Cryogenic optical testing of space telescope mirrors

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Space Transportation, Propulsion Systems
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

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**History**


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

- **Science Instrument Module (ISIM)**
  - Houses all of Webb's cameras and science instruments.

- **Trim flap**
  - Helps stabilize the satellite.

- **Solar power array**
  - Always facing the Sun, panels convert sunlight into electricity to power the observatory.

- **Earth-pointing antenna**
  - Sends science data back to Earth and receives commands from NASA's Deep Space Network.

- **Spacecraft bus**
  - Contains most of the spacecraft steering and control machinery, including the computer and the reaction wheels.

- **Star trackers**
  - Small telescopes that use star patterns to target the observatory.

- **Primary Mirror**
  - 18 hexagonal segments made of the metal beryllium and coated with gold to capture faint infrared light.

- **Secondary Mirror**
  - Reflects gathered light from the primary mirror into the science instruments.

- **Multilayer sunshield**
  - Five layers shield the observatory from the light and heat of the Sun and Earth.
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

Hubble primary mirror

JWST primary mirror

2.4 m dia.

3.6 m²

6.5 m (18 mirror segments)

25 m²
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

Array matched to detector array pixels
Small chamber for mirror characterization
Cryo test of 12 SiC mirrors (~150 mm dia. each)
Test configuration for < 800 mm dia. mirror
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

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

<table>
<thead>
<tr>
<th>Chamber</th>
<th>Max Diameter</th>
<th>Max radius of curvature</th>
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<tbody>
<tr>
<td>Large</td>
<td>4.25 m</td>
<td>22.5 m</td>
</tr>
<tr>
<td>Small</td>
<td>0.8 m</td>
<td>2.5 m</td>
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XRCF Mirror Test Capabilities

- **AMTD-1**
- **AMTD-2**
- **AMTD-2**
- **JWST**
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
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
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