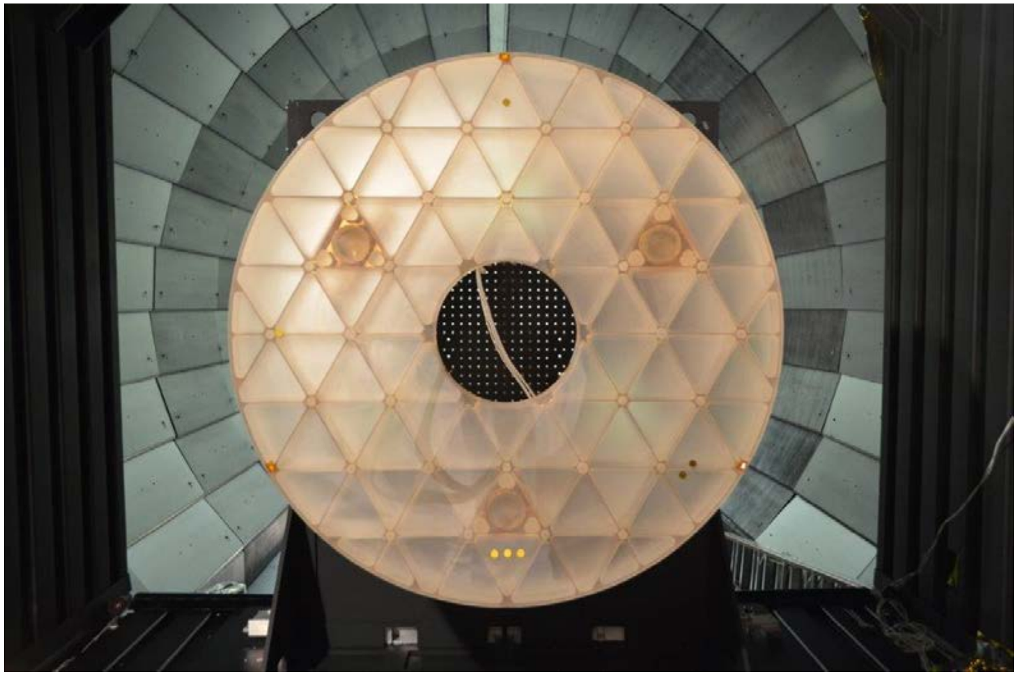
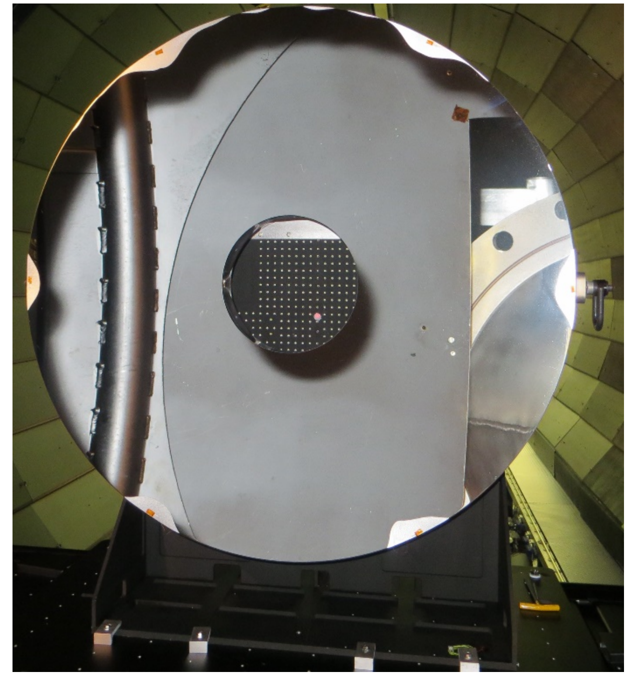
Future space telescope development at NASA





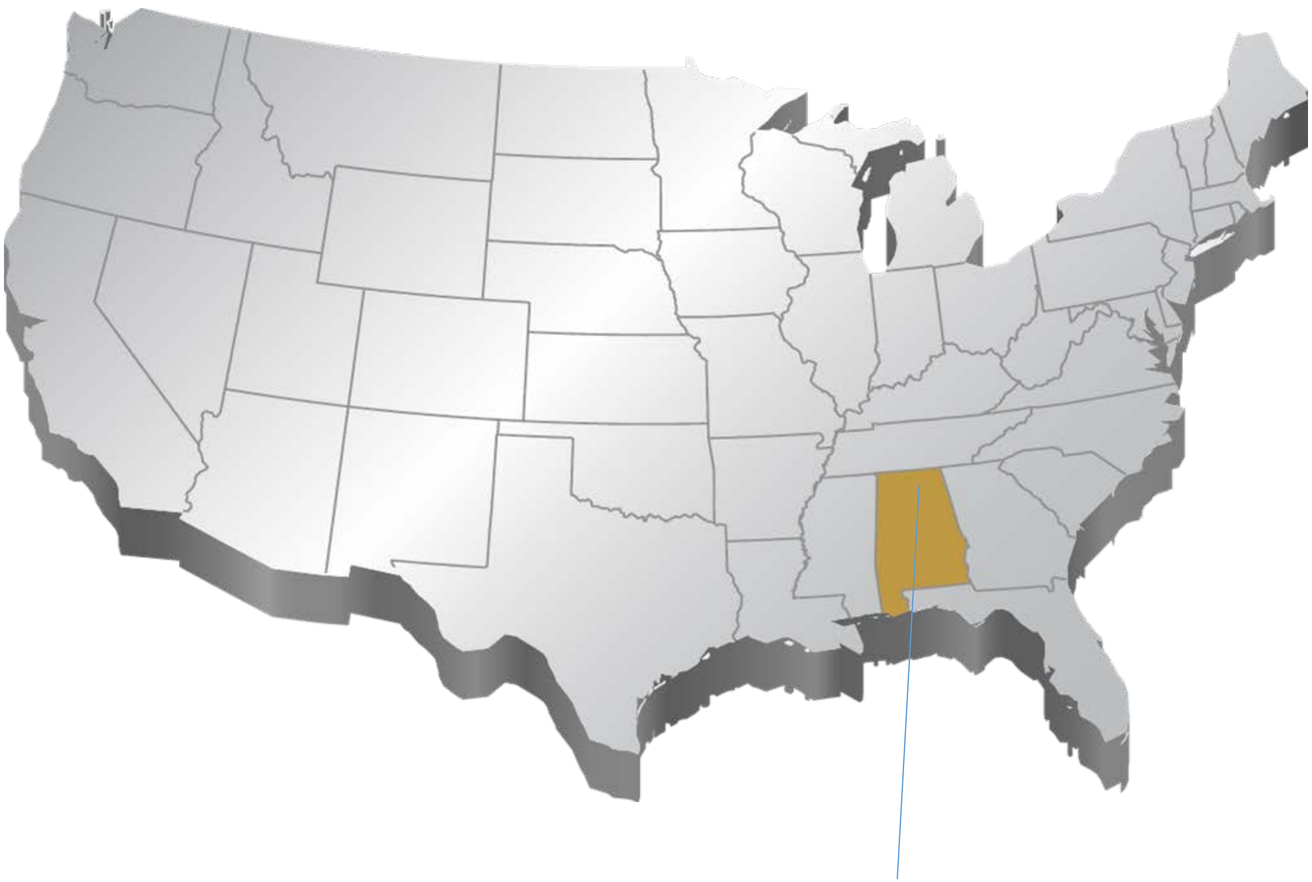
Ron Eng

Optics and Imaging Branch

NASA Marshall Space Flight Center

Korean Space Science Society (KSSS) 2018 fall conference

NASA Marshall Space Flight Center

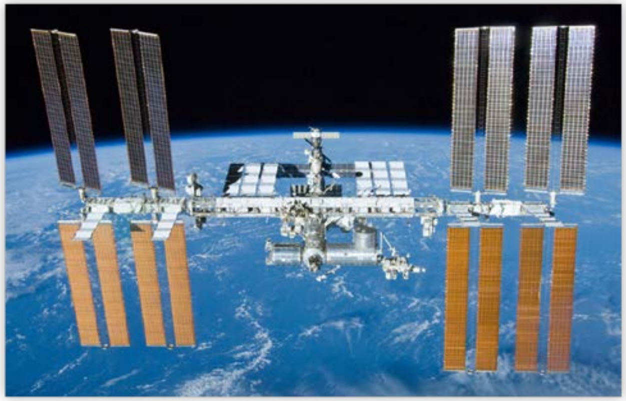


Marshall Space Flight Center
Space Transportation, Propulsion Systems, Space Systems, and Science
Huntsville, Alabama

Space Transportation, Propulsion Systems

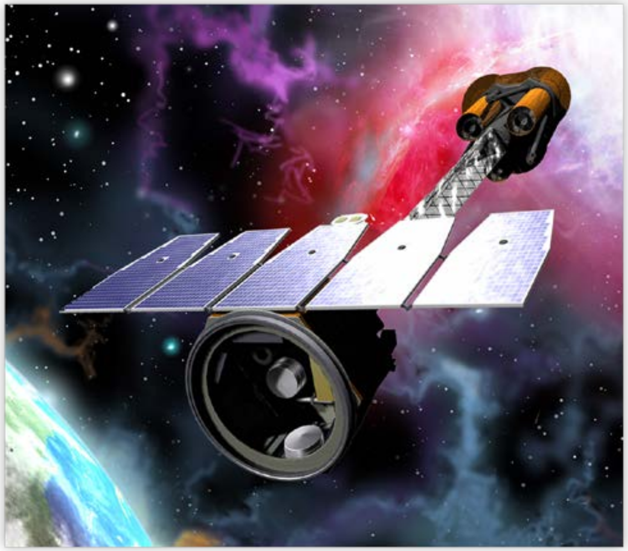
Space Systems and Science

High Energy Astronomy Observatories (1977-1981)



International Space Station (1998-present)

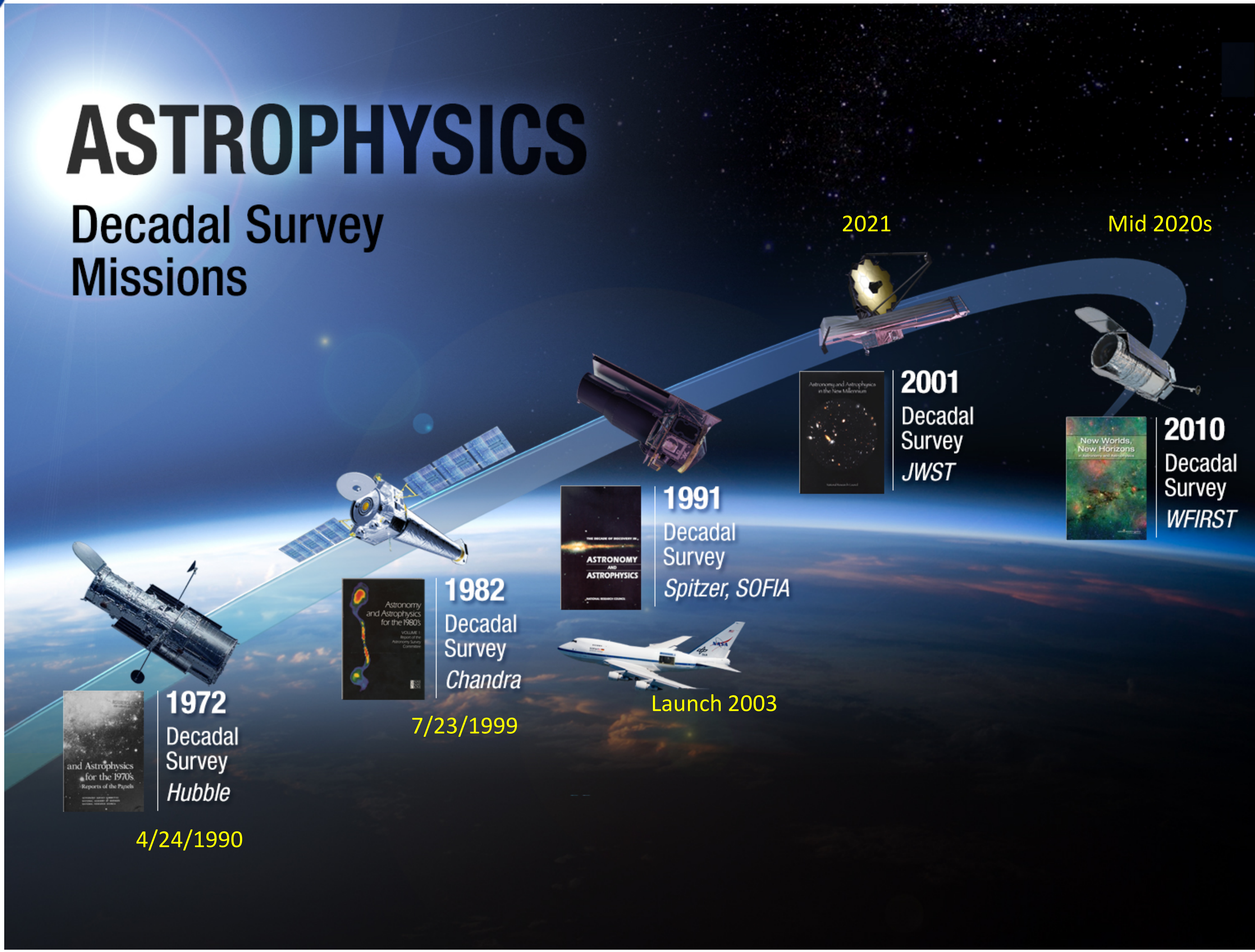
Chandra X-Ray Observatory (1999-present)



Imaging X-ray Polarimetry Explorer (IXPE)
Under development

Hubble Space Telescope (1990-present)

Current and planned astrophysics missions



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

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.

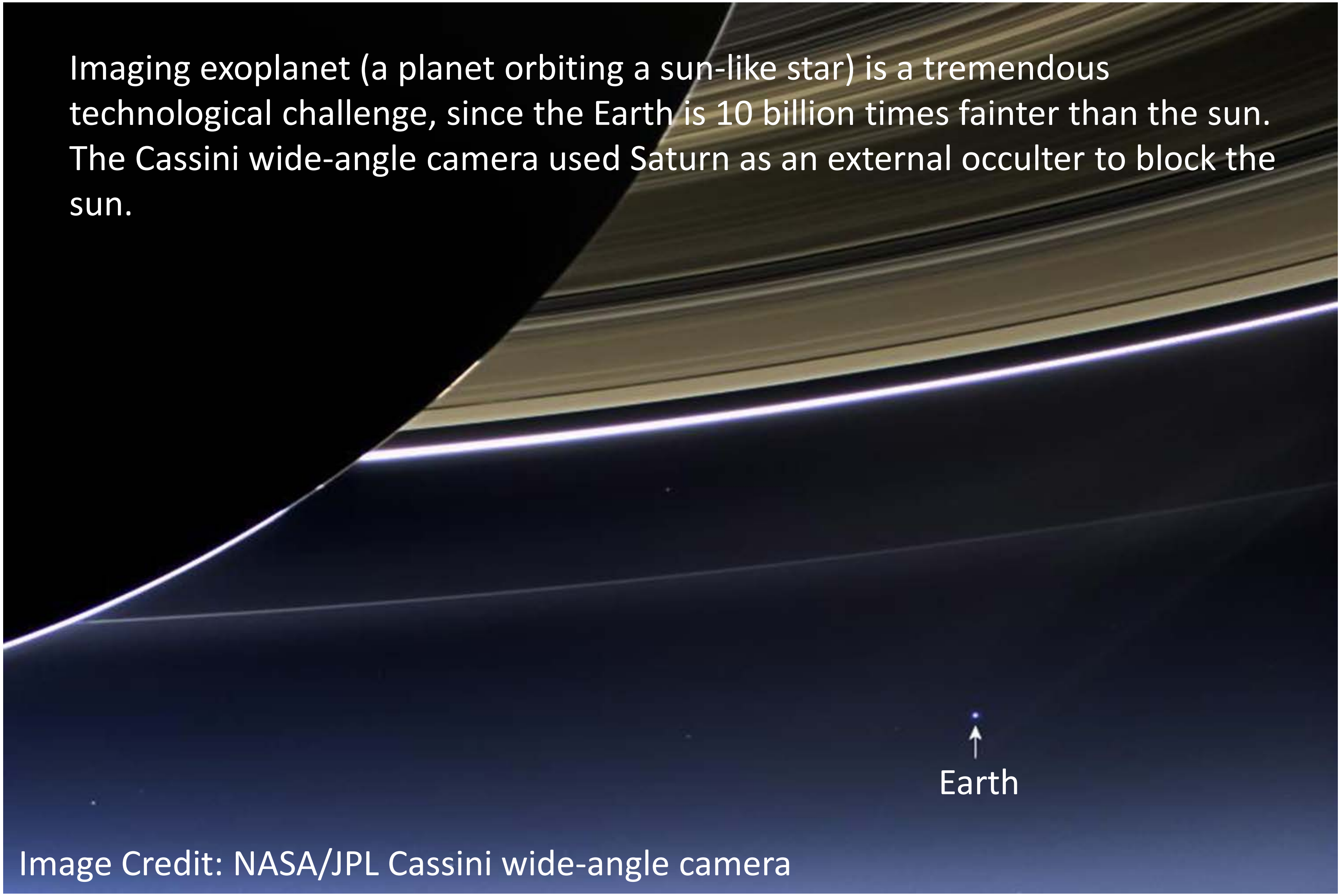
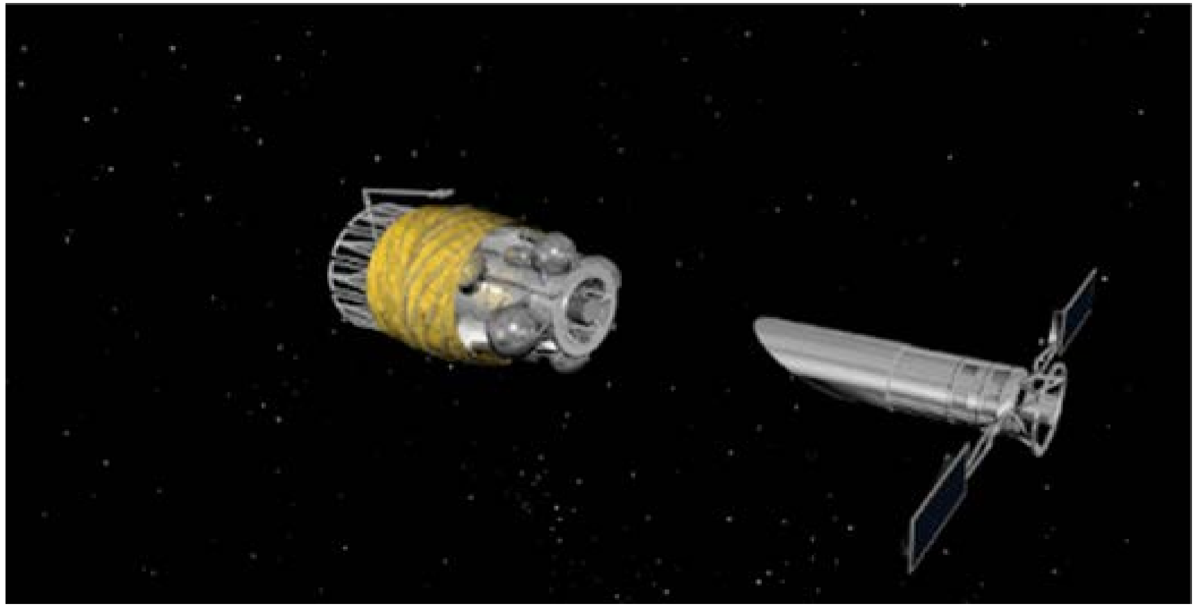
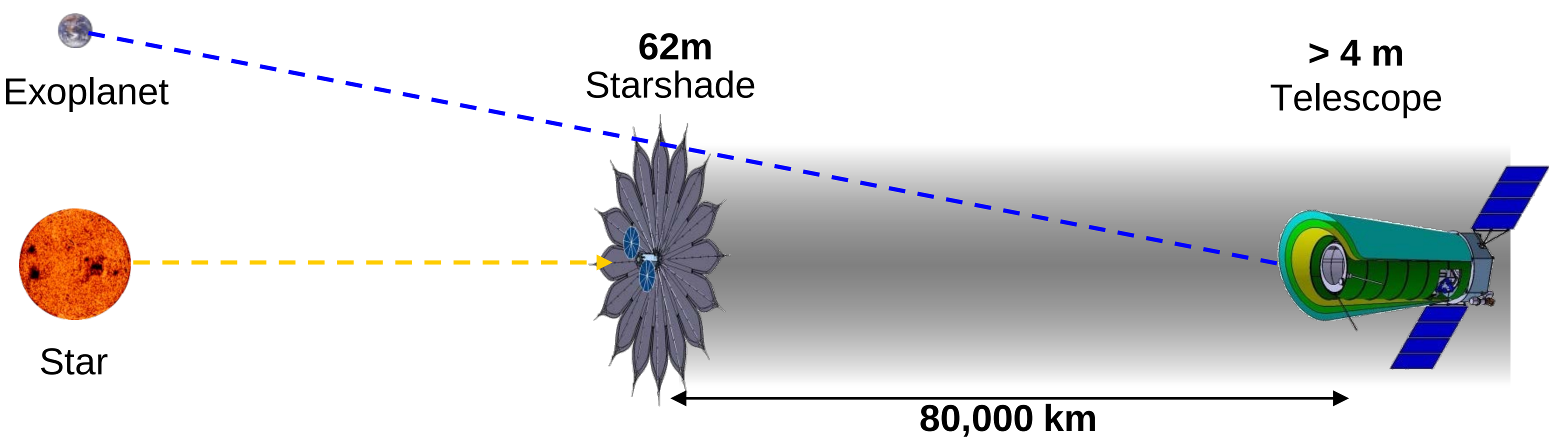


Image Credit: NASA/JPL Cassini wide-angle camera

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

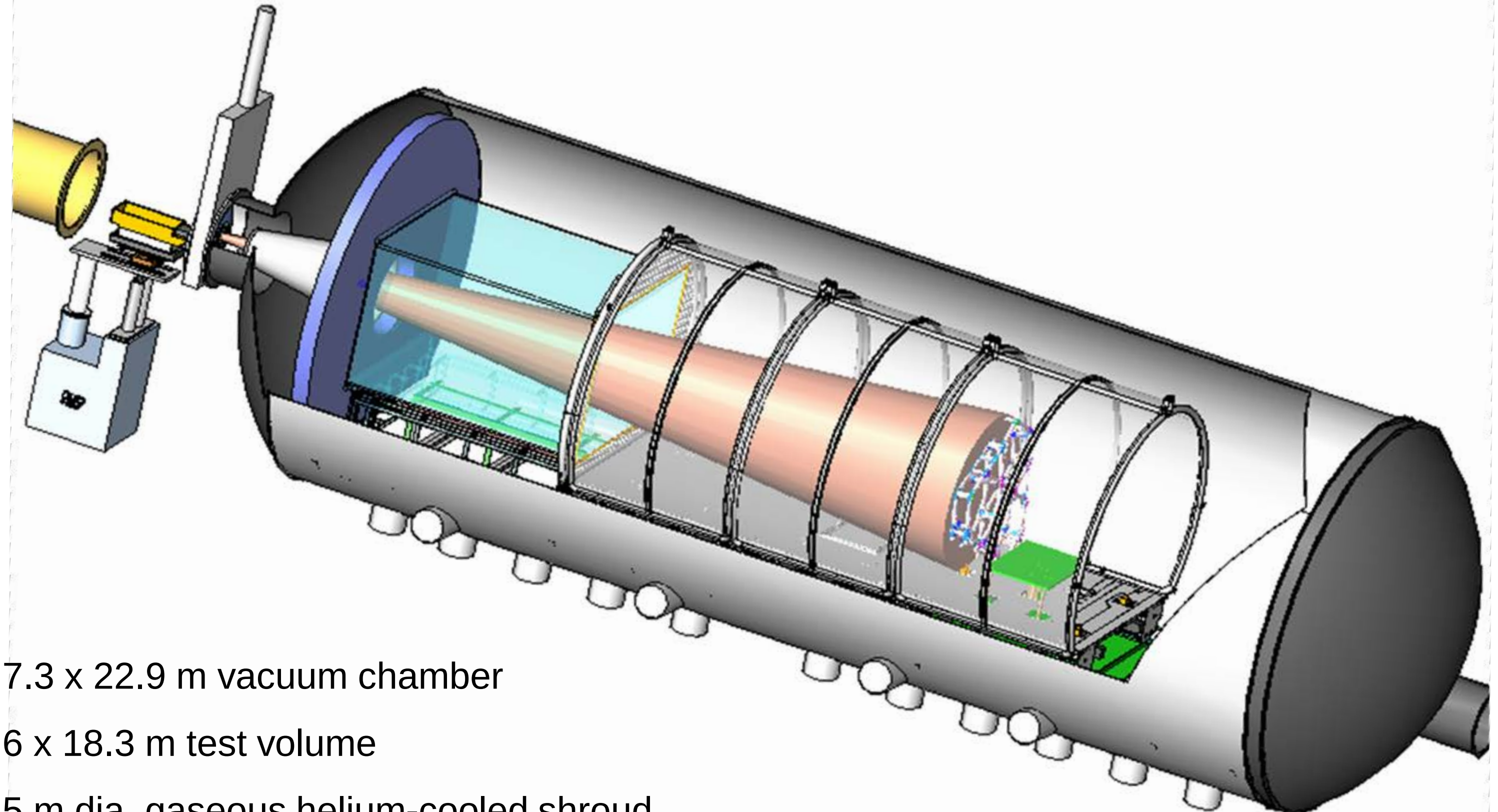
X-ray source: 527 m guide tube

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)

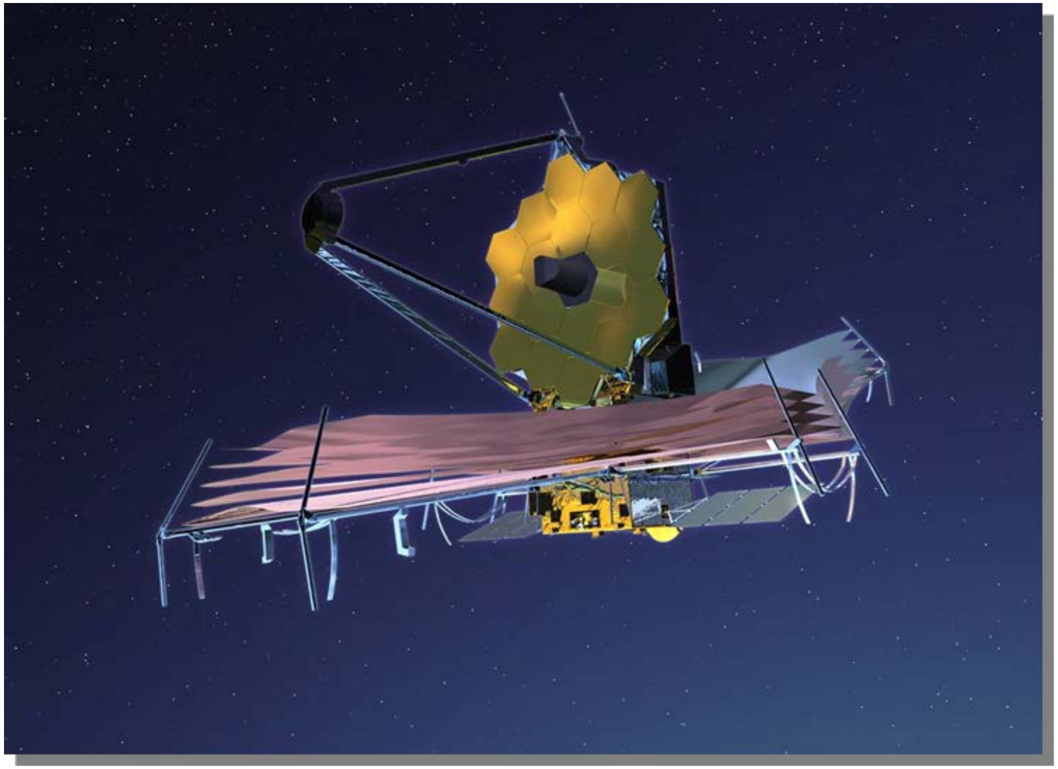
2 closed-loop helium cryogenic refrigeration systems <20 deg. K (2 KW capacity)

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

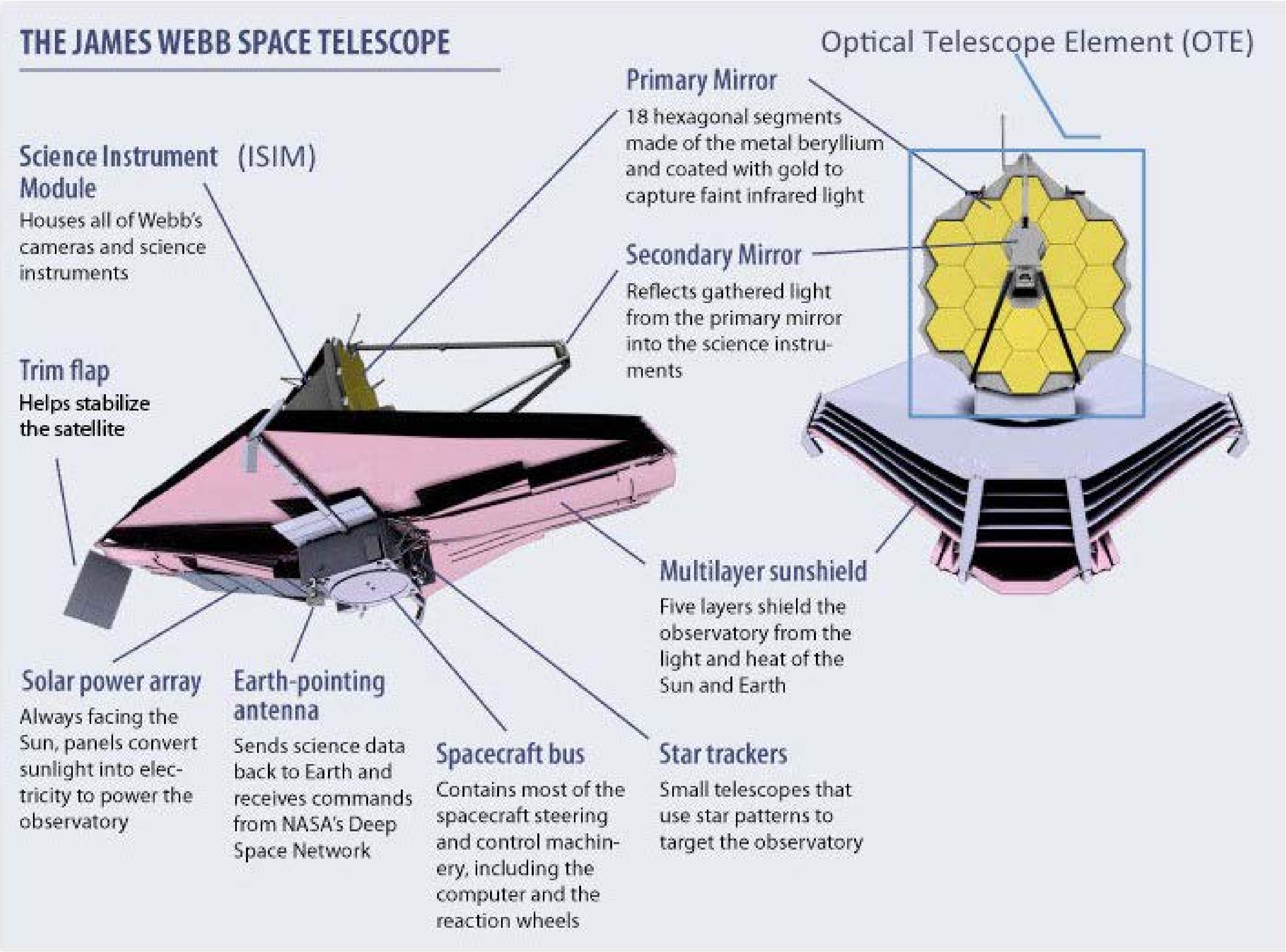
6.5m primary mirror

L2 orbit, 1,500,000 km

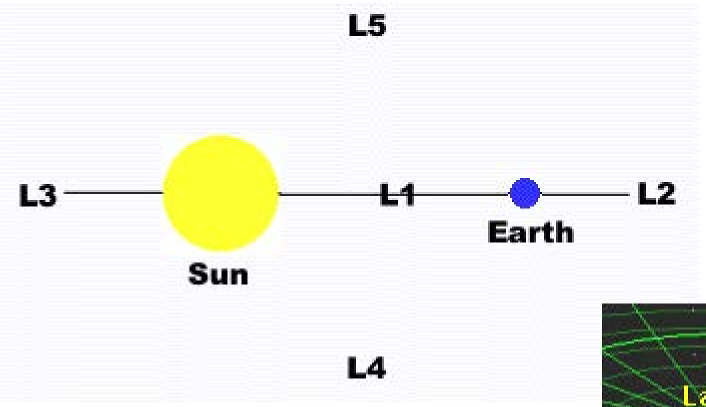
Science objectives: first light, formation of galaxies, birth of stars and planets, and origin of life.

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

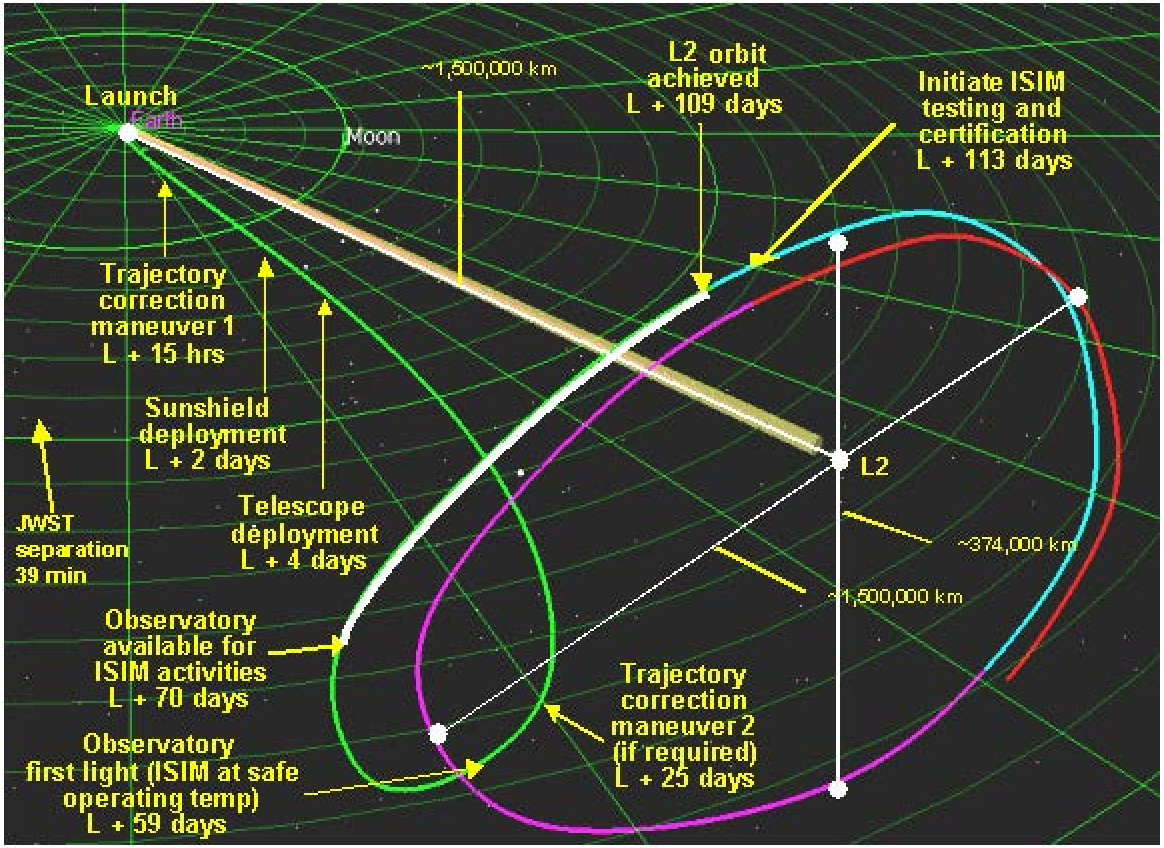
James Webb Space Telescope (JWST)



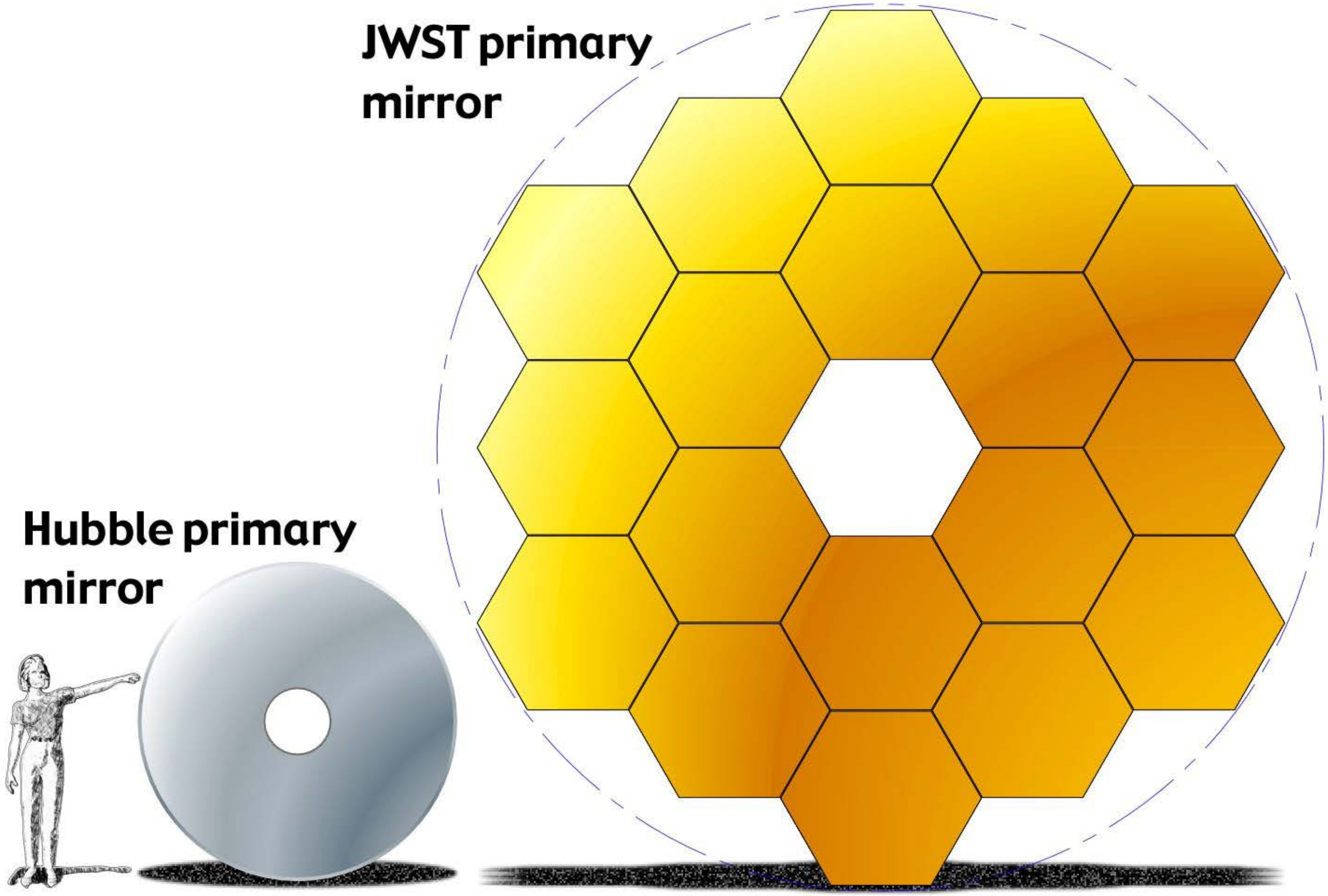
JWST orbit



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



HST & JWST primary mirror comparison



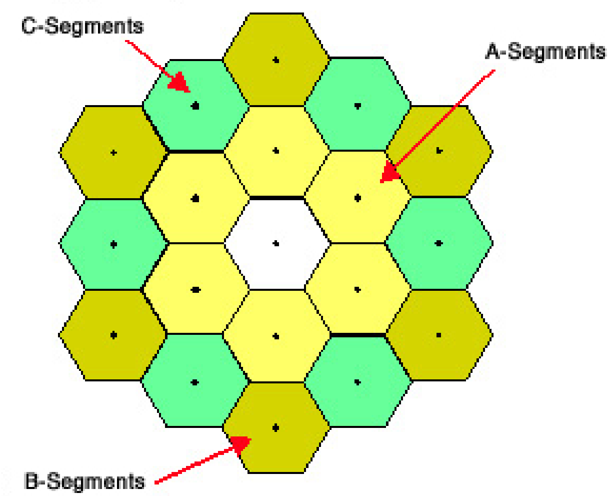
2.4 m dia.

$3.6\ m^2$

6.5 m (18 mirror segments)

$25\ m^2$

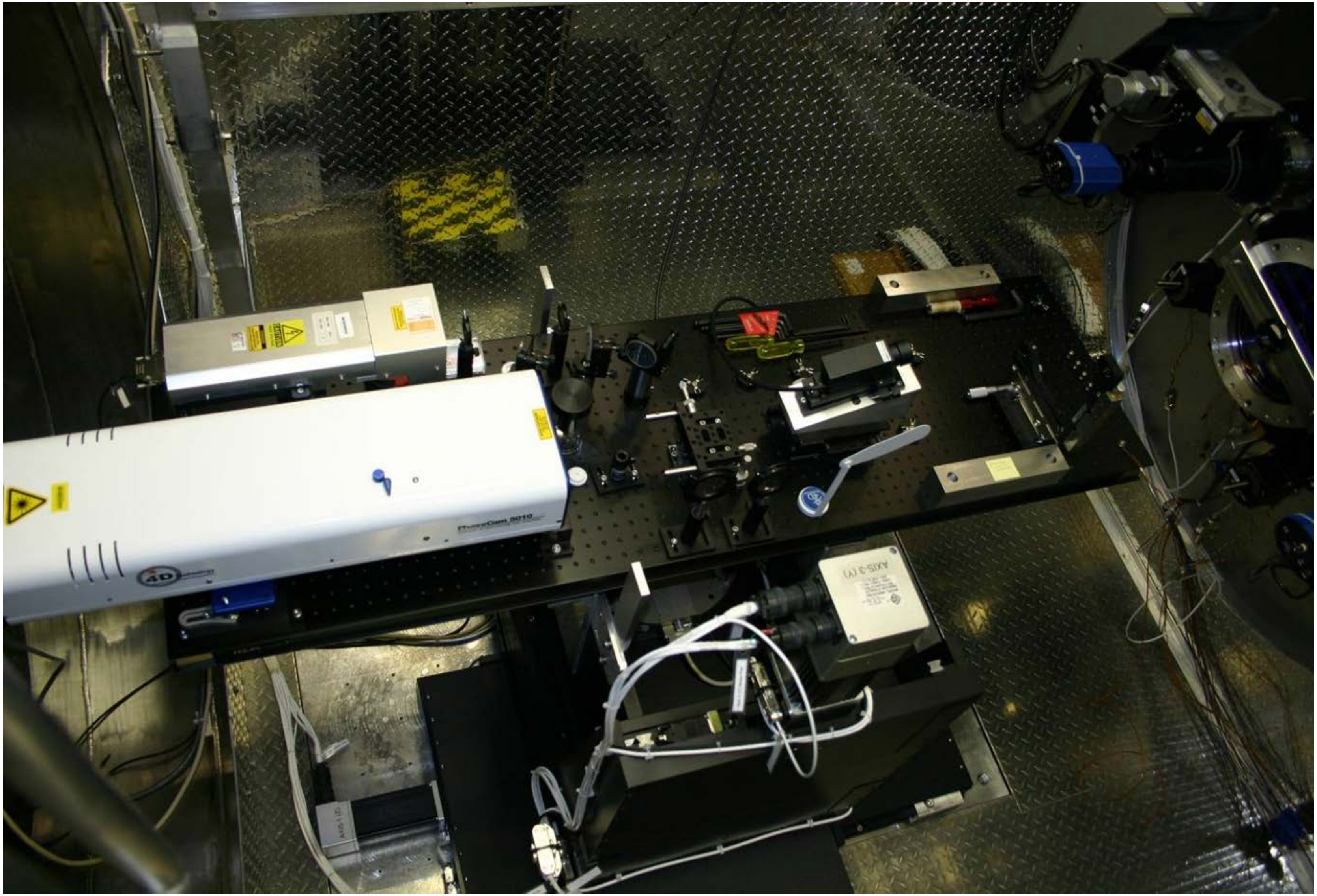
6 of 18 mirror segments cryo test at MSFC



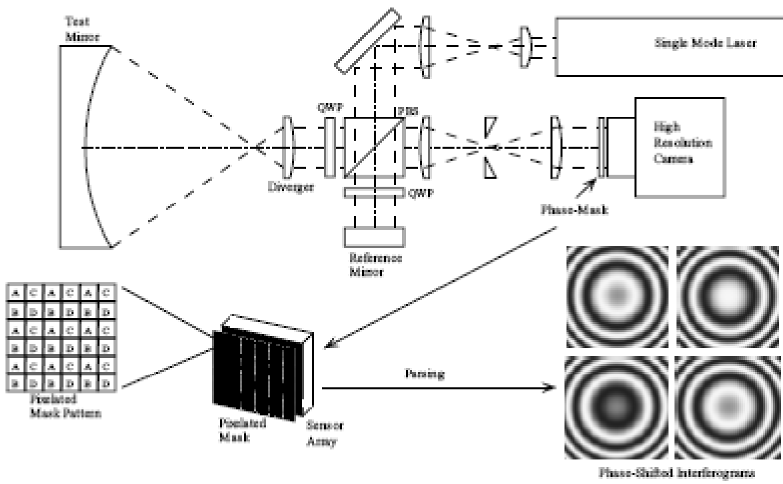
OTE deployment test at GSFC

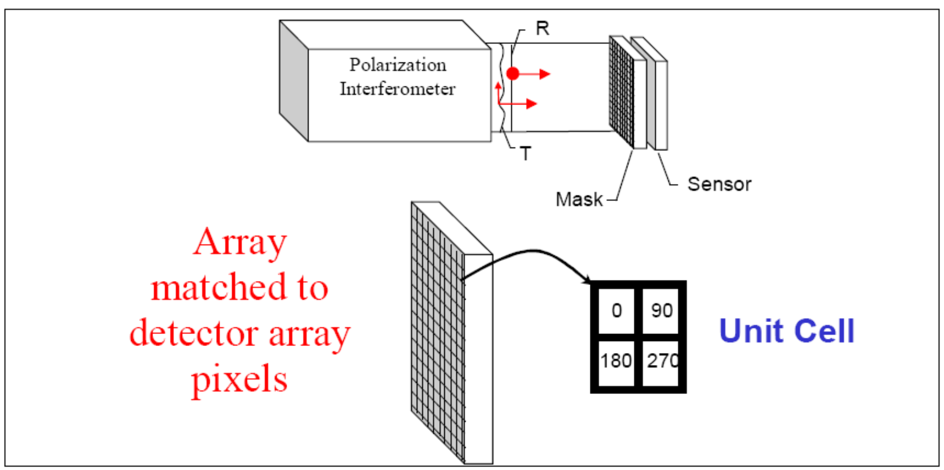
OTE cryo test at JSC

JWST mirror optical test instrument



Simultaneous phase shifting interferometer



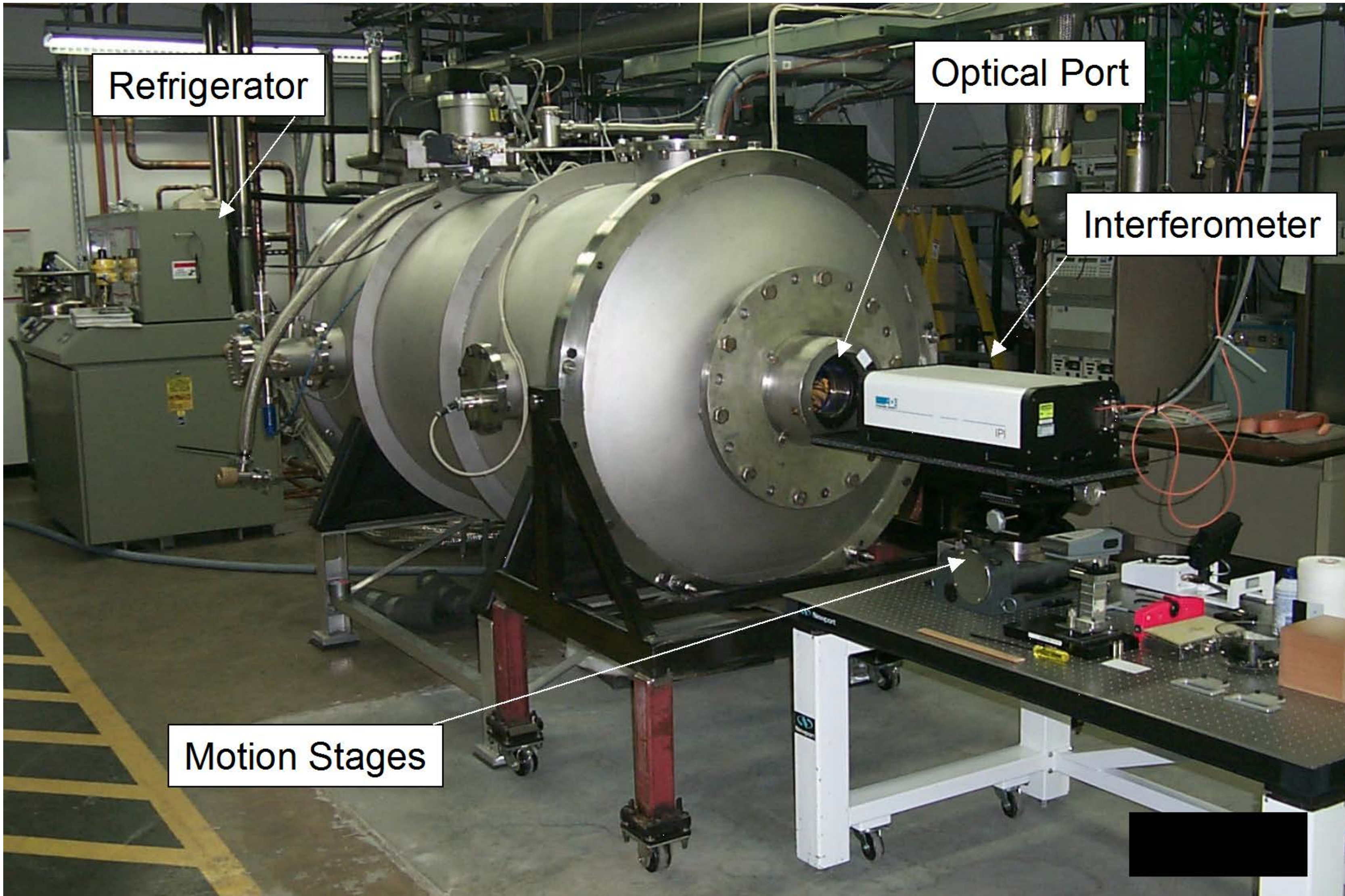


Micro-polarizer array camera sensor

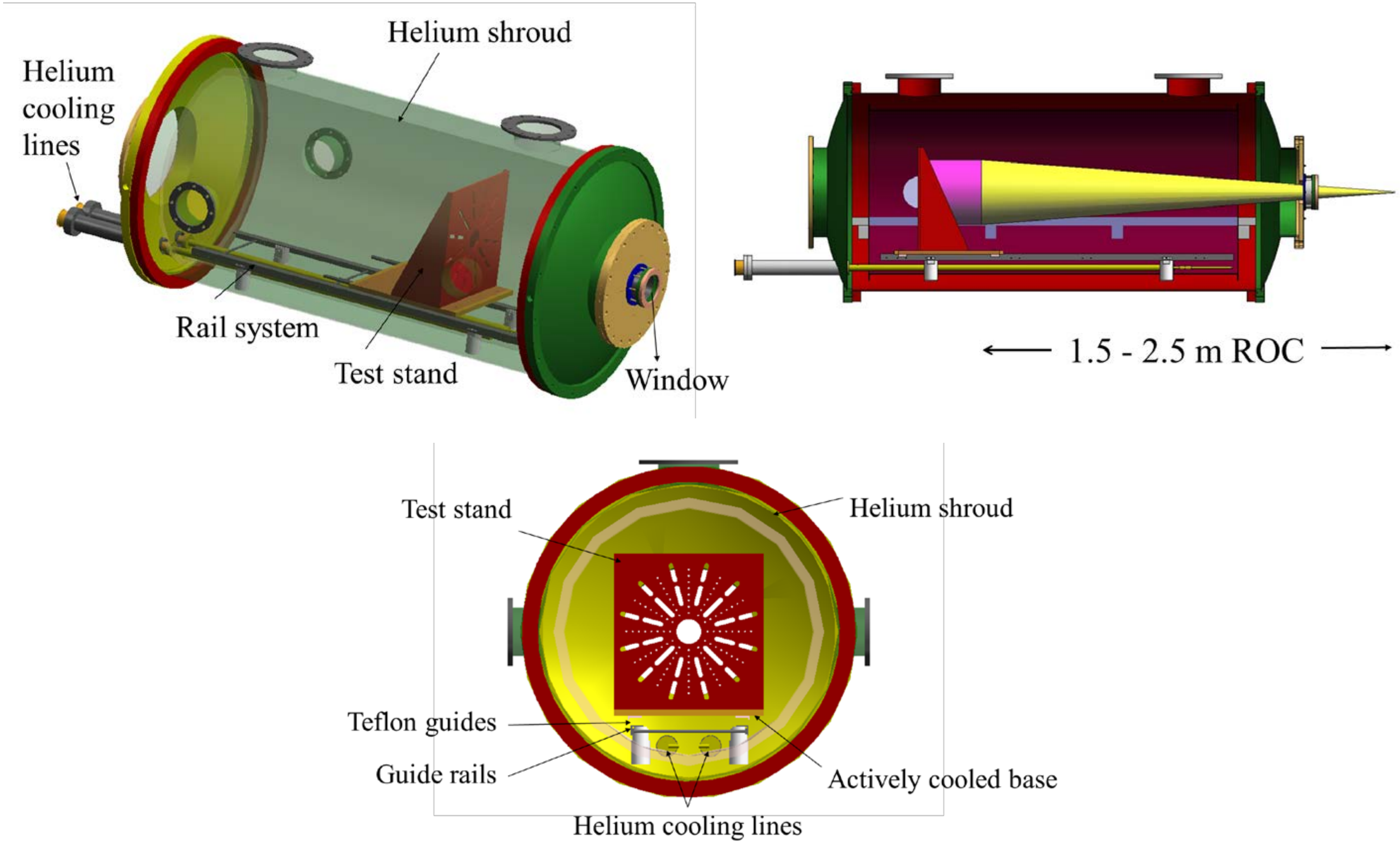
Spatial phase shifting overcomes previous single frame or temporal phase shifting interferometer technique

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

1 x 2 m cryo test chamber for mirror characterization



Test configuration for < 0.8 m dia. mirror



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

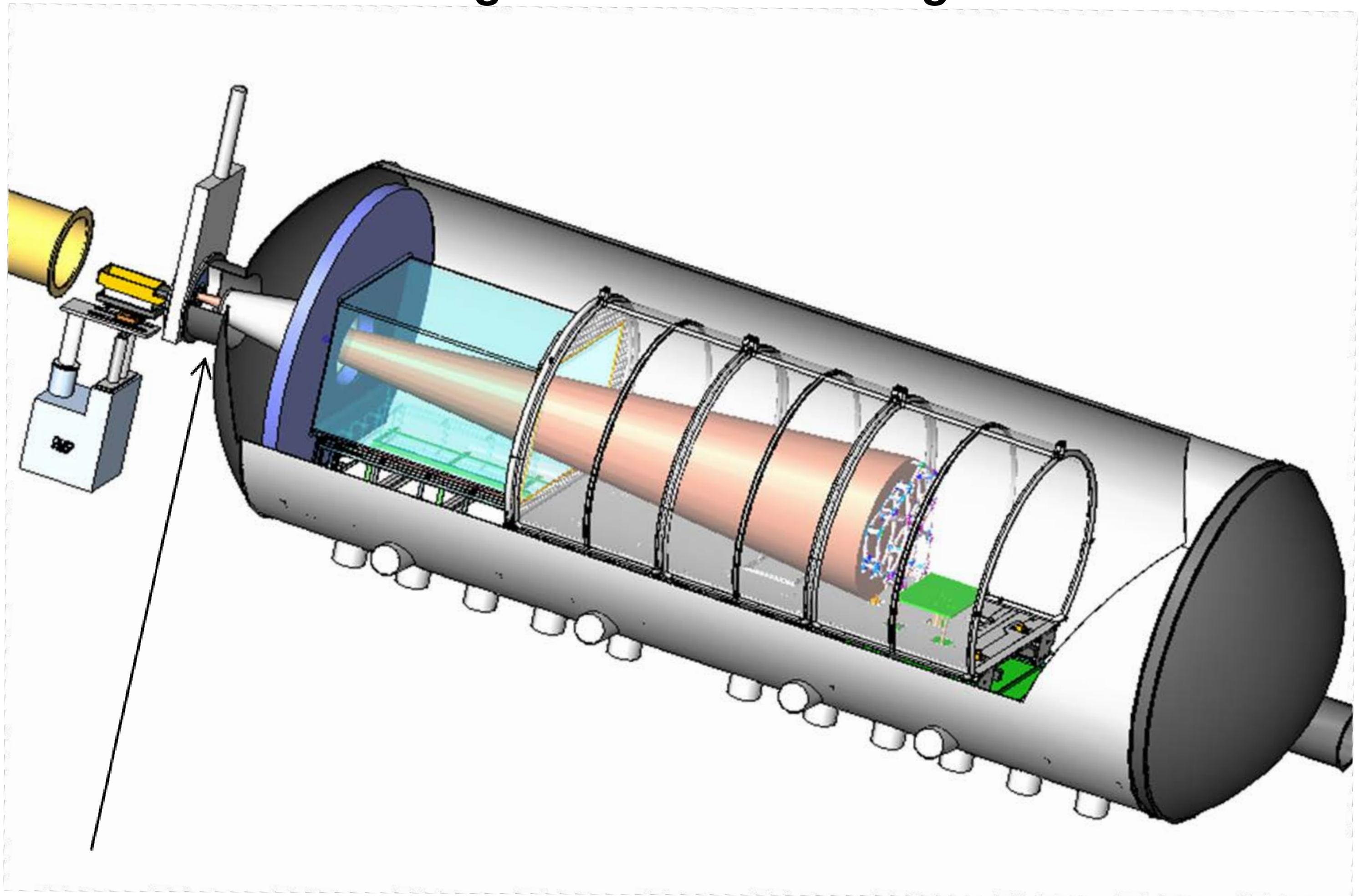
Six enabling technologies

1. Large-aperture, low-areal density, high-stiffness mirror
2. Mirror support system
3. Integrated model validation
4. Mid & high spatial frequency figure error
5. Segment edges
6. Segment to segment gap phasing

Approach

- Develop structural, thermal and optical performance (STOP) models of candidate mirror assembly
- Models are validated by testing of **subscale** mirror assembly in relevant thermo-vacuum environments
- Develop & improve test methods to characterize mirror performance
- Using same test setup, facility to characterize competing mirror architecture
- Utilize and add capabilities to existing test facilities
- Gain valuable testing experience for personnel

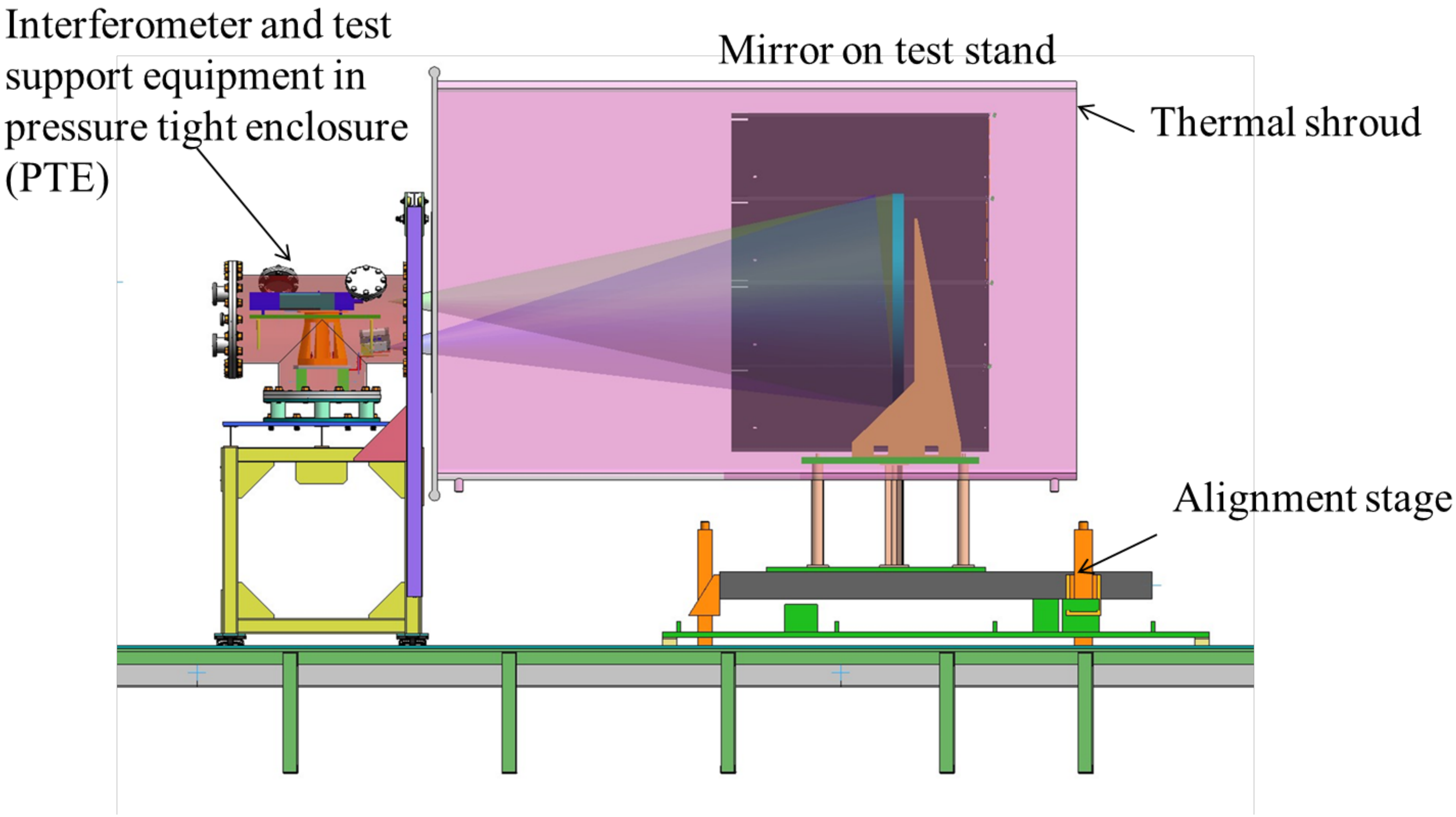
Pressure tight enclosure in large chamber



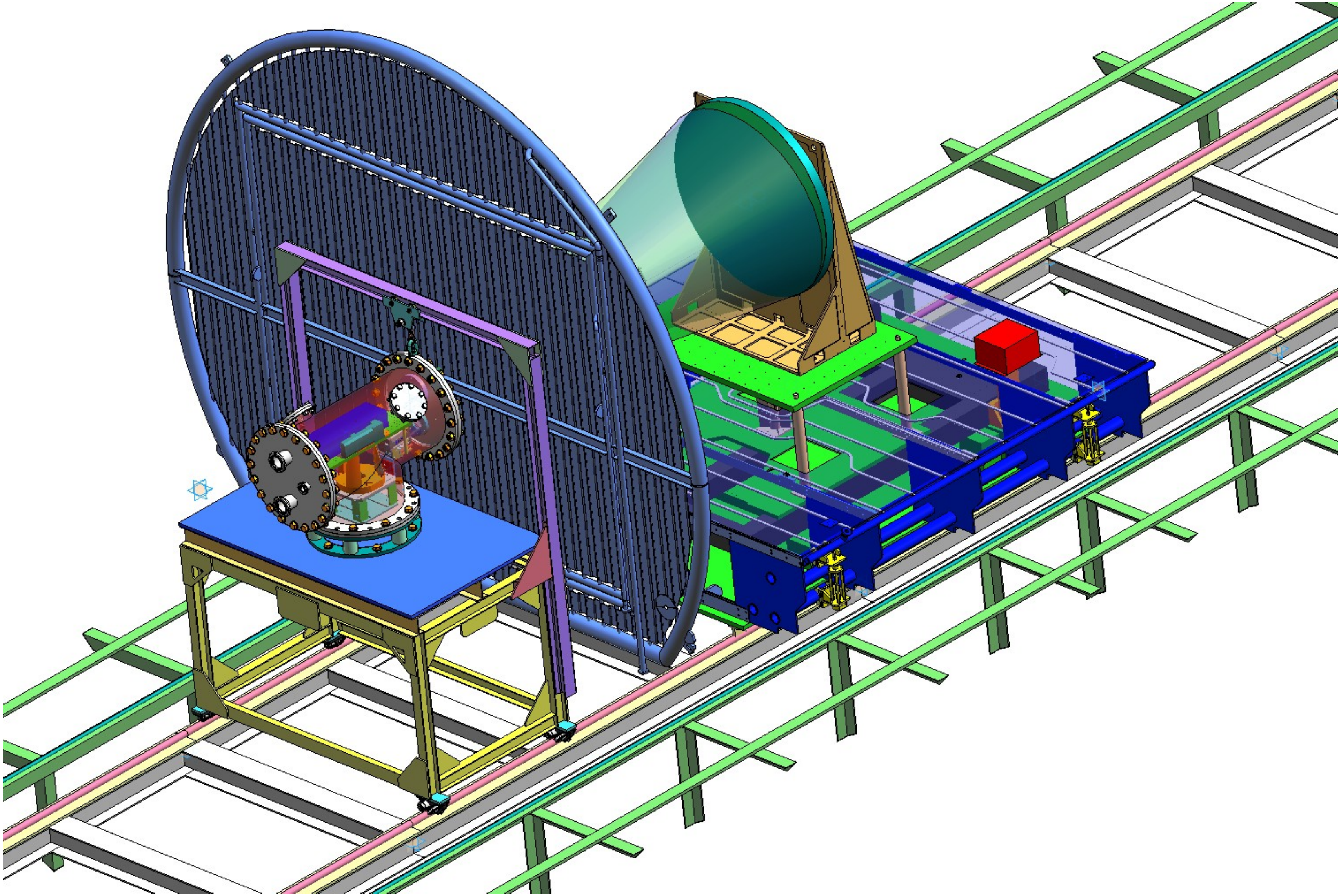
Existing structure prevents testing mirrors in this configuration with ROC < 3.5 meters

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

Test configuration for < 3.5 m radius of curvature mirror

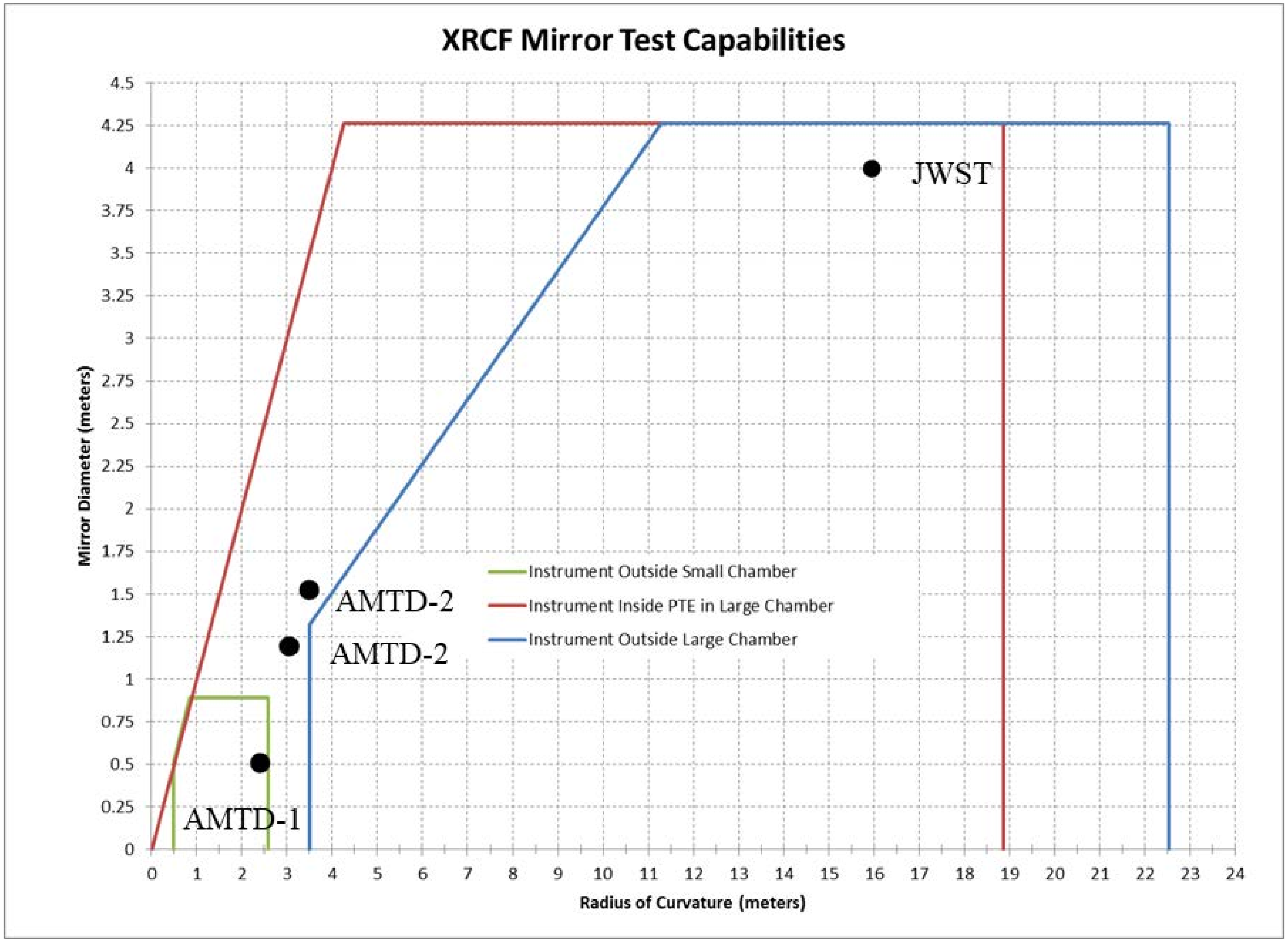


Test configuration for < 3.5 m radius of curvature mirror

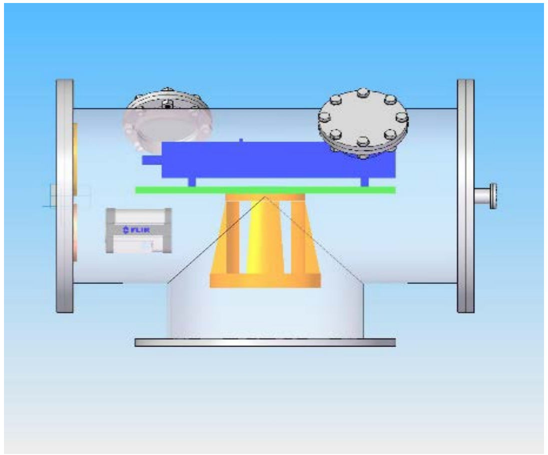


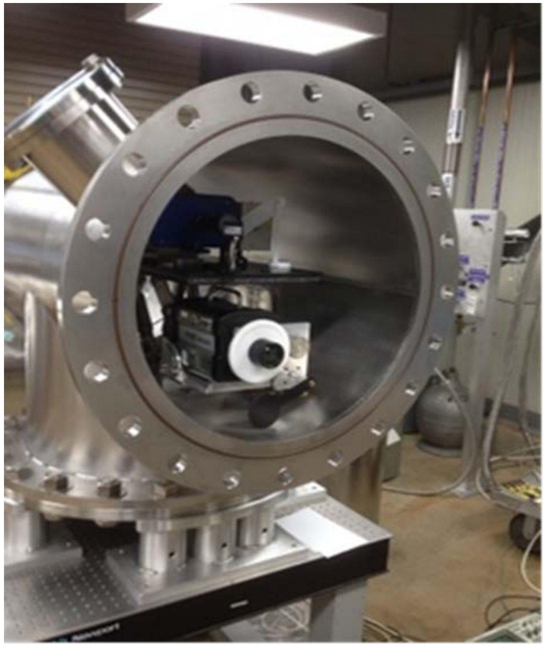
Test envelop for large and small chambers

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



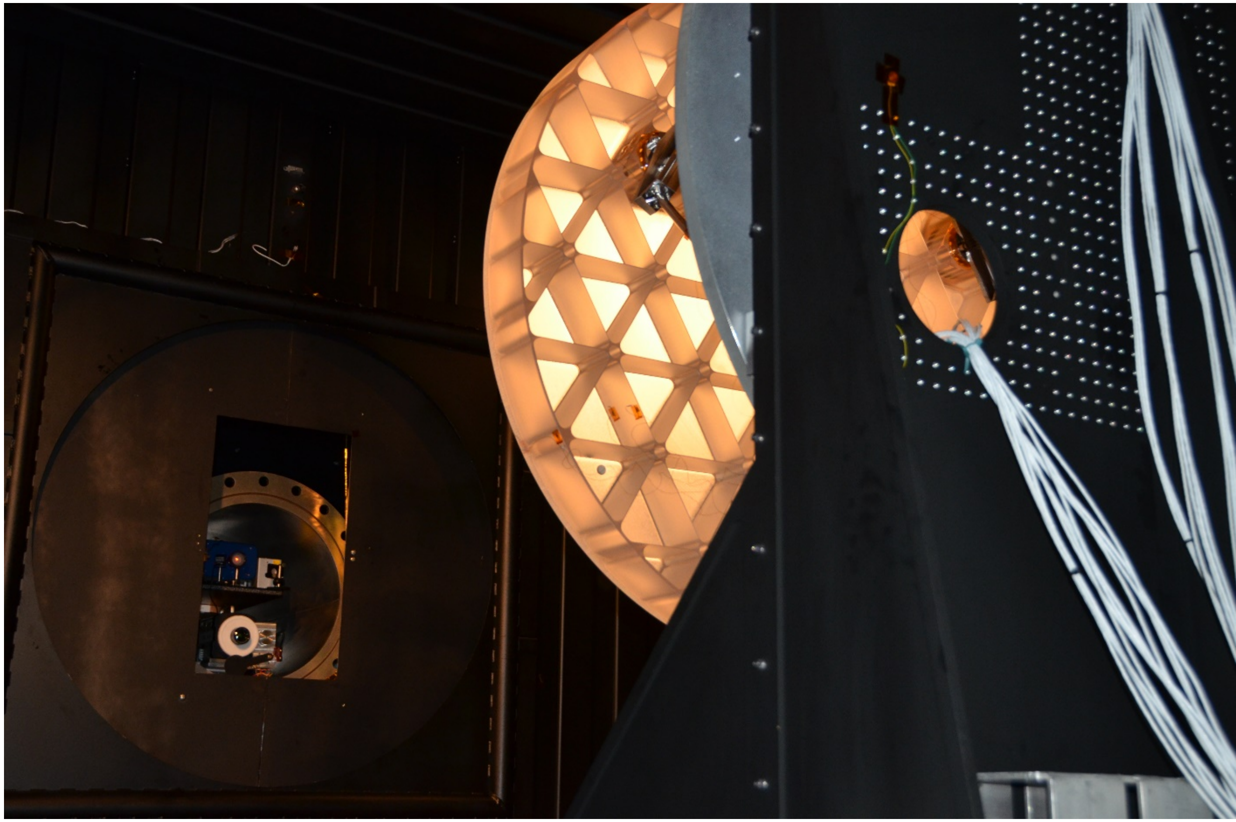
Optical test equipment inside pressure tight enclosure (PTE)



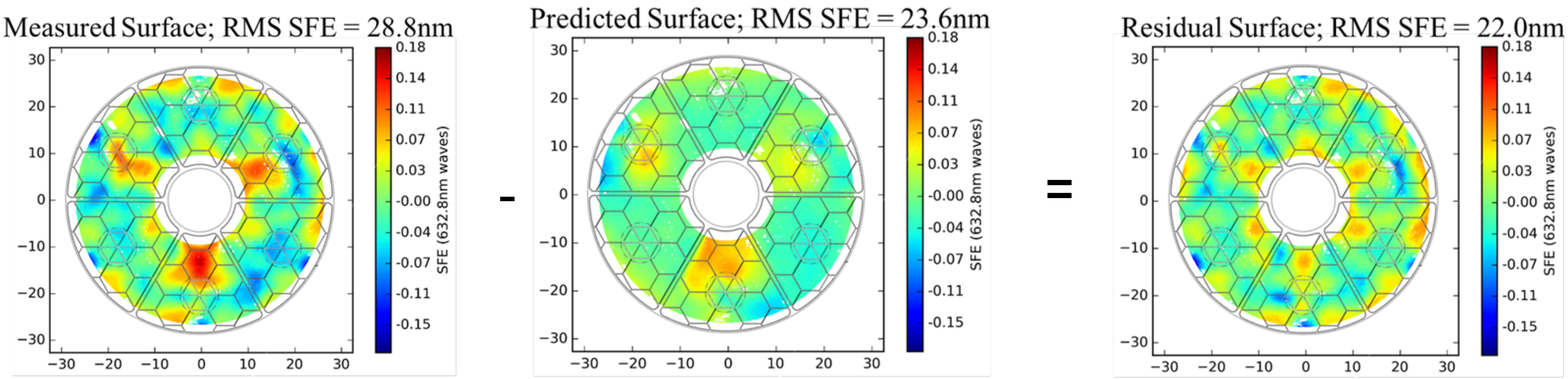


1. alignment CCD
2. alignment pinhole
3. interferometer
4. ADM
5. IR camera stage
6. hexapod

Cryo optical test with PTE

Thermal optical test surface figure error

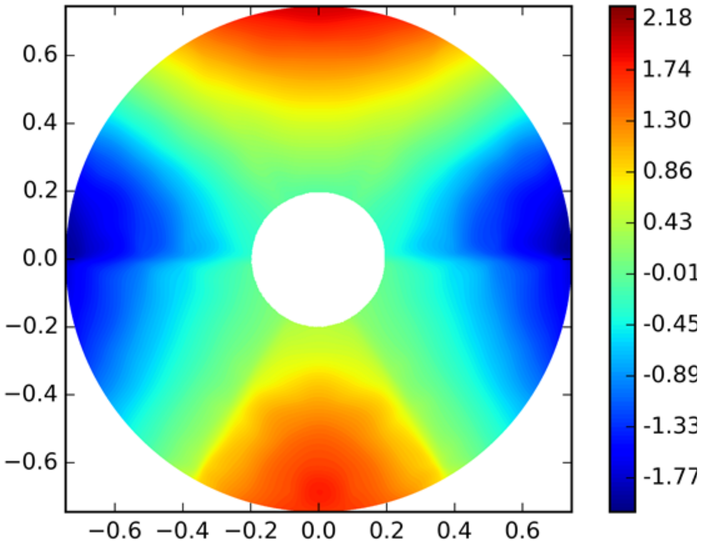


Predicted SFE uses:

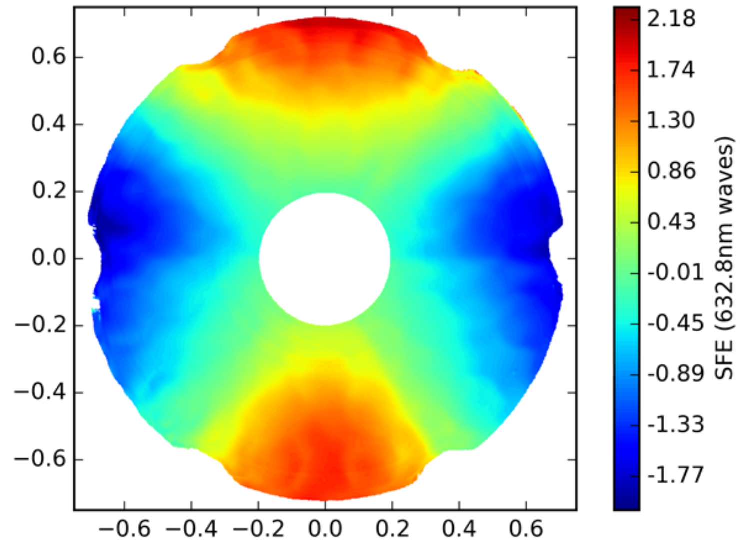
- as-built CTE distribution
- as-built shape from X-ray CT
- includes prying (due to aluminum frame) and all possible forces reacting between mount and bond pad

Residual SFE could be CTE inhomogeneity

Gravity sag (predicted vs measured)

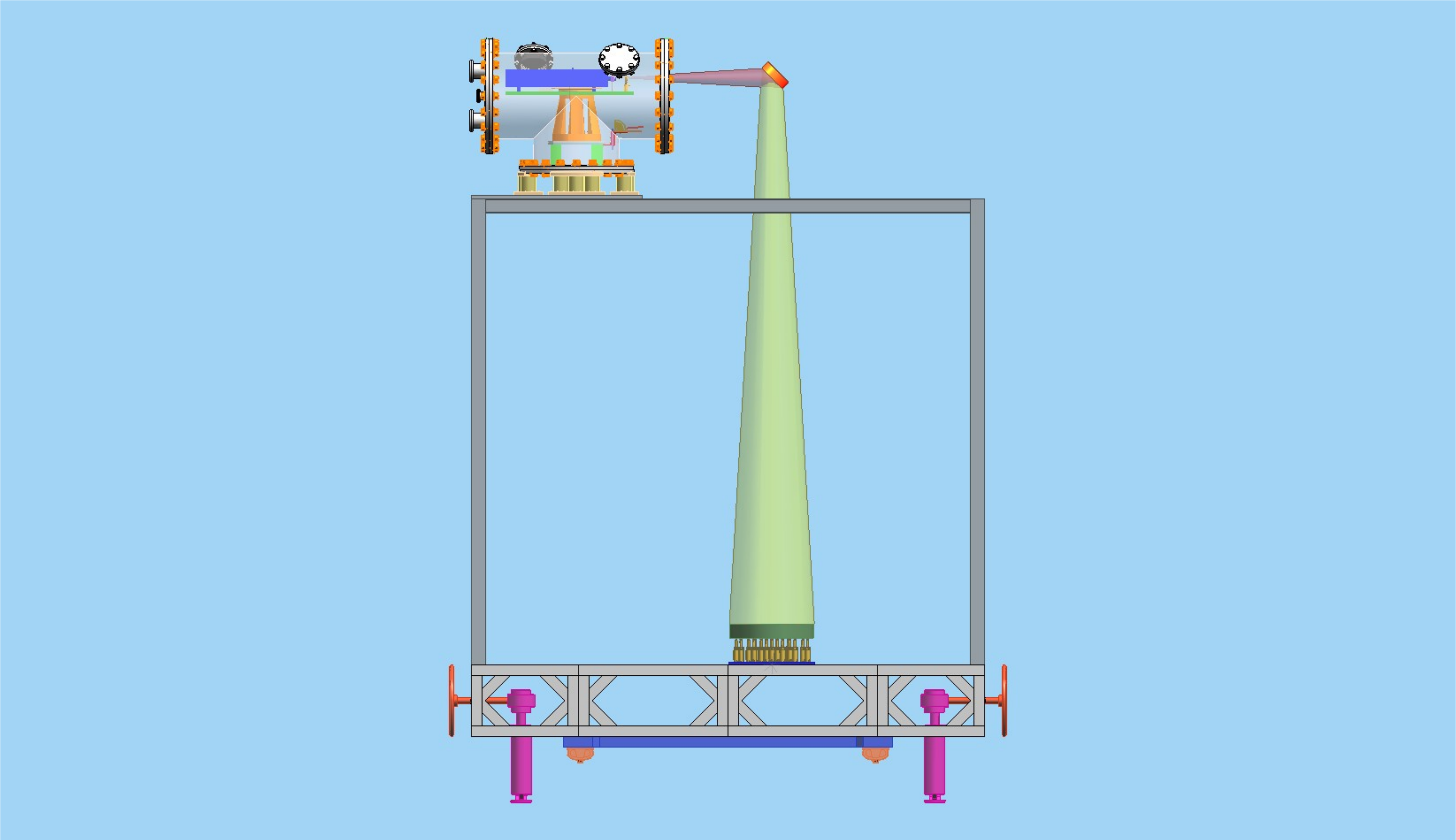


Predicted
580 nm rms

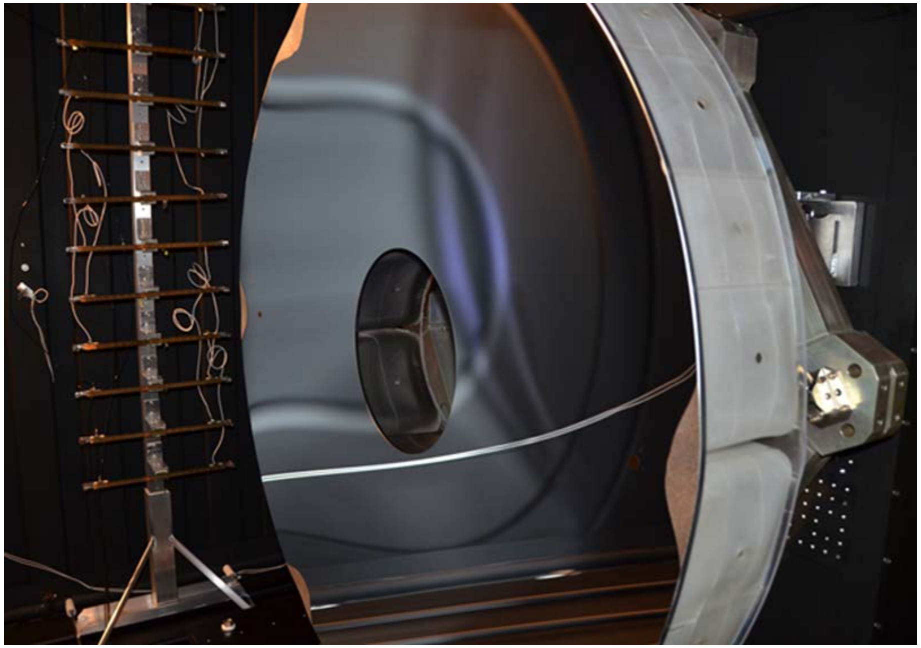


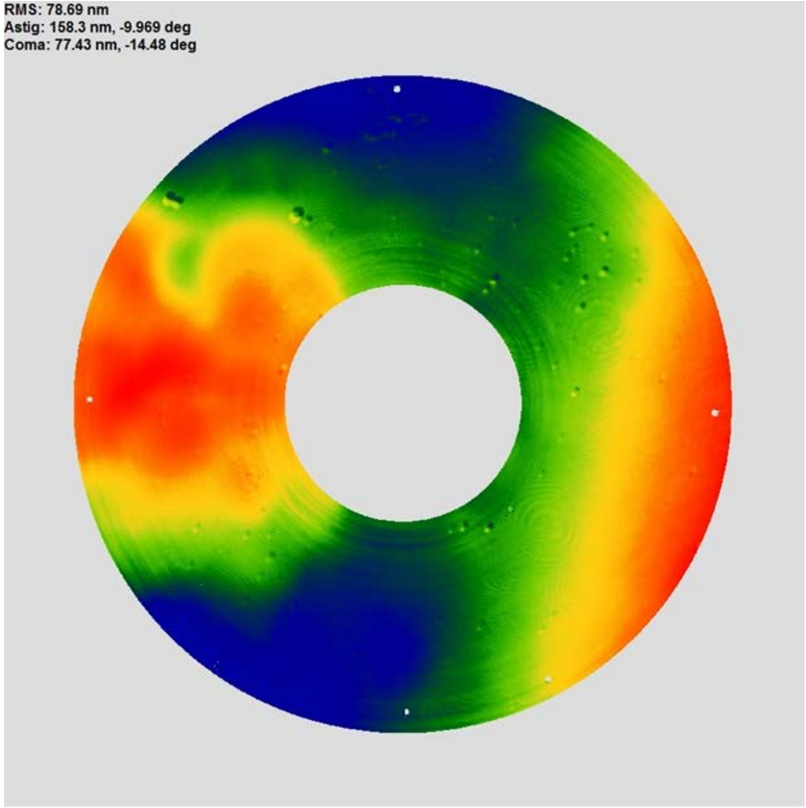
Measured
582.5 nm rms

Vertical optical test configuration



Thermal gradient test



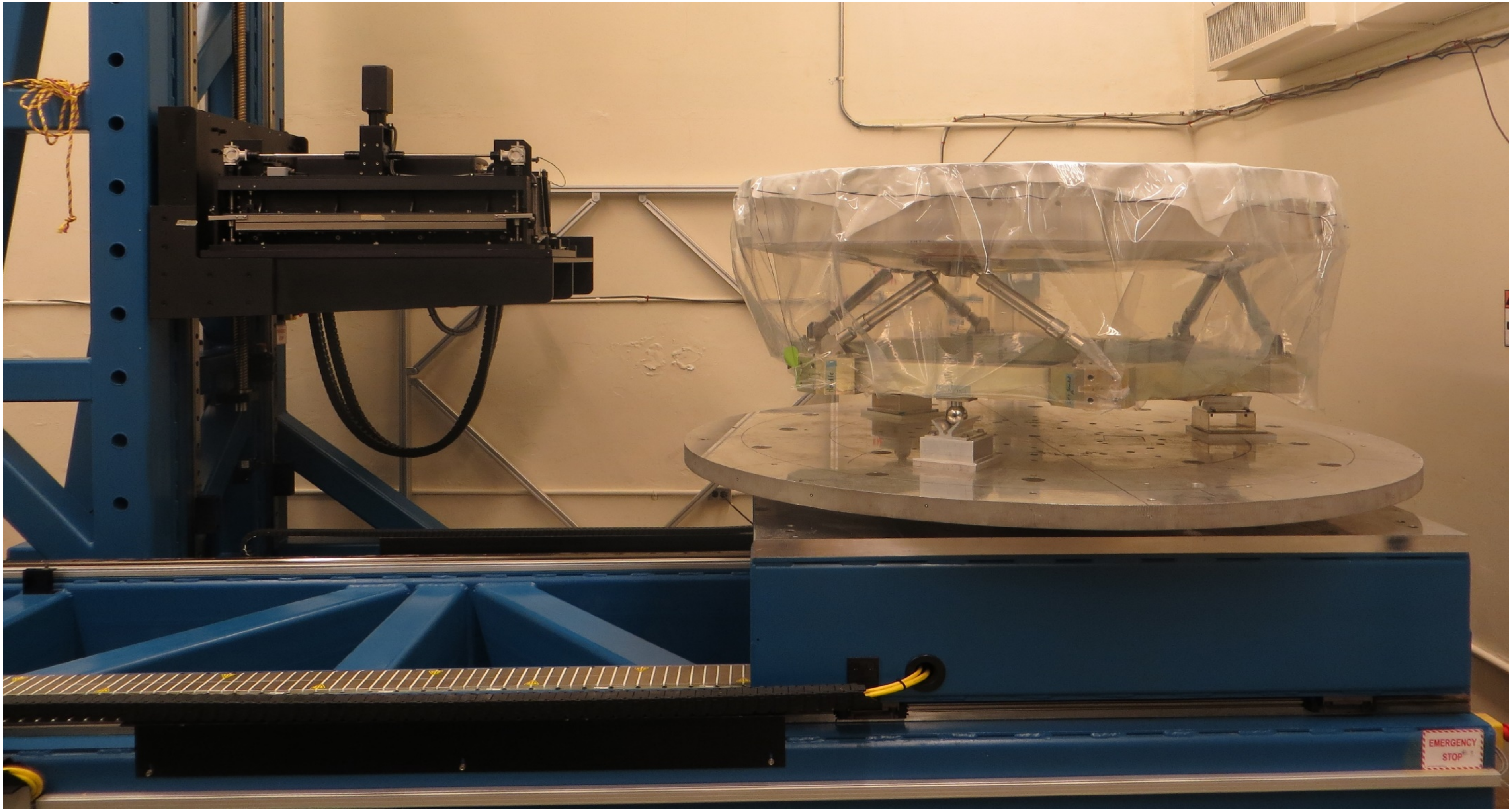


Mirror assembly modal test

- 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
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 한국천문연구원 Korea Astronomy & Space Science Institute

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

National Aeronautics and Space Administration