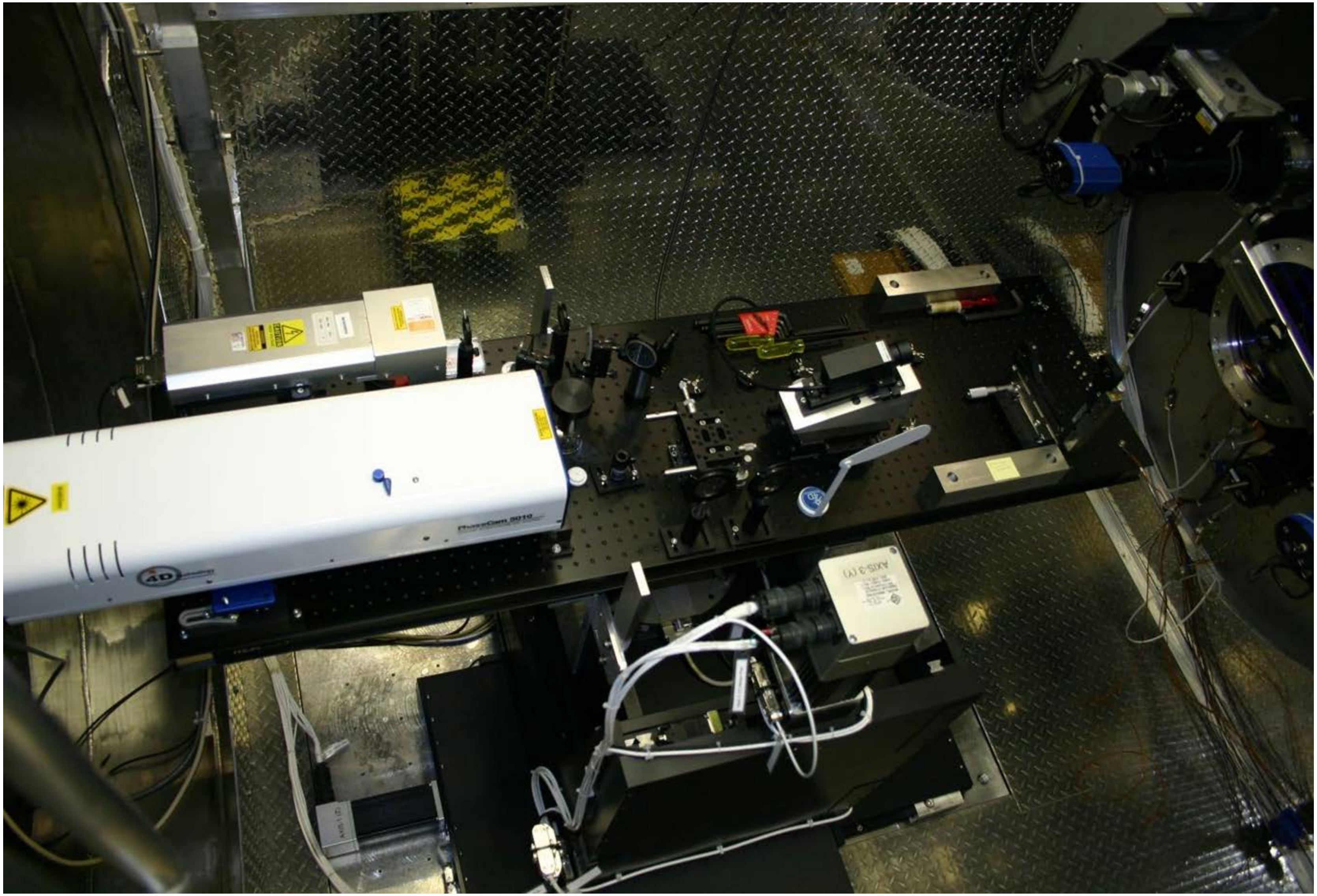
6 of 18 mirror segments cryo test at MSFC



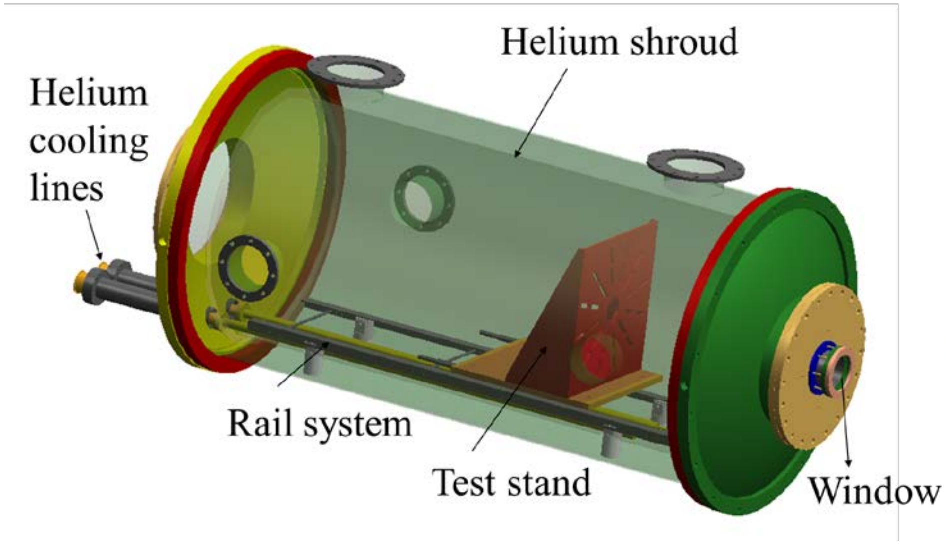
OTE deployment test at GSFC

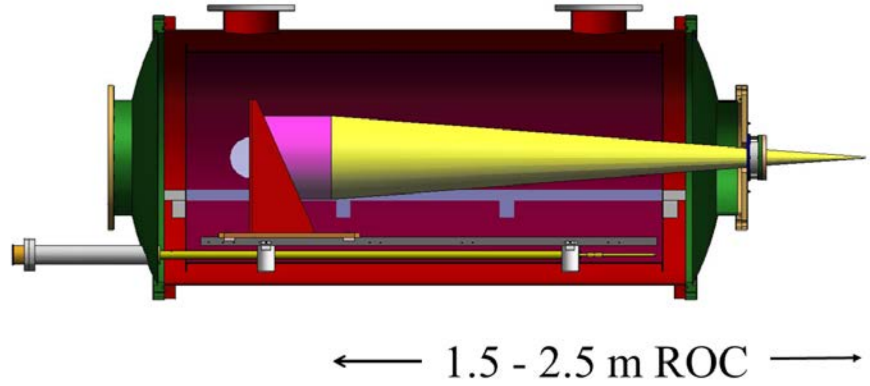
OTE cryo test at JSC

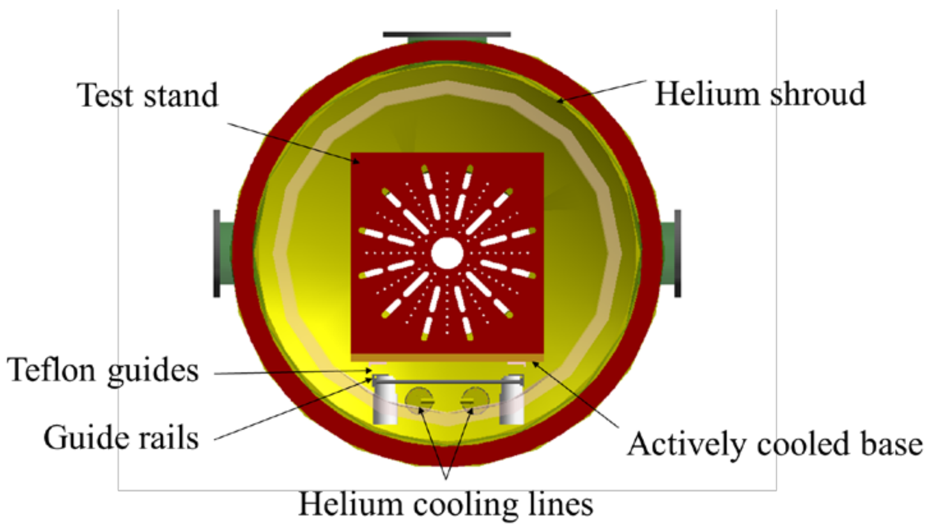
JWST mirror optical test instrument



Test configuration for < 0.8 m dia. mirror







Motivation for SiC testing

- Silicon Carbide for mirror substrate and structural support material
- Low density and CTE, high modulus or stiffness and thermal conductivity
- Can be polished to < 10Å rms
- More than a dozen SiC mirror substrate manufacturers in US
- Over 70 types of SiC: converted SiC, C-SiC, CVC SiC, CVD SiC, CVD SiC on structural graphite core, hot pressed SiC, monolithic CVD-SiC, reaction bonded SiC, siliconized Carbon, sintered SiC, etc.
- Need for independent material properties database

Approach

- **OBJECTIVE**
  - – provide test data on materials using consistent test methods
  - – vendor independent test data
  - – characterize vendor's process and lot uniformity

- **APPROACH**
  - – phase I : samples from 2 or more lots from each participating vendors
  - – phase 2 : samples from 3 additional processing lots
  - – final report and material properties database

Test plan

- **Phase 1**

– incoming surface roughness evaluation; polish if needed
– **cryogenic strain tests (from room temperature down to 30° K)**
– metallographic analysis/chemical analysis
– microstructure analysis/X-Ray diffraction
– density/porosity measurements

- **Phase 2**

– CTE
– thermal conductivity
– tensile strength and elastic modulus
– 4-point bending tests
– fracture toughness
– Analysis: metallographic, chemical, microstructure, X-Ray diffraction
– density/porosity measurements

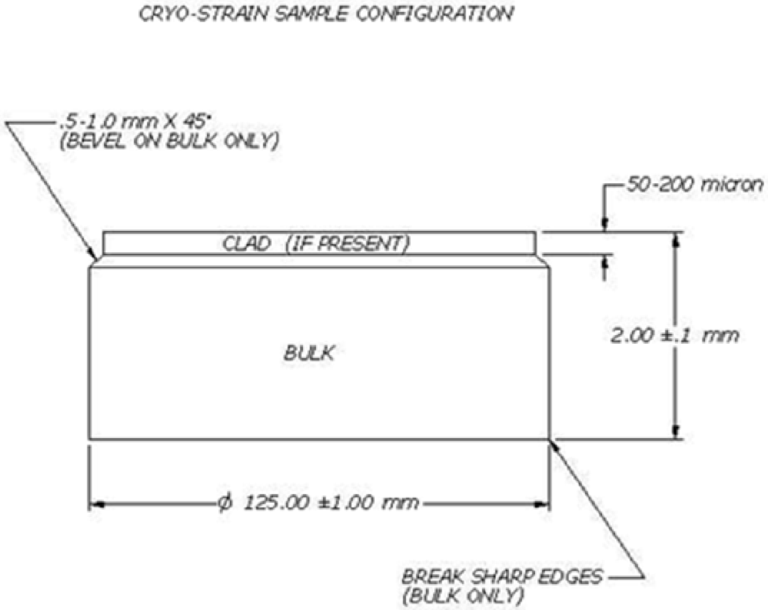
Cryogenic strain test plan

- **Sample Description:** 125 mm plano disk, P-V and 100Å rms or best effort. Vendor supply 1 unclad + 1 cladded sample from 2 lots/batches. If unclad sample is not polish-able, then supply 2 cladded samples from 2 batches

- **Objective:** measures optical figure changes from room temperature to 30° K. The data output will be figure map, rms value, and power as a function of temperature

- **Test Method:** interferometric test will be performed under vacuum at room temperature 290°, 200°, 100°, 70°, 50°, 30°, and 290° Kelvin

Cryo strain SiC sample geometry

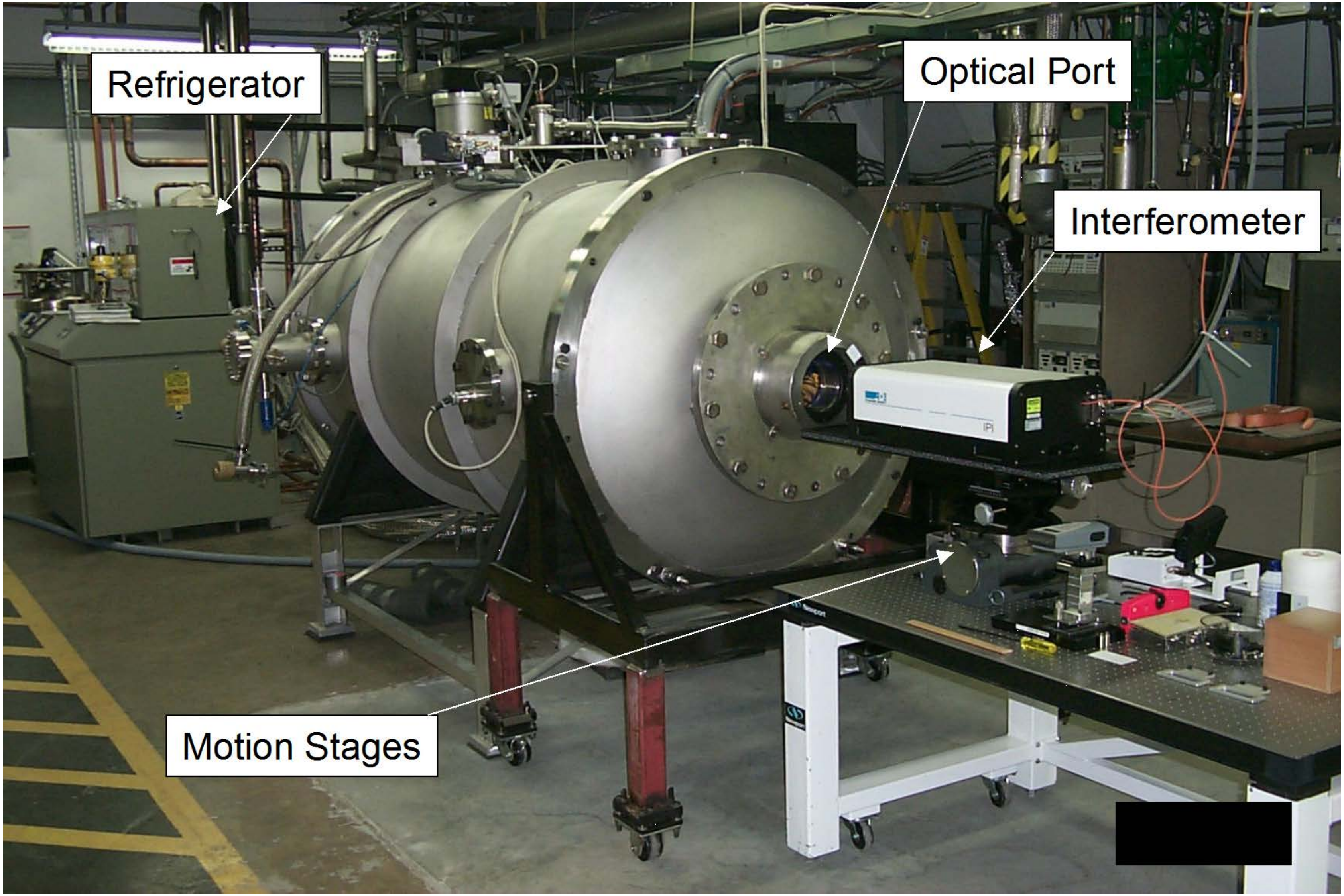


Participating SiC vendors

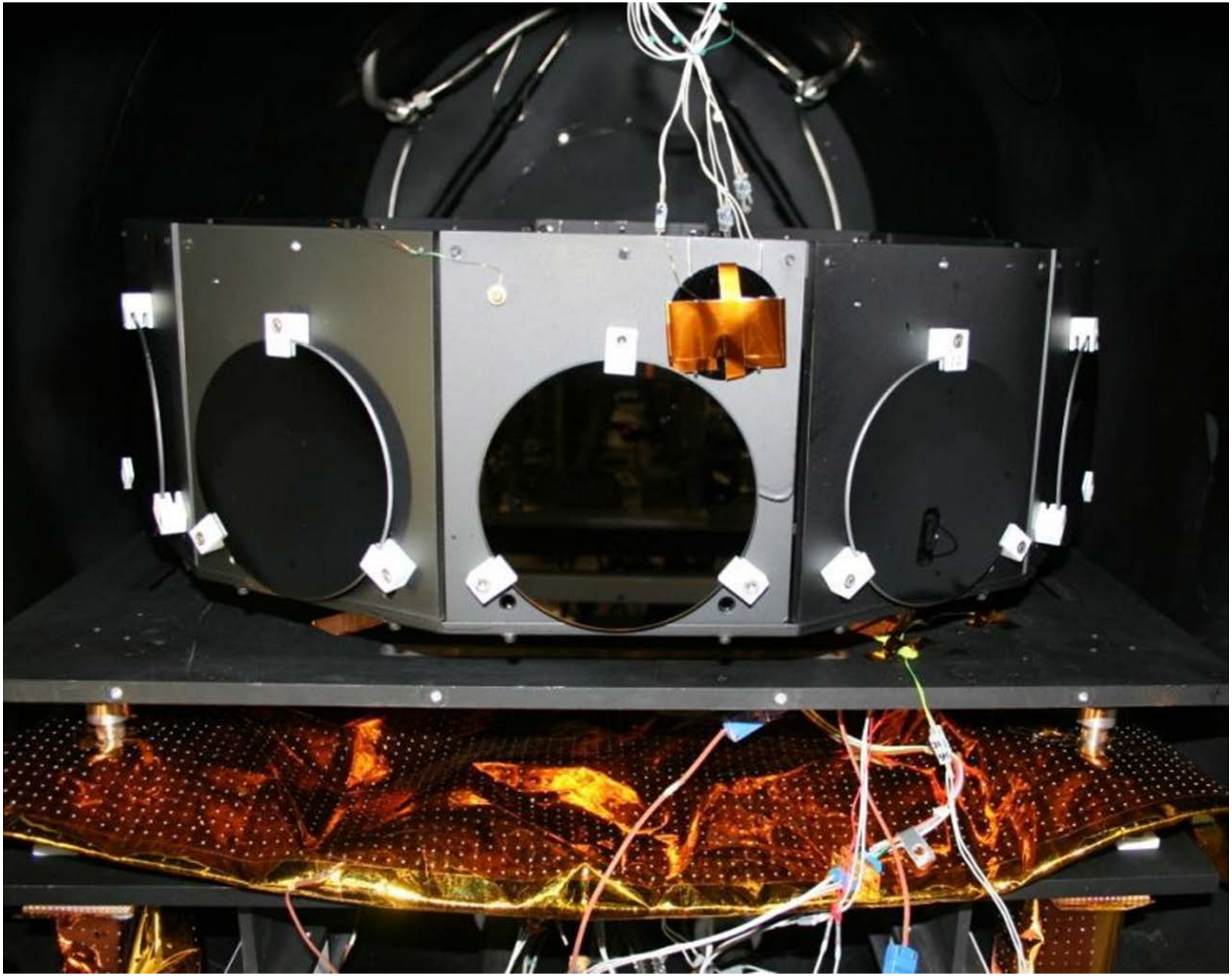
- **Phase 1:** tested 46 samples for cryogenic optical strain
  – Boostec S.A.
  – CoorsTek
  – GE Power Systems Composites, LLC / ECM
  – M-Cubed Technologies, Inc.
  – Poco Graphite, Inc.
  – SSG Precision Optronics, Inc.
  – Trex Enterprises Corp.

- **Phase 2:**
  – CoorsTek
  – Poco Graphite, Inc.
  – SSG Precision Optronics, Inc.
  – Trex Enterprises Corp.

1 x 2 m cryo test chamber for mirror characterization



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



Cryo strain test setup

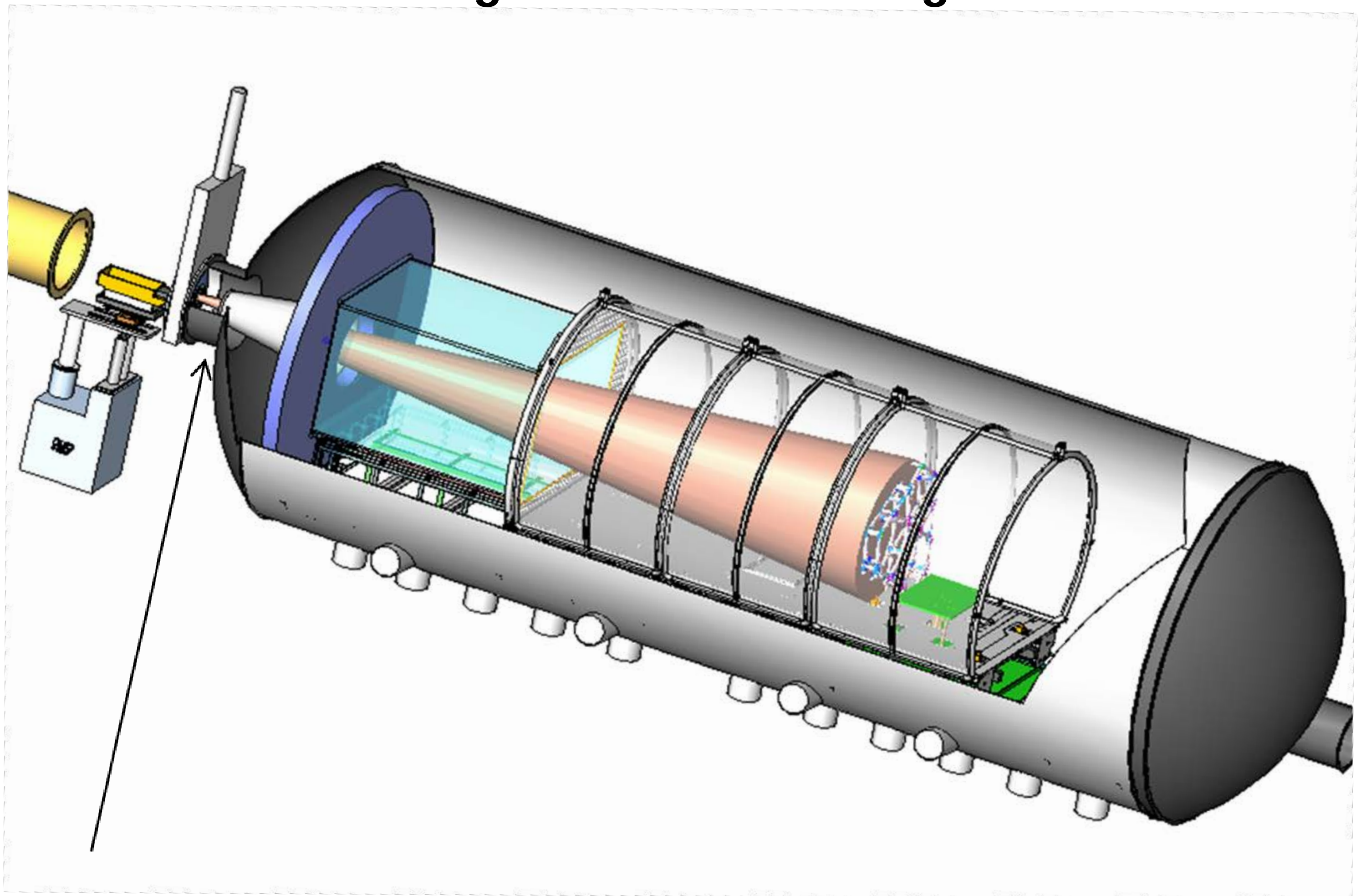
Observations

- large variance among each vendor’s samples
- SiC cryo strain caused by materials and more importantly, residual stress from polishing
- Test results along with vendor part # will be given to each perspective vendor

Advanced Mirror Technology Development (AMTD)

- Develop enabling technology for 4 meters or larger monolithic or segmented, UV, optical, and IR space telescope primary mirror assemblies for general astrophysics, and ultra-high-contrast observations of exoplanet missions
- Large UV optical IR (LUVOIR) surveyor mission concept
- HabEx mission concept
- Mission concepts for the 2020 Decadal Survey

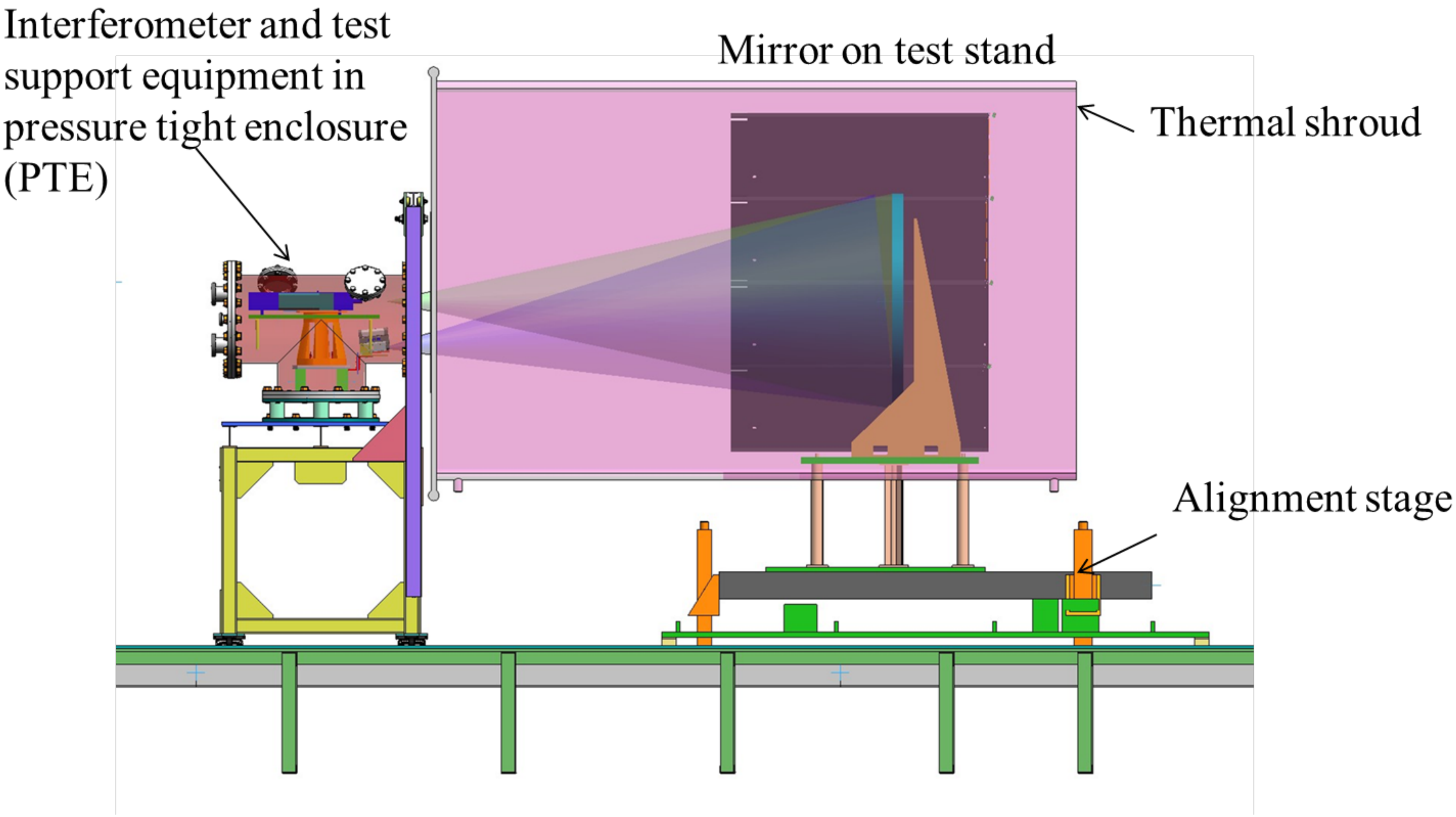
Pressure tight enclosure in large chamber



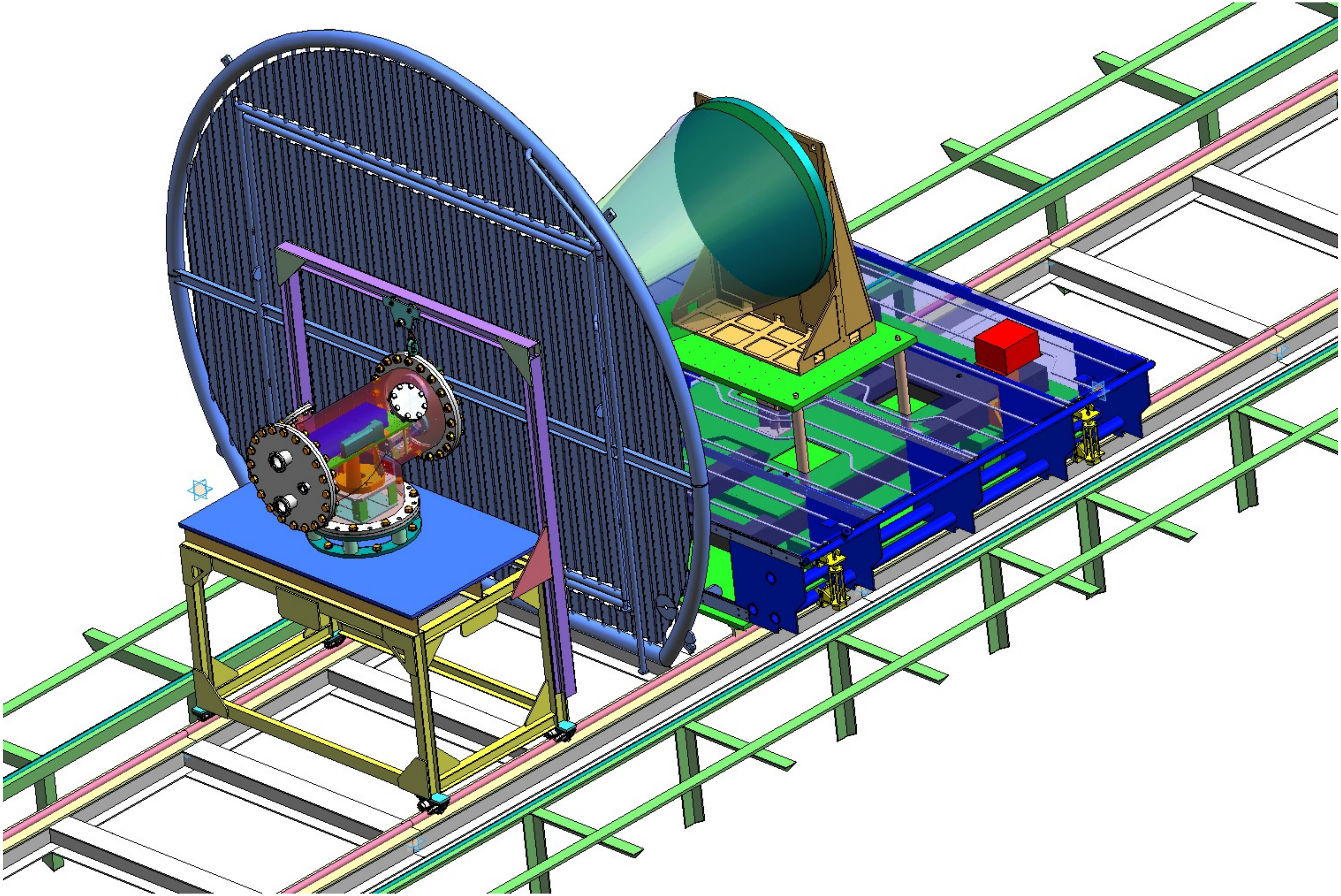
Existing structure prevents testing mirrors in this configuration with ROC < 3.5 meters

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

Test configuration for < 3.5 m radius of curvature mirror

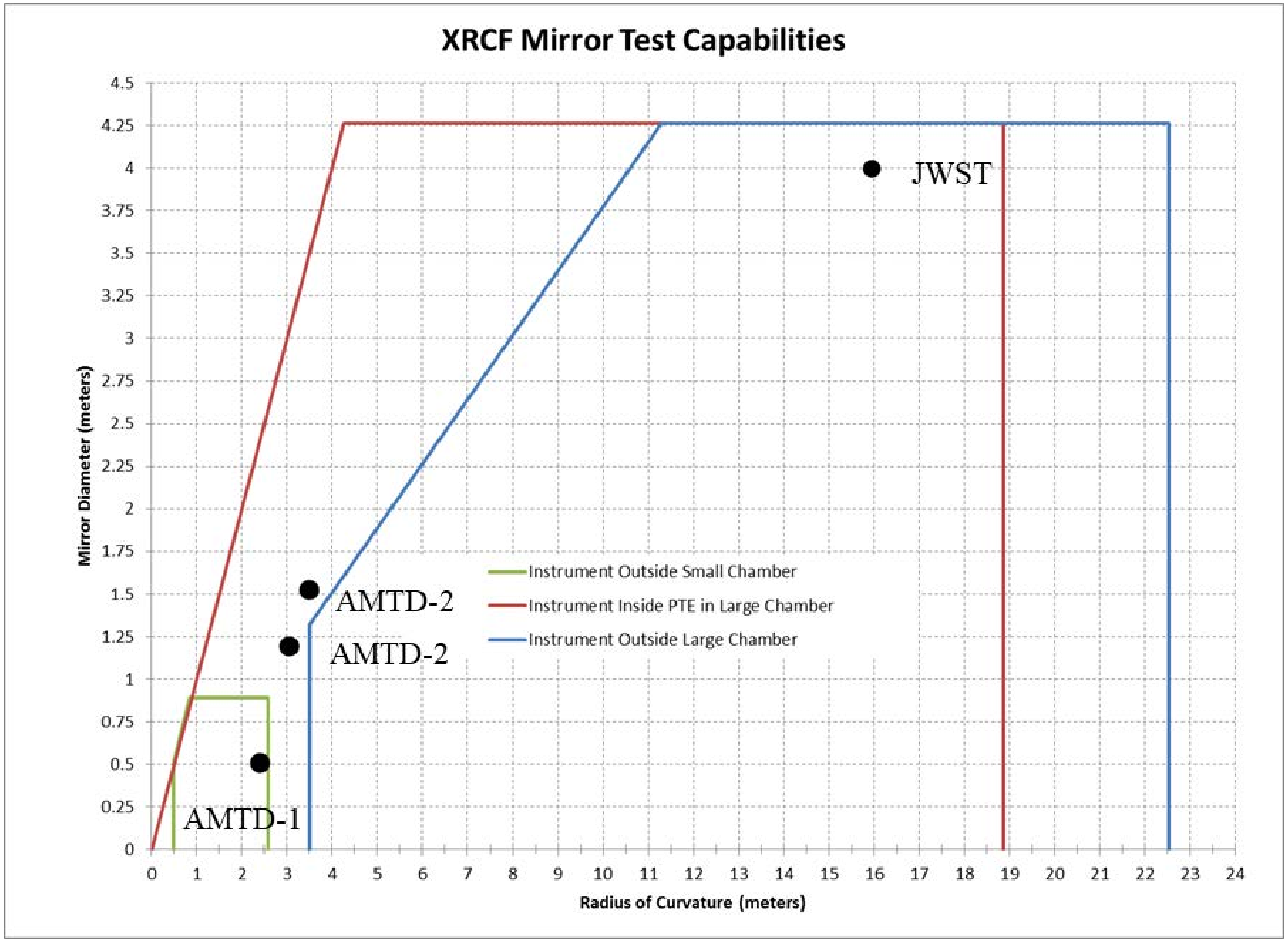


Test configuration for < 3.5 m radius of curvature mirror

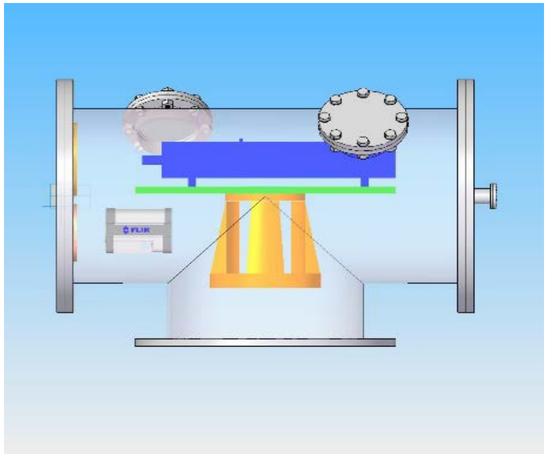


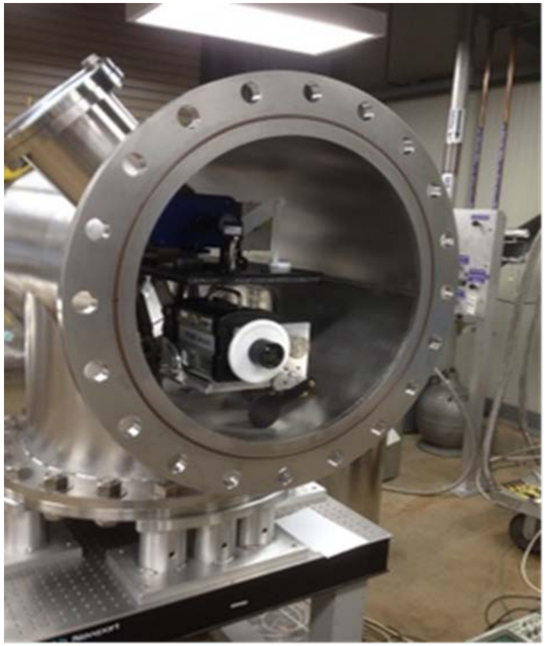
Test envelop for large and small chambers

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



Optical test equipment inside pressure tight enclosure (PTE)

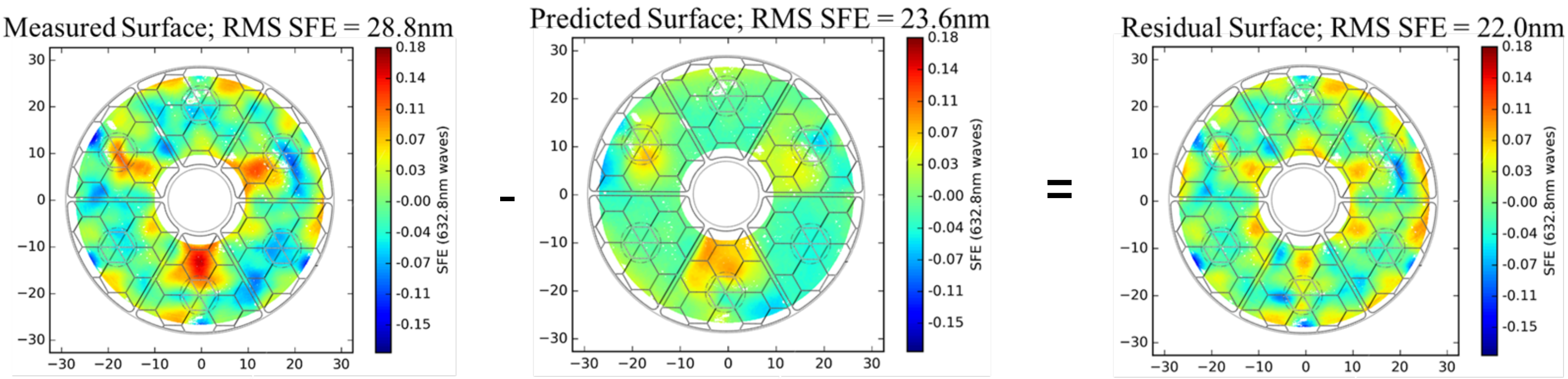




1. alignment CCD
2. alignment pinhole
3. interferometer
4. ADM
5. IR camera stage
6. hexapod

Cryo optical test with PTE

Thermal optical test surface figure error

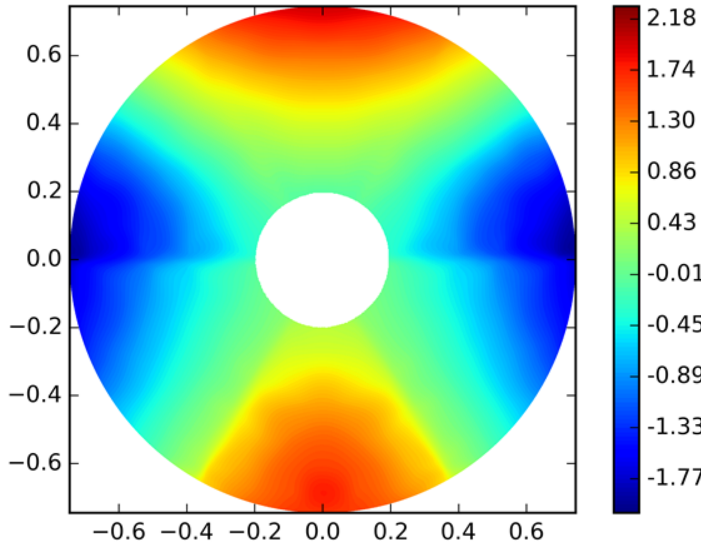


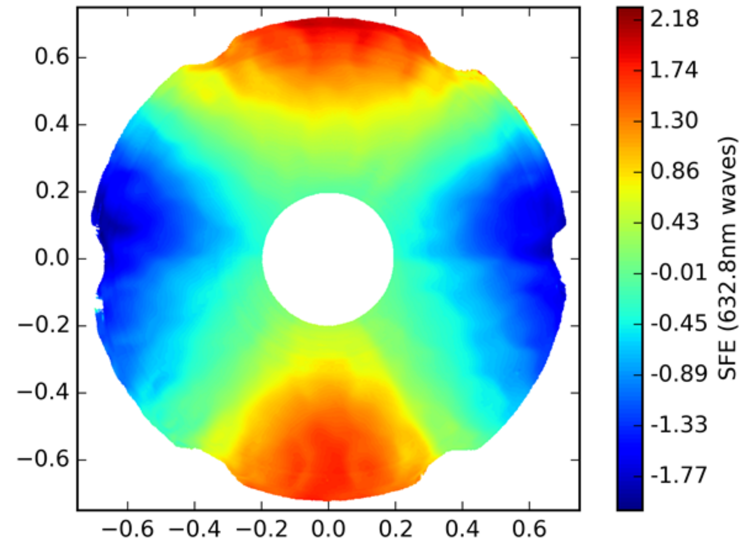
Predicted SFE uses:

- 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)

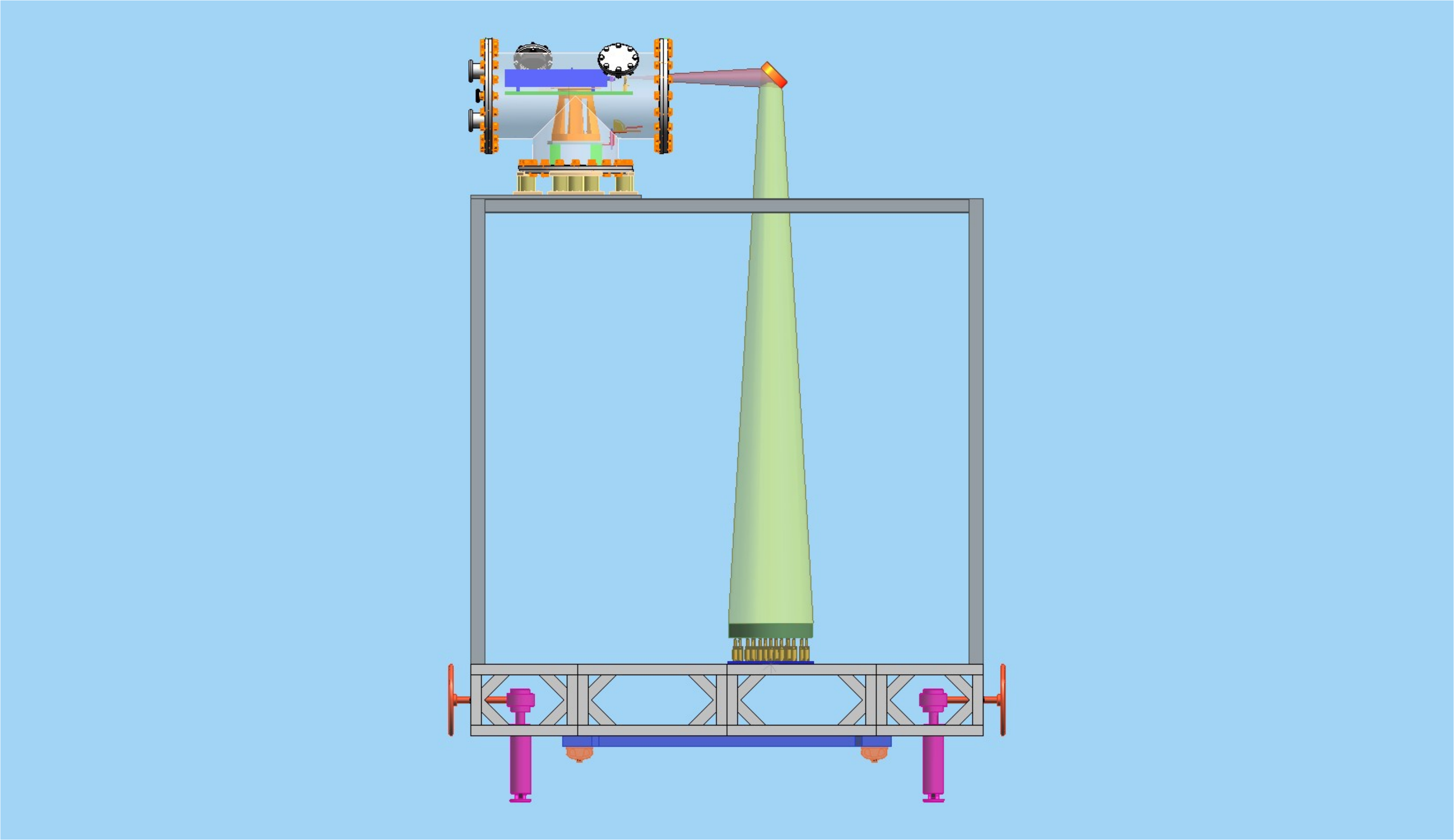




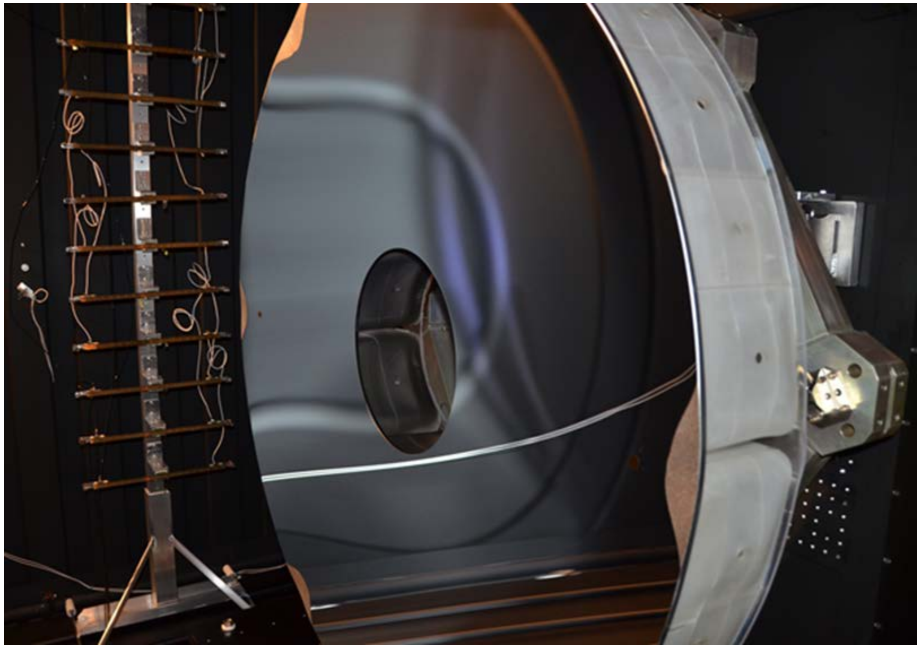
Predicted
580 nm rms

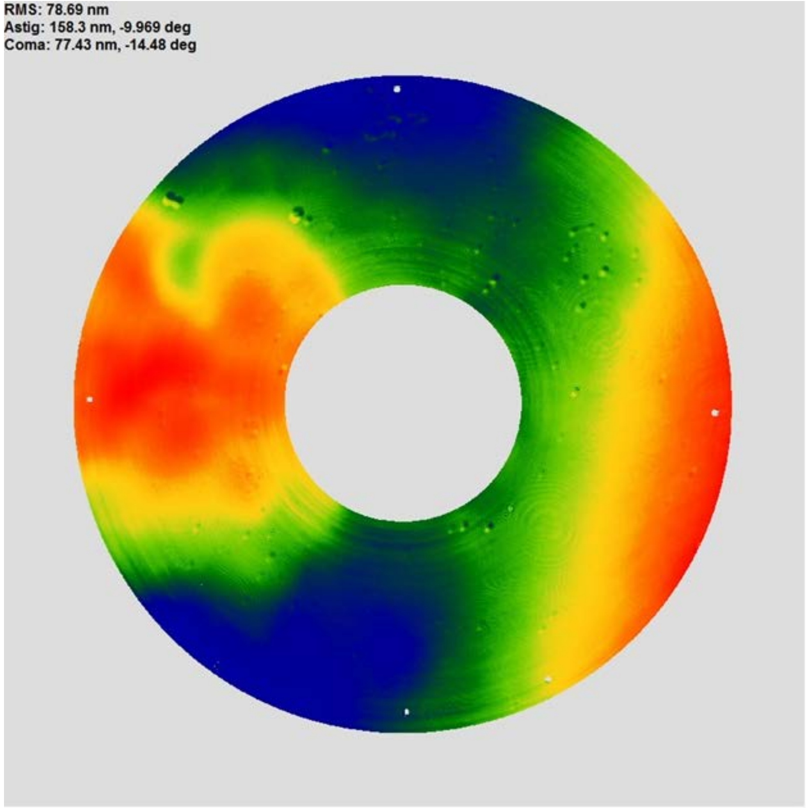
Measured
582.5 nm rms

Vertical optical test configuration



Thermal gradient test



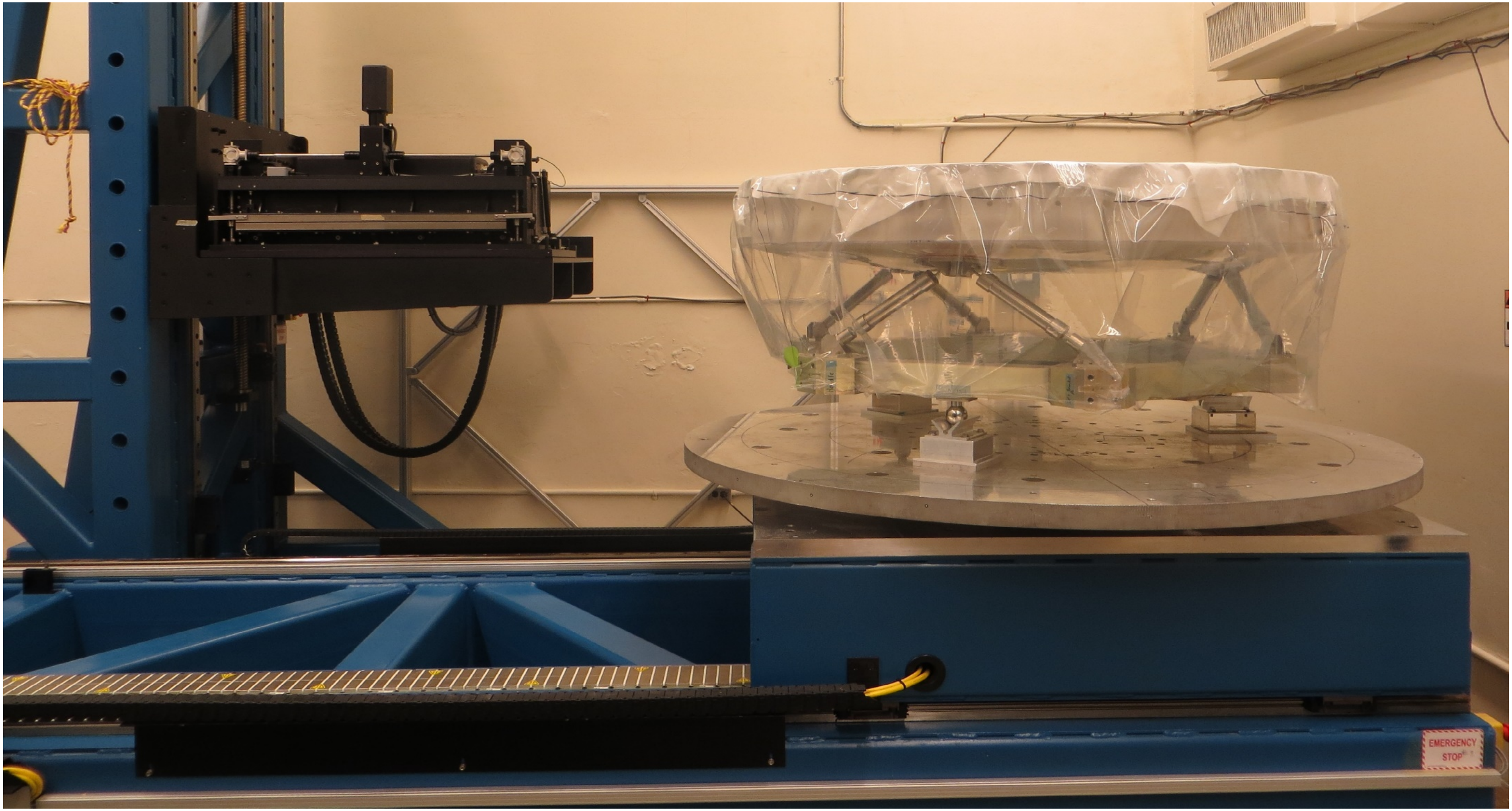


Mirror assembly modal test

- Tapped at 42 locations with an instrumented modal test hammer
- Each location was tapped 5x and averaged

Mirror assembly suspended with bungees to simulate free-free condition

X-Ray computed tomography



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
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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

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title