James Webb Space Telescope:

TPF Test

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[Mat. 1136]

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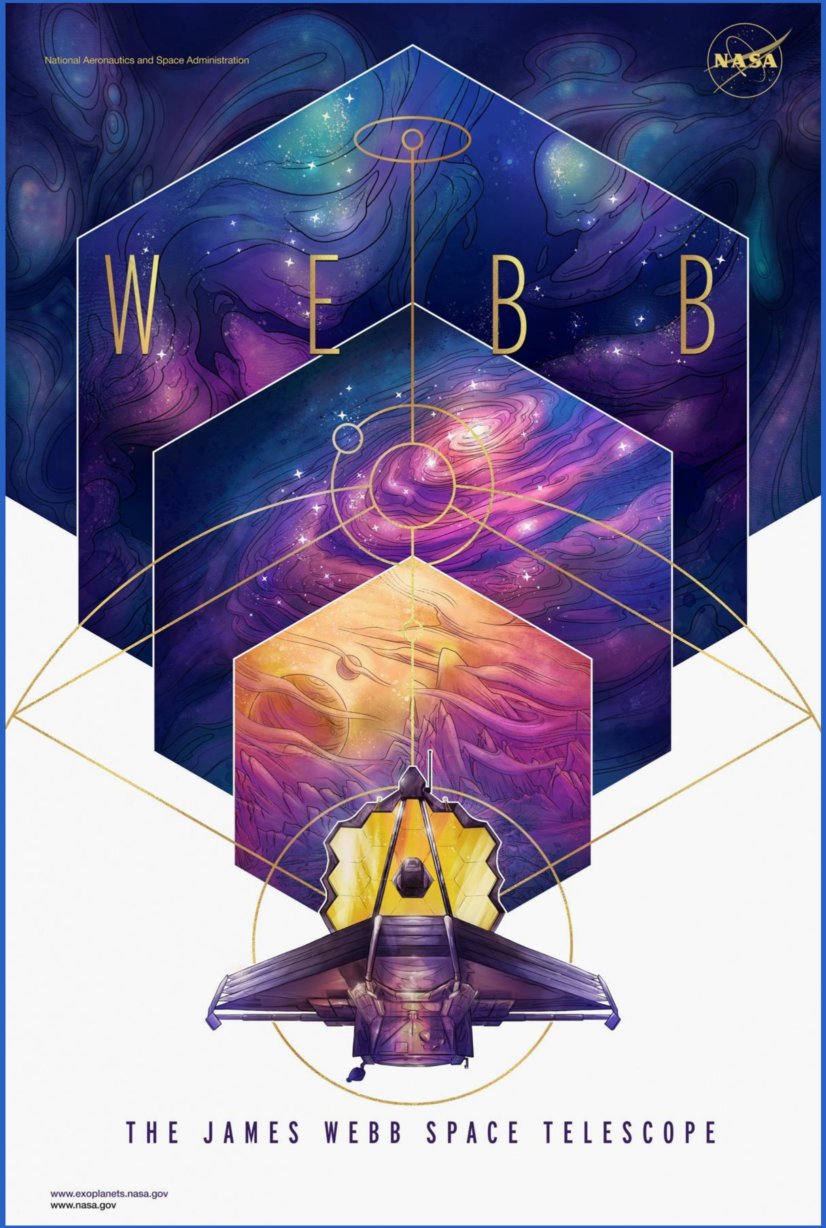
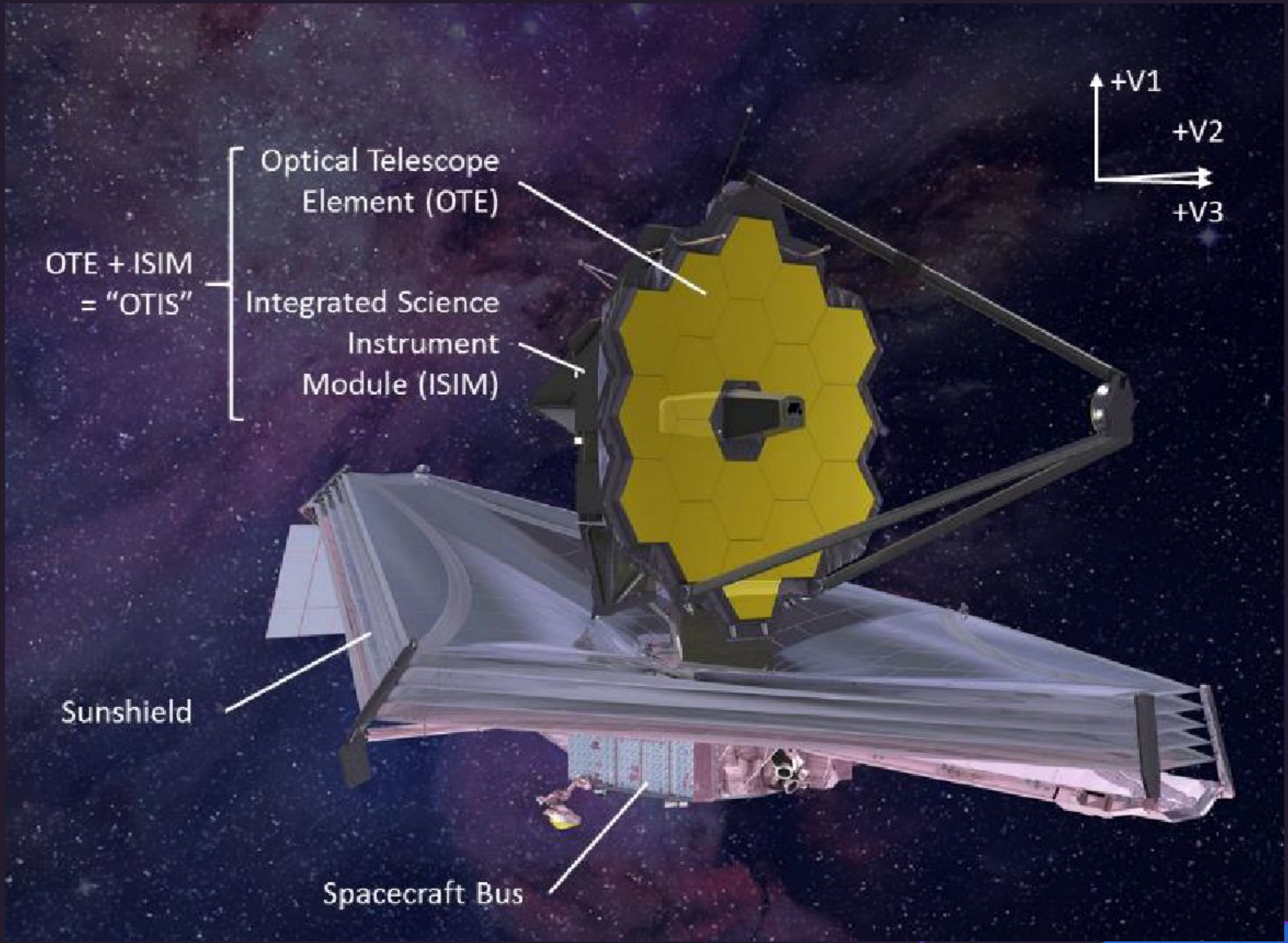
Next Generation Space Telescope

JWST is a space telescope developed by NASA, ESA and CSA

It succeeds the Hubble Space Telescope as NASA's Flagship astrophysics mission



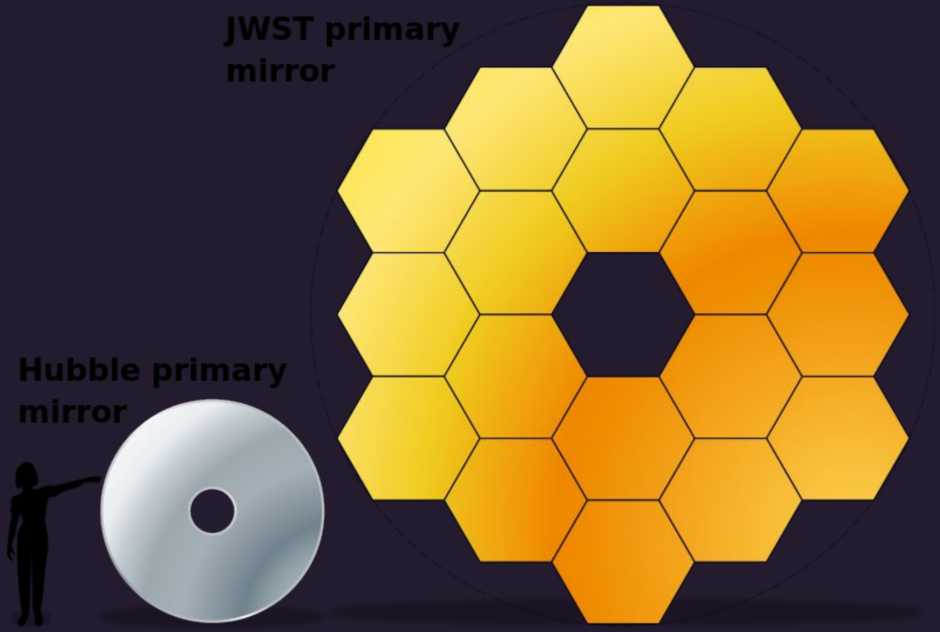
The JWST



+V1
+V2
+V3
Optical Telescope
Element (OTE)
OTE + ISIM
= "OTIS"
Integrated Science
Instrument
Module (ISIM)
Sunshield
Spacecraft Bus

What’s new?

The primary mirror of the JWST, the Optical Telescope Element, consists of 18 hexagonal mirror segments made of gold-plated beryllium which combine to create a 6.5 m diameter mirror, considerably larger than Hubble's 2.4 m mirror



About JWST…

JWST will observe $[0.6 - 28.3]\mu m$ from long-wavelength visible light through mid-IR: this will allow it to observe high redshift objects

Telescope is deployed in space near the Sun–Earth L2 Lagrange point, 1,500,000 km beyond Earth's orbit

Objects near L2 can orbit the Sun in synchrony with the Earth, allowing the telescope to remain at a constant distance and with constant orientation of the sunshield, towards the Earth and the Sun, to block heat and light from both and maintain communications

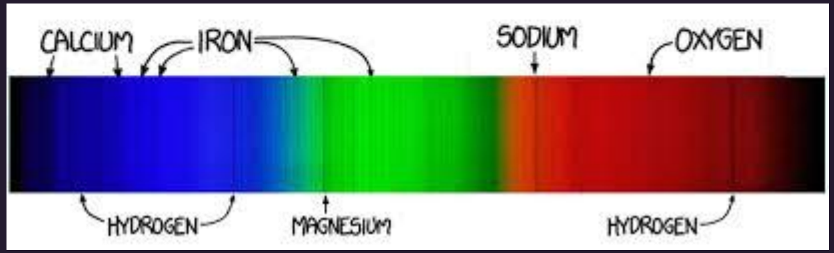
Moreover a large sunshield made of silicon – and aluminum – coated Kapton keeps its mirror and instruments below 50 K

This arrangement keeps the temperature of the spacecraft below 50 K, necessary for IR observations

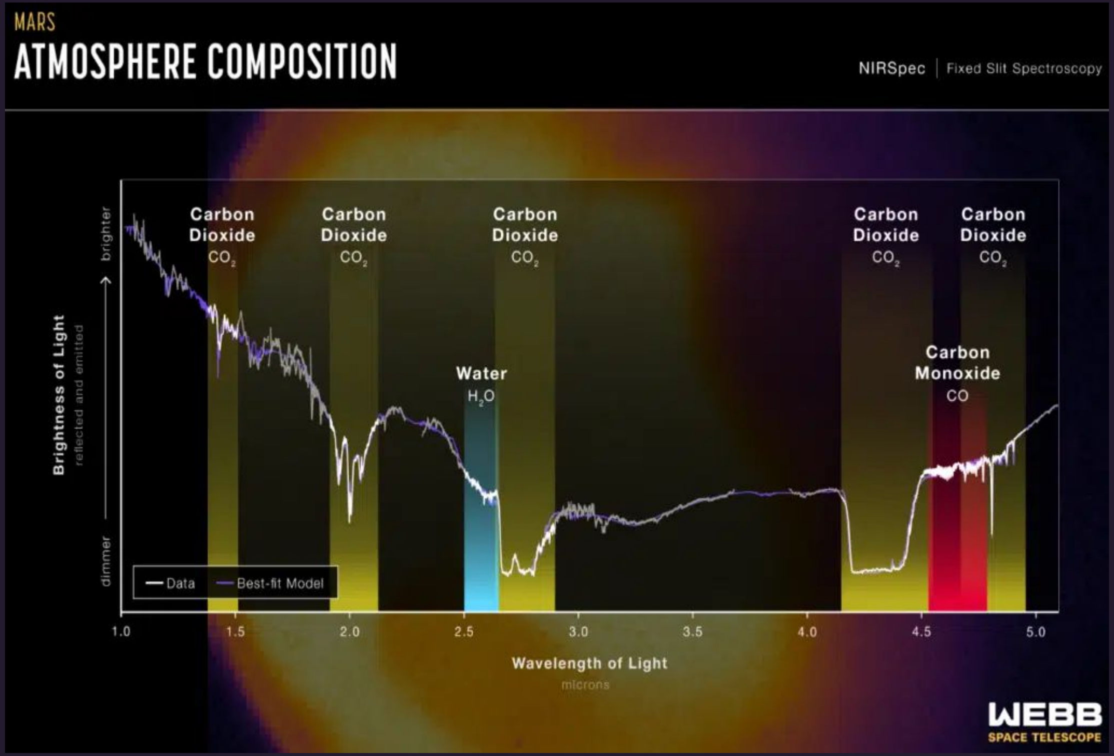
Disadvantages

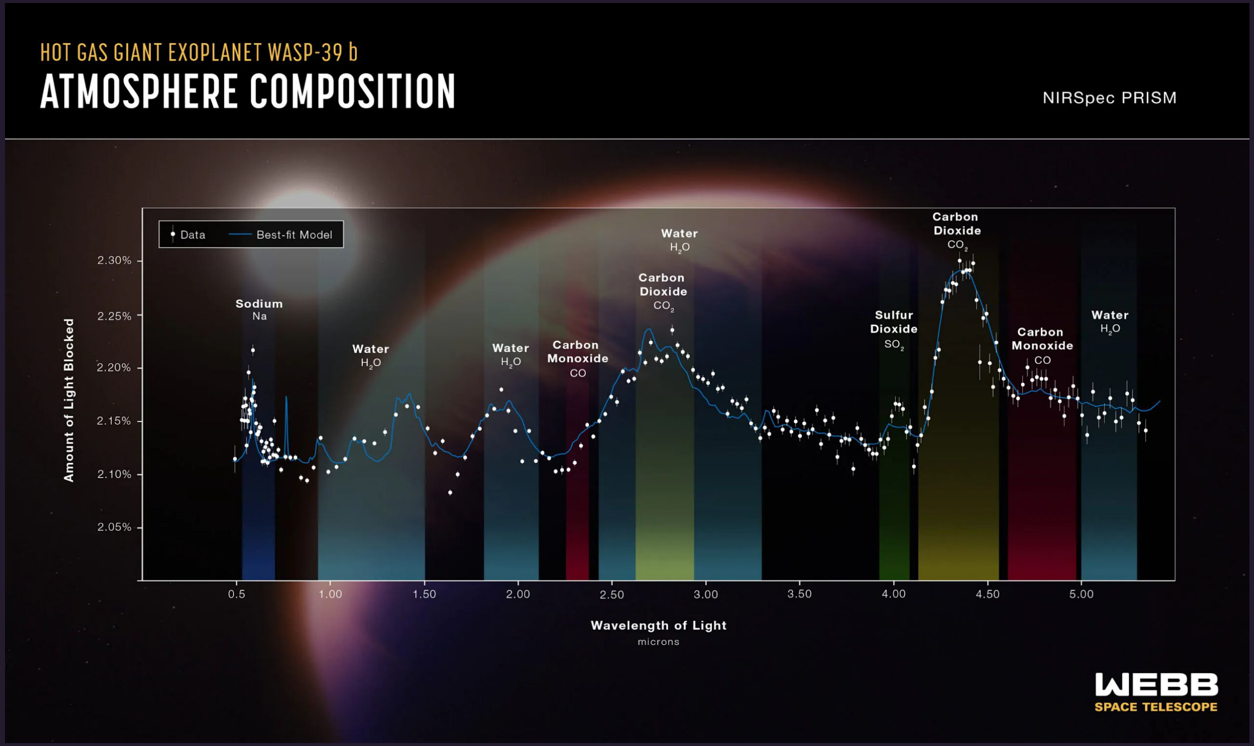
IR telescopes need to stay extremely cold (the longer the wavelength of IR, the colder they need to be), although the background heat of the device itself overwhelms the detectors, making absorption spectra unintelligible.
Old telescope used to be placed in an extremely cold substance, such as liquid helium

JWST is designed to cool itself, using a combination of sunshields and radiators



Is it working?





Thermal Pathfinder Test

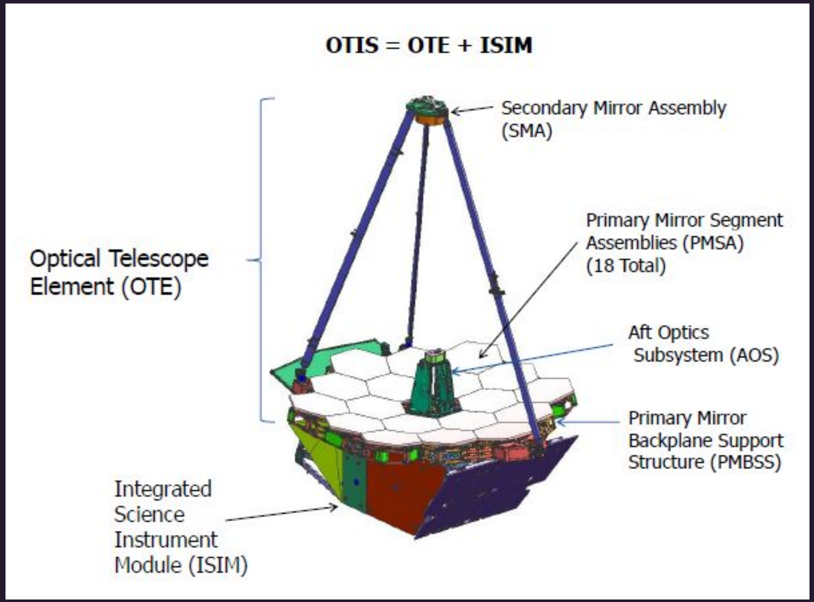
Biggest issues: need for cold temperature, so a Thermal Pathfinder Test has been developed to test the apparatus.

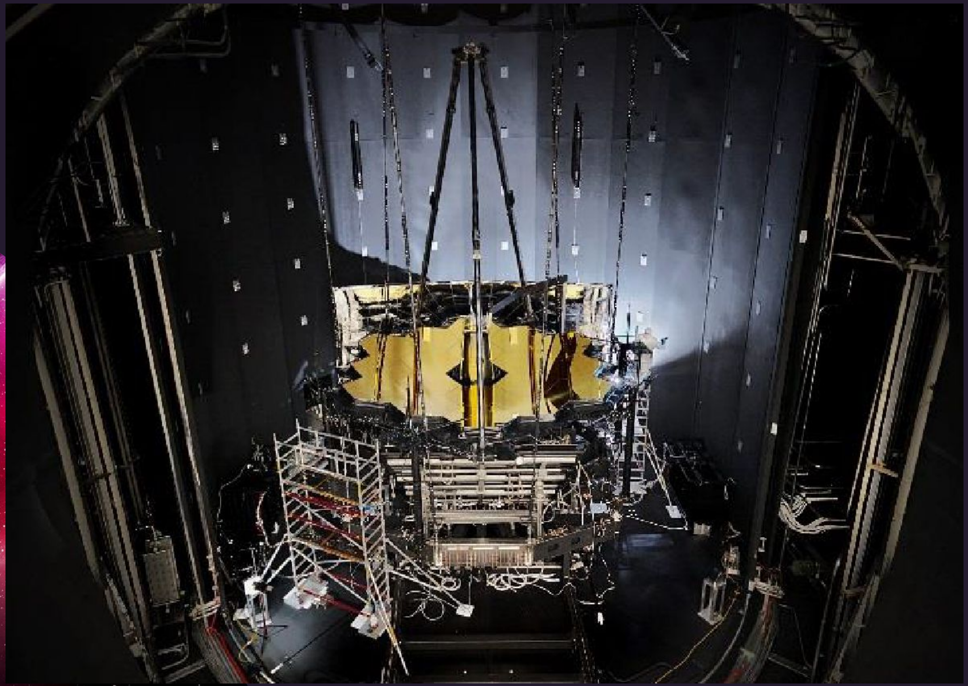
The observatory could not be optically or thermally tested as a system at flight temperatures due to its large sunshield, so the telescope was divided in sub-assemblies, each of them tested as a single unit

In this presentation the optical sub-assembly tests are discussed

OTIS

The JWST optical system includes the Integrated Science Instrument Module (ISIM) and the Optical Telescope Element (OTE)



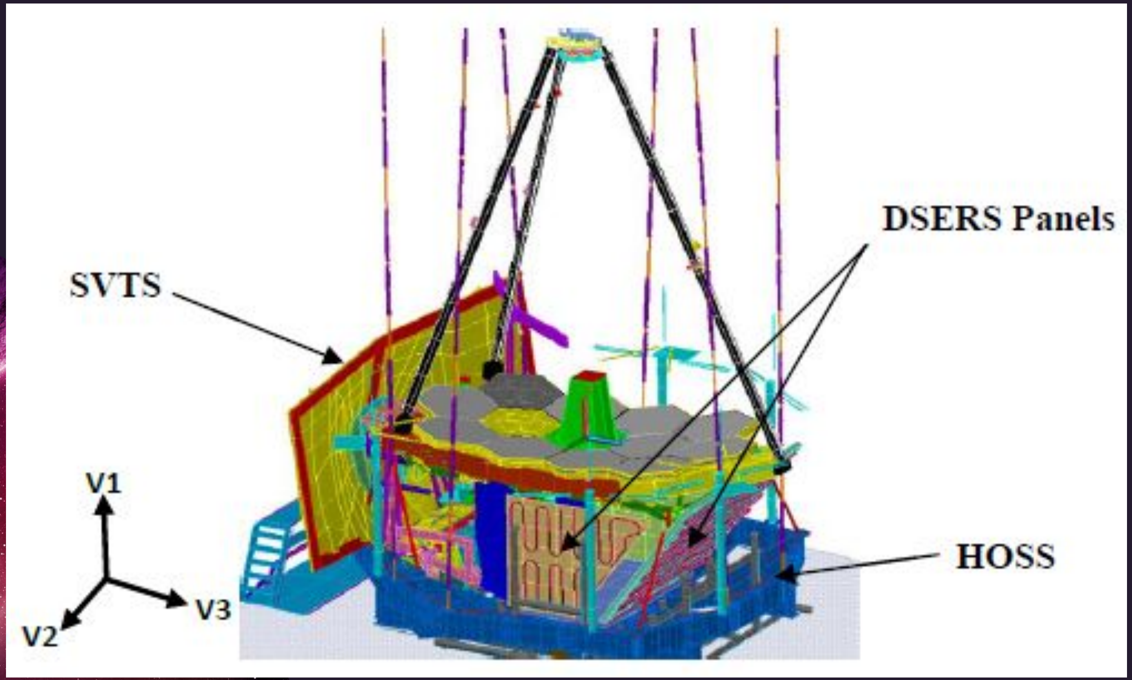


The OTIS was optically, mechanically and functionally tested at NASA/Goddard Space Flight Center (GSFC) and underwent end-to-end optical and thermal tests at flight temperature levels in the NASA Johnson Space Center (JSC) Chamber A thermal vacuum facility

Test configuration

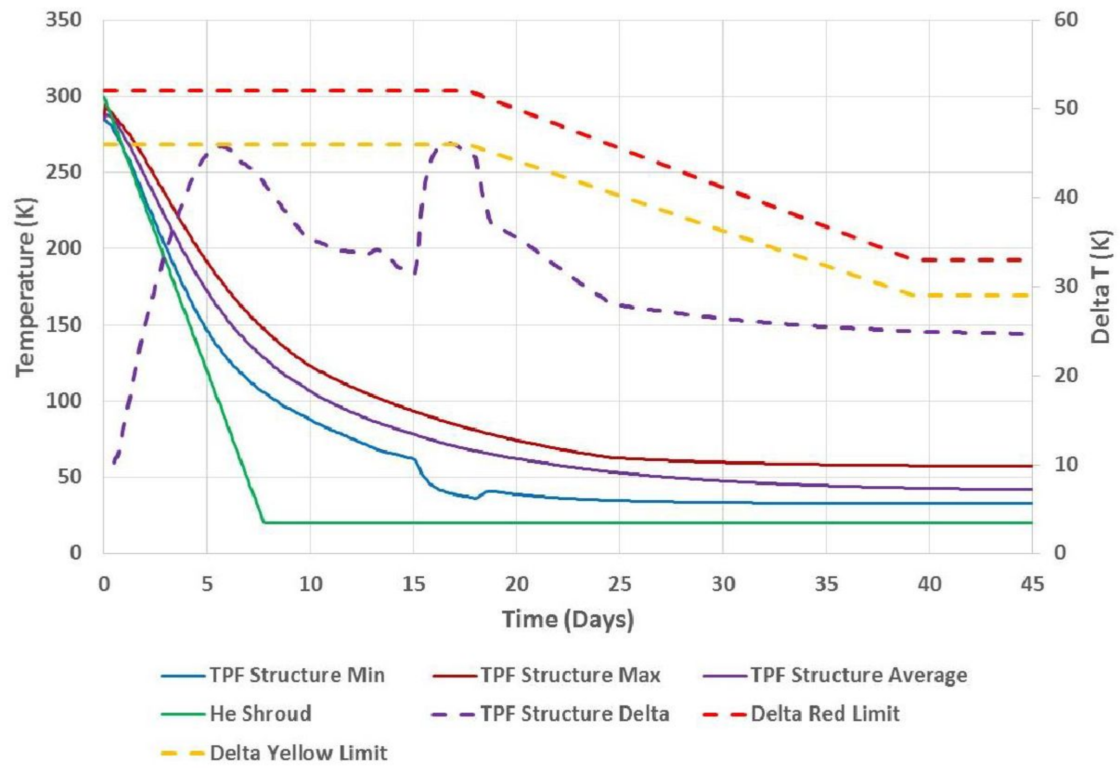
The JSC Chamber A was upgraded to prepare for the JWST OTIS test program

- SVTS: Space Vehicle Thermal Simulator simulated flight JWST sunshield, spacecraft and other interfaces
- DSERS: Deep Space Edge Radiation Sink panels, located under the backplane structure, provide a controlled sink for the ISIM during OTIS testing
- HOSS: Helium-cooled Hardpoint/Offloader Support Structure, suspended from the ceiling of Chamber A, supported the Pathfinder during TPF and the telescope during the OTIS test



Thermal Pathfinder Configuration

Structure Gradient Constraint I



Predicted Thermal Pathfinder Cooldown

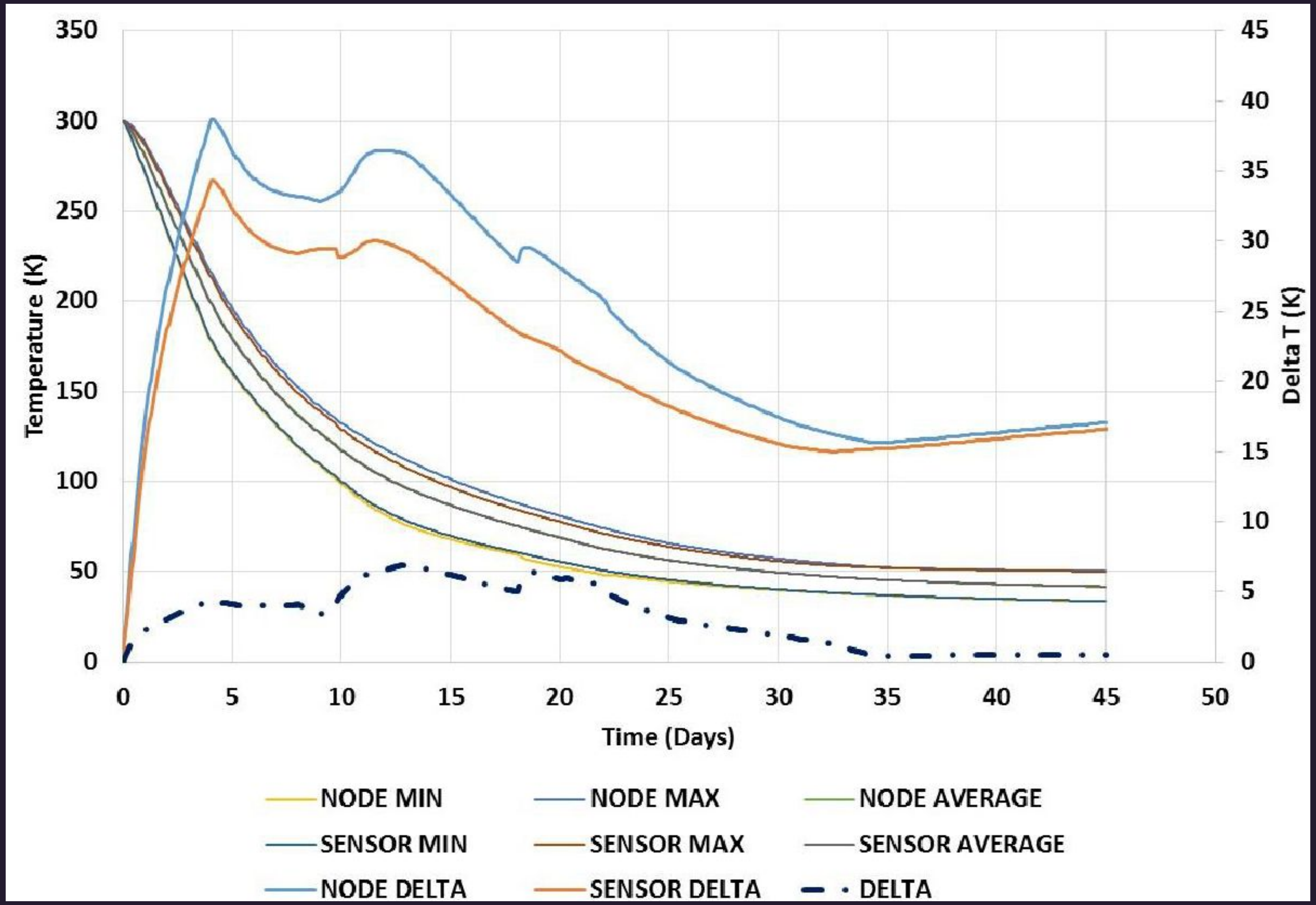
Thermal stresses during transitions must be considered when cooling a cryogenic structure

OTIS simulations showed that a 1.5 K/hr helium shroud cooling rate would ensure all OTIS structure stress requirements were met

The lower-strength TPF had lower allowable stresses, so this cooldown curve showed much less margin to the allowable structure deltas as compared to OTIS, anyways the OTIS-like cooldown remained the baseline since shroud rate adjustments could be made if necessary to preserve the TPF structure

Structure Gradient Constraint II

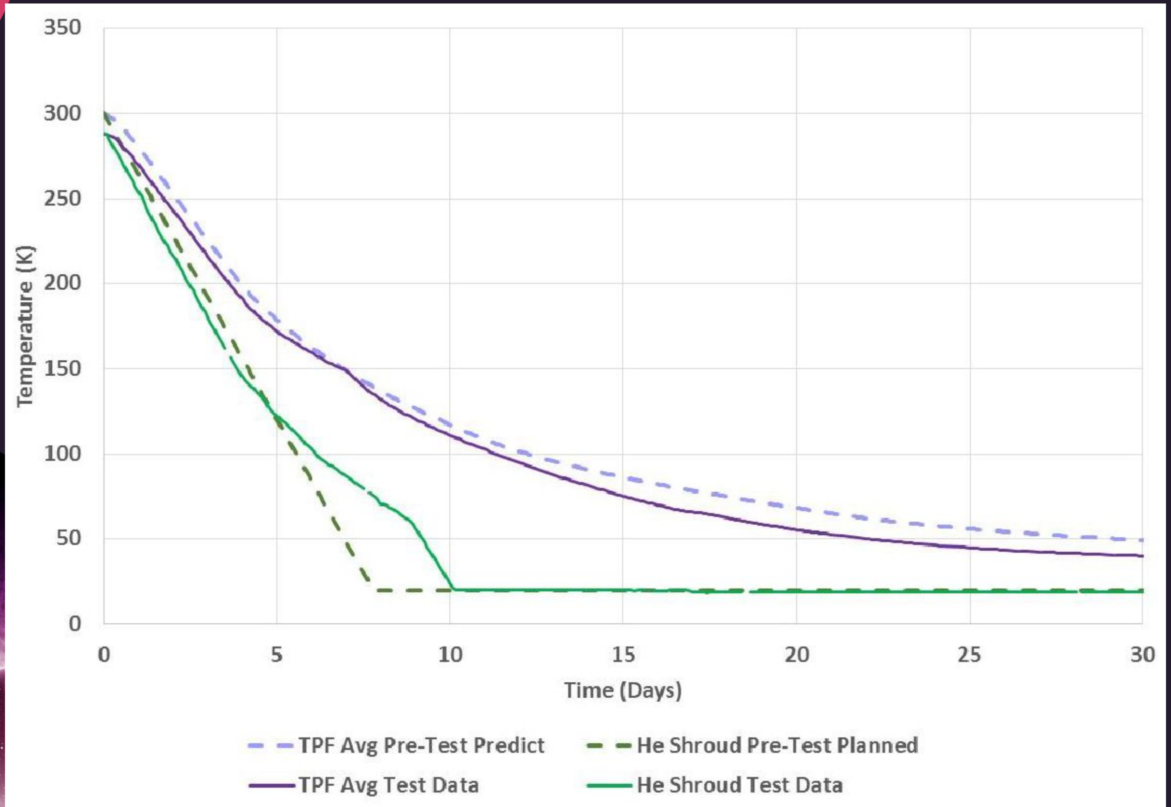
Only about 200 sensors were available to monitor over 20,000 structure nodes, so pre-test analysis was used to determine test limits that would ensure TPF structure ΔT compliance



Comparison of Sensor and Node Data: the maximum difference between ΔT sensor locations vs all the node locations was 7K

Step A: Cooling

It officially commenced on 11 September 2016 at 21:00 UTC
Operators were directed to cool the Helium shroud at a rate of 1.5 K/hr as planned



In two days, structure was cooling 10% faster than predicted: structure gradients approaching yellow limits

Cooldown day 3: one of the Backplane Support Fixture interface heaters failed, increasing structure gradients, so facility operators reduce the shroud cooling rate, which reduced structure gradients quickly as expected
Shroud cooling rates remained below 1K/hr for the next 5 days

The 0.027K/hr stability point was achieved in 30 days

The test finished 2-days early

Step B: Primary Mirror Segment Assembly Heating Test

It showed that the thermal effects of motor heating were well-characterized

Step C: Thermal Balance 2

The backplane structure, mirrors, and blanks were the focus of Thermal Balance 2 efforts
Six days after the backplane heaters were powered, 98% of thermal sensors achieved a thermal stability of 0.01 K/hr

Step D: Warmup

Key payload temperatures well-predicted with model: no structure gradient exceedances

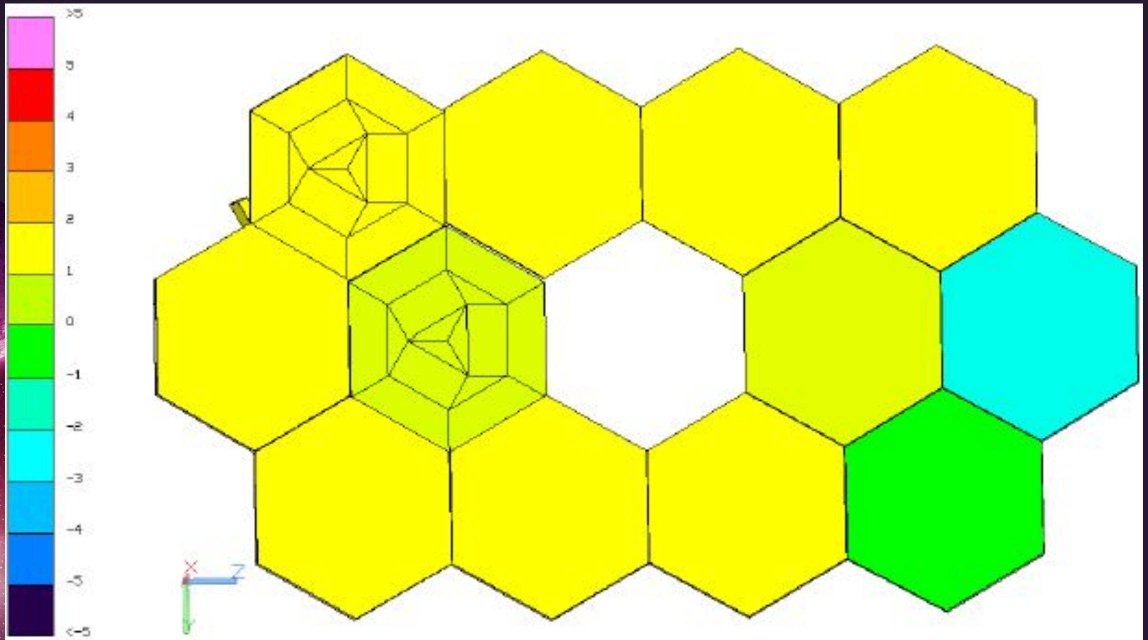
In one thermal event, the secondary mirror support frame seemed to experience a sudden temperature gradient, it was the evidence of a temperature sensor that had fallen off the frame and landed on the mirror below.
More excitement when water pipe leak near the chamber control area caused a shutdown of He shroud temperature control
Warmup of the shroud was halted for 24h for pipe repairs and drying operations, then was resumed with no payload issues.

Warmup was concluded on 30 October, ending the 52-day test

Thermal Correlation Analysis

- In TPF model, He Shroud modeled as single node boundary temperature, test data showed that relatively uniform temperature of Shroud could be adequately represented by one value
- Pre-test average shroud temperature, assumed to be 20K, was adjusted to 19K for post-test model correlation
- Temperatures during test were cooler than expected ones based on pre-test predict
- At the end of the 30-day cooldown: 9K difference between predicted TPF structure $T(K)$ and the TPF average test one with correlated model, difference in temperature between model predict and test data reduced from 9K to 3K

As for the mirrors…



Mirror Test to Correlated Model Comparison

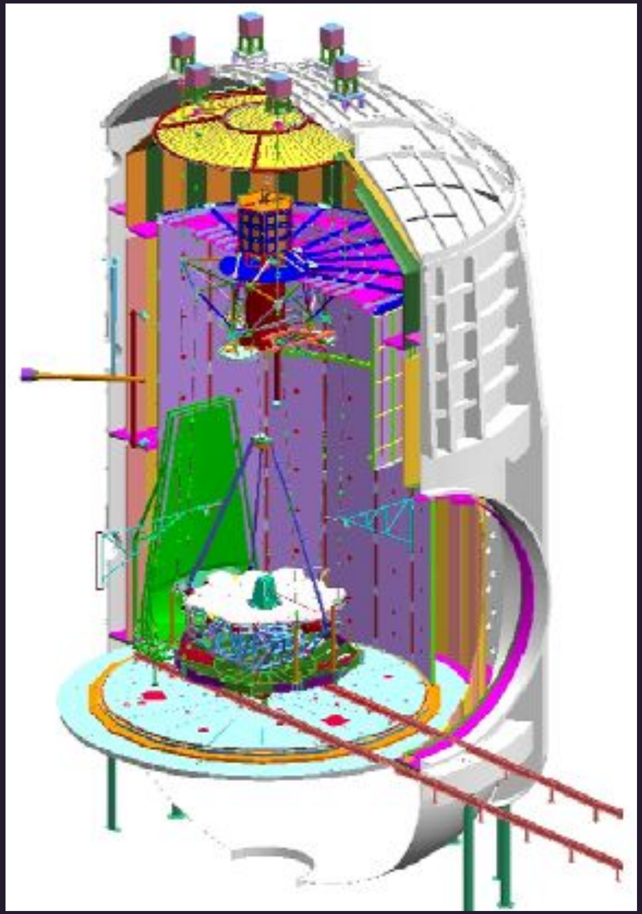
Location	Temperature (K)		
	Test Data	Model Predict	Delta (Predict-Test)
PM A4	39.3	40.2	0.9
PM C4	39.9	41.1	1.2
SIM A4	33.6	34.0	0.4
SIM A5	36.6	38.3	1.7
SIM A3	37.8	39.3	1.5
SIM A2	34.8	35.9	1.1
SIM A6	34.1	35.2	1.1
SIM B1	33.8	32.0	-1.8
SIM B4	44.2	45.9	1.7
SIM C1	34.1	33.8	-0.3
SIM C3	42.0	43.8	1.8
SIM C6	32.6	33.7	1.1

Mirror Test Data to Correlated Model

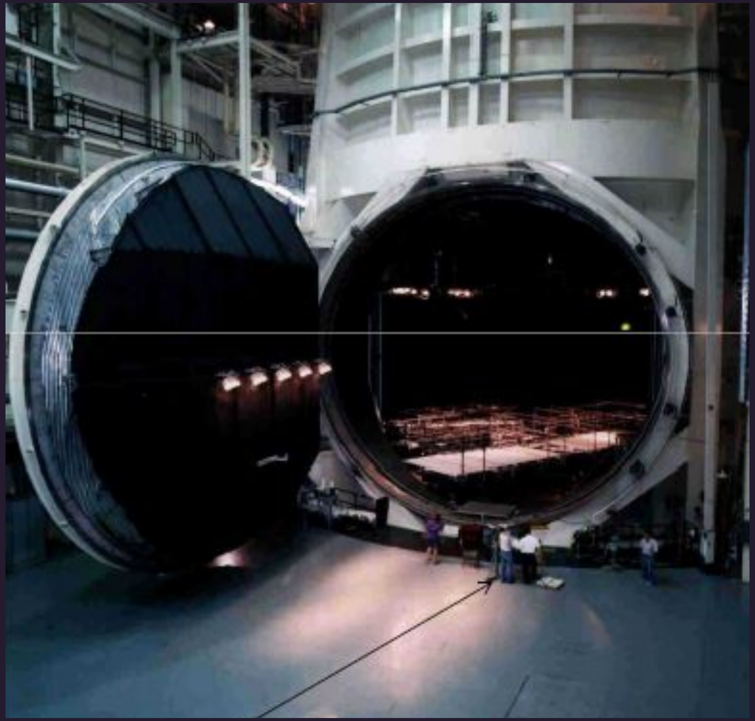
Thank you
for your attention

Backup

OTE Testing – Chamber A at JSC



Scheme of the apparatus



Arrow indicates people to have knowledge of the size of the apparatus

Key goals

The JWST provides a unique capability to study the evolution of galaxies, the history of the Milky Way, and origin and formation of planetary systems

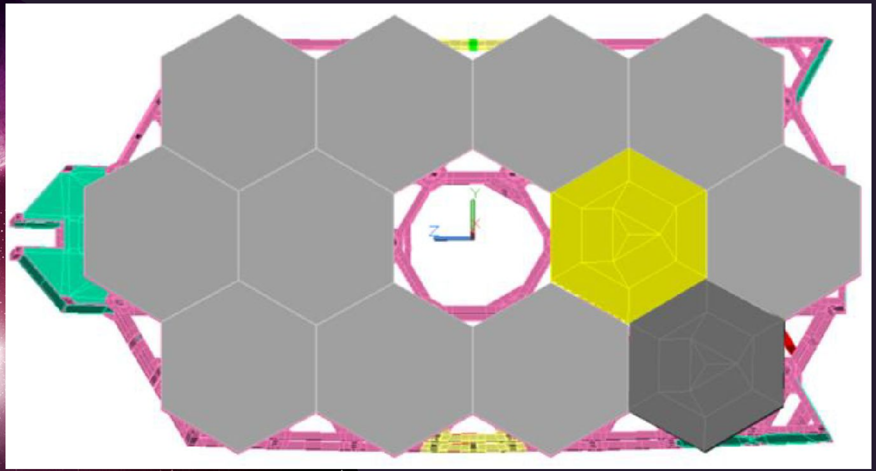
JWST has two main goals:

- search for light from the first stars and galaxies that formed in the Universe after the Big Bang
- study planetary systems and the origins of life

Pathfinder Mirror Configuration

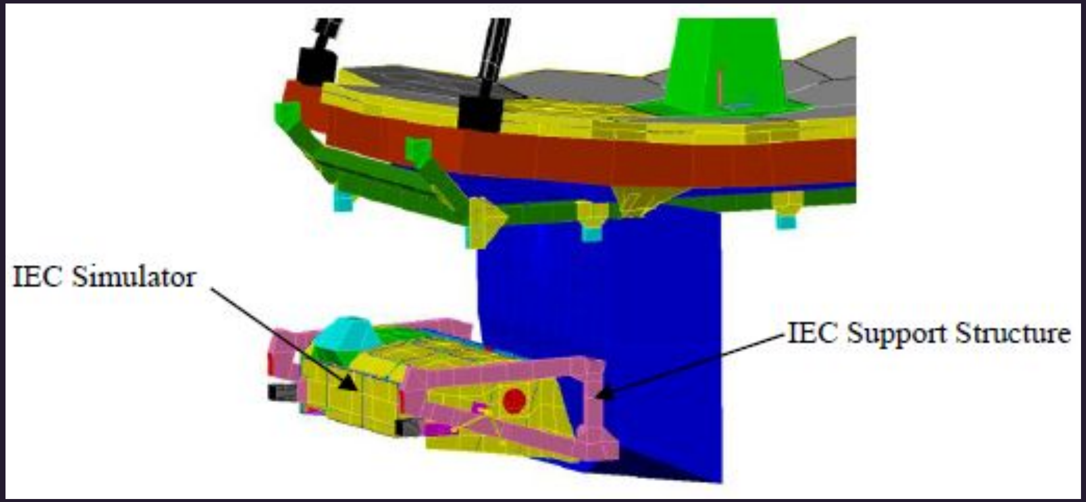
Even though the fully OTIS backplane features 18 primary mirrors, with 12 of the mirrors on the center section, Pathfinder was built with only two flight-similar mirrors, so for TPF mirror blanks simulated the thermal effects of other 10 center section mirrors

The blanks were gold coated on the top side with a black paint pattern on the back side to match flight mirror emissivity (~0.04)



The grey hexagons are the mirrors, while the dark grey and the yellow ones are Flight-Like Mirror

IEC



ISIM Electronics Compartment (IEC) contributed to the backplane thermal environment in flight

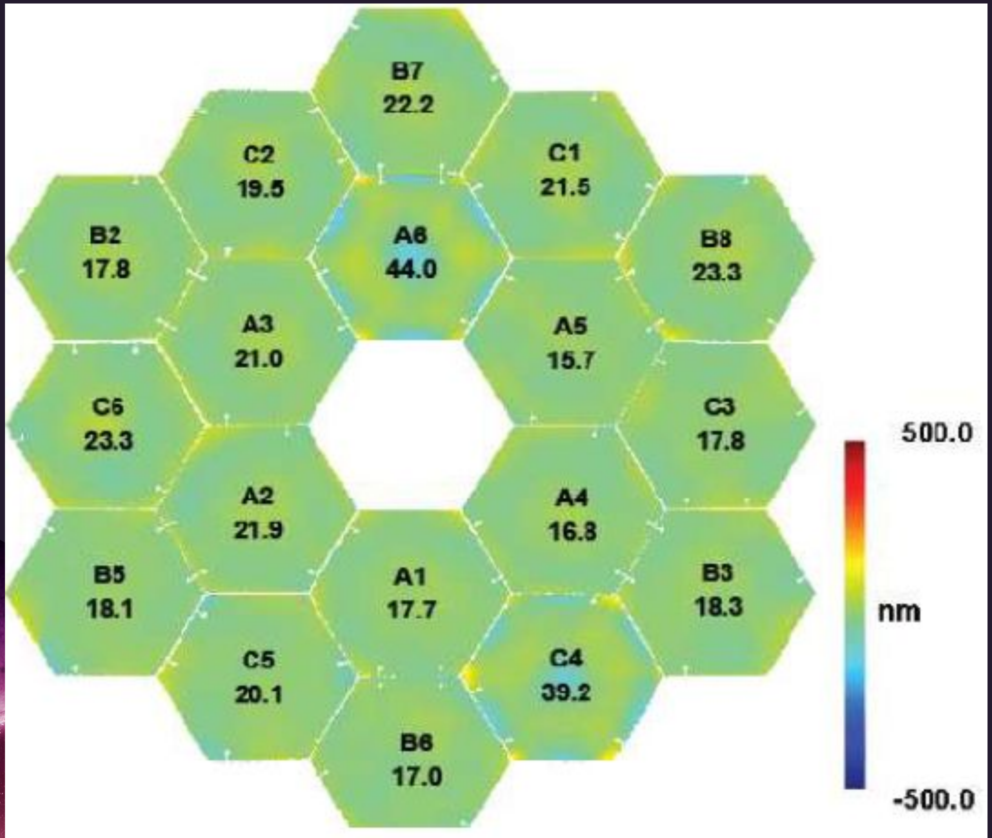
A flight-like Conformal Shield thermal isolation system and flight-like simulation of nearby structures allowed thermal effects on those structures and the backplane to be simulated

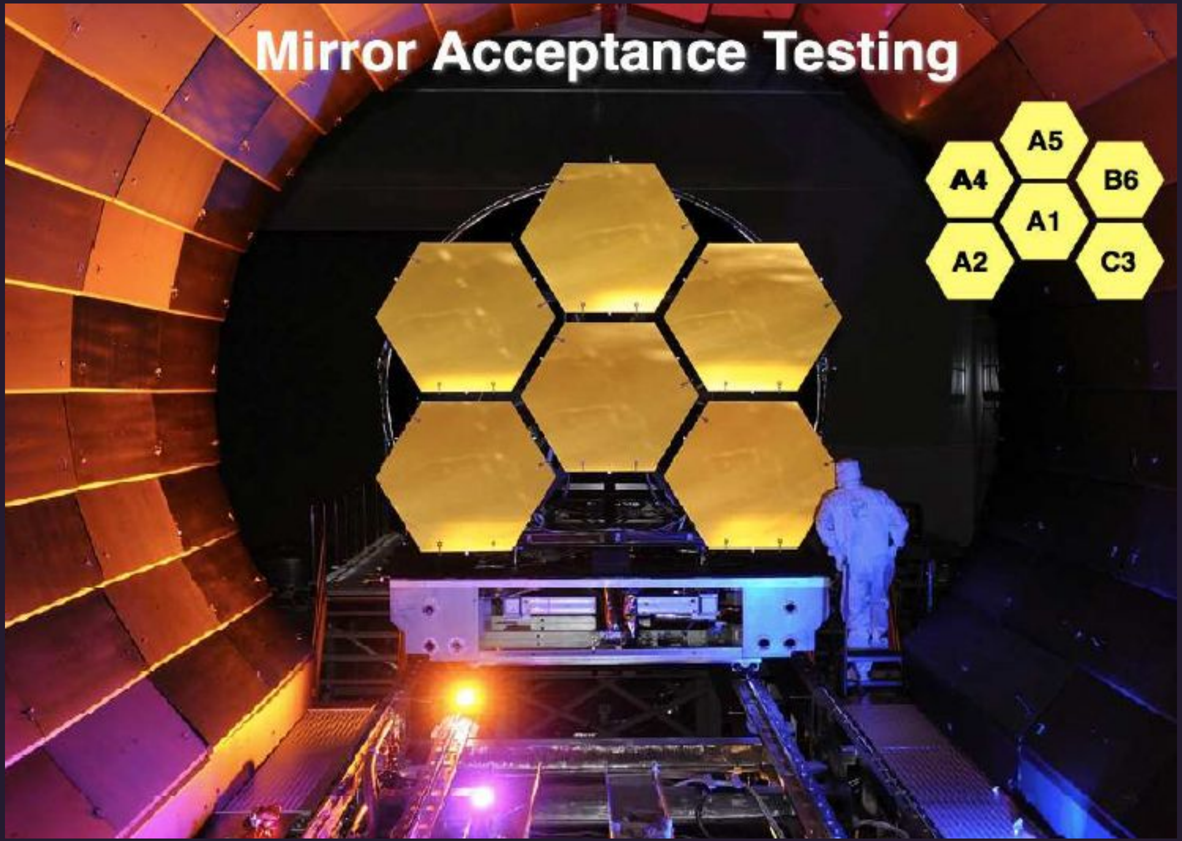
He Shroud– Chamber A at JSC

He Shroud at JSC

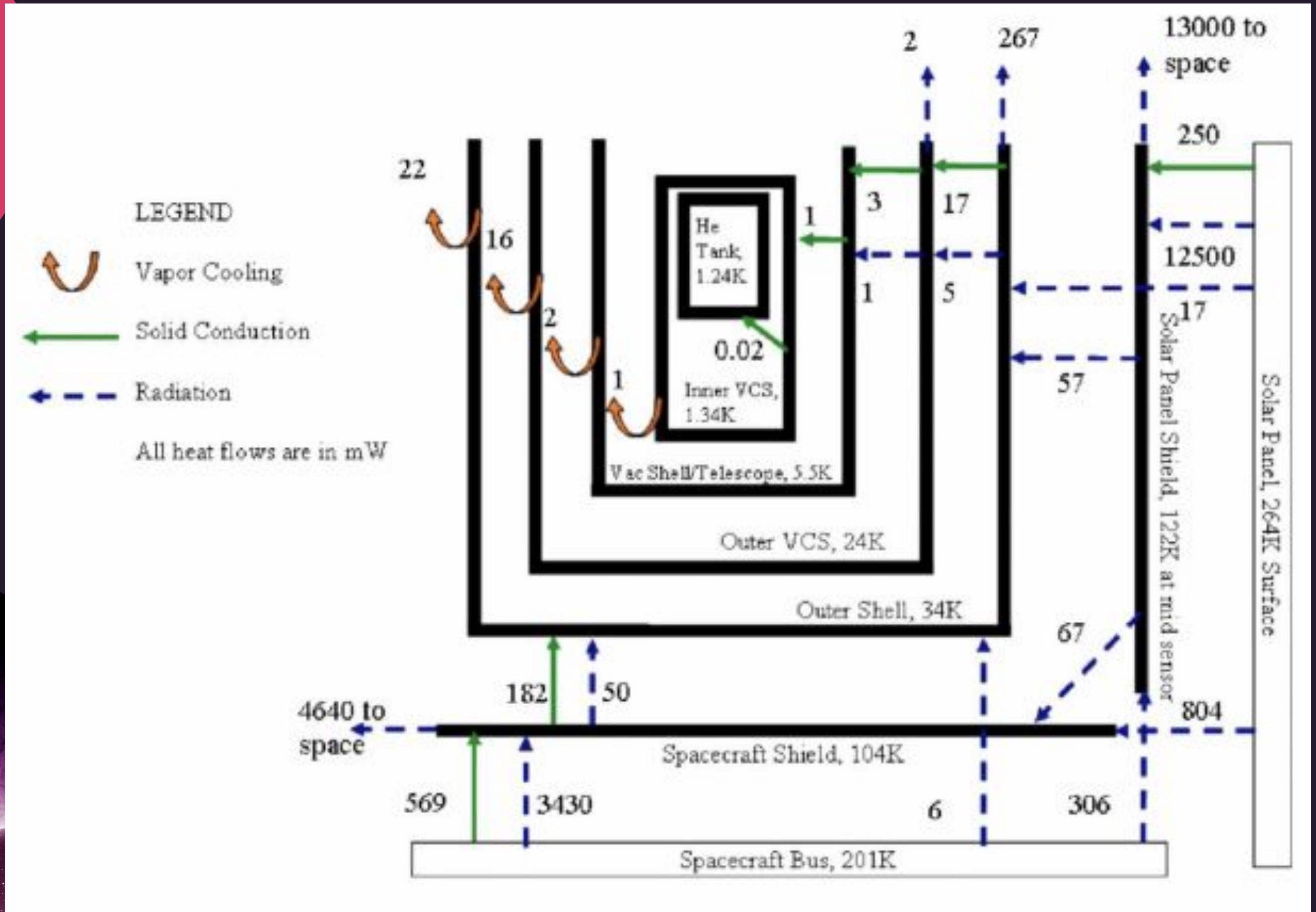
JWST's Mirrors Get 'Shrouded'

Mirror Acceptance Test





Ball Aerospace Thermal Model



Heat input is from insolation on solar panel

Cooling of the cryogenic telescope assembly is accomplished by radiation and vapor cooling

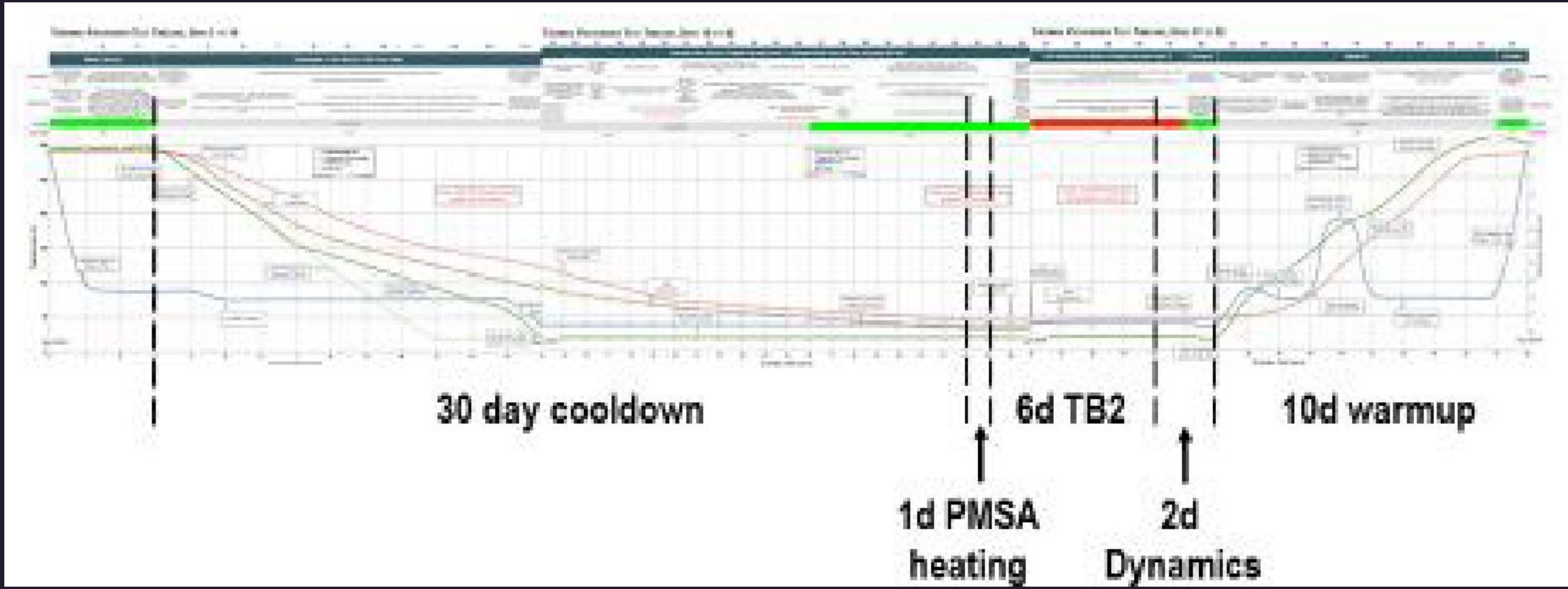
Heat is transferred through system along paths indicated by arrows by radiation, conduction and vapor cooling

Equilibrium temperatures for various observatory components are given for the case when cryogenic telescope is operating at 5.5 K

Model assumes a focal-plane heat dissipation of $4\ mW$ and an insolation of $5.3\ kW$

Test operations

The Thermal Pathfinder test had a 52-day allocation, including room-temperature vacuum opto-mechanical testing, cooldown, two thermal tests, a dynamics verification, and warmup but after the initial ambient-temperature vacuum portion, the payload cooled a bit faster than expected, so the cooldown ended two days early



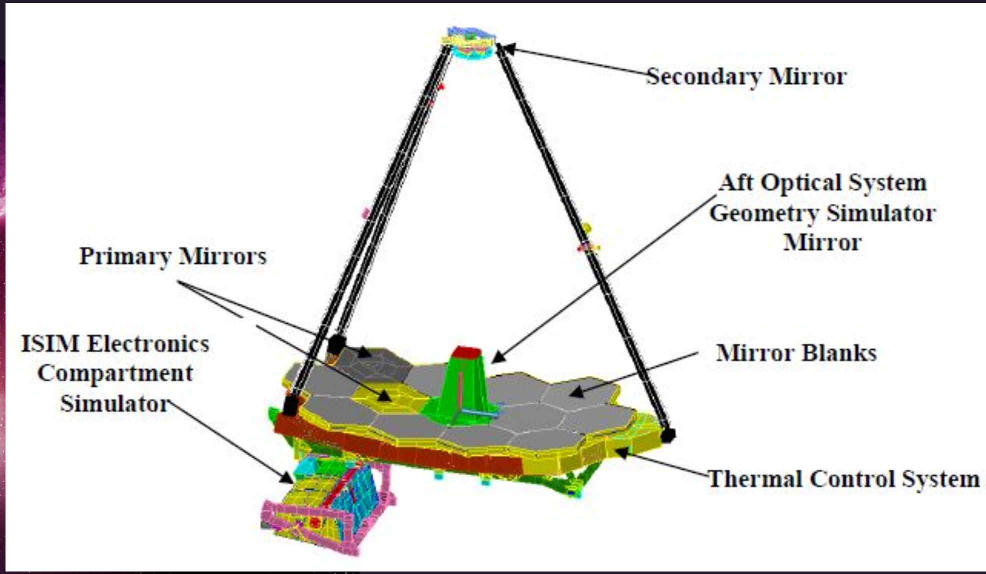
Actual Test Timeline

Thermal Pathfinder Test Objectives

Simulated an OTIS cool-down procedure using an OTIS-like thermal system and verified it

The initial cooldown was considered complete when optical stability criteria were met
Thermal effects of motor operations were then simulated for the apparatus

Stabilized that case, another thermal balance featured a small heat input imposed on the warm end of the backplane to stimulate gradients and allow more insight into backplane heat transfer characteristics

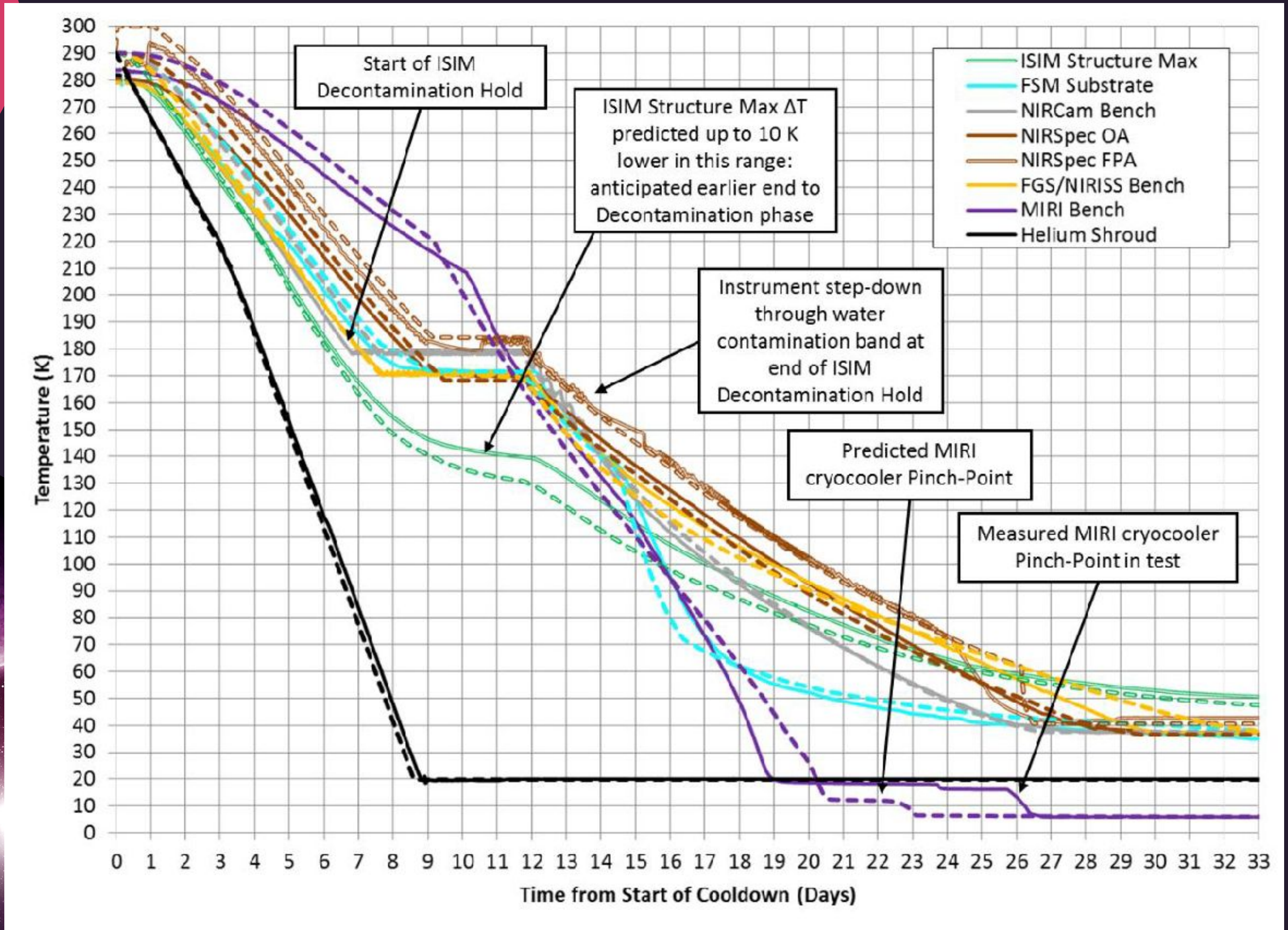


The test also provided data on:

- structure temperature gradients and heat flows
- measured chamber background

Thermal Pathfinder Test Components

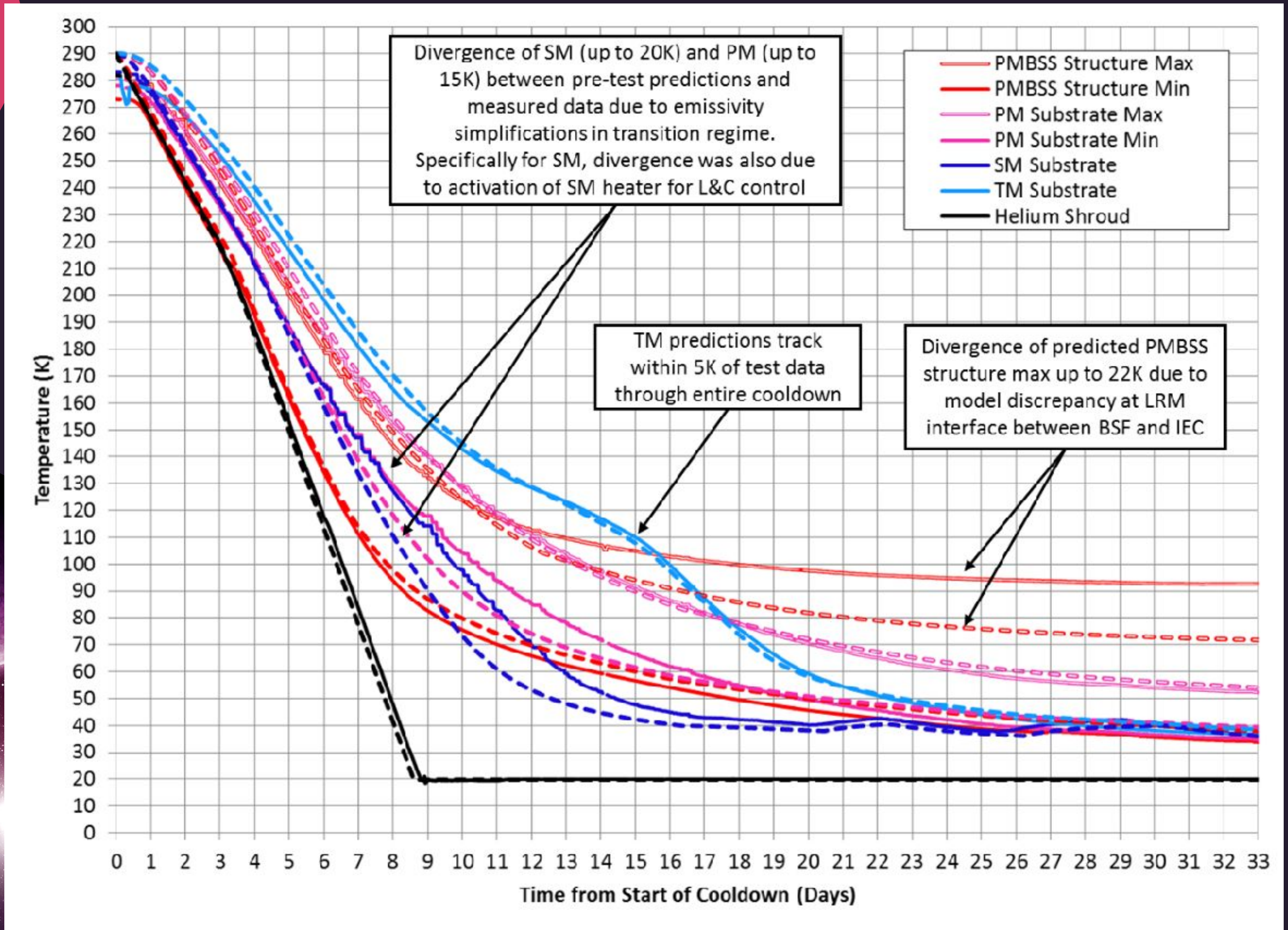
Thermal Model Performance against Test Data



Temperature Comparison for ISIM Components between Model Predictions (Dashed) and Test Measurements (Solid) during Cooldown

Results from 48th International Conference on Environmental Systems ICES-2018-35 8-12 July 2018, Albuquerque, New Mexico

Thermal Model Performance against Test Data



Temperature Comparison for OTE Components between Model Predictions (Dashed) and Test Measurements (Solid) during Cooldown

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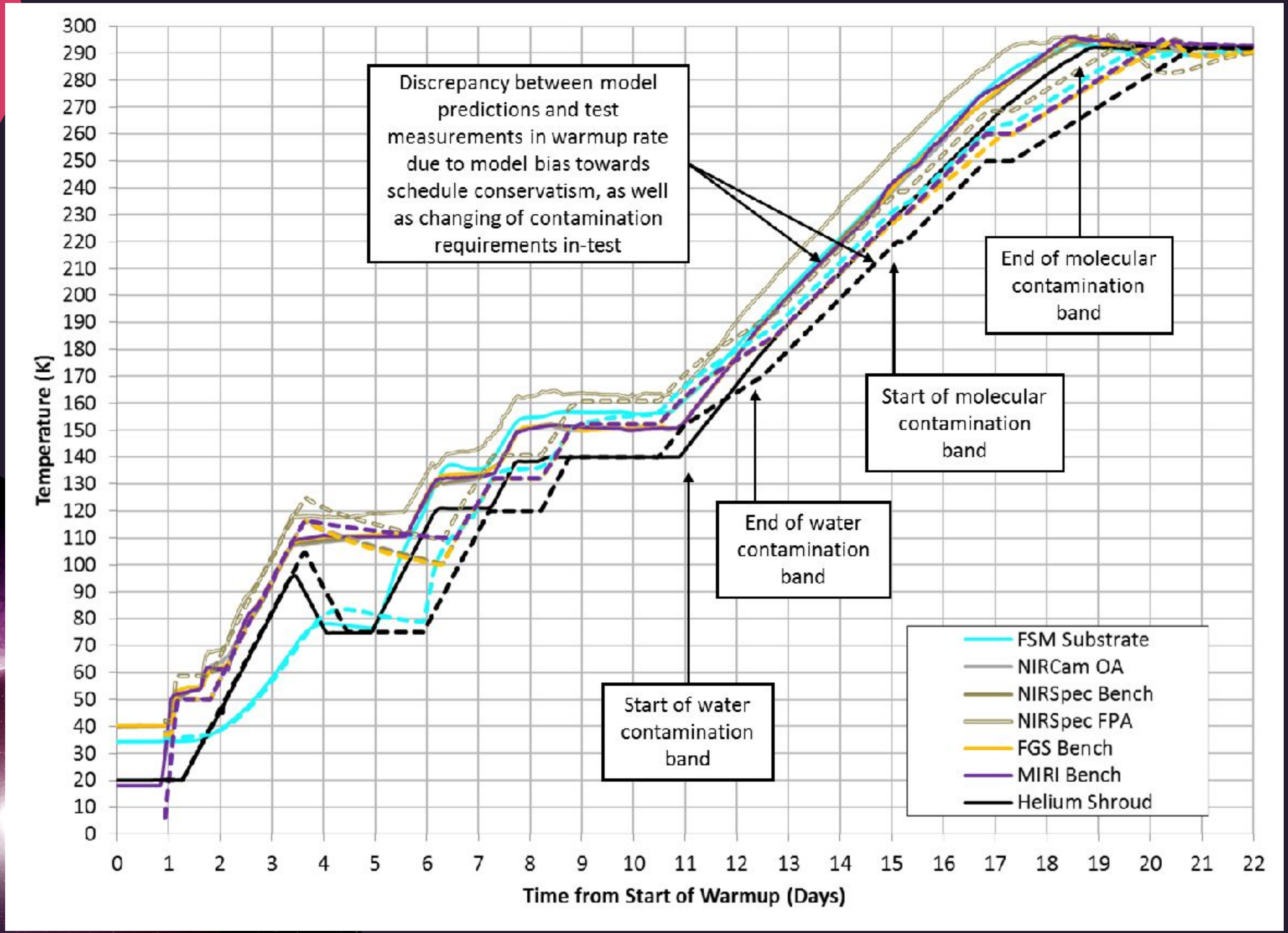
Thermal Model Performance against Test Data



Temperature Comparison for ISIM Components between Model Predictions (Dashed) and Test Measurements (Solid) during Warmup

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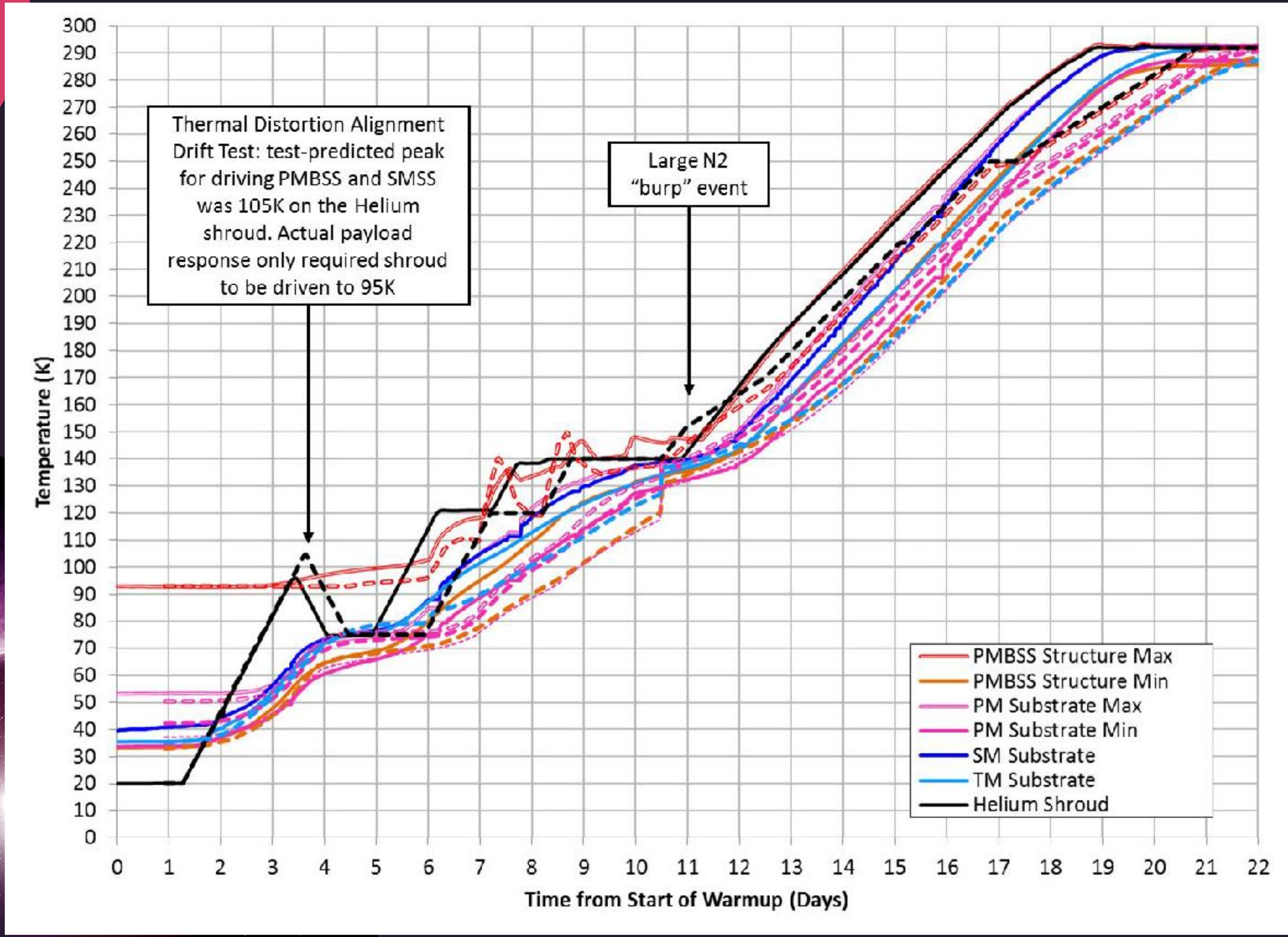
Thermal Model Performance against Test Data



Temperature Comparison for OTE Components between Model Predictions (Dashed) and Test Measurements (Solid) during Warmup

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Transient Correlation Analysis

- Temperatures during test were cooler than expected ones based on pre-test predict
- At the end of the 30-day cooldown: 9K difference between predicted TPF structure $T(K)$ and the TPF average test one

with correlated model, difference in temperature between model predict and test data reduced from 9K to 3K