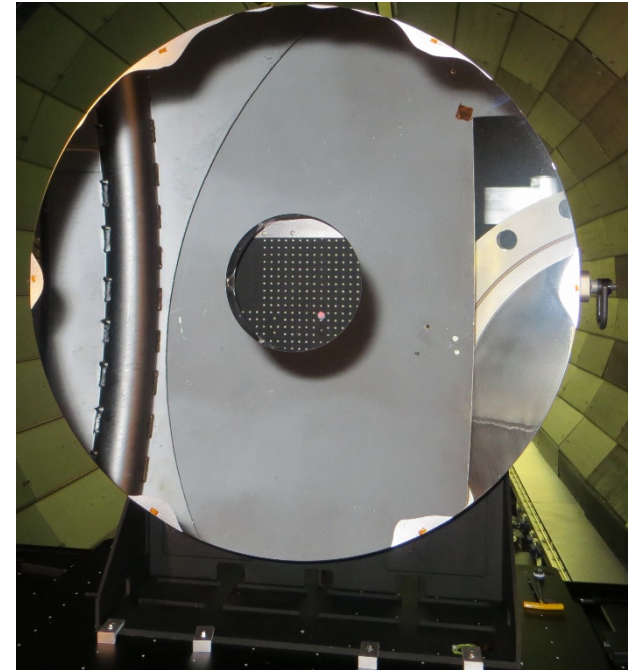
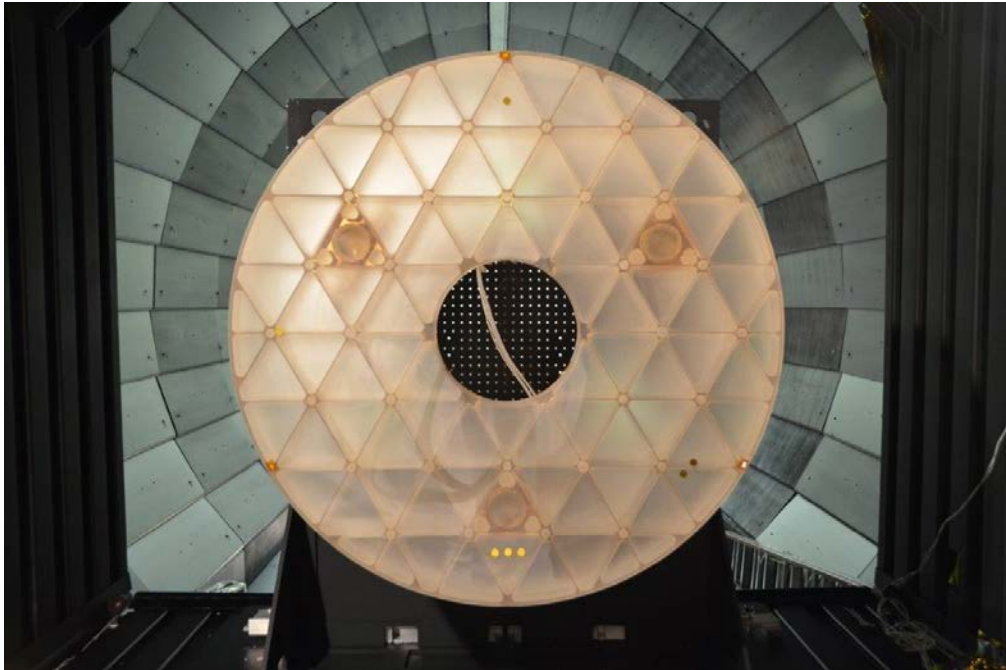


# Large space telescope development programs



**Ron Eng**

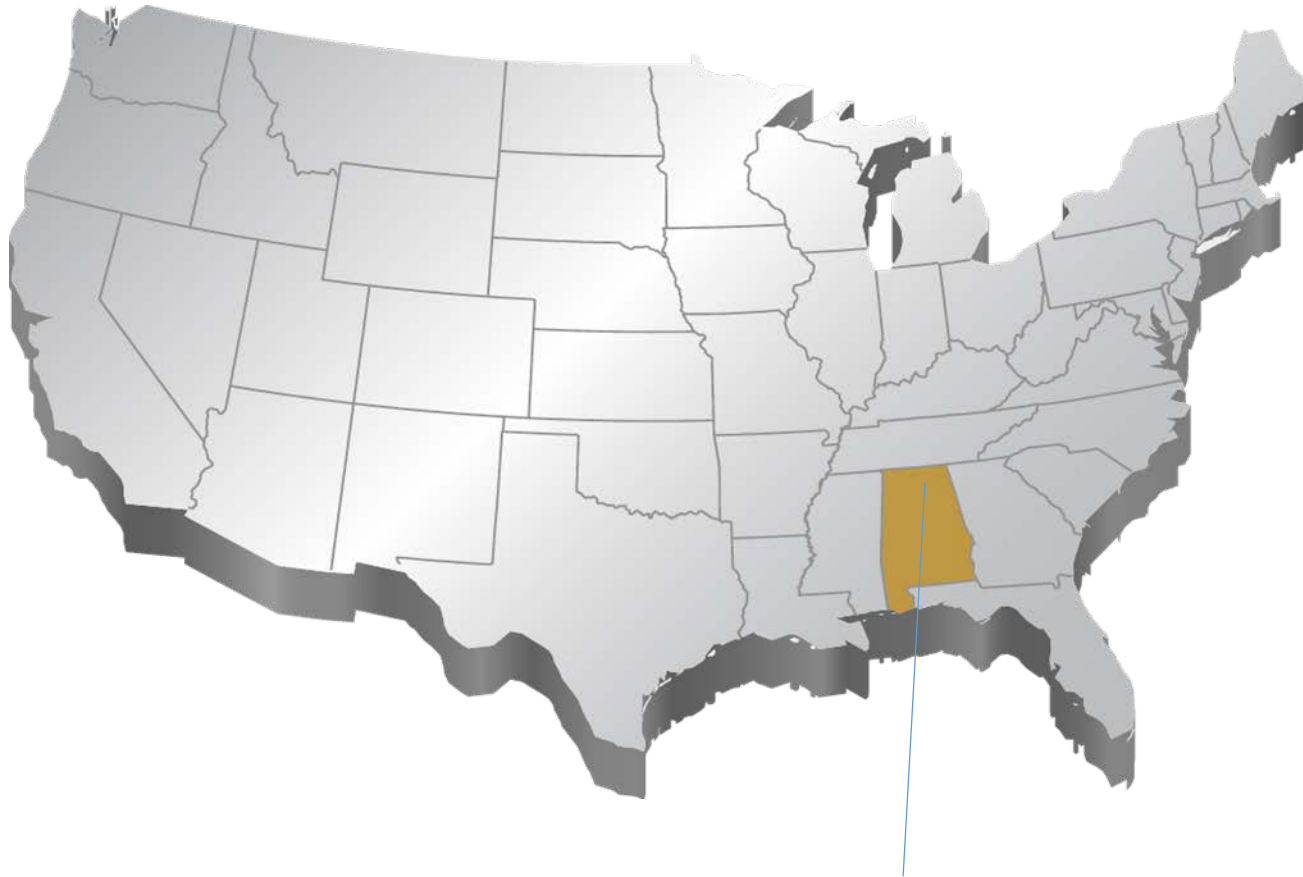
Optics and Imaging Branch

**NASA Marshall Space Flight Center**

1<sup>st</sup> Silicon Carbide International workshop



# NASA Marshall Space Flight Center



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

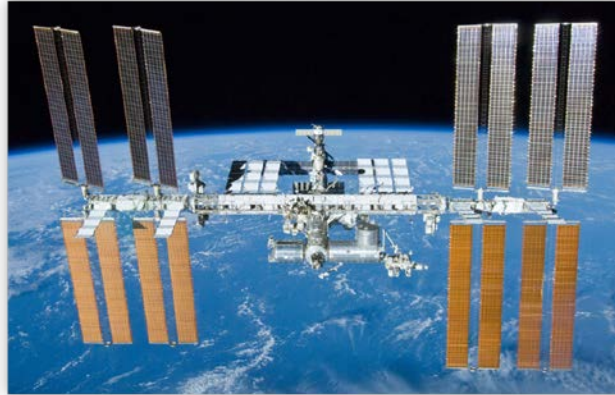


# Space Transportation, Propulsion Systems

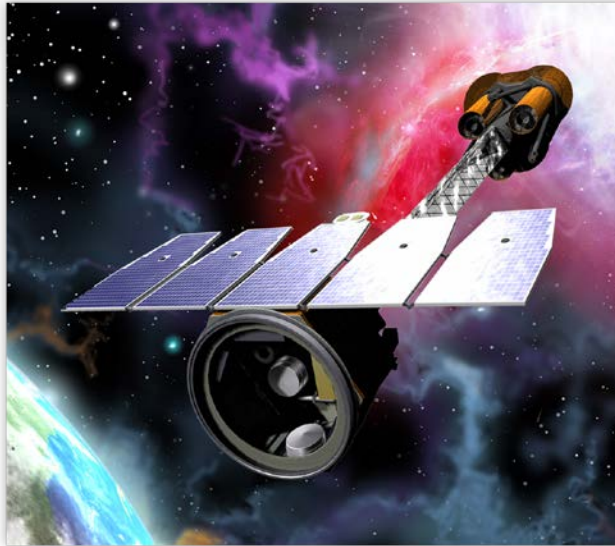




**High Energy Astronomy Observatories (1977-1981)**



**International Space Station (1998-present)**



**Imaging X-ray Polarimetry Explorer (IXPE)  
Under development**



**Hubble Space Telescope (1990-present)**



**Chandra X-Ray Observatory  
(1999-present)**





# Current and planned astrophysics missions



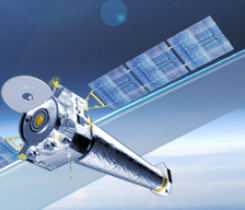
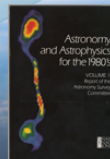


# ASTROPHYSICS

## Decadal Survey Missions

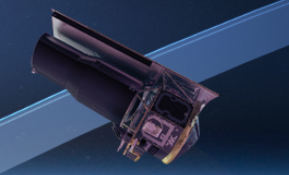
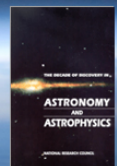
**1972**  
Decadal Survey  
*Hubble*  
4/24/1990

**1982**  
Decadal Survey  
*Chandra*  
7/23/1999



Launch 2003

**1991**  
Decadal Survey  
*Spitzer, SOFIA*




**2001**  
Decadal Survey  
*JWST*

2021




**2010**  
Decadal Survey  
*WFIRST*

Mid 2020s



# 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.

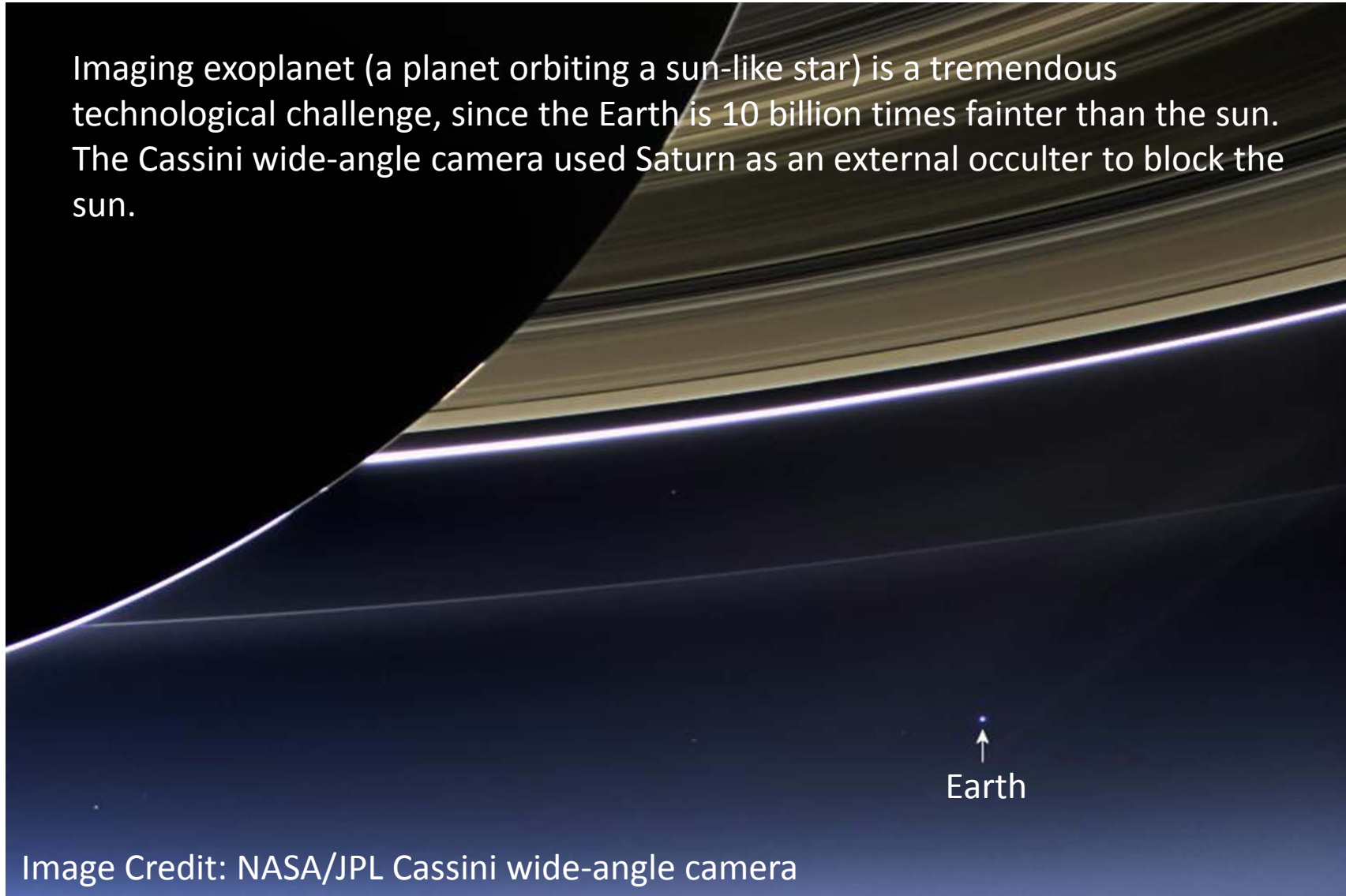
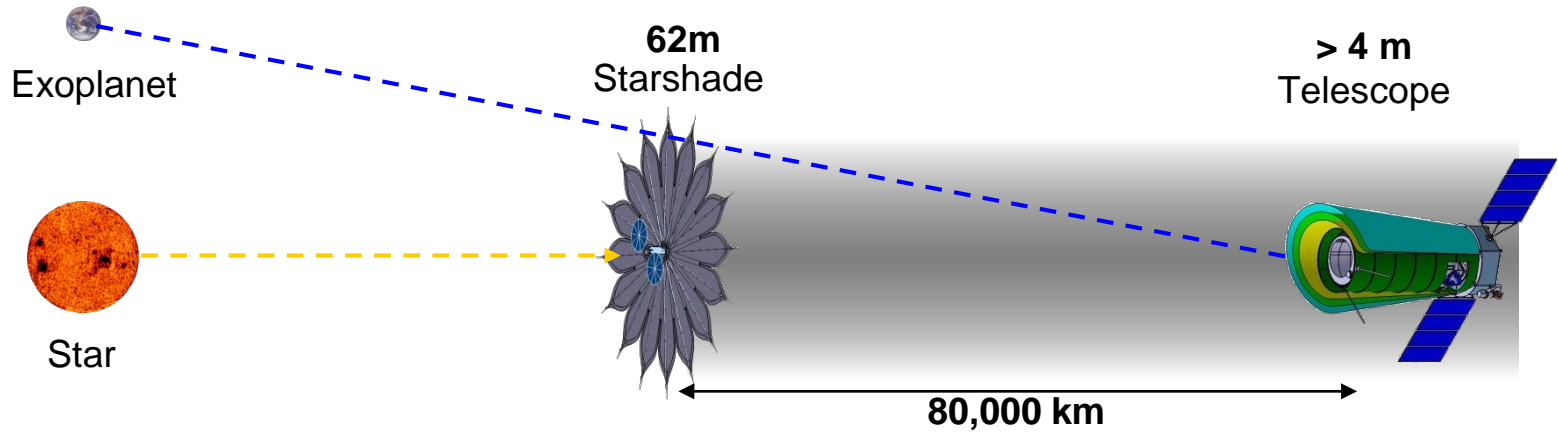
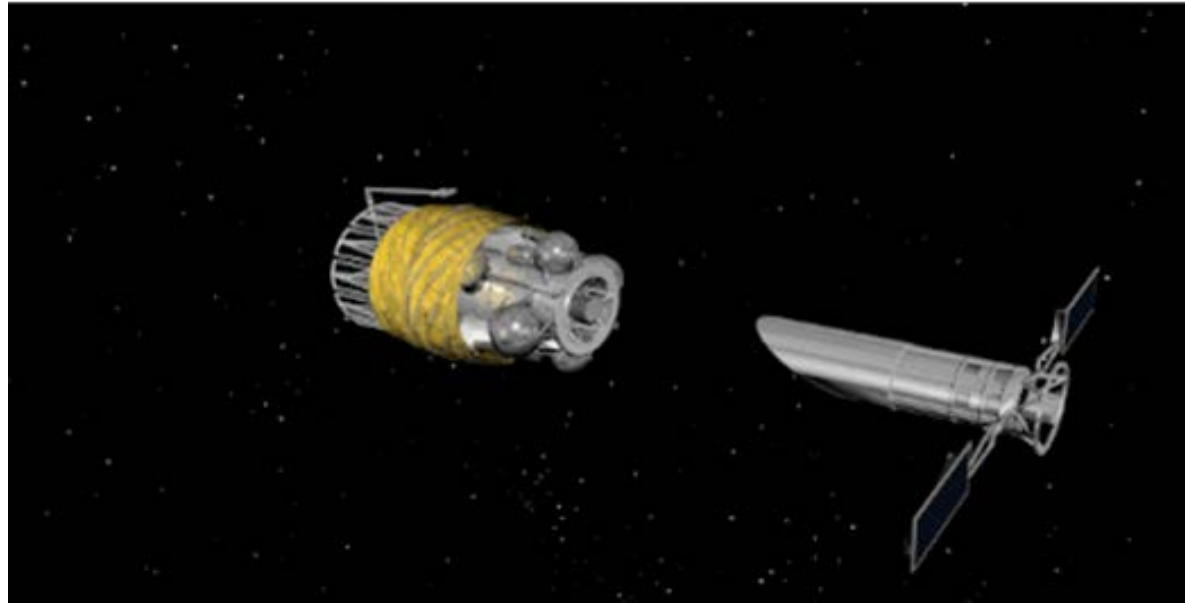
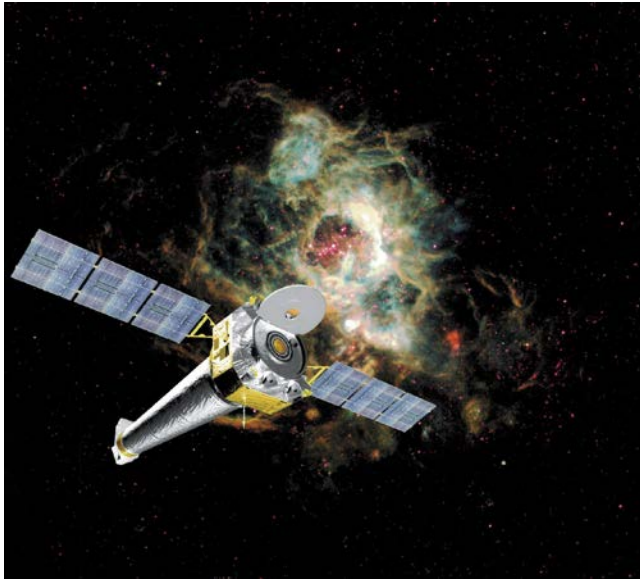


Image Credit: NASA/JPL Cassini wide-angle camera

# Direct imaging technique with external starshade









# 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: 320° to 20° K

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

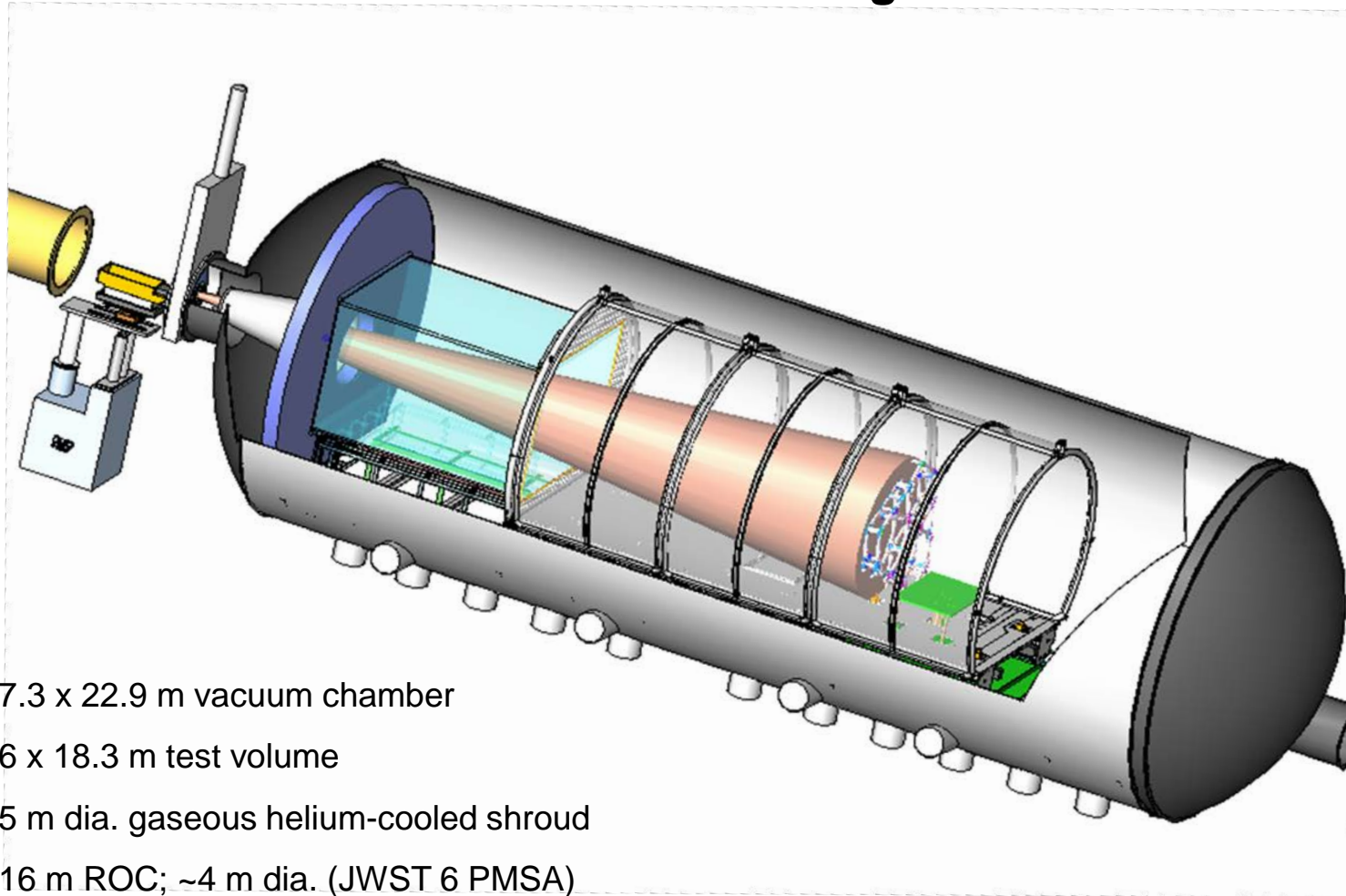
**Vacuum systems:** 10<sup>-8</sup> Torr

**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.



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

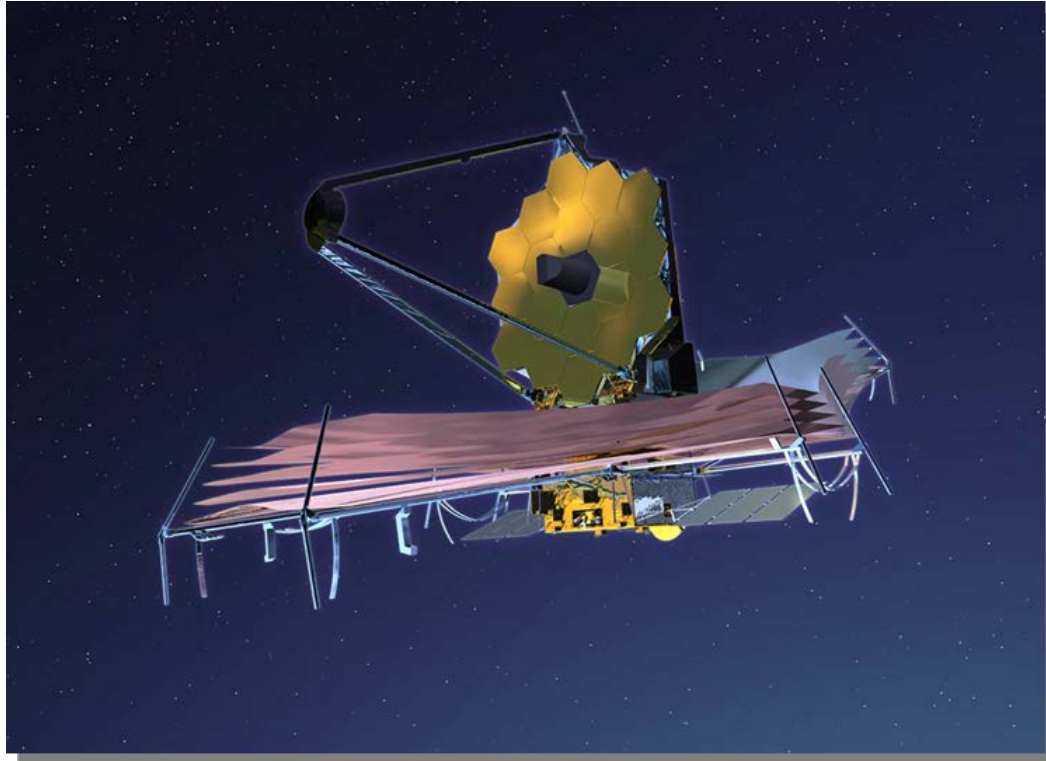


# XRCF class 2K clean room





# James Webb Space Telescope (JWST)



**NASA, ESA, and CSA**

**Planned launch date 3/30/2021**

**0.6 – 30 microns (visible to mid IR)**

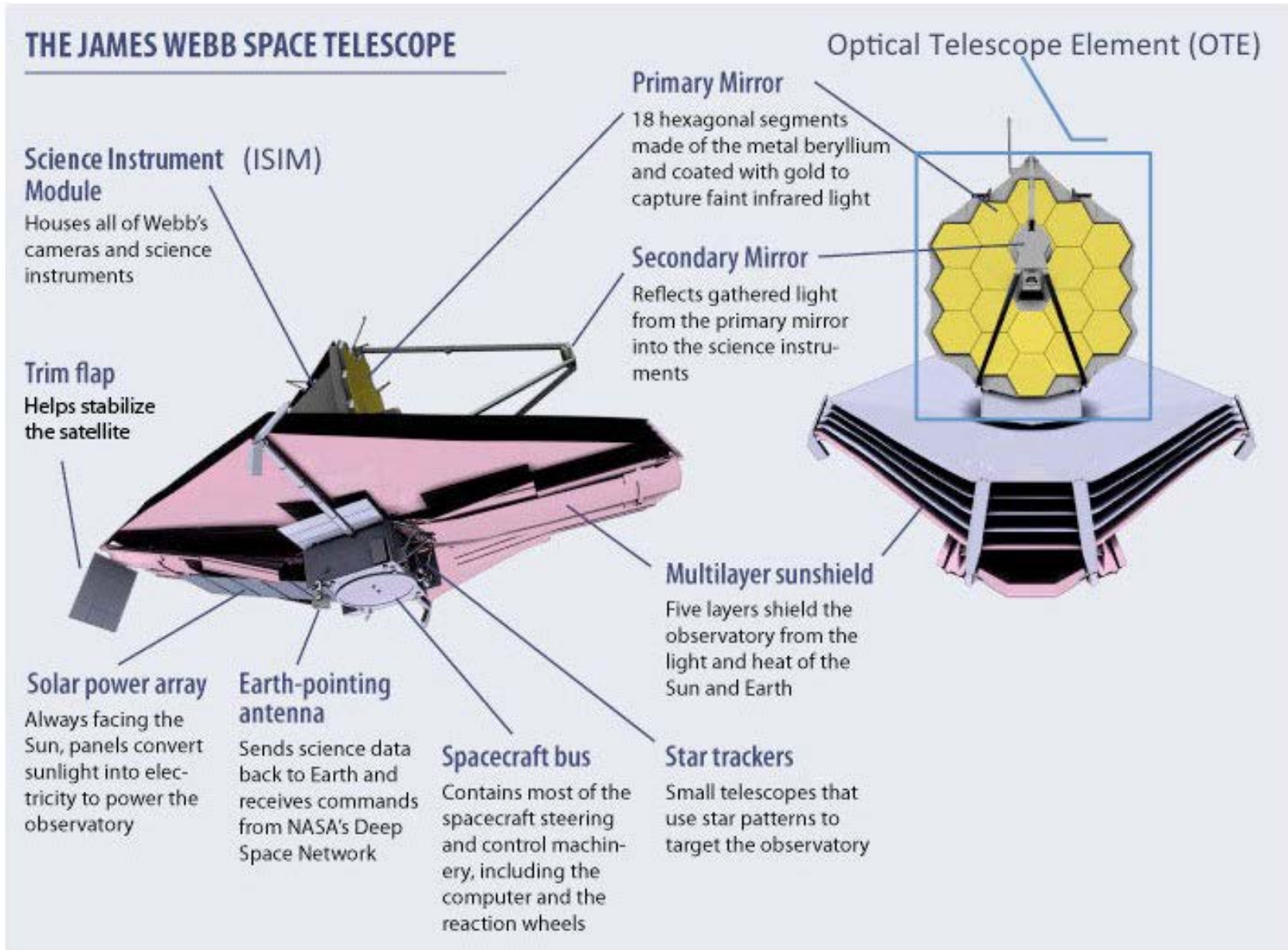
**4 scientific instruments**

**6.5m primary mirror**

**L2 orbit, 1,500,000 km**

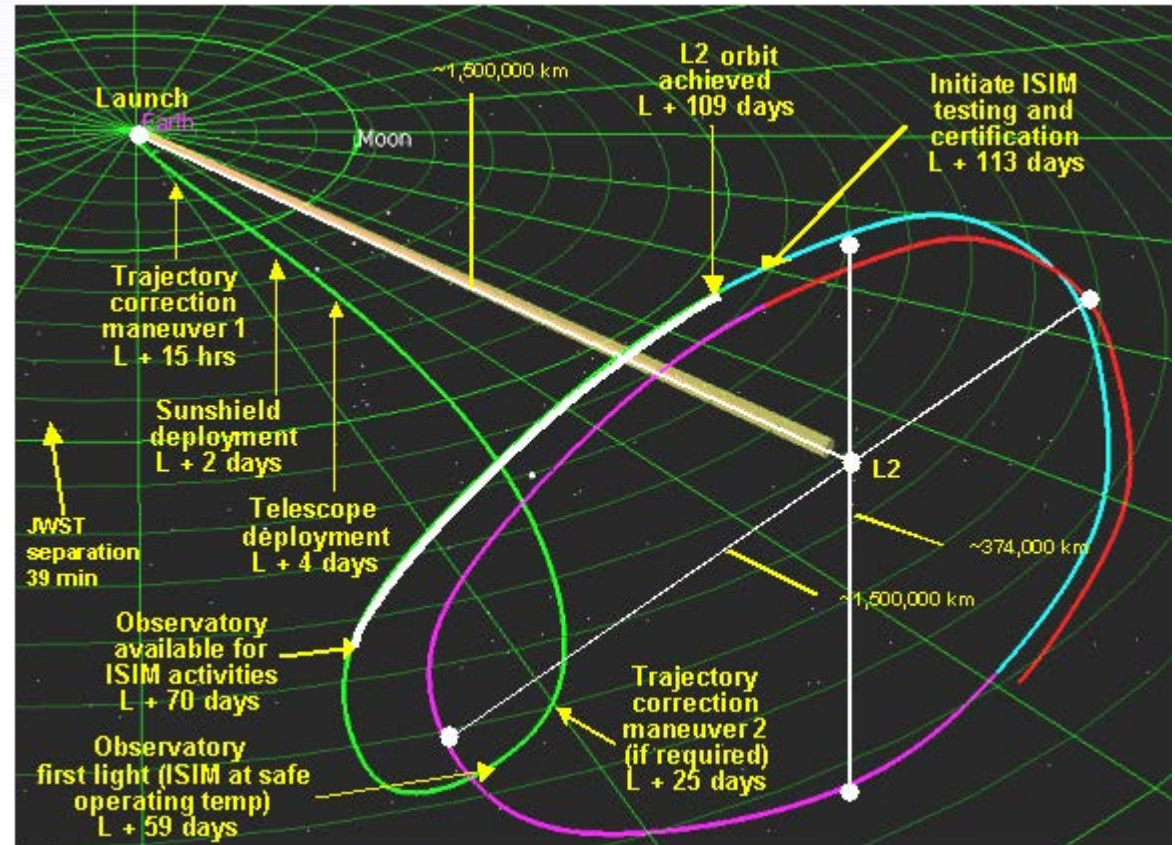
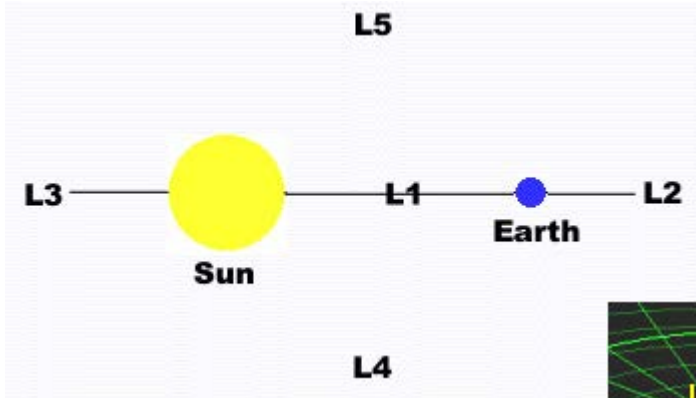
**Science objectives: first light, formation of galaxies, birth of stars and planets, and origin of life.**

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

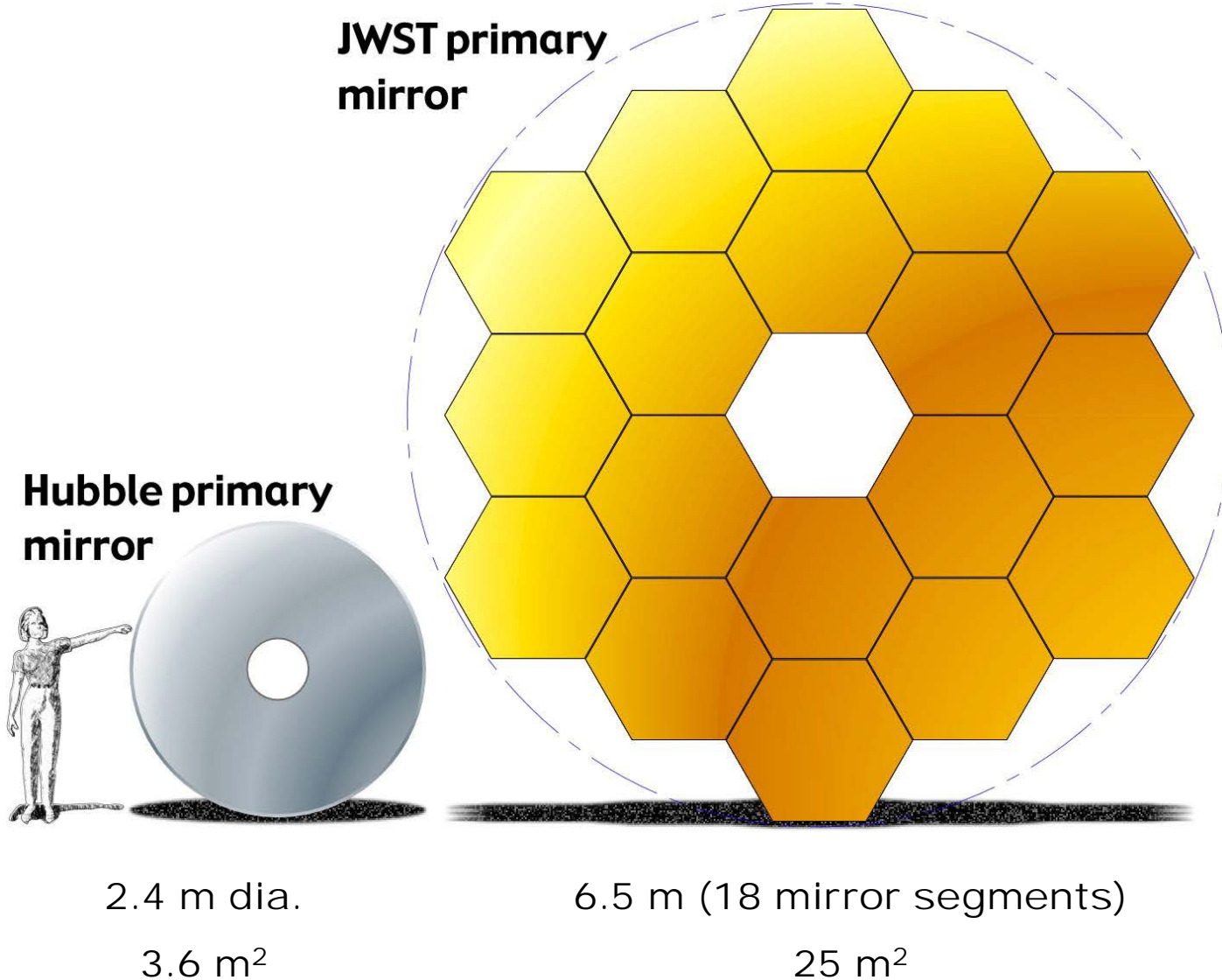


# JWST orbit

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



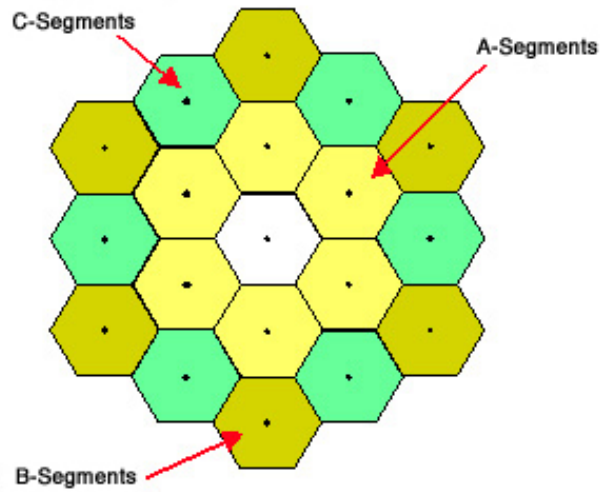
# HST & JWST primary mirror comparison







# 6 of 18 mirror segments cryo test at MSFC







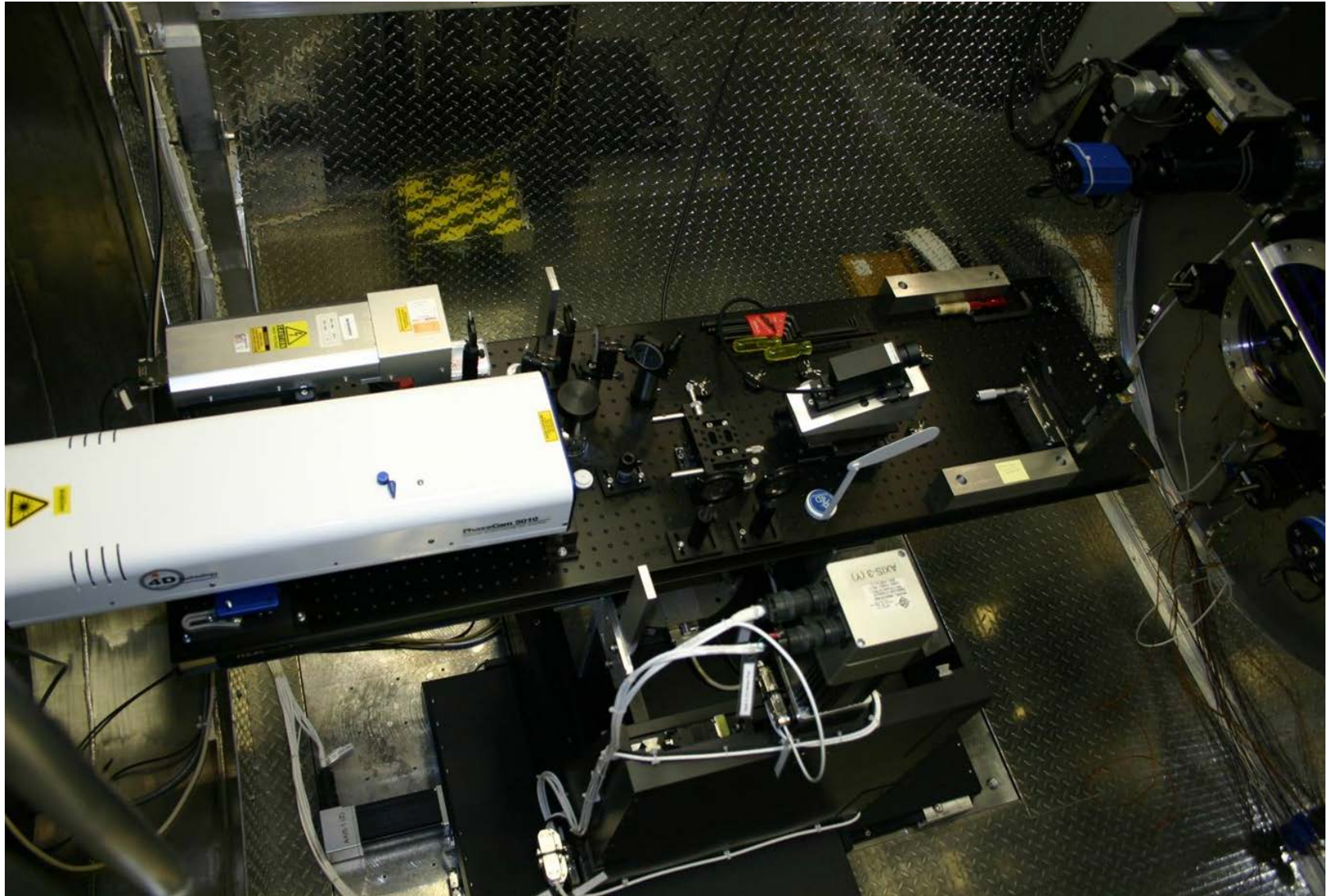
# OTE cryo test at JSC



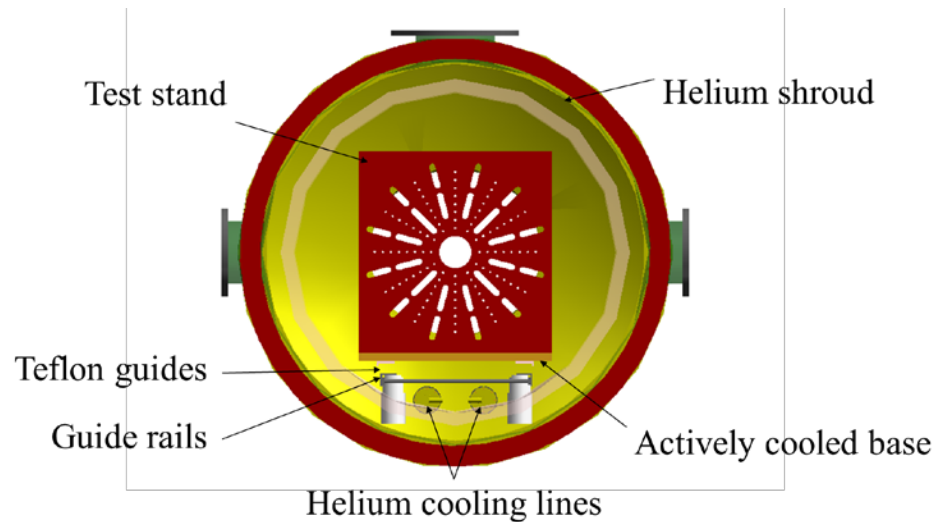
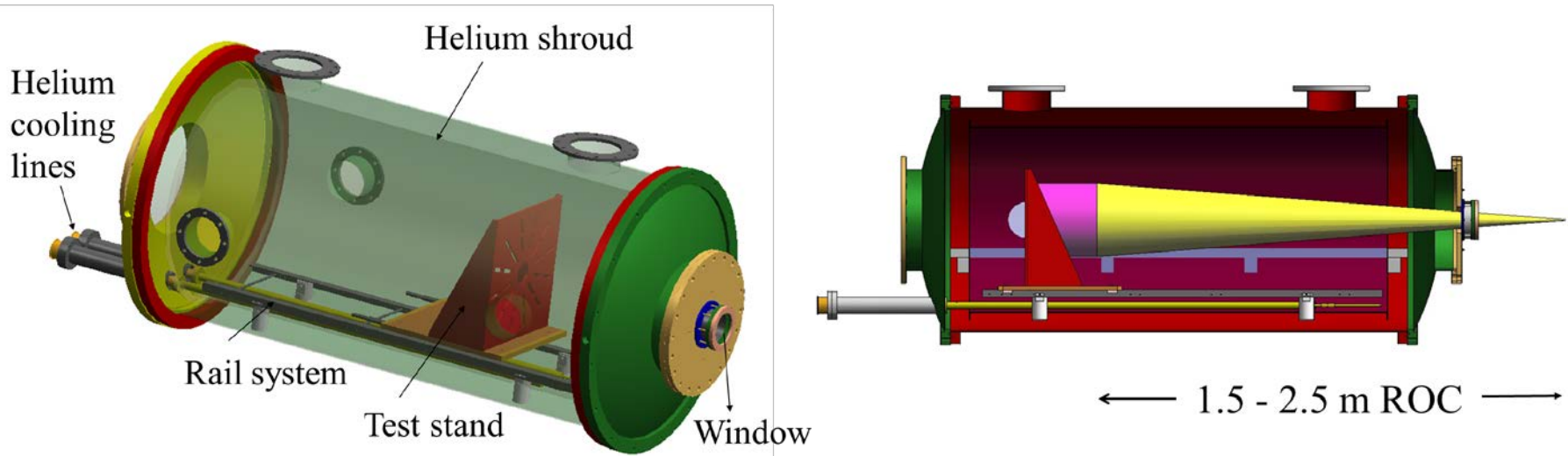
Oct 29, 2018

1st SiC international workshop

19



# 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  $< 10\text{\AA}$  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 1 : 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

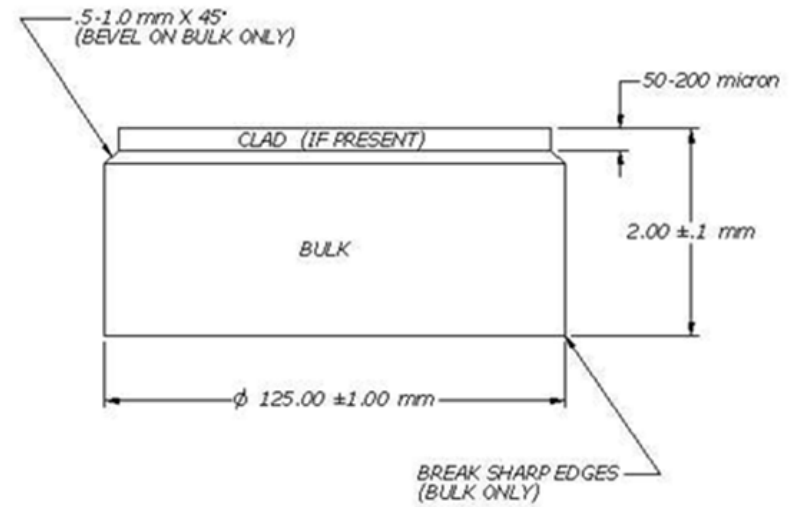


- **Sample Description:** 125 mm plano disk, P-V and 100Å rms or best effort. Vendor supply 1 unclad + 1 clad sample from 2 lots/batches. If unclad sample is not polish-able, then supply 2 clad samples from 2 batches
- **Objective:** measures optical figure changes from room temperature to 30° K. The 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



CRYO-STRAIN SAMPLE CONFIGURATION

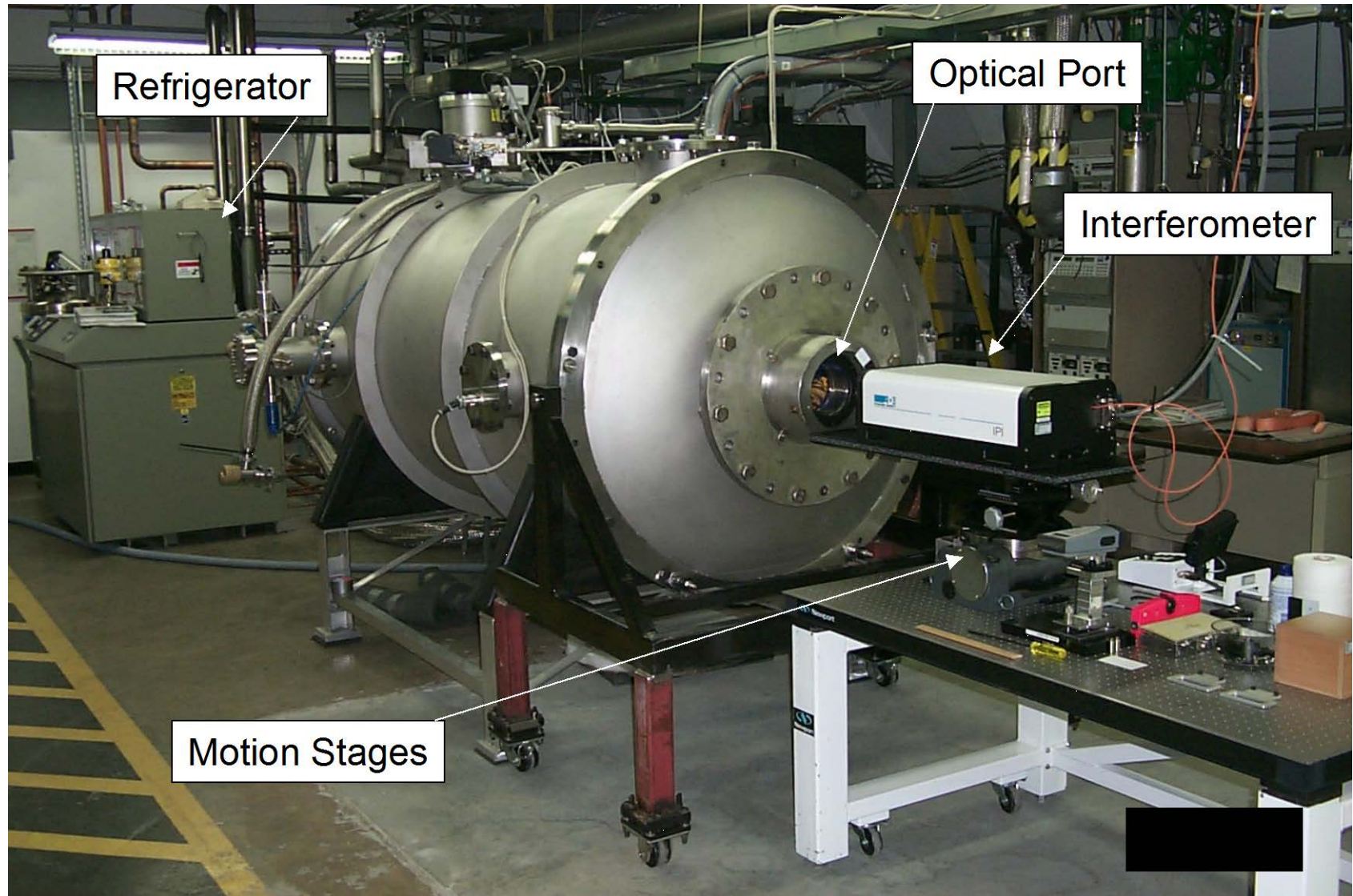




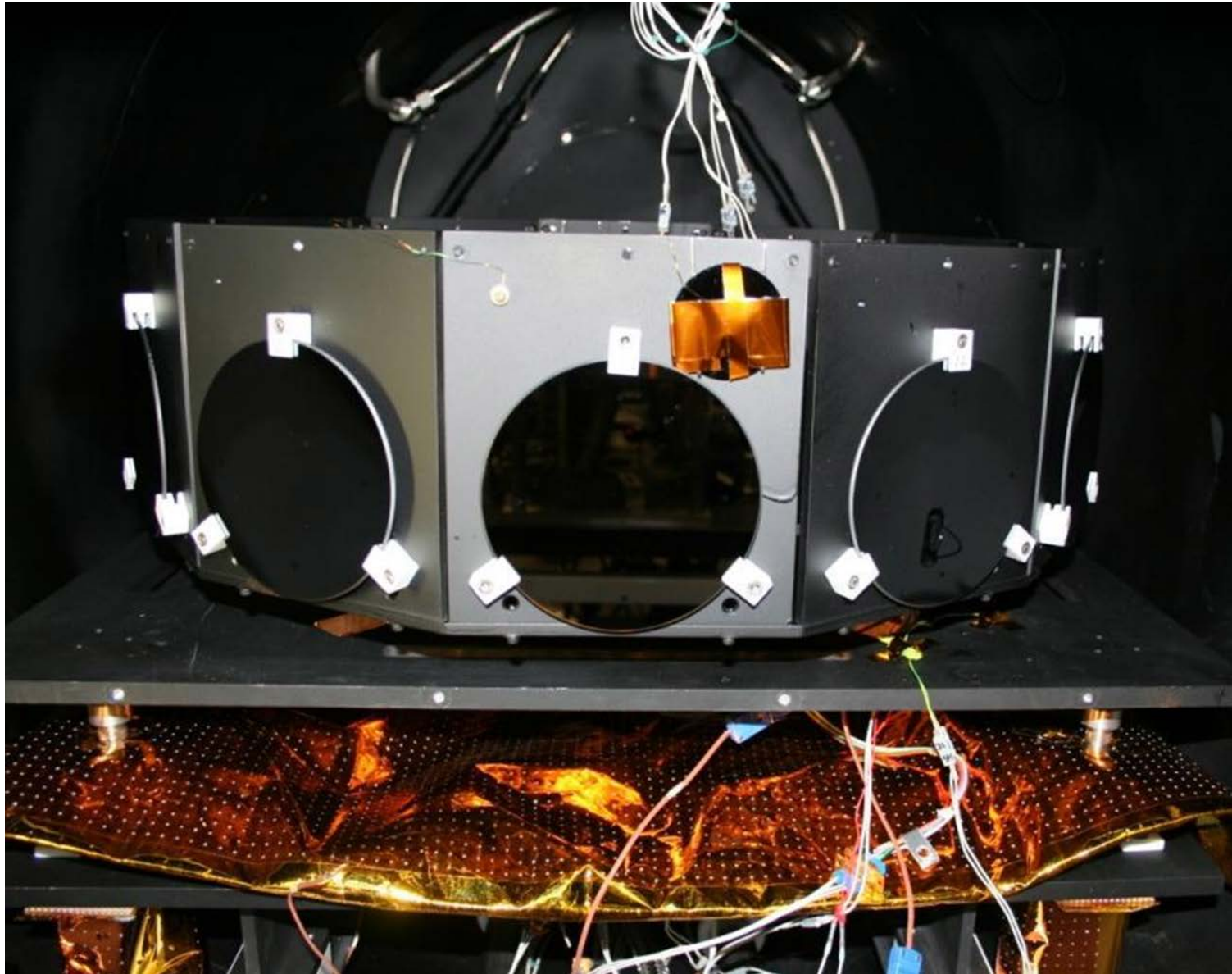
## Participating SiC vendors

- **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**



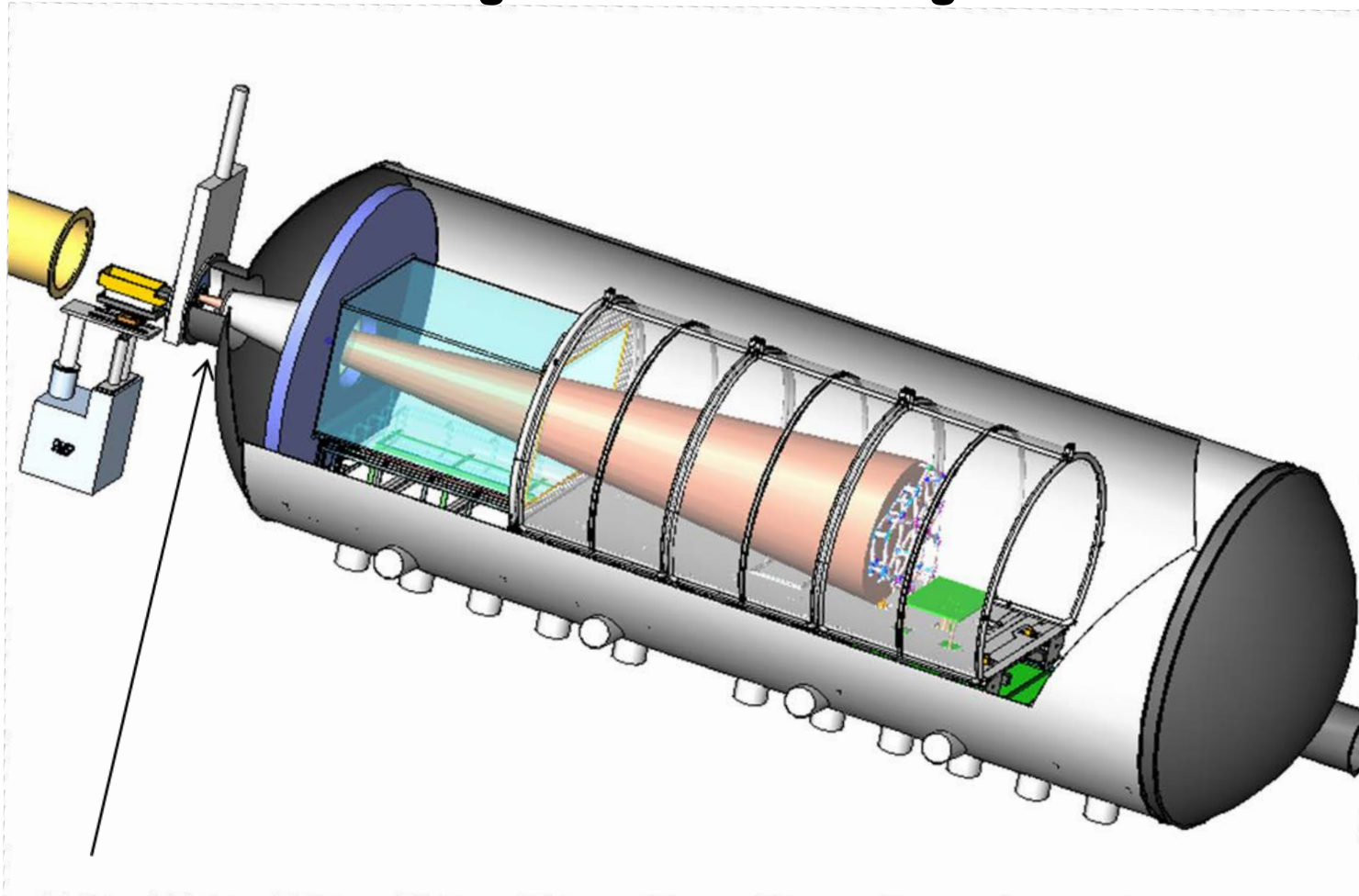
# Advanced Mirror Technology Development (AMTD)



- 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



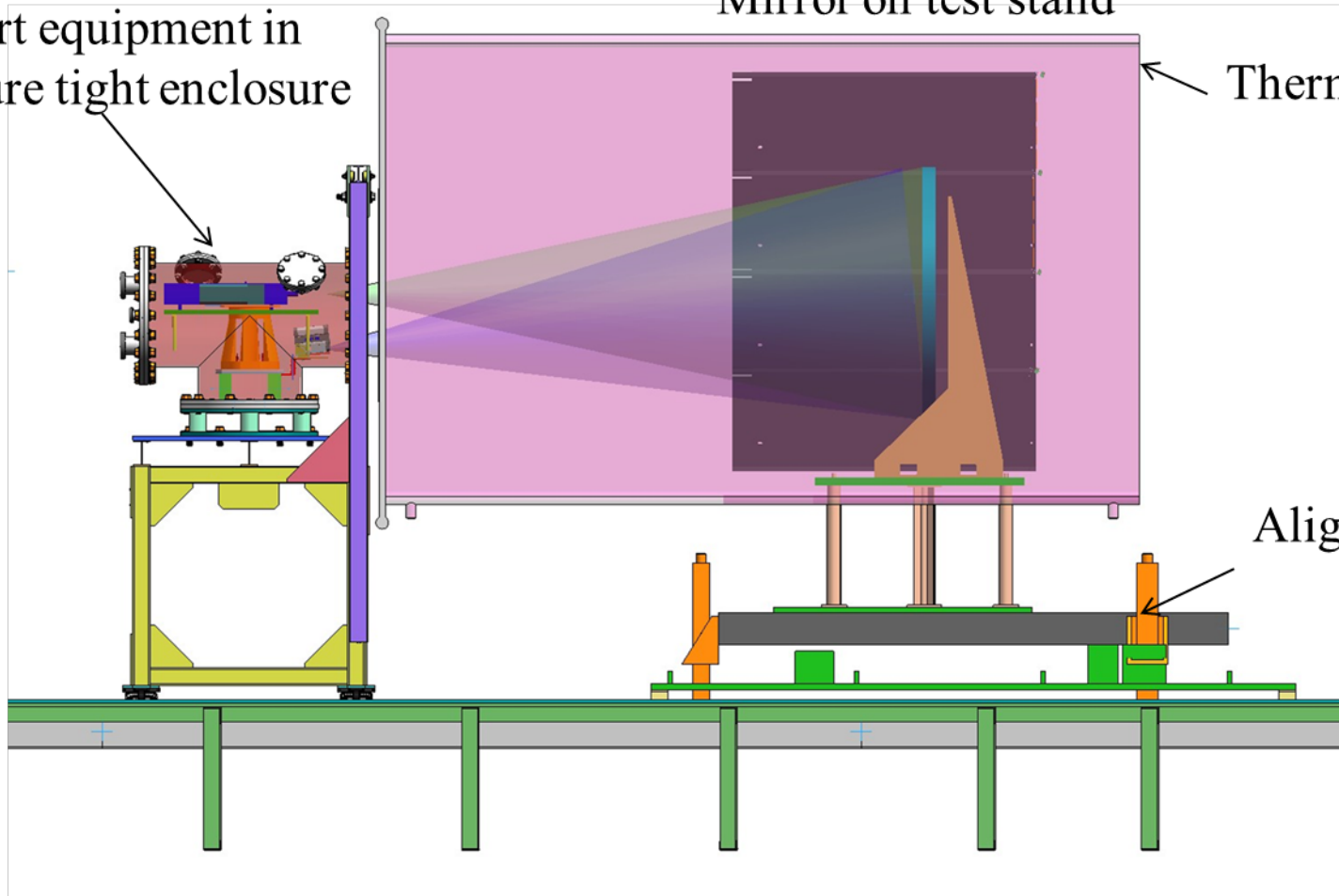
Existing structure prevents testing mirrors in this configuration with ROC < 3.5 meters  
A pressure tight enclosure (PTE) configuration to test mirror with ROC < 3.5 meter

Interferometer and test support equipment in pressure tight enclosure (PTE)

Mirror on test stand

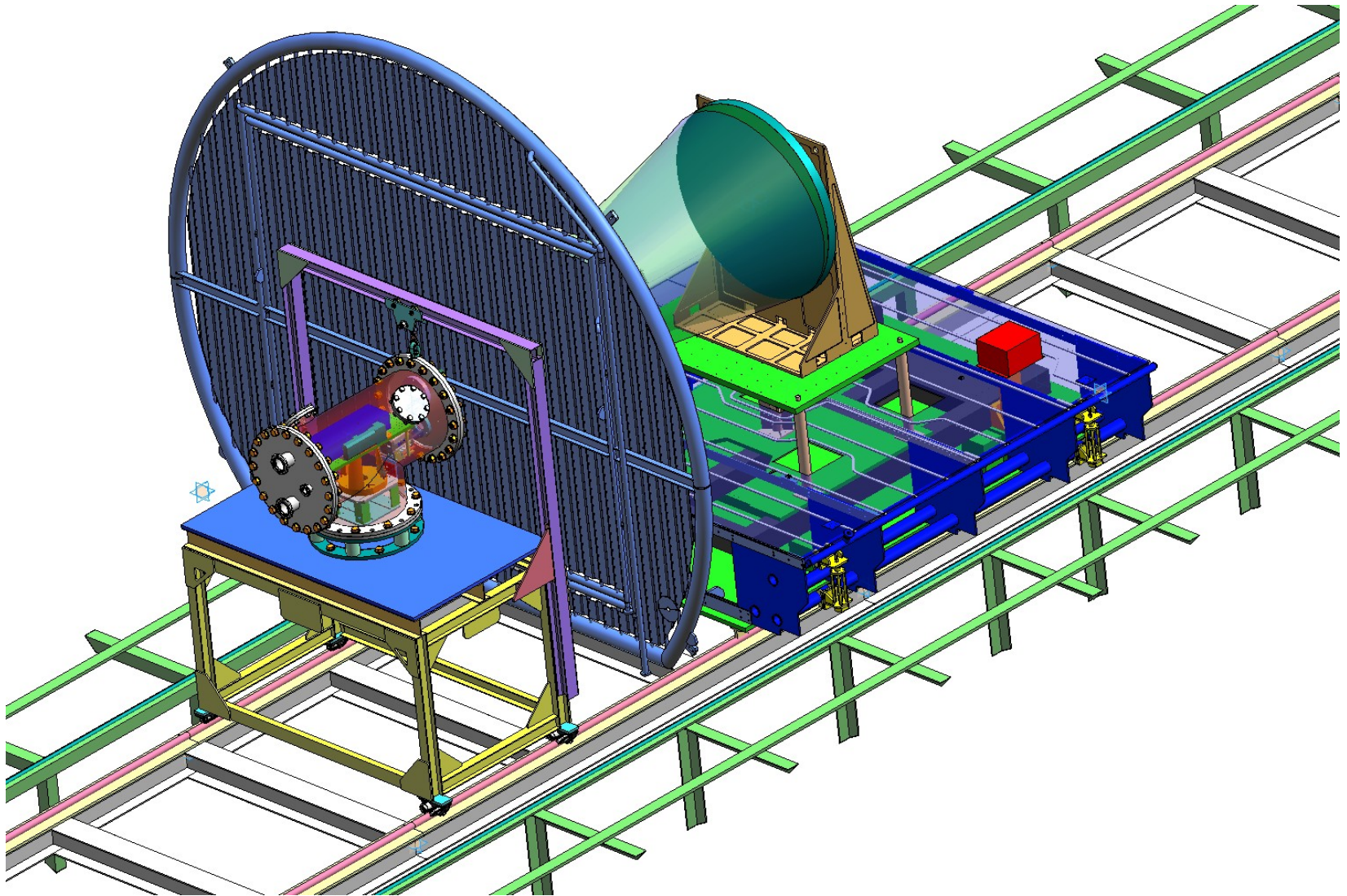
Thermal shroud

Alignment stage





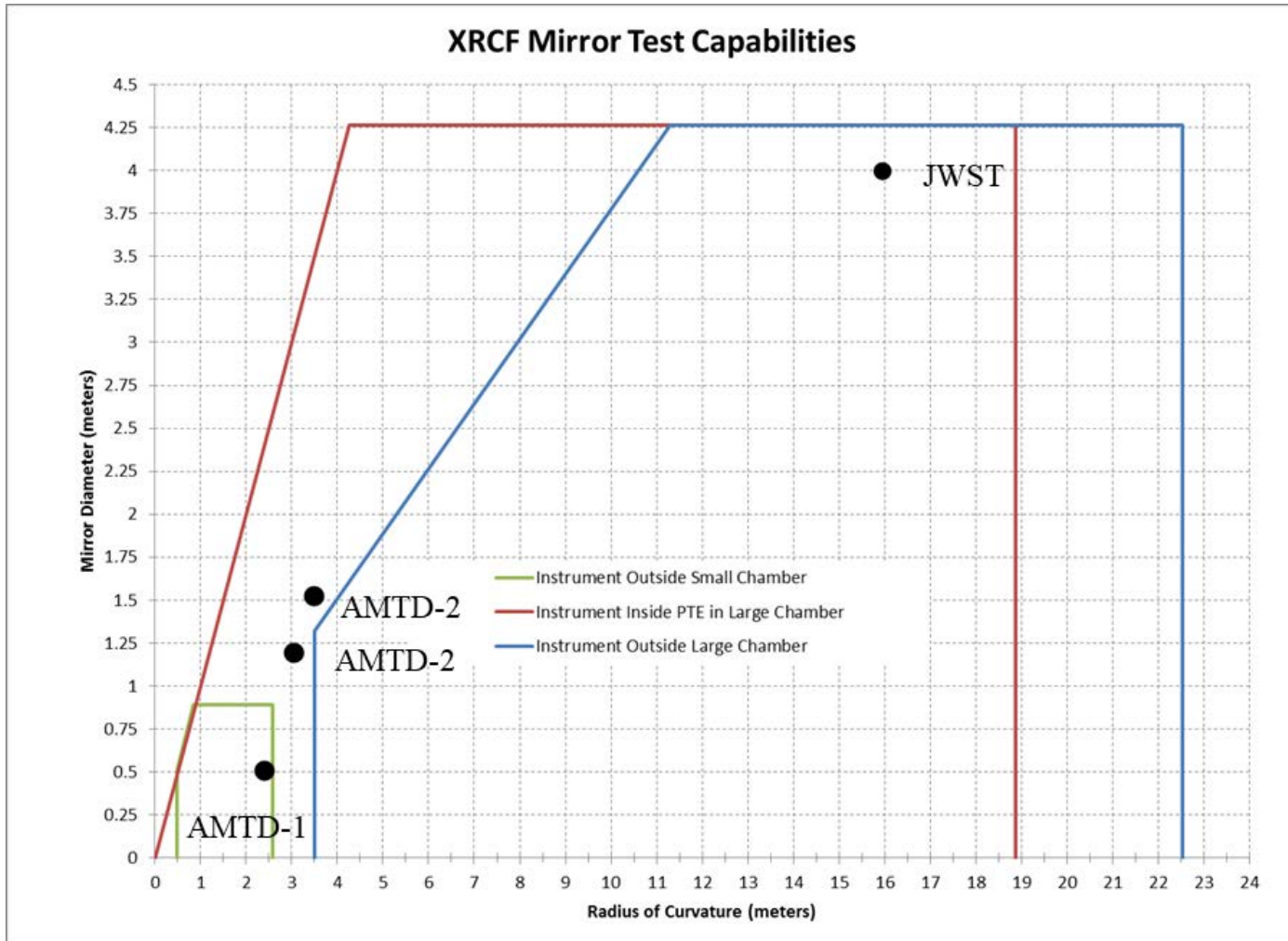
# Test configuration for $< 3.5$ m radius of curvature mirror



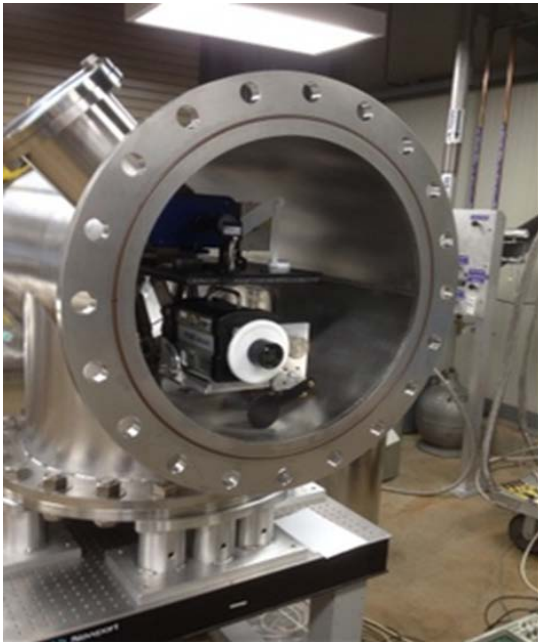
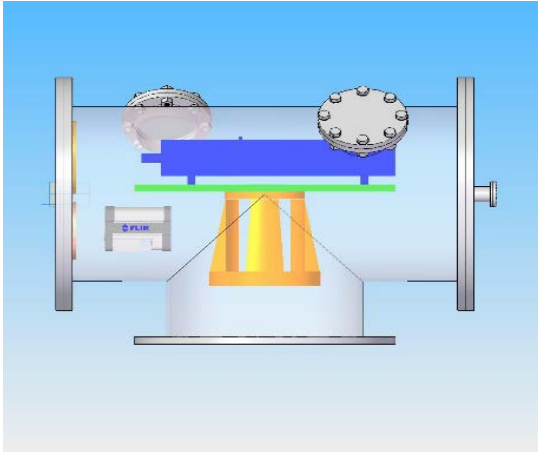


# Test envelop for large and small chambers

<u>Chamber</u>	<u>Max Diameter</u>	<u>Max radius of curvature</u>
Large	4.25 m	22.5 m
Small	0.8 m	2.5 m



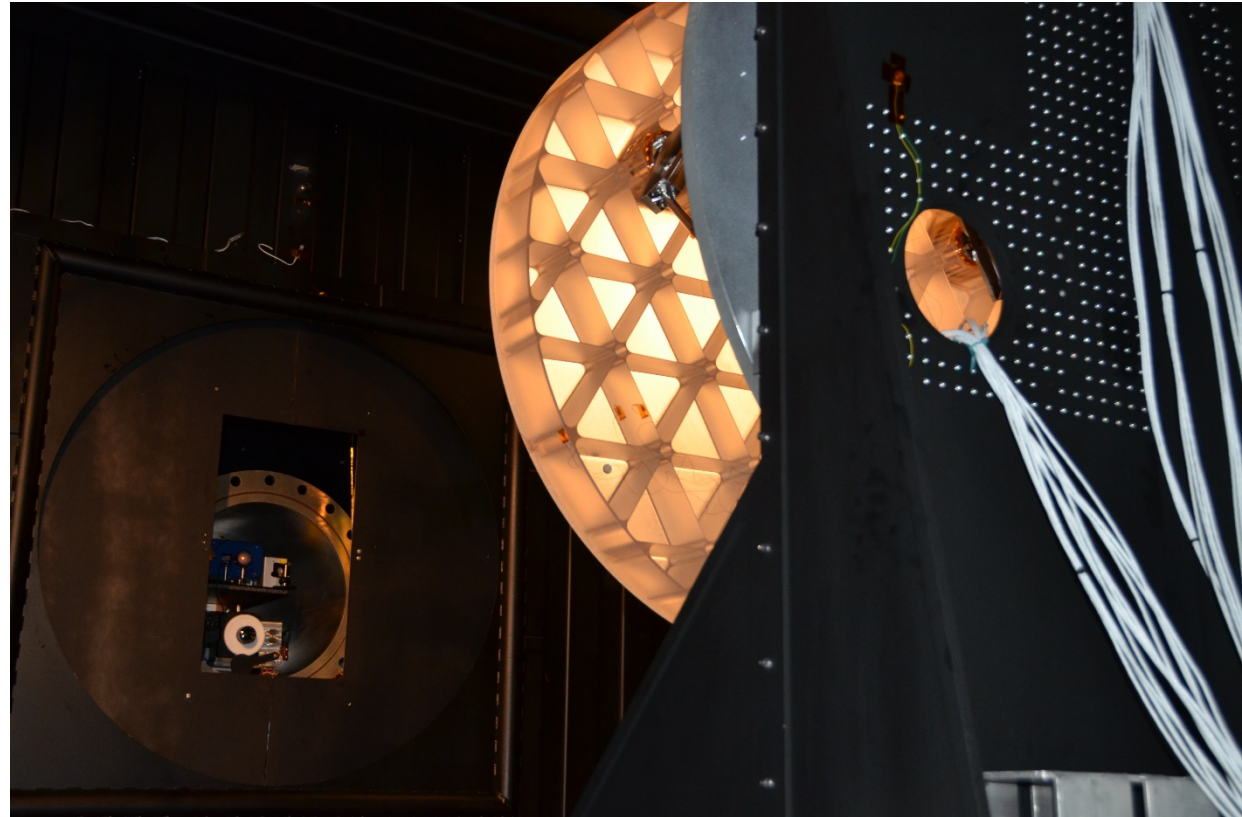
# Optical test equipment inside pressure tight enclosure (PTE)



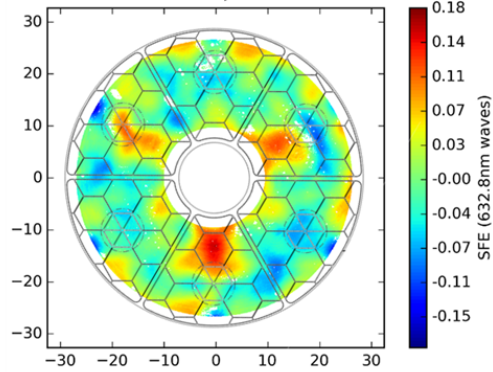
1. alignment CCD
2. alignment pinhole
3. interferometer
4. ADM
5. IR camera stage
6. hexapod



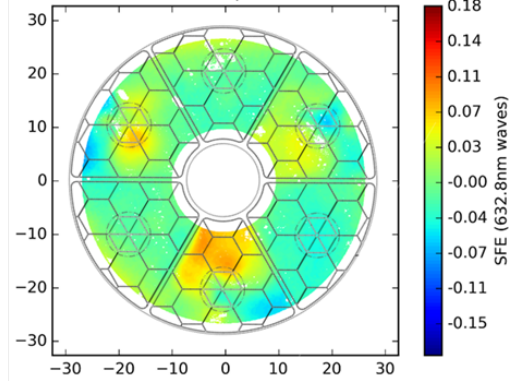
# Cryo optical test with PTE



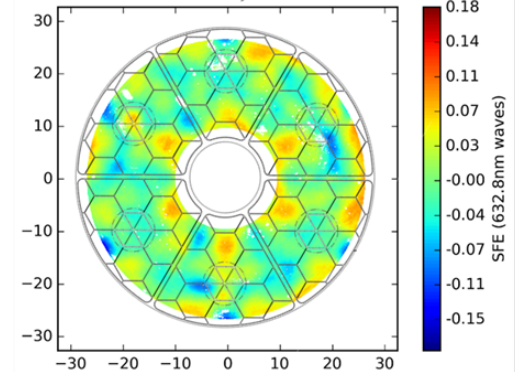
Measured Surface; RMS SFE = 28.8nm



Predicted Surface; RMS SFE = 23.6nm



Residual Surface; RMS SFE = 22.0nm



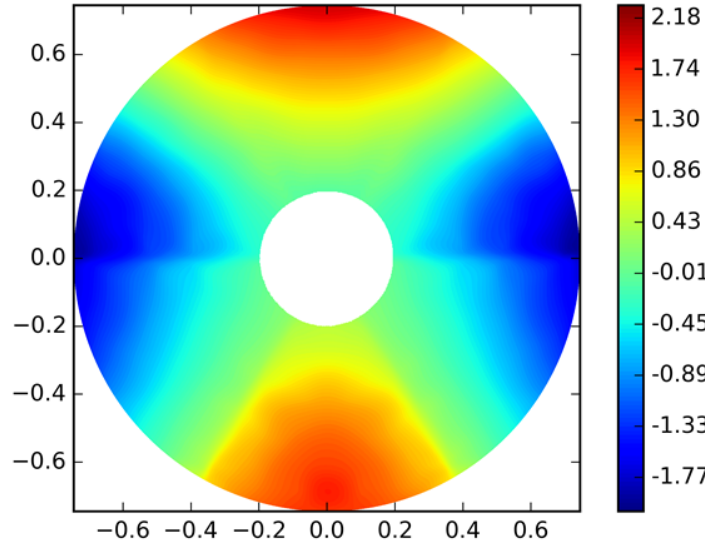
Predicted SFE uses:

- 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

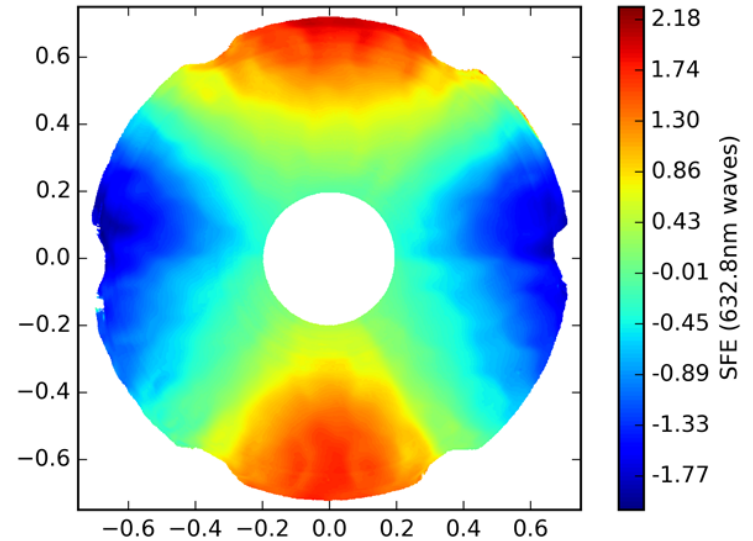
Residual SFE could be CTE inhomogeneity



# Gravity sag (predicted vs measured)



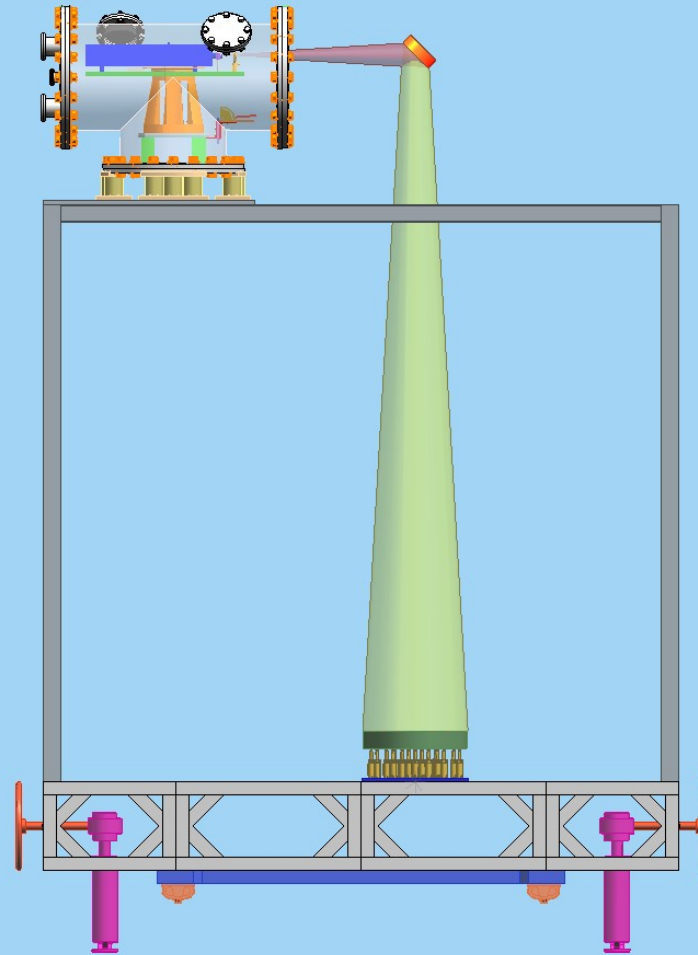
Predicted  
580 nm rms



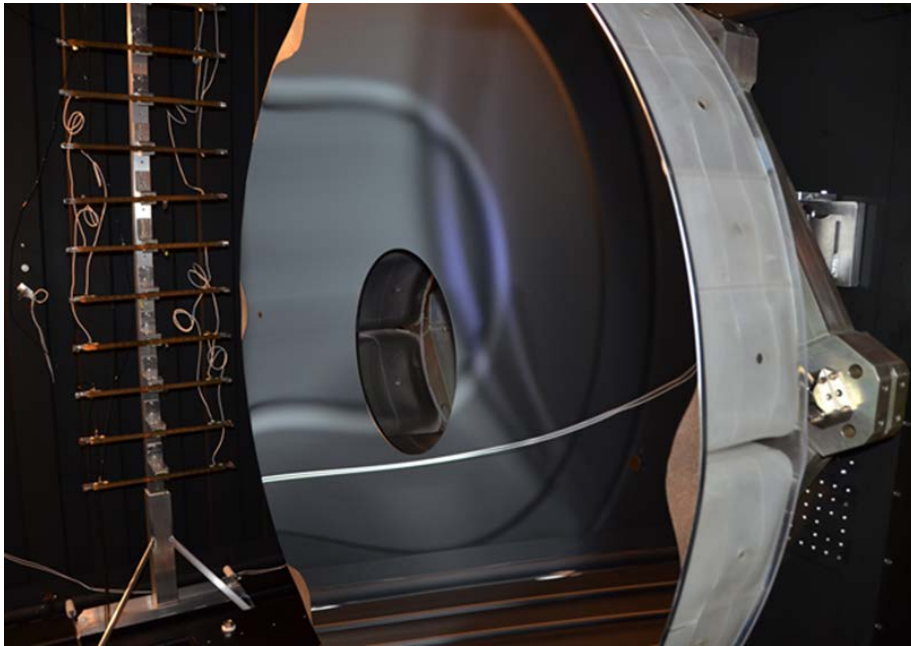
Measured  
582.5 nm rms



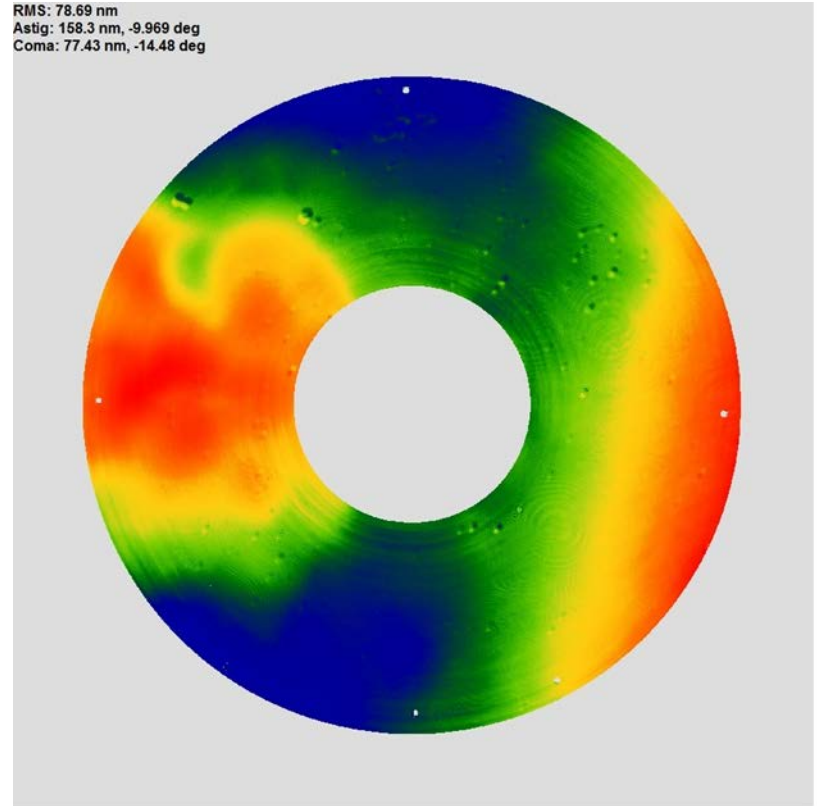
# Vertical optical test configuration



# Thermal gradient test



RMS: 78.69 nm  
Astig: 158.3 nm, -9.969 deg  
Coma: 77.43 nm, -14.48 deg



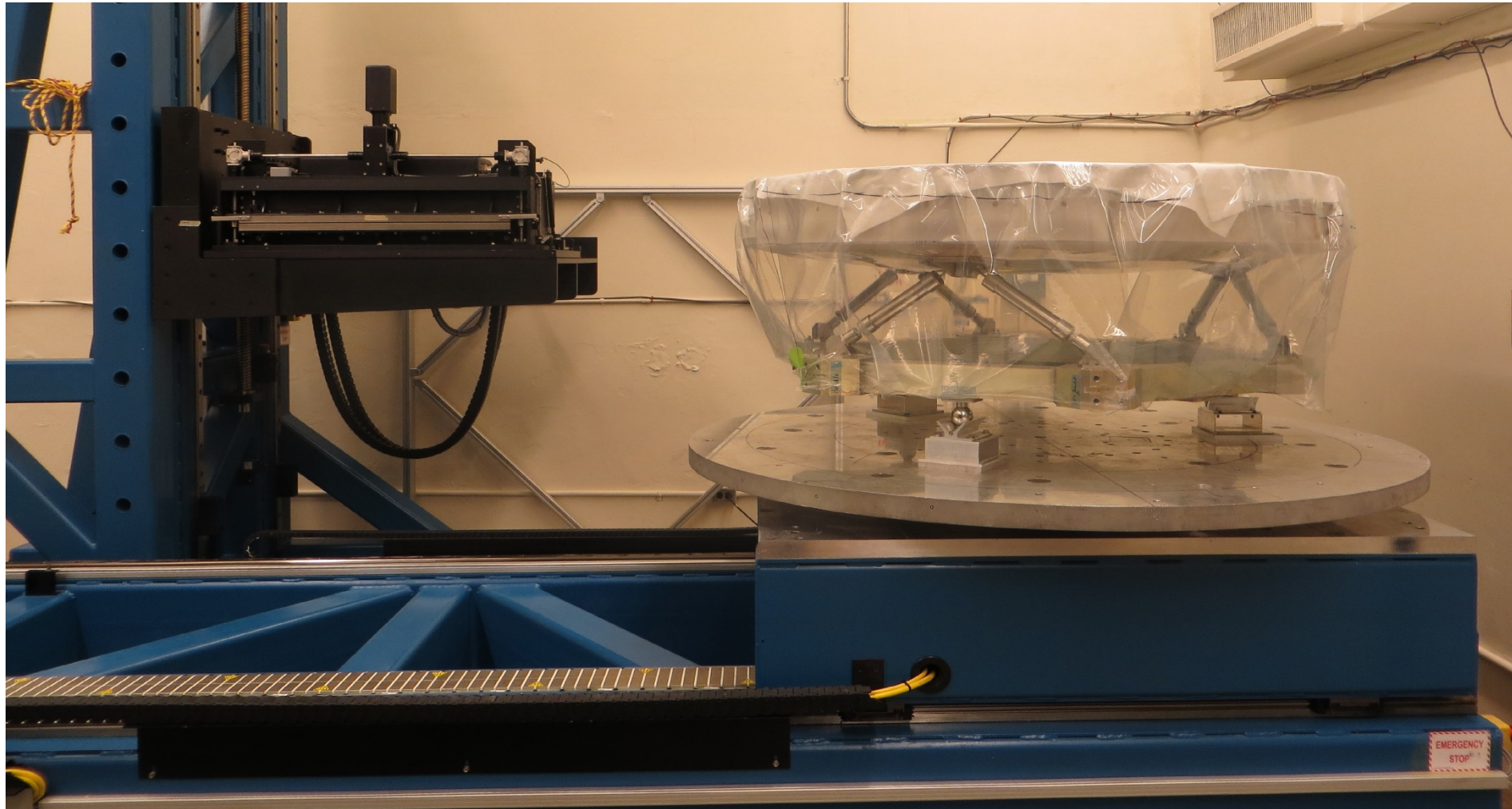


- Tapped at 42 locations with an instrumented modal test hammer
- Each location was tapped 5x and averaged

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**

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**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**



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**Dr. Jeong-Yeol Han**

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**<https://optics.nasa.gov>**



**title**

