National Aeronautics and
Space Administration

The James Webb Space Telescope

NASA’s Engineering Marvel for the Next Era of Astronomy

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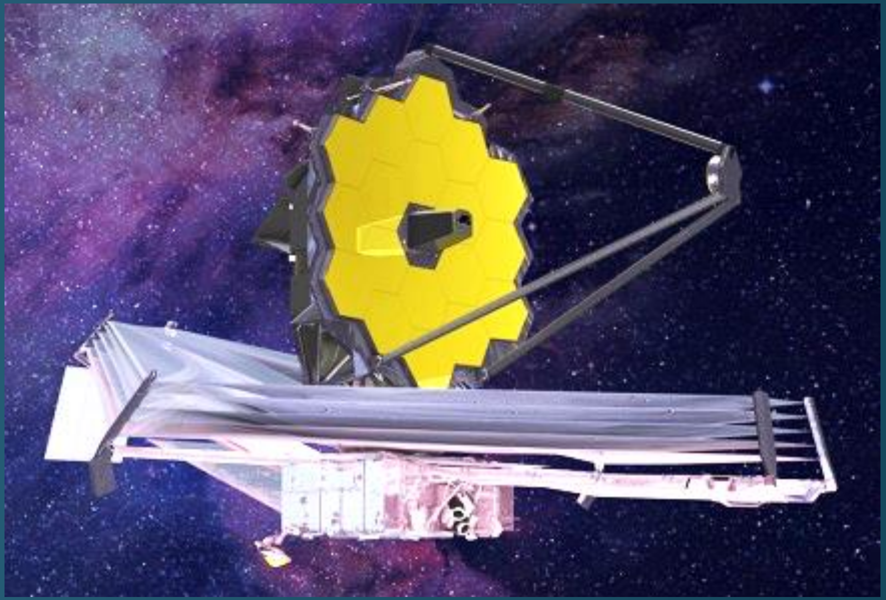
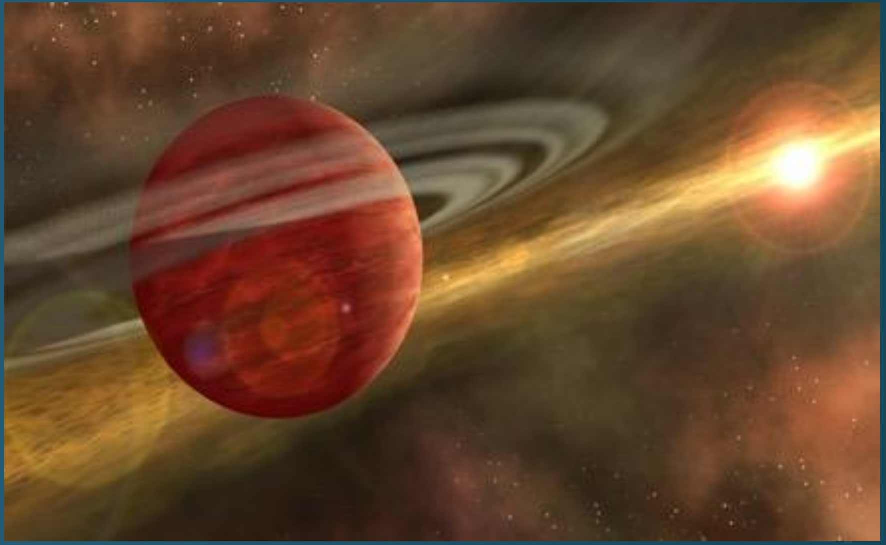




What is the James Webb Space Telescope (JWST)?

- A mission to seek light from the first galaxies in the universe and to explore distant worlds
  - Observe the first luminous objects in the early universe, as well as galaxy and stellar system evolution
  - Explore the Solar System and Exoplanets orbiting other stars
- Observations will be performed by thousands of astronomers worldwide
  - Optimized to observe in near-to-mid infrared wavelengths (0.6 – 28.5 μm)
- Led by NASA, in partnership with ESA and CSA

Who Was James Webb?

James Webb (1906 – 1992)

- Second Administrator of NASA (1961 – 1968)
- Oversaw first manned spaceflight program (Mercury)
- Oversaw second manned spaceflight program (Gemini)
- Oversaw Mariner and Pioneer planetary exploration programs
- Oversaw Apollo program
- Insisted that NASA have a strong science program

WHAT WILL WEBB DO?

Study Every Phase in the History of Our Universe

1

END OF THE COSMIC DARK AGES:
LIGHT FROM THE FIRST GALAXIES

2

ASSEMBLY OF GALAXIES

3

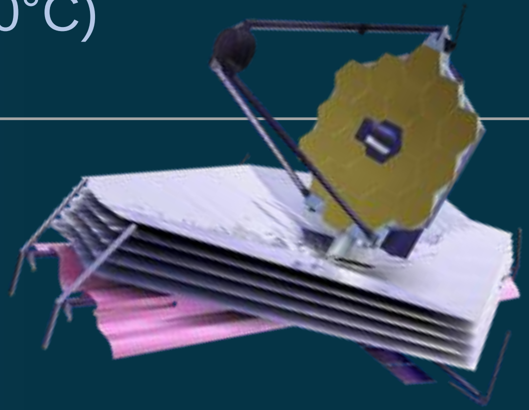
BIRTH OF STARS
AND PLANETS

4

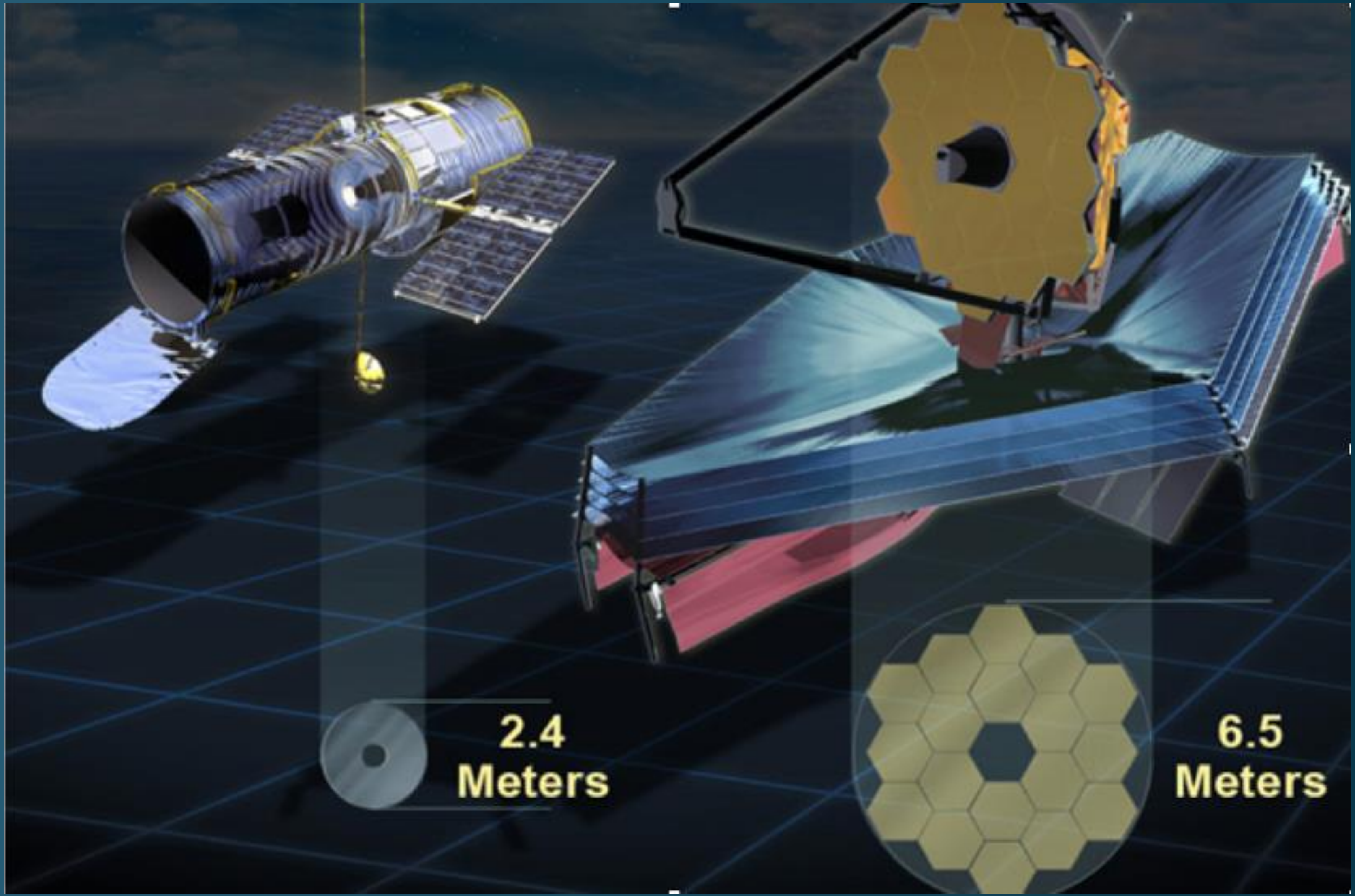
PLANETS, SOLAR SYSTEMS,
AND THE BEGINNING OF LIFE

Scientific Successor to Hubble

Hubble		Webb
7.9 ft (2.4 m)	**MIRROR DIAMETER**	21.3 ft (6.5 m)
44 ft (13.2 m); 24,500 lbs (11,110 kg)	**LENGTH & WEIGHT**	72 ft (22 m); 13,500 lbs (6,124 kg)
Ultraviolet, Visible, Near Infrared (0.1-2.5 micrometers)	**WAVELENGTHS**	Visible, Near Infrared, Mid Infrared (0.6-28.5 micrometers)
Orbiting Earth, 350 miles (570 km) from Earth	**LOCATION**	Orbiting the Sun around L2 940,000 miles (1,500,000 km) from Earth
70°F (21°C)	**TEMPERATURE**	-370°F (-230°C)



JUST HOW BIG IS WEBB?

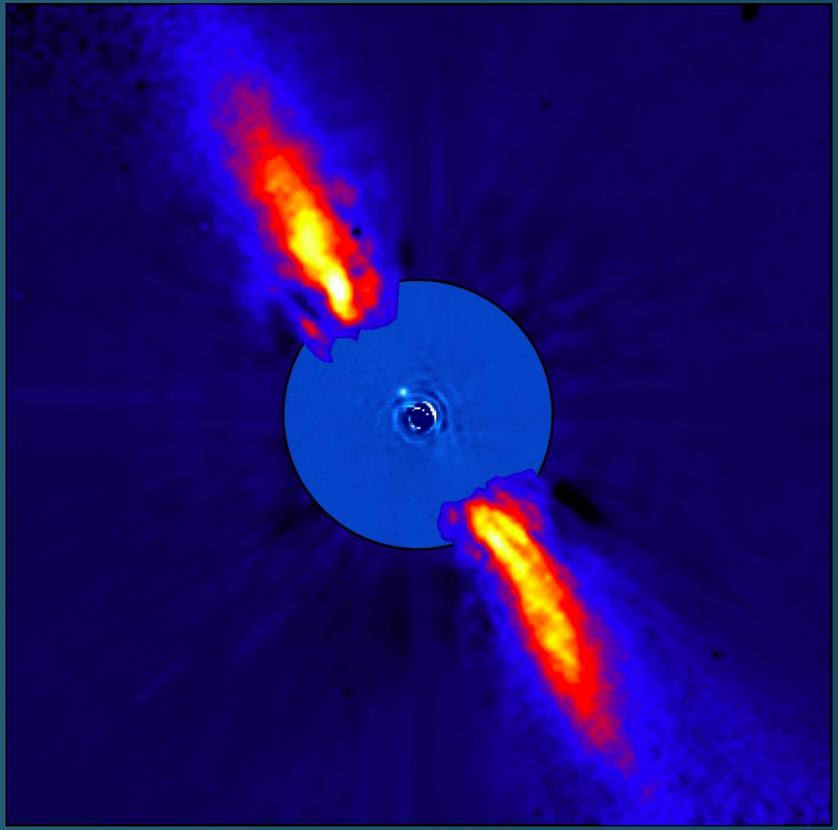


WEBB IS 6x LARGER THAN HUBBLE

HUBBLE is about the size of a school bus

JWST's sunshield is the size of a tennis court, and the overall telescope's height is that of a three-story building

Why do we need to observe in infrared light?



Beta Pictoris and its planet, Beta Pictoris b, in Infrared
Source: European Southern Observatory

- The Hubble Space Telescope has clued us in to the many questions we've had about the early universe
  - However, it does not have the wavelength coverage to image the first galaxies since the light from them has been shifted out to the infrared by the expansion of the universe
- JWST's infrared observation capabilities allow us to detect the heat coming from the first stars and galaxies, 100-250 million years after the Big Bang
  - Infrared also allows us to view through interstellar dust clouds to view star and planetary formation
- Measurements in the infrared require JWST to be very cold
  - Since we are detecting the faintest stars and galaxies through their heat, we don't want JWST's own electronics heat to swamp our measurement

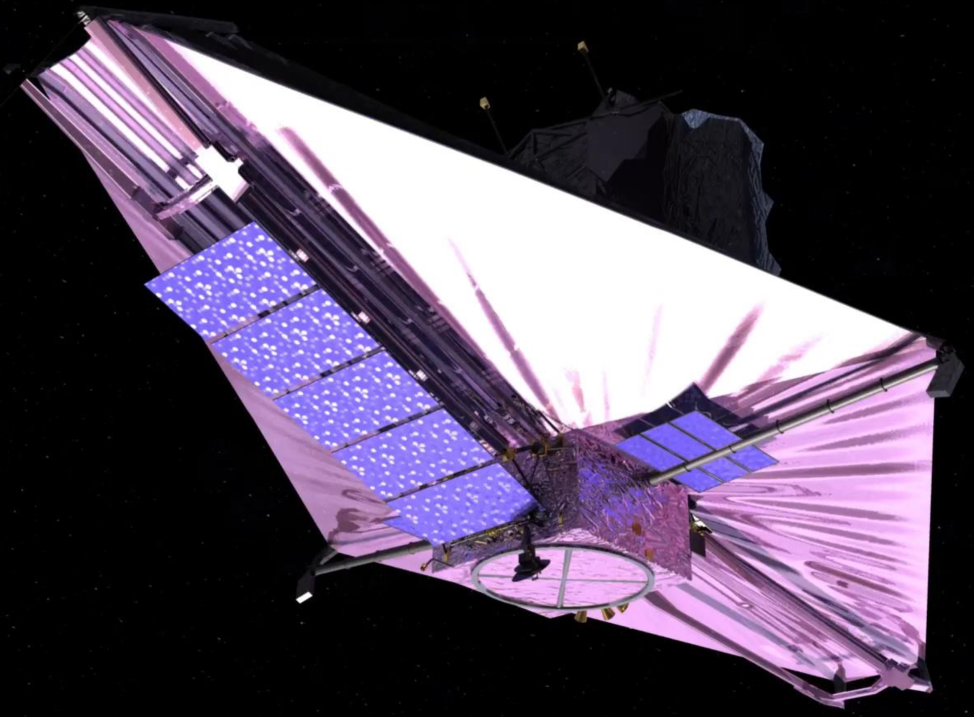
Major System-Level Assemblies of JWST

Optical Telescope Element (OTE)

- Primary Mirror
- Secondary Mirror
- Backplane

Spacecraft Element (SCE)

- Sunshield
- Bus (hosts structural, communications, and propulsion components)

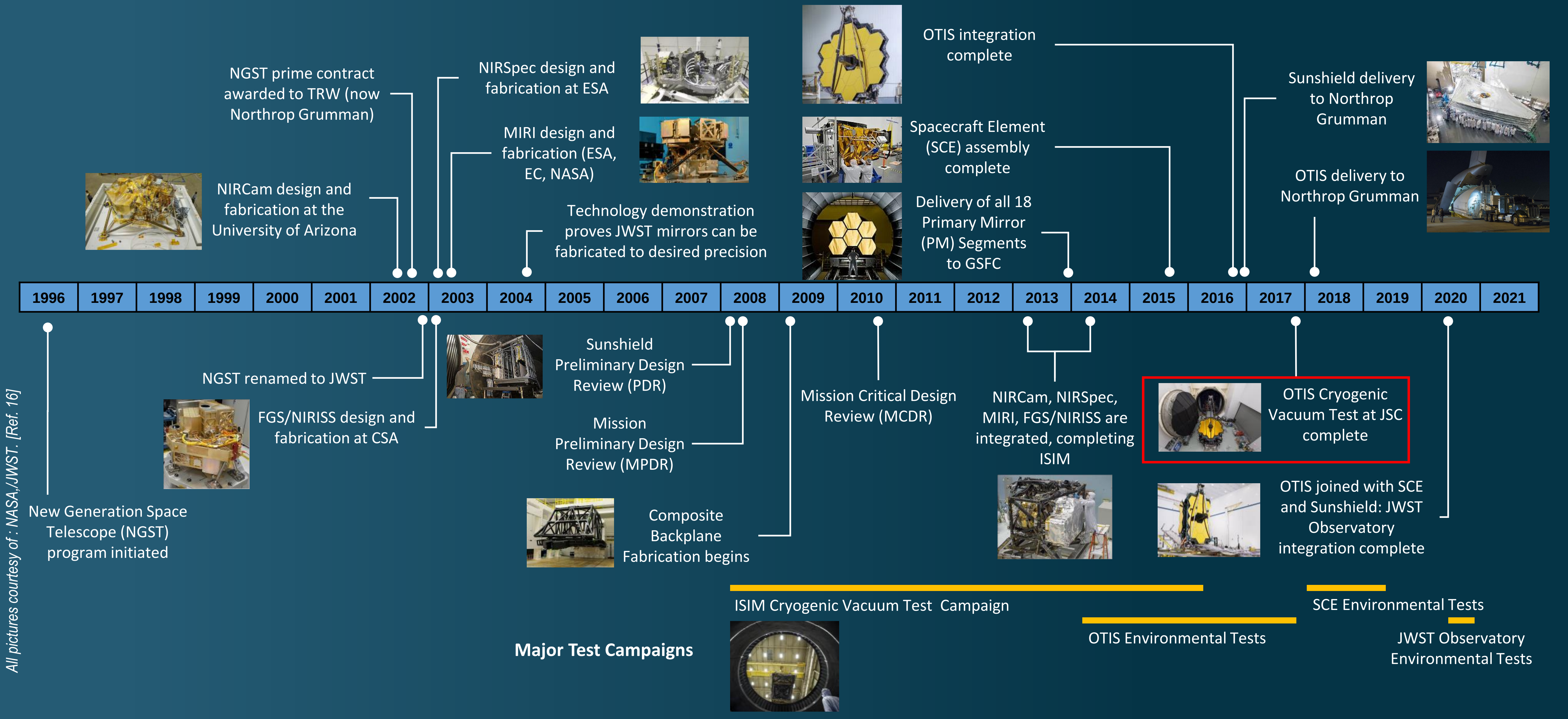


Integrated Science Instrument Module (ISIM)

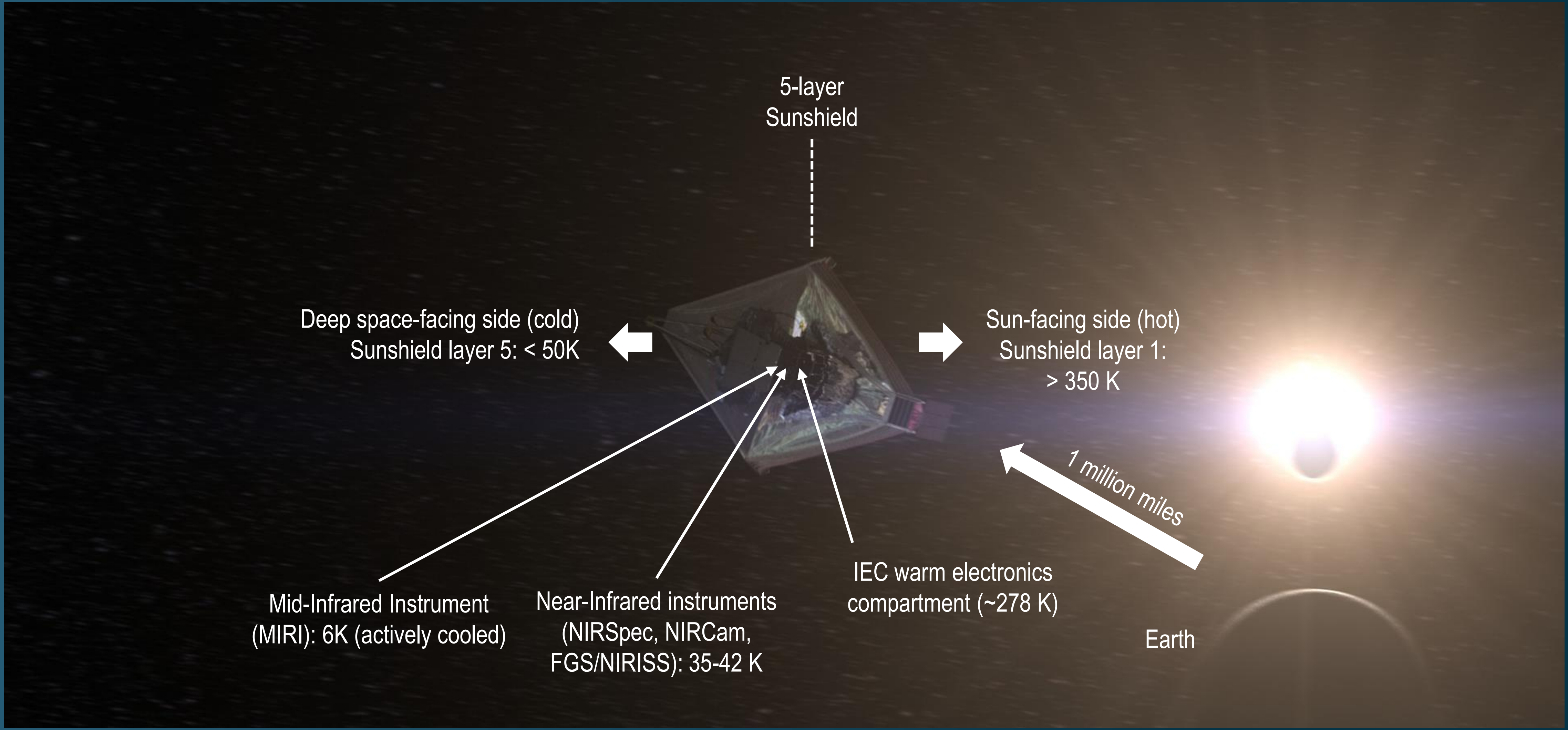
- Mid Infrared Instrument (MIRI)
- Near Infrared Spectrograph (NIRSpec)
- Near Infrared Camera (NIRCam)
- Fine Guidance Sensor/ Near Infrared Imager & Slitless Spectrograph (FGS/NIRISS)

OTE + ISIM = “OTIS”

TIMELINE OF JWST'S DEVELOPMENT



THERMAL ENVIRONMENT OF JWST

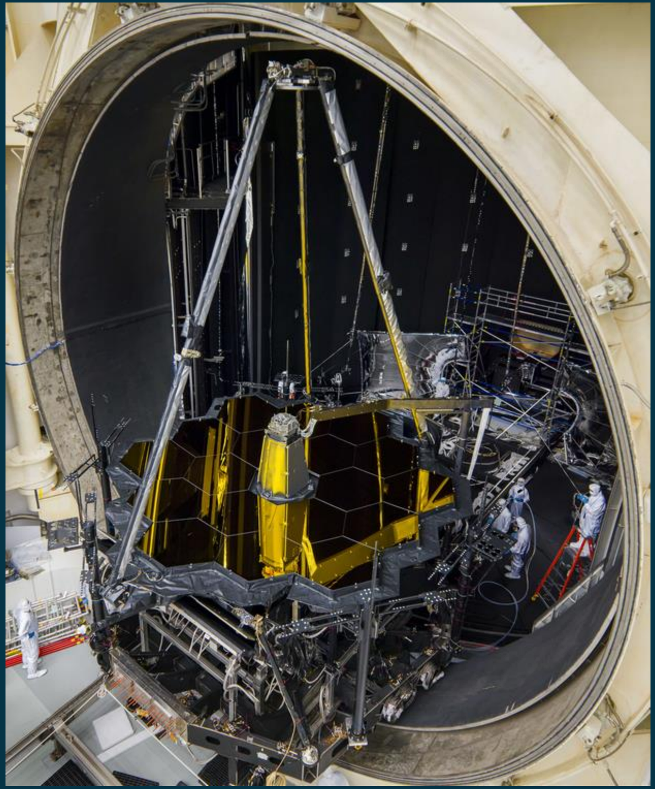


Source: svs.gsfc.nasa.gov [Ref. 18]

SIMULATING FLIGHT ENVIRONMENT IN TEST

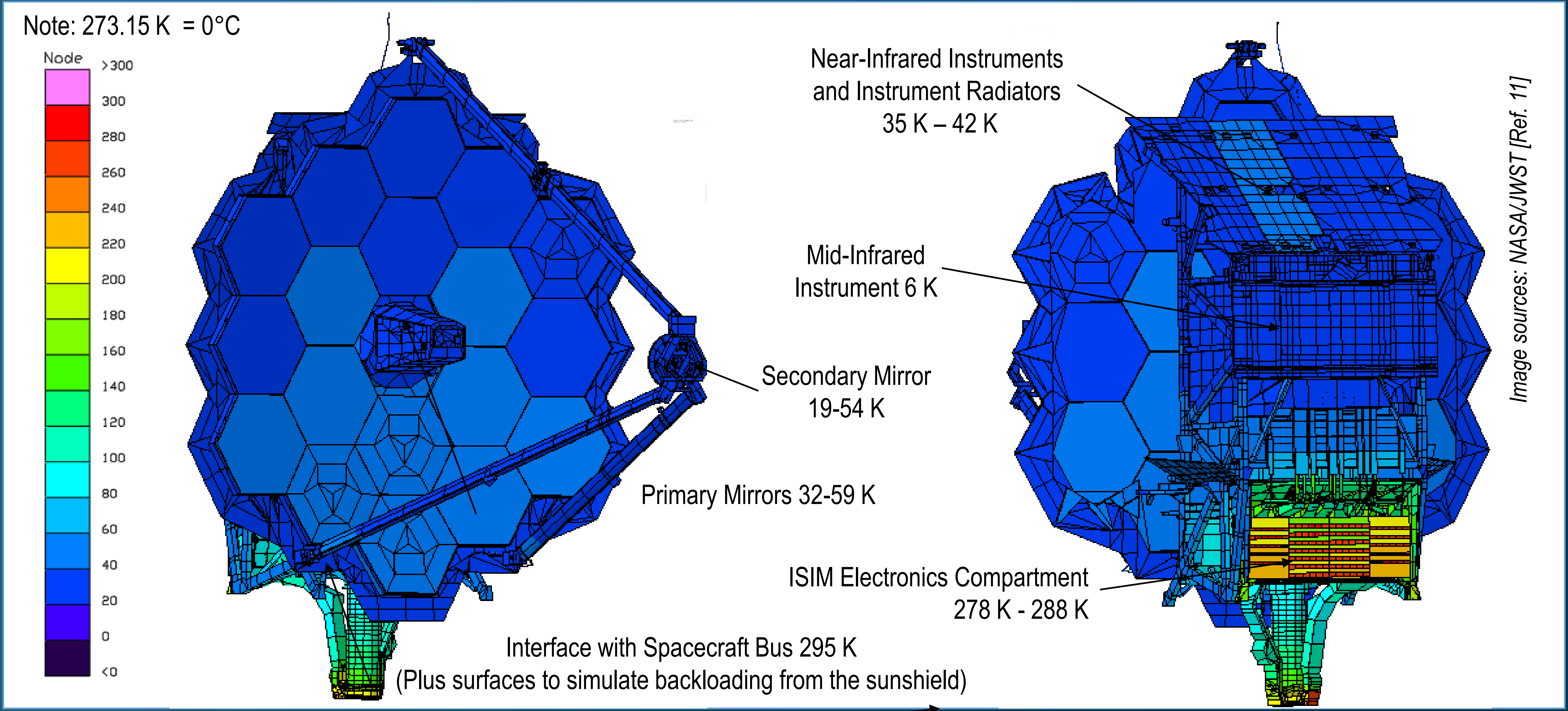
- How do we replicate JWST's flight thermal environment in test? Use one of the largest thermal vacuum chambers in the world (NASA Johnson Space Center's Chamber A)
  - Reduce pressure to one-billionth of atmospheric pressure
  - Install a gaseous helium shroud to lower the payload temperatures to 20K, and an LN2 shroud to reduce the environmental loads on the helium shroud
  - Unfortunately, even this chamber is not large enough to fit all of JWST, so we need to test in separate system-level assemblies (OTIS being the major cryogenic test)
    - Install Ground Support Equipment (GSE) to simulate heat from the flight spacecraft bus
- Rely on analytical tools and data from its major system-level tests to confirm JWST's observatory-level performance in flight

NASA Johnson Space Center's Chamber A
Source: NASA/Chris Gunn [Ref. 16]



OTIS entering Chamber A door
Source: NASA/Chris Gunn [Ref. 16]

OTIS CV TEST TEMPERATURE GOALS



THERMAL TESTING

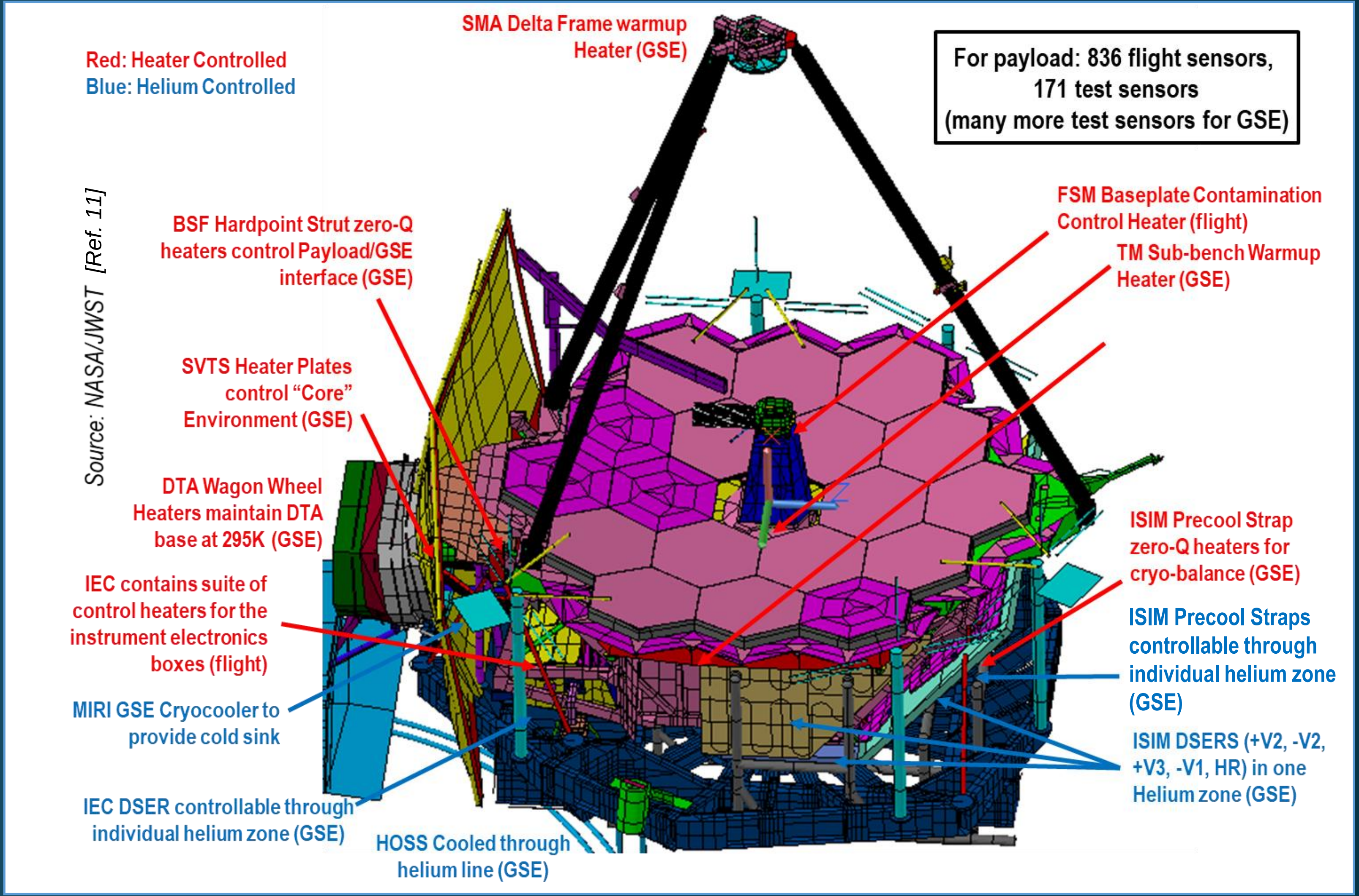
- Thermal testing is done in a vacuum chamber at *margined* temperature extremes and is designed to verify workmanship, demonstrate performance, and collect data to be used in correlating thermal models
- JWST's OTIS Cryogenic Vacuum Thermal Test Objectives:
  - Preserve hardware integrity upon transition to cryogenic thermal balance (cryo-balance) conditions and transition back to ambient temperatures by respecting all imposed limits and constraints (L&Cs): **OTIS had over 1000 limits and constraints, of which 92 were thermal-specific!**
  - Achieve the simulated on-orbit payload temperature levels and stability for optical, mechanical, and instrument tests: **flight-like cryogenic environment with thermal stability of 27 mK/hr!**
  - Predict and measure thermal balance test data for model crosscheck, both on ISIM and OTE components
  - Achieve a workmanship thermal conductance assessment of the flight instrument heat straps which for the first time would be connecting all the payload flight instruments and radiators
  - Achieve test timeline optimization by executing the OTIS CV cooldown and warmup in a time-efficient manner

HOW DID WE COOL AND WARM OTIS?

- How do we perform a controlled cooldown and warmup of OTIS while maintaining it within all of its limits and constraints to ensure that all hardware components were safe?
  - Use thermal analysis leveraging the principles of heat transfer to see where we can optimize temperature transitions
  - **Radiation heat transfer:** helium shroud cooldown rate controlled to 1.5 K/hr or less to maintain gradient requirements on composite structure (note we needed to cool over 270 K!)
    - Certain components had their own, specialized Deep Space Environment Radiative Sinks (DSERs): panels separately controlled via gaseous helium lines to provide more precise thermal control
  - **Conduction heat transfer:** The science instruments are so cold that radiative heat transfer is not as effective at cryogenic temperatures
    - In flight, the instruments release their ~300 mW of heat to heat straps which terminate at their own radiators, but radiating heat to space takes 90 days reach instrument operating temperatures on-orbit!
    - In test, additional heat straps were added to directly conduct the ISIM instrument’s heat to a gaseous helium line at 20K, so that cooldown could be completed in ~30 days
  - **Thermal (Foil or Cartridge) Heaters:** Provided thermal stability and warmup control
  - MIRI has its own active cryocooler: convective exchange with gaseous helium to 6K

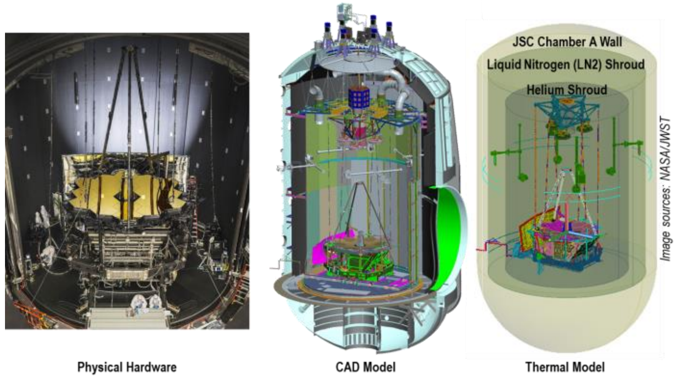
THERMAL CONTROLS FOR OTIS

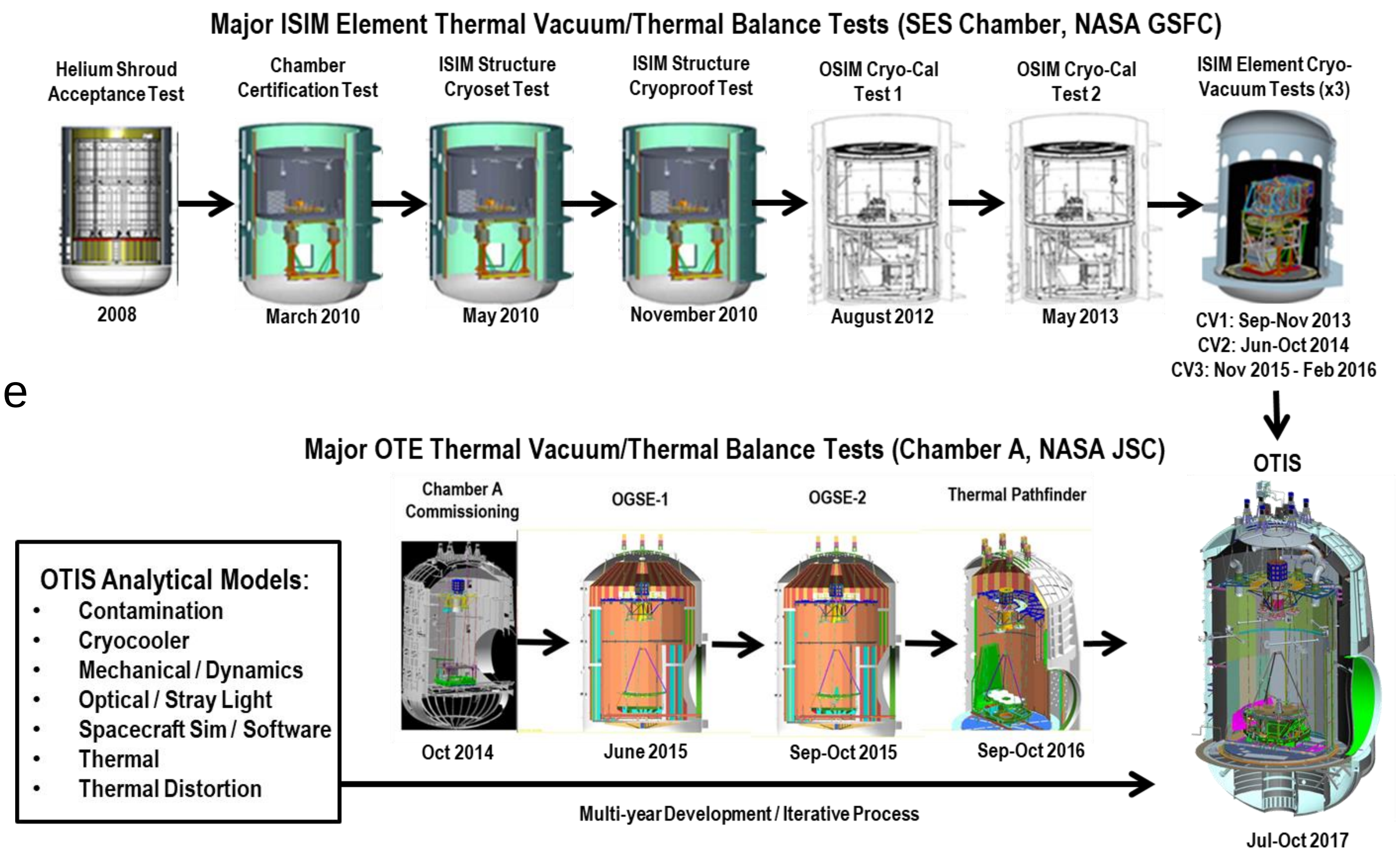
- In test, these thermal controls were implemented in the form of hardware integrated into the OTIS payload and its test support equipment
- The operations of these hardware controls require monitoring by a team of >100 engineers and technicians 24/7 throughout the duration of the test (about 3 months)



HOW DID WE PREPARE FOR OTIS?

- Preparation for OTIS required a multi-year process of risk-reduction tests on the hardware, as well as an integrated analytical modeling campaign between all of the separate discipline models

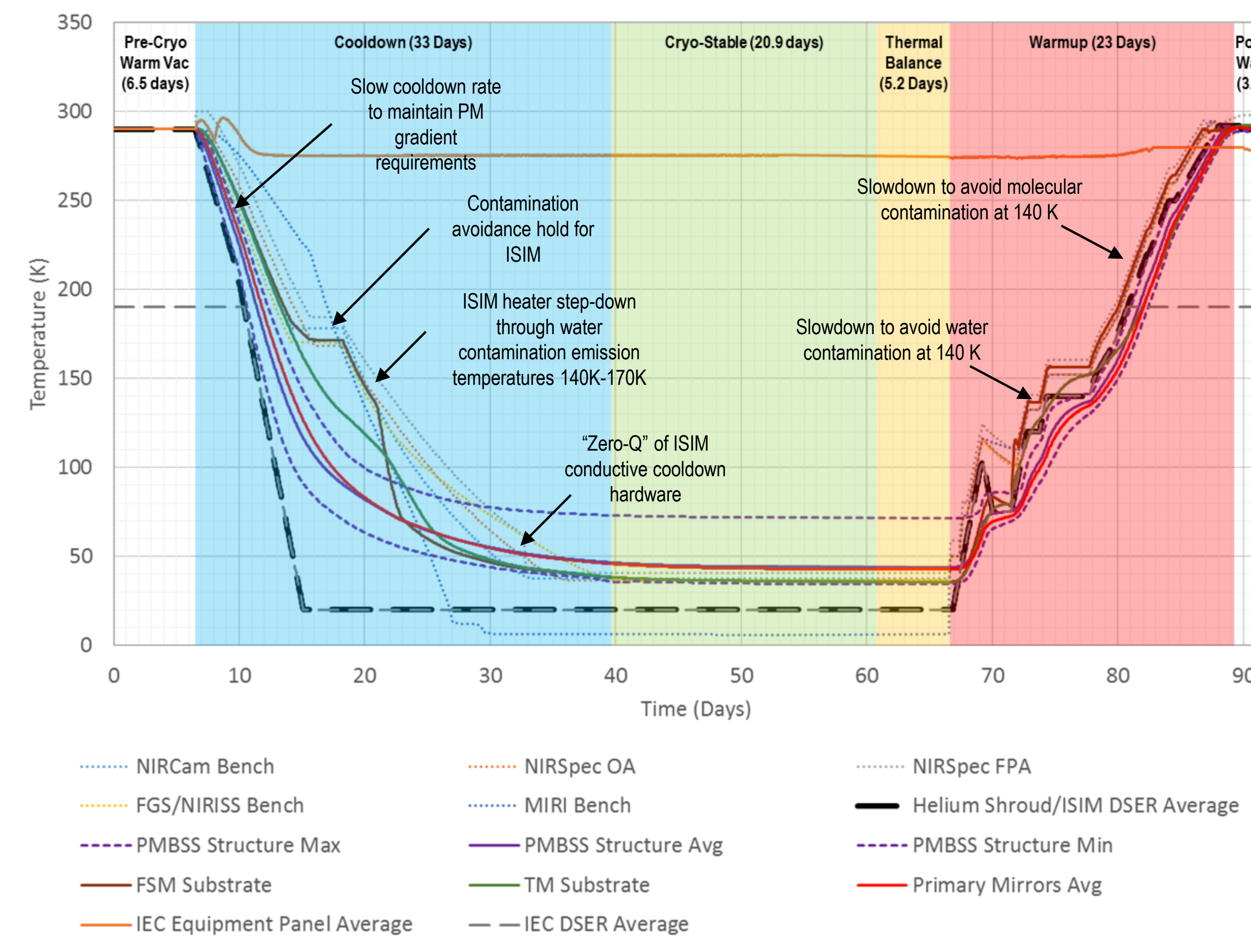




Source: NASA/S. Glazer/K. Yang [Refs. 12, 17]

PREDICTED OTIS CV TEST PROFILE

- Detailed thermal modeling and analysis were also required to understand which knobs to turn and when to turn those knobs: effort began in 2013 in preparation for test in 2017
- Due to sheer size and complexity of JWST thermal model, each thermal model run required about 1 week of wall-clock time to simulate 33 days of cooldown, and another week of wall-clock time to simulate 23 days of warmup



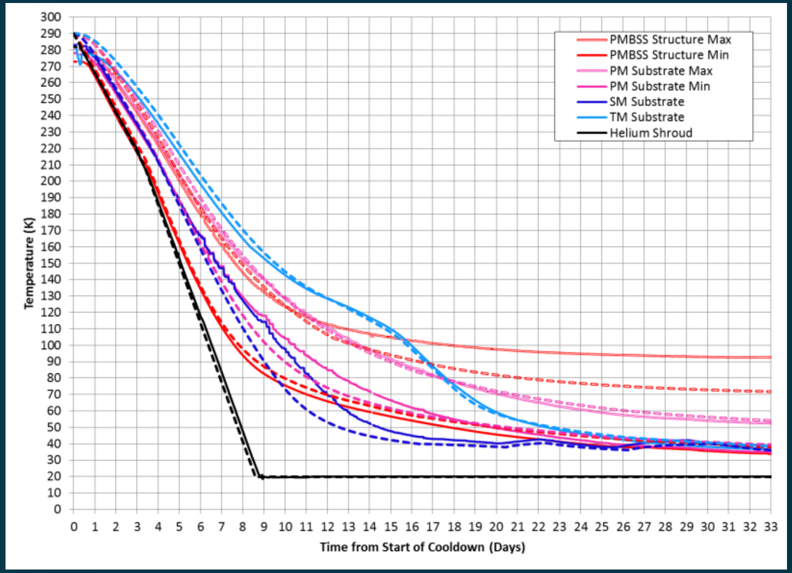
Source: NASA/K. Yang [Ref. 11]

SO HOW DID THE TEST GO?

- The OTIS CV Test was executed almost exactly as planned
  - Predicted cooldown time was **33 days,** actual cooldown time was **32 days** to reach 27 mK/hr stability goal
  - Predicted warmup time was **23 days,** actual warmup time was **20 days**
- Model predictions of payload behavior and heat flows were extremely close to actual hardware performance
- Even with more than four years of planning and preparation, we could not fully anticipate all of the surprises that a 90+ day test in Houston during the summer would bring us…
  - On August 21st, 2017, just after we reached our thermal stability goal for optical testing, we noticed in the weather reports that there was a disturbance in the Gulf of Mexico with a greater than 60% cyclone formation chance…

Source: NASA/K. Yang

The OTIS CV Test Control Room



Source: NASA/K. Yang [Ref. 11]

Comparison of predicted cooldown (dashed) vs. actual cooldown (solid) profile for OTE components

HURRICANE HARVEY

- August 25th –August 29th, 2017: 51 inches of rain!
- The most costly storm in US history

Post-storm damage in Clear Lake, TX
Source: NASA/K. Yang

Strong winds as Harvey hits Clear Lake on 8/25/17
Source: NASA/L. Feinberg

Parking lot outside NASA/JSC Chamber A
Source: NASA/L. Feinberg

Water Damage in OTIS CV Test Control Room
Source: NASA/L. Feinberg

NASA volunteers for post-Harvey cleanup in Clear Lake, TX
Source: NASA/The Harbor Church [Ref. 15]

POST-TEST GLAMOUR SHOT

JWST's OTIS at NASA's Johnson Space Center Chamber A

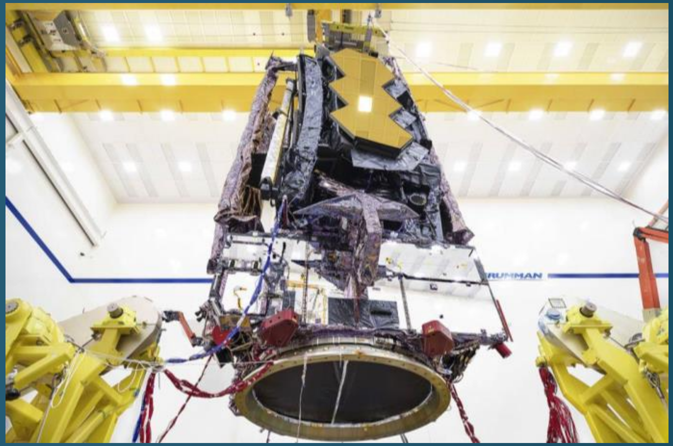
Source: NASA/JWST/ Chris Gunn [Ref. 16]

FINAL INTEGRATION & TESTING

Feb 2018: OTIS is transported from Houston, TX to Redondo Beach, CA for final JWST integration

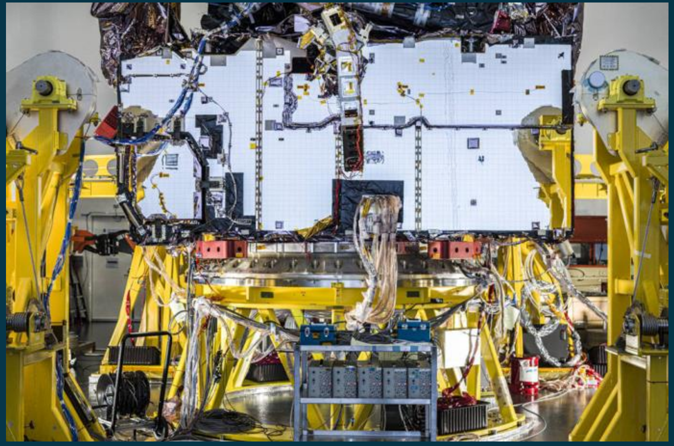
May 2019: Spacecraft Element Thermal Vacuum Testing Complete

Aug 2019: OTIS is joined to the Sunshield and SCE, completing the assembly of the JWST observatory



Oct 2020: Acoustic and Vibrational Testing complete for JWST Observatory

Dec 2020: Final sunshield deployment test complete



Mar 2021: Final Comprehensive Systems Test (CST) Complete

All pictures courtesy of : NASA,/JWST/Chris Gunn [Ref. 16]

Preparations for Launch!

- JWST arrived at the launch site in Kourou, French Guiana via ship on October 12th, 2021!
- JWST has been fueled and folded up to fit inside the Ariane 5 Launch Vehicle fairing (“The world’s most complex piece of origami”)

The MN Colibri Arrives with JWST in the port of Kourou, French Guiana
Source: NASA/Chris Gunn [Ref. 16]

JWST is unloaded from the MN Colibri
Source: NASA/Chris Gunn [Ref. 16]

Launch and Orbit

Webb is set to launch on top of ESA's Ariane 5 in December 2021

It will undergo a month long 1.5 million km journey to its destination at the second Lagrange point

Photo credit: ESA

On-Orbit Deployment

Source: NASA,/JWST [Ref. 16]

Thank You! Questions?

Follow JWST!

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nasa.gov/webb
jwst.nasa.gov
webbtelescope.org

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