The James Webb Space Telescope

Unfolding the Universe

Paul Geithner, Webb Deputy Project Manager-Technical at NASA’s Goddard Space Flight Center

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Acronyms

CAR = Commissioning Activity Request

CoC = Center of Curvature

CP = Consent to Proceed

CSA = Canadian Space Agency

DSN = Deep Space Network

DSN = Deep Space Network

DTS = Deployable Tower Assembly

ECA = Evolved Cryogenic, model A

ESA = European Space Agency

F = Fahrenheit

FGS = Fine Guidance Sensor

FSM = Fine Steering Mirror

GHe = Gaseous Helium

GSFC = Goddard Space Flight Center

IEC = ISIM Electrical Compartment

IF = Interferometer

IFU = Integral Field Unit

IR = Infrared

IRSU = ISIM emote Services Unit

ISIM = Integrated Science Instrument Module

JPL = Jet Propulsion Laboratory

JSC = Johnson Space Center

K = kelvin

L2 = Lagrange Point 2

LN2 = Liquid Nitrogen

MIRI = Mid-Infrared Instrument

MLI = Multi-Layer Insulation

mW = milliwatts

NASA = National Aeronautics and Space Administration

NGAS = Northrop Grumman Aerospace Systems

NIRCam = Near-Infrared Camera

NIRISS = Near-Infrared Imaging Slitless Spectrograph

NIRSpec = Near-Infrared Spectrograph

OTE = Optical Telescope Element

OTIS = Optical Telescope Element + Integrated Science Instrument Module

PM = Primary Mirror

PMBA = Primary Mirror Backplane Assembly

PMBSS = Primary Mirror Backplane Support Structure

PTC = ParasiticTray Radiator

R = Resolution

RAL = Rutherford Appleton Laboratory

SES = Space Environment Simulator

SLI = Single-Layer Insulation

SM = Secondary Mirror

SMSS = Secondary Mirror Support Structure

SS = Sunshield

TM = Tertiary Mirror

TV/TB = Thermal Vacuum/Thermal Balance

UK ATC = United Kingdom Advanced Technology Centre

W = watts

James Webb Space Telescope

Description

- Deployable infrared observatory w/ 6.5-m diameter, 25-m^2 segmented adjustable primary mirror and165-m^2 sunshield
- Cryogenic temperature telescope and instruments for background-limited infrared performance
- Launched Dec 25, 2021 aboard an ESA-supplied Ariane 5 ECA rocket to Sun-Earth L2
- 25-year development, 6-month post-launch commissioning, 5-year minimum duration science mission (>10-year goal)

Contributors

- Mission Lead: NASA/Goddard Space Flight Center
- International Partners: ESA & CSA
- Major U.S. Contractors: Northrop Grumman, Ball Aerospace, L3 Harris
- Science Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona/Lockheed
  - Near Infrared Spectrograph (NIRSpec) – ESA/Astrium
  - Mid-Infrared Instrument (MIRI) – JPL/ESA/UK ATC/RAL
  - Fine Guidance Sensor (FGS)+Near Infrared Slitless Spectrograph (NIRISS) – CSA/Honeywell
- Operations: Space Telescope Science Institute w/ support from ESA and CSA

- The case for Webb
  - Unanswered science questions
  - The tool for the job
- Designing, building, and testing Webb
- Using Webb and expectations

Telescopes are powerful tools of exploration

- The universe is overwhelmingly vast compared to our notions of space and time
  - 1:10 billionth scale universe for illustration (locations relative to DC-Baltimore area):
    - Sun=grapefruit
    - Earth=1.3mm ice cream sprinkle 15m from Sun, Moon=poppy seed ~4cm from Earth
    - The 'speed of causality,' i.e. the speed of light c=3cm/s – crawling speed of an ant; 8 min for ant to crawl from Sun to Earth
    - Nearest other star, Proxima Centauri=walnut in Seattle, 4.2 light-years away; familiar bright star Sirius is a volleyball in Lagos, Nigeria, 8.6 light years away
    - Farthest man-made object=Voyager 1, launched in 1977, only 2.3km or ~21hrs 35min light travel time away
    - Observable universe is ~46.5 billion light-years in radius; actual universe is larger
- Telescopes can probe far, far beyond where we can go ourselves or send our robots
  - Imagery tells us structure, spectroscopy tells us composition and speed

Why Infrared?

1) How did the 'lights turn on' in the universe?

The first luminous objects to form in the universe emitted ultraviolet and visible light, but this light has been 'redshifted' by cosmic expansion and reaches us here and now as infrared light

> This is an old question that Hubble cannot answer and requires a very large, very sensitive <u>infrared</u> telescope → very cold and in deep space

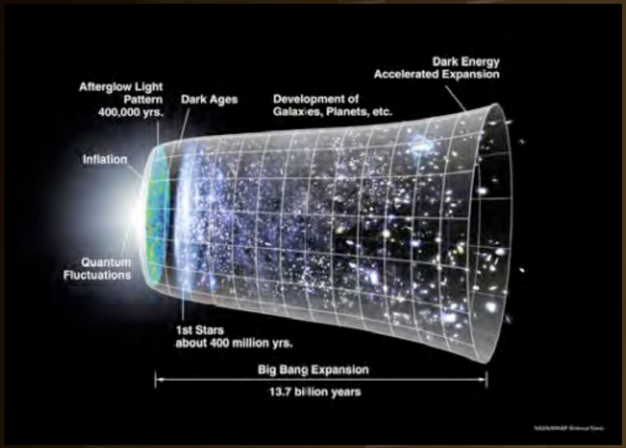
2) What are exoplanets like, and could any be habitable?

Exoplanets are relatively cool (brightest in the infrared) and are often formed inside dusty disks (which scatters visible light but that infrared light can penetrate), and many "spectral fingerprints" are found in the infrared.

> Not even a 'thing' when Webb was conceived, exoplanets are now a hugely-interesting field of science. A very large, very sensitive infrared telescope is ideally suited to study exoplanets 'nearby.'

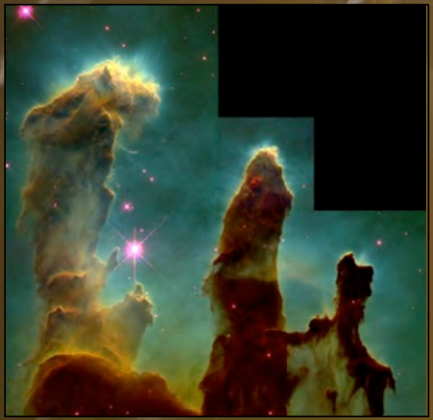
Webb Science Themes

Early Universe

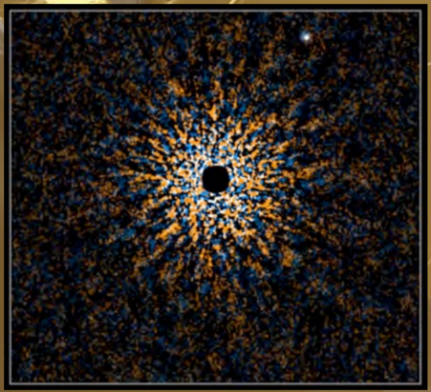


Galaxies Over Time

Star Lifecycle



Other Worlds



Webb Characteristics

Large telescope optics for resolution and sensitivity

Cold optics and instruments for infrared sensitivity

Multi-layer sunshield instead of a tubular light baffle around the telescope to provide shade for telescope and instruments and enable passive cooling

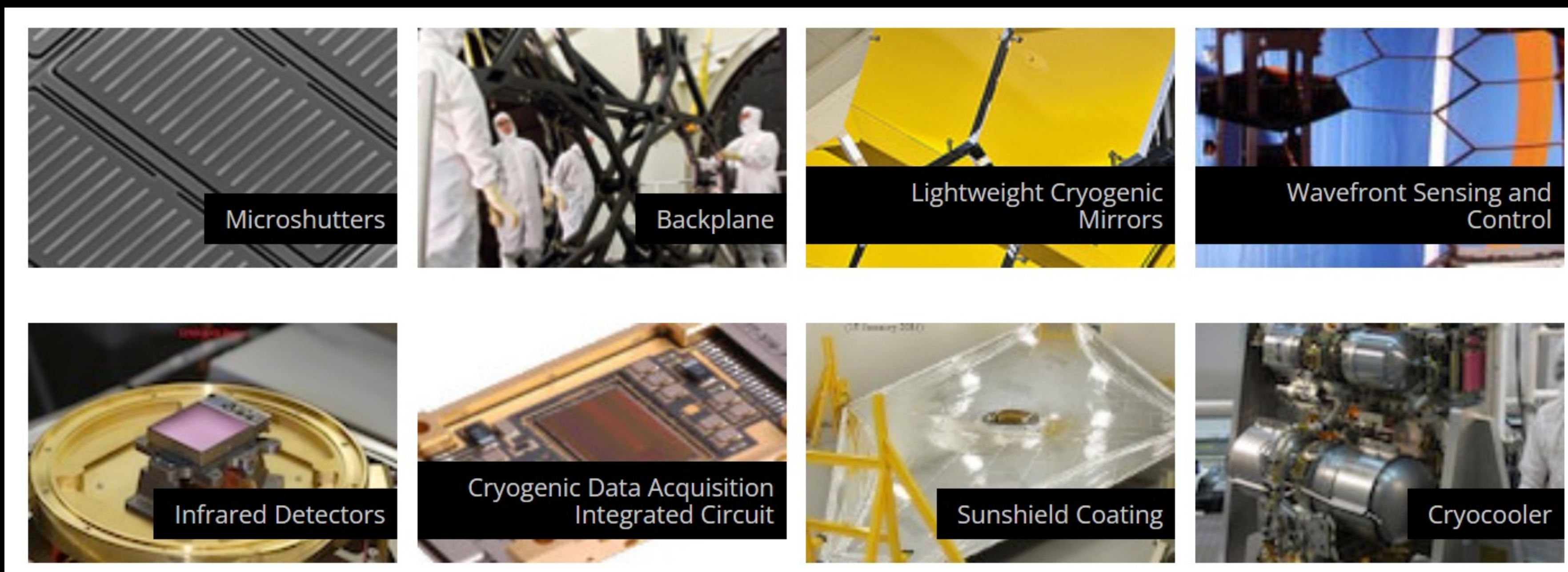
Folded-up for launch, unfolded in space for operations – *the "Origami Observatory"*

Location at Sun-Earth L2 to enable sensitivity and observing efficiency

Engineering Webb was Hard
Size + Cold = Difficult!

- Webb must be cold so it can detect faint signals rather than 'see itself'
  - Webb runs colder than 60K to be limited only by its orbital environment
- Webb had to be built *"perfectly wrong"* at room temperature so that it's *"exactly correct"* at cryogenic operating temperature
  - Typically, materials expand with warmth and contract with cold. Different materials change dimensions differently with temperature. Webb had to be made of different materials, and made so that it's the right size and shape when cold.
- Testing Webb was extremely difficult due to size and temperature
  - Deployment testing of something so large required big offloading equipment
  - Much testing performed in vacuum chambers at cryogenic temperatures
  - Testing everything all at once all in one piece in a vacuum at full range of operating temperatures not feasible on the ground

Webb Technologies:
necessary advancements and inventions



Testing Webb Pre-Flight

Proving and Knowing Webb Would Work

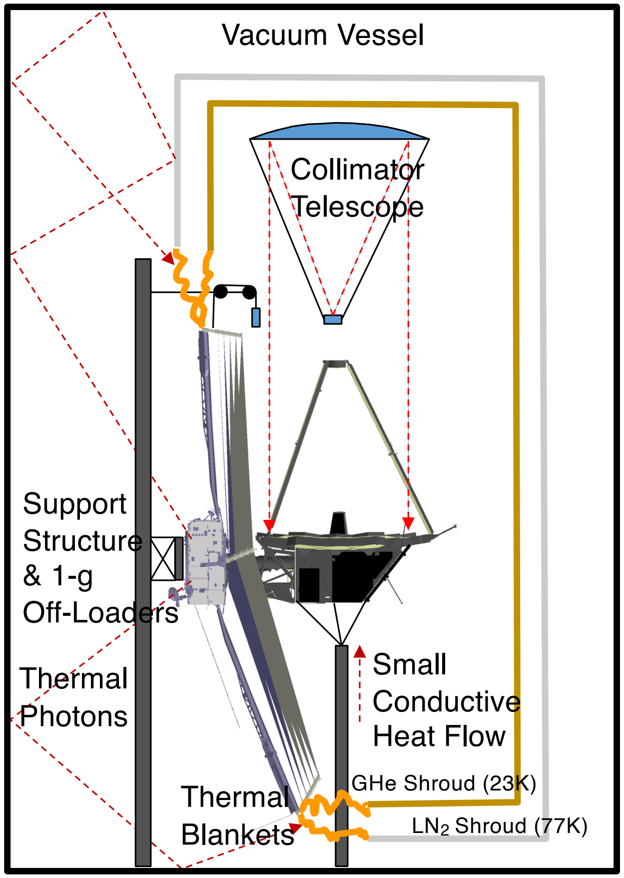
- Verification is the process that proves that the as-built hardware meets its requirements in a flight-like environment
  - Verifies both performance and workmanship; surviving launch and operating in space
- There are four “classical” methods for verification of requirements:
  - Test
  - Similarity to Previously Flown Hardware
  - Analysis
  - Inspection
- At the Goddard Space Flight Center, the historical approach is “Test as You Fly”
  - Satellite design is qualified and workmanship is verified by vibration testing it in its launch configuration using sine sweep or random vibration (<100Hz) plus acoustics (>100Hz)
  - Satellite performance is verified by testing it in its operational configuration in a thermal vacuum chamber that simulates flight temperatures and environments
- The combination of size and temperature range prohibited this for Webb
  - In its operational configuration, Webb covers the area of tennis court and is as tall as a 3-story building
  - Operational temperatures range from 400K to 40K (about 260F to -400F)
  - Webb is lightweight and needs extra support in 1g

Vibration Qualification and Workmanship

- Webb was structurally *qualified* in 'protoflight' fashion as two halves subjected to sine sweep testing: 1) telescope+instruments (aka "OTIS") and 2) spacecraft bus+sunshield (aka "Spacecraft")
  - Qualification levels (i.e., ~3dB over predicted flight environment)
- *Workmanship* of the final assembly of the observatory was verified by sine sweep and acoustic testing
  - Acceptance levels (i.e., similar to predicted flight environment)
  - *Avoids invalidating optical performance testing performed at OTIS level*
- Both sine and acoustics testing required extensive analysis to develop the input level vs. frequency profiles to adequately test but not over-test and break the hardware
  - OTIS and Spacecraft were very complicated test articles with many non-linearities

Performance Testing the Webb Observatory (idealized)

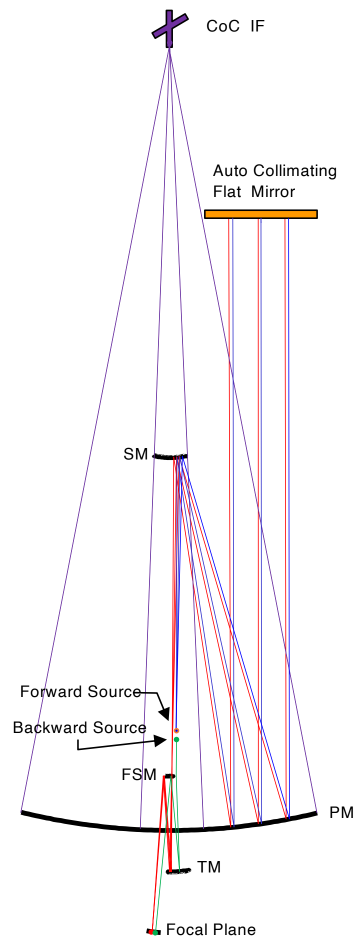
- To test the 6.5 m diameter cryogenic telescope, we need either another 6.5 m cryogenic telescope as a test source or a 6.5 m cryogenic test flat and test sources internal to the flight hardware
- To simulate the thermal environment, a "black" shroud colder than 30K needs to enclose the cold side to make sure thermal emission from the observatory doesn't bounce back
    - Requires a two-stage shroud system, LN_2 and GHe
- Thermal radiation from the Observatory's hot side has to be "strictly" prohibited from leaking to the cold side of the observatory
    - Careful blanketing and a large chamber to minimize bounces of thermal radiation (small fill factor)
- The observatory must be supported with gravity off-loaders to maintain its 0-g shape, particularly the Sunshield
    - The off-loaders cannot introduce excessive radiative or conductive perturbations that alter the thermal environment
- The vacuum chamber must be very large, the Ground Support Equipment complicated, and the Optical Test Equipment as demanding as the flight telescope

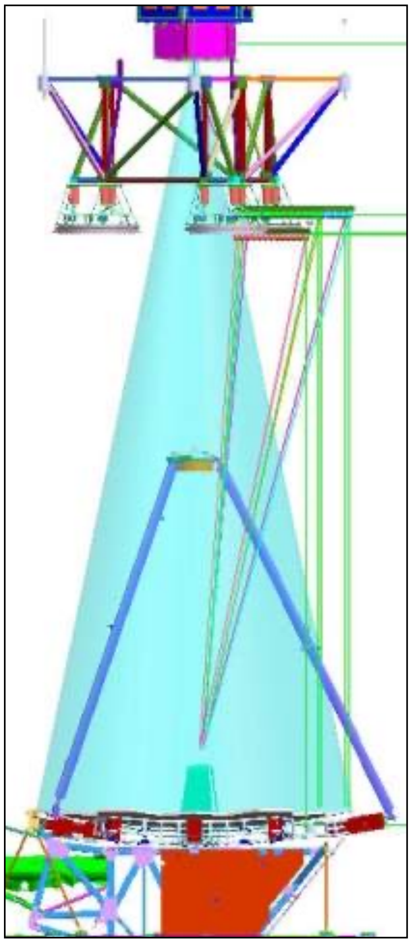


'As-You-Fly' Observatory Level Testing is Not Practical

End-To-End Optical Verification (as-performed)

- All optical components, Primary Mirror (PM), Secondary Mirror (SM), Tertiary Mirror (TM) and Fine Steering Mirror (FSM) are individually tested
- The figure of the primary mirror is verified by testing with a Center of Curvature Interferometer (CoC IF)
- The performance of the “conic” match of the PM, SM and TM is verified by using three 1-meter auto collimating flats, and a “1 ½ pass” test from *forward* sources located near the Cassegrain focus
- Separate sources at the Cassegrain focus pointing *backward* test the optical performance of the Aft Optics Subsystem
- This complement of tests verifies that the flight telescope can achieve the required performance with more than 100% of the range of all the actuators.

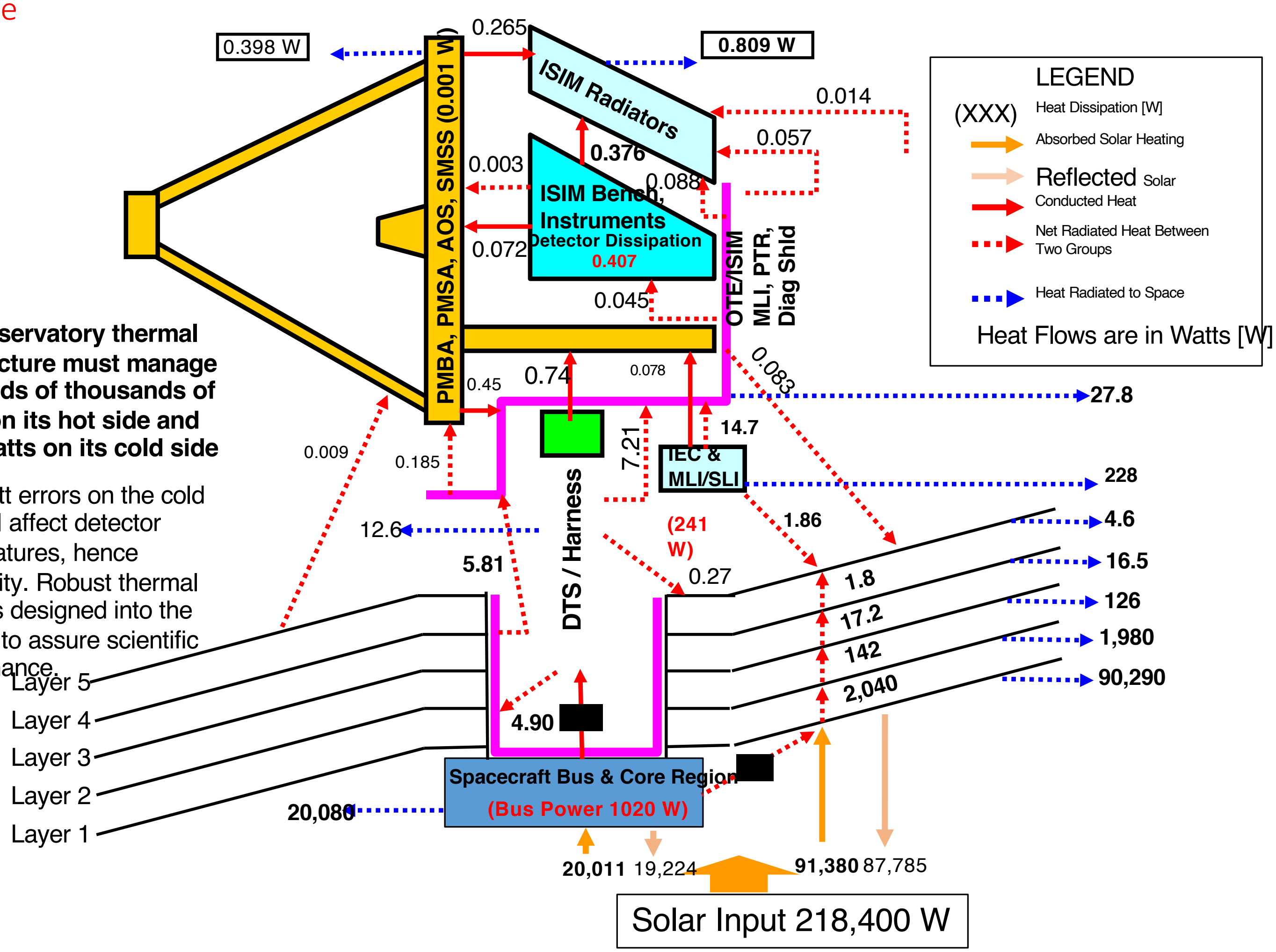




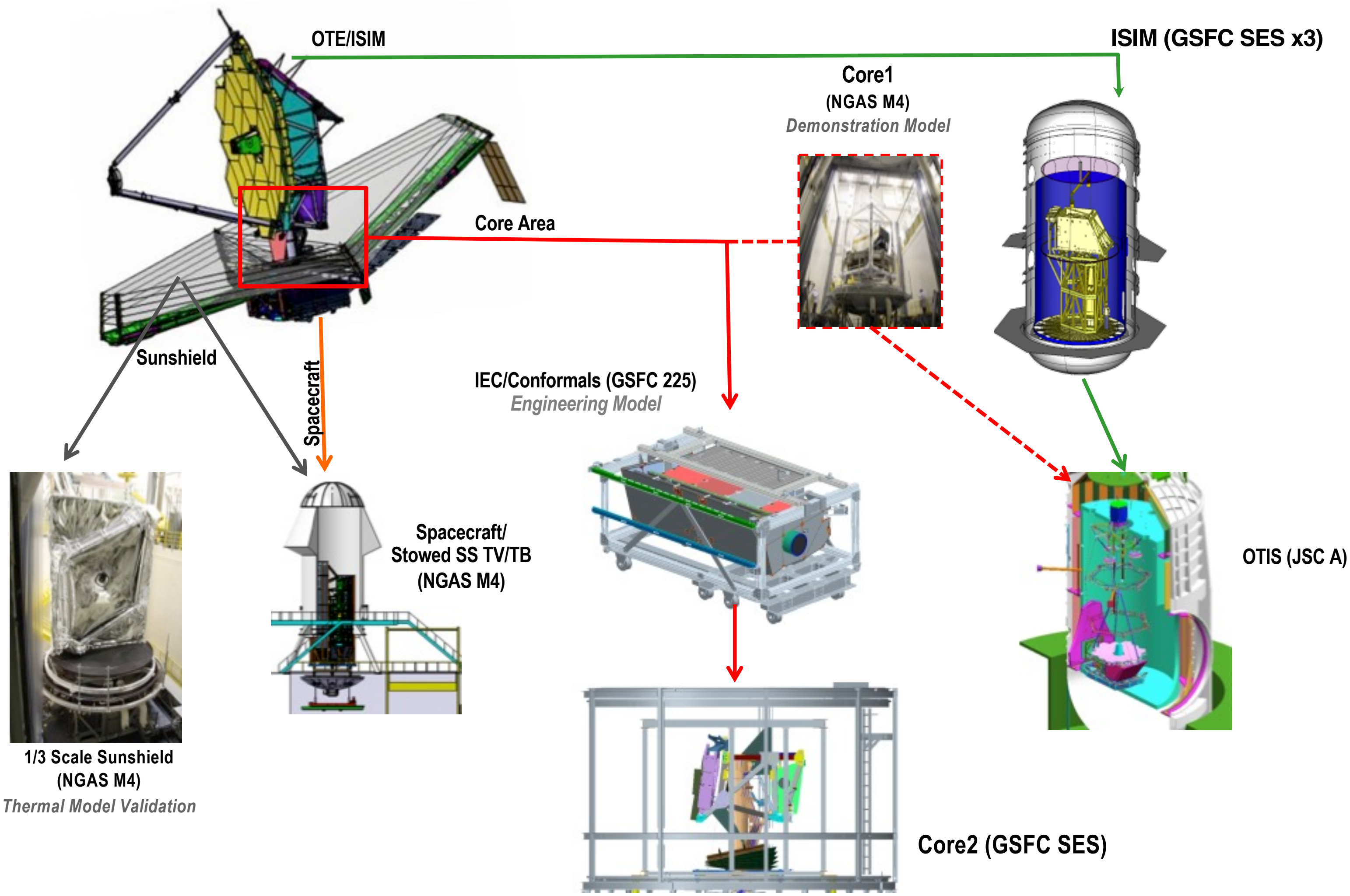
Thermal Performance - Observatory Heat Flows are Complicated

10^7 dynamic range

- **The observatory thermal architecture must manage hundreds of thousands of watts on its hot side and milli-watts on its cold side**
- Milli-watt errors on the cold side will affect detector temperatures, hence sensitivity. Robust thermal margins designed into the system to assure scientific performance.



Thermal Verification: Piecing Together Multiple Tests



Webb Status

Just completed a 6-month commissioning program, ready for Science Operations

- Launched into space Dec 25, 2021
  - Virtually perfect launch saved on-board propellant for operations; >20 year supply
- Deployments were successful and Observatory is orbiting Sun-Earth L2
  - Large portion of mission risk is retired
- Telescope is aligned and optical performance is spectacular
- Observatory is at operating temperatures
- Science instruments are calibrated and working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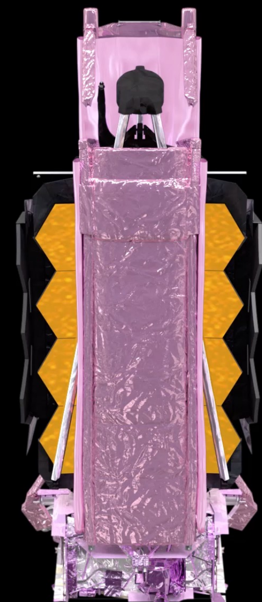
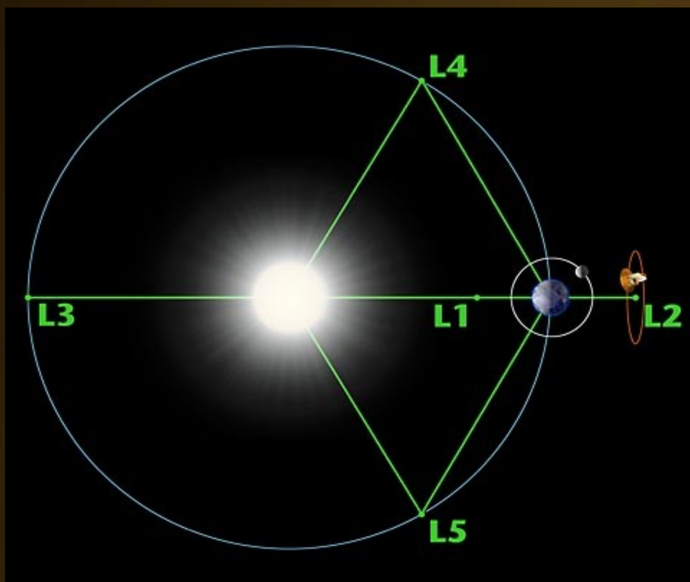
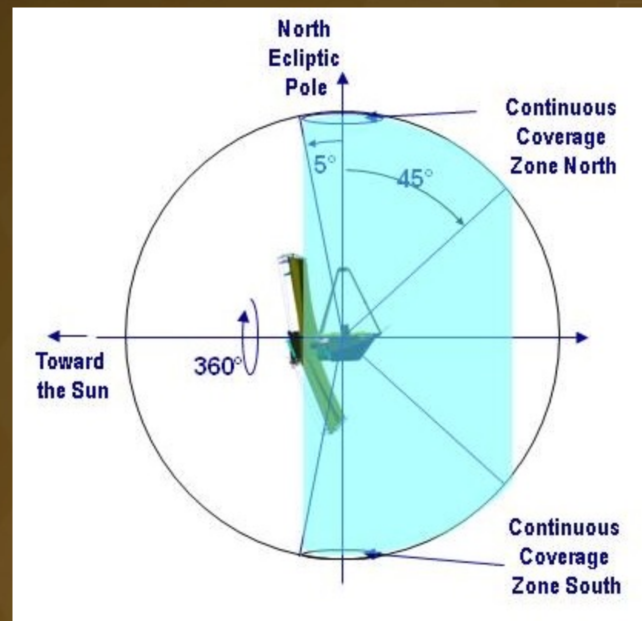
Webb Deployment



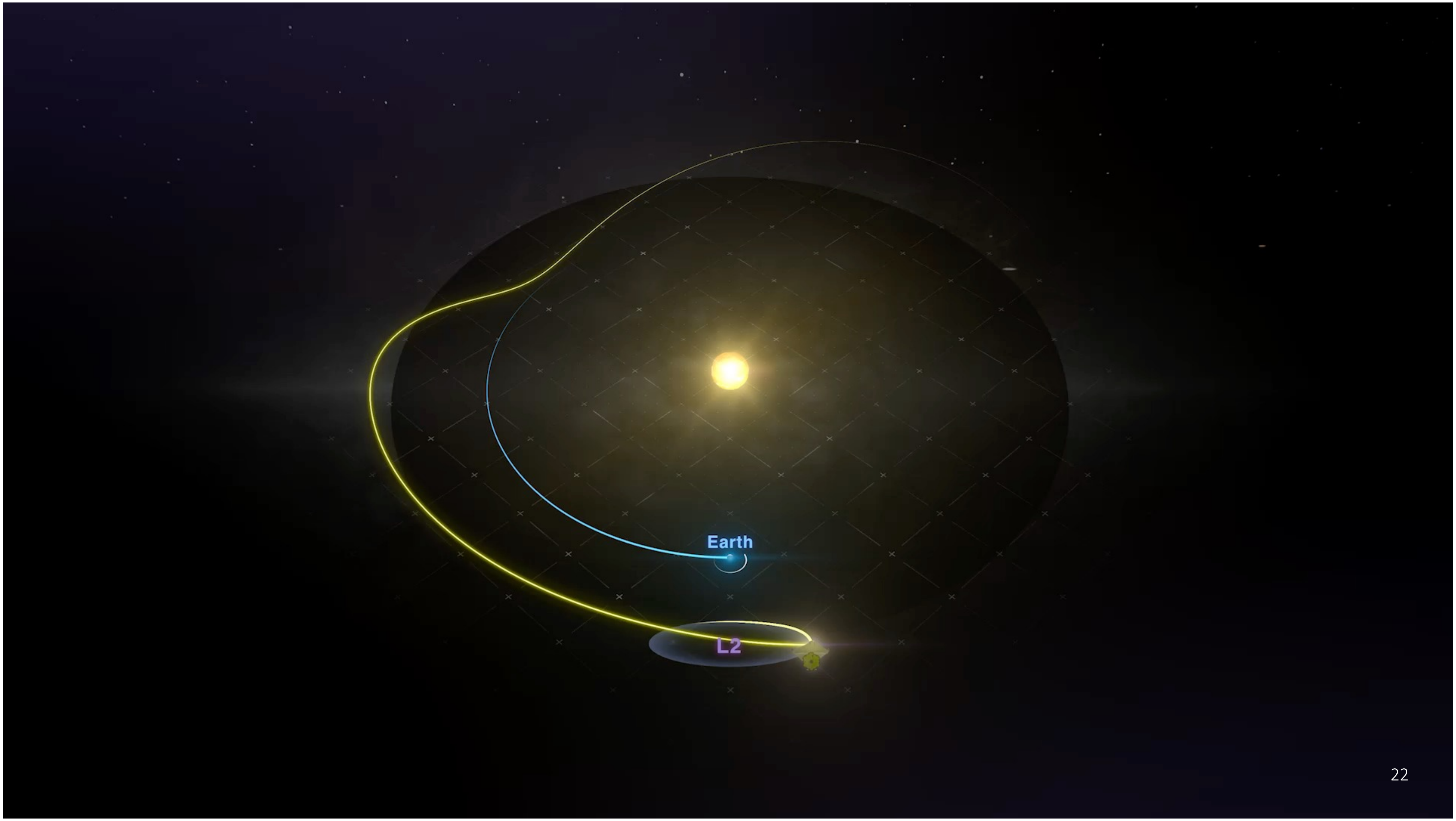
L2 – the 'Goldilocks' location



Lagrange Points

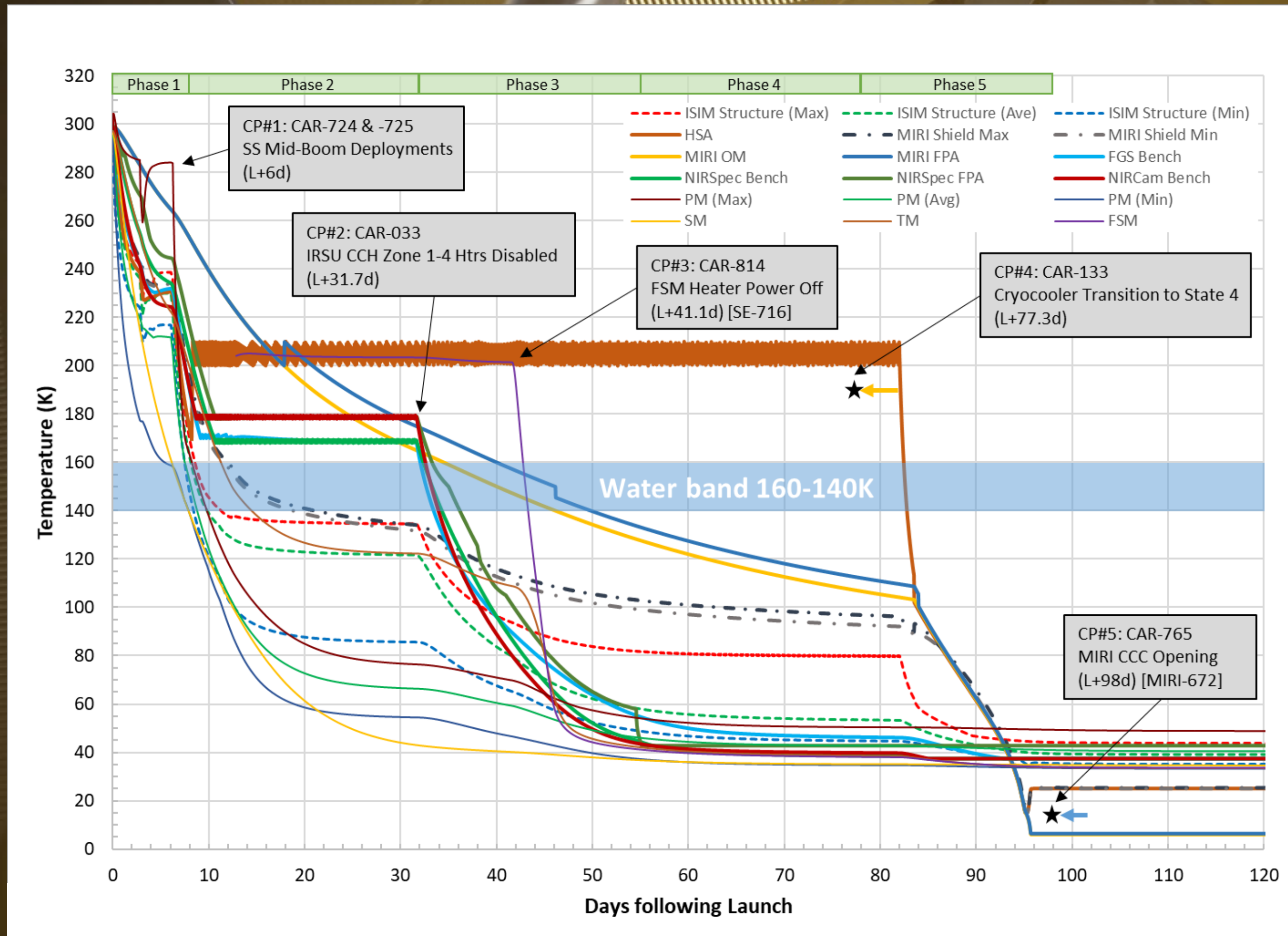


Webb's Field Of Regard (FOR)

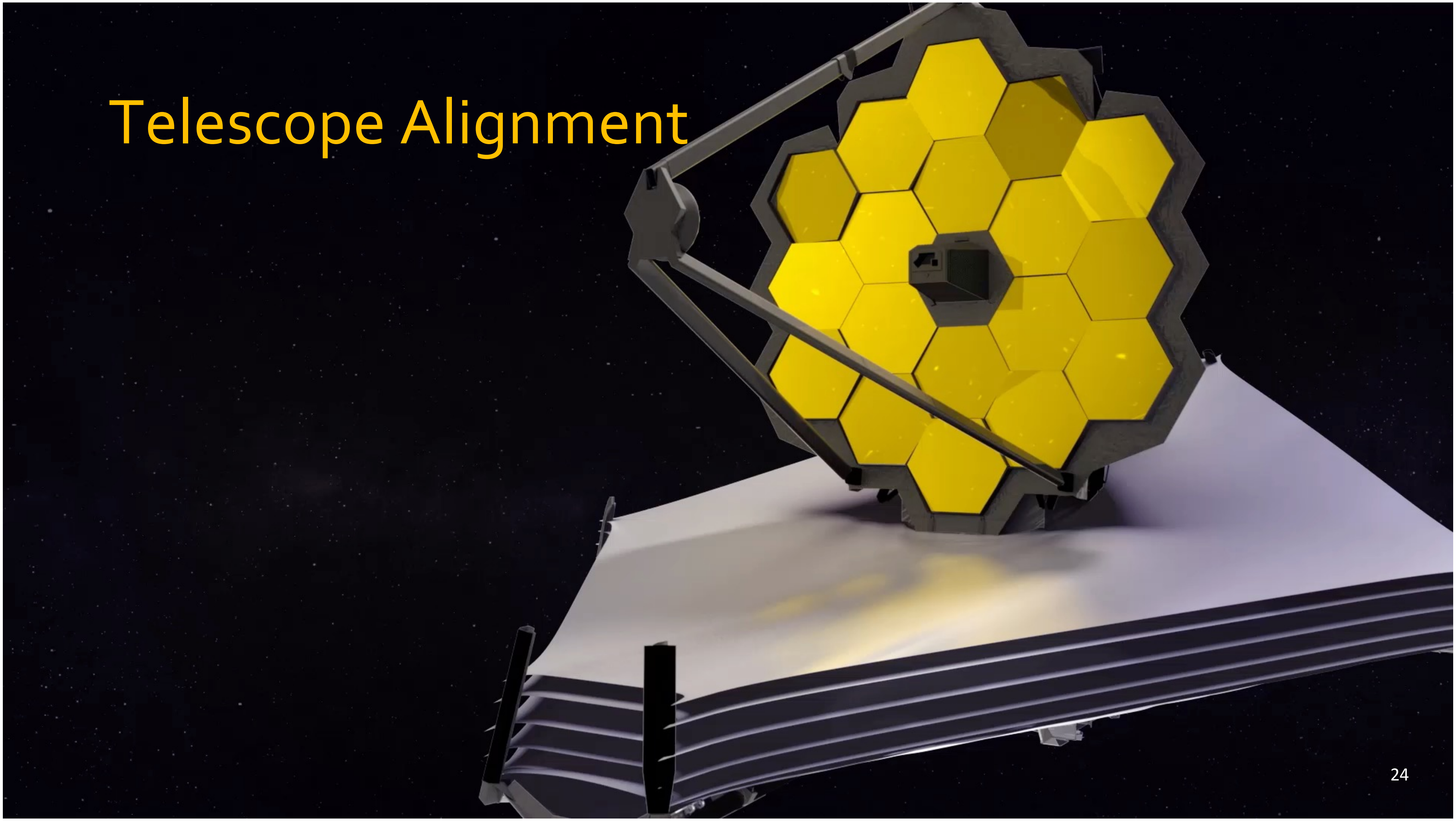

Earth
L2

Cooldown

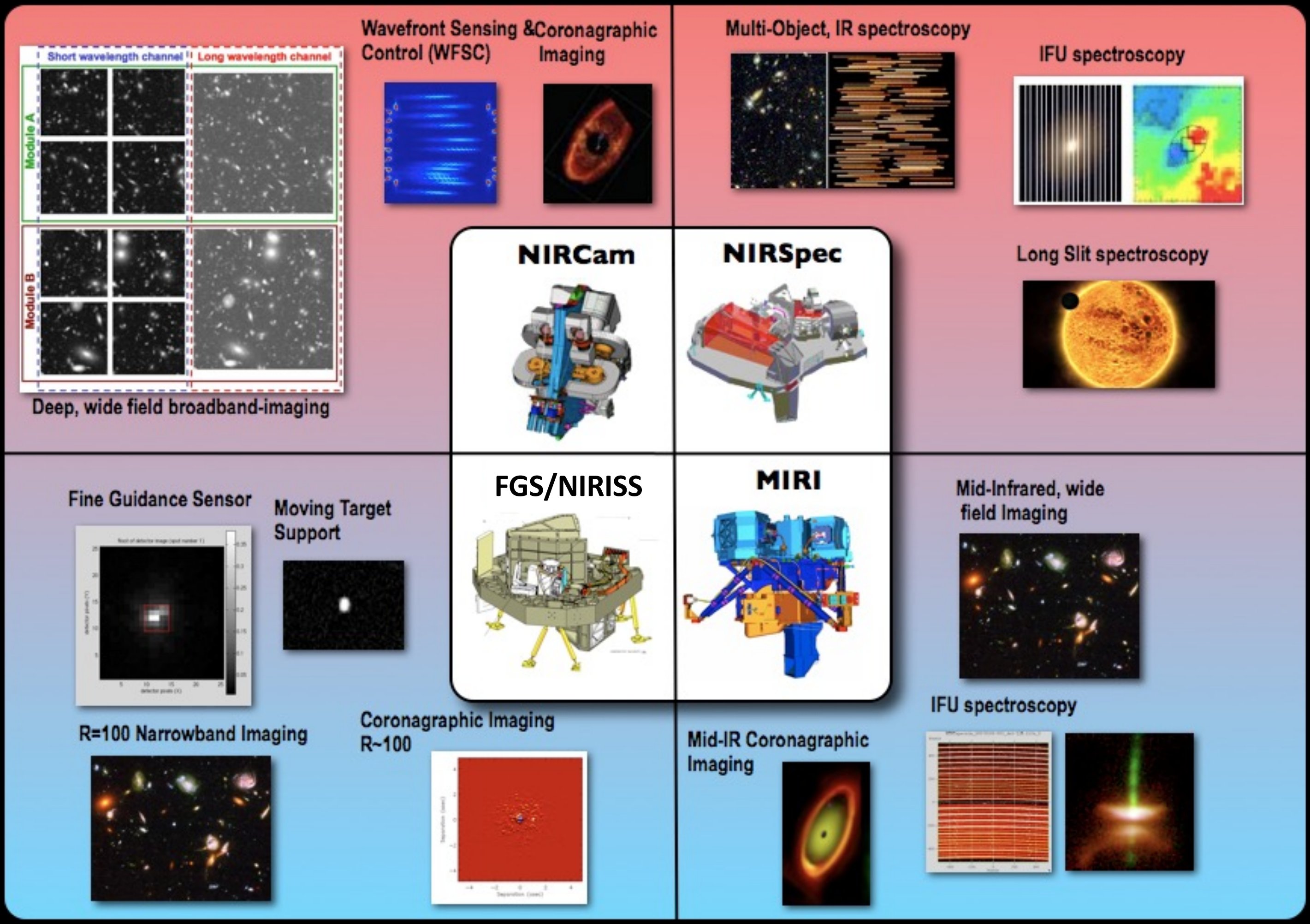
- Once sunshield deployment began, things began to get cold quickly!
- Cooldown was about managing water – allowing water molecules absorbed on the ground to escape to space and *not* stick to and freeze onto sensitive surfaces (optics, detectors, radiators)
- Key components were heated with electrical strip heaters to control what got cold, how fast, and in what order



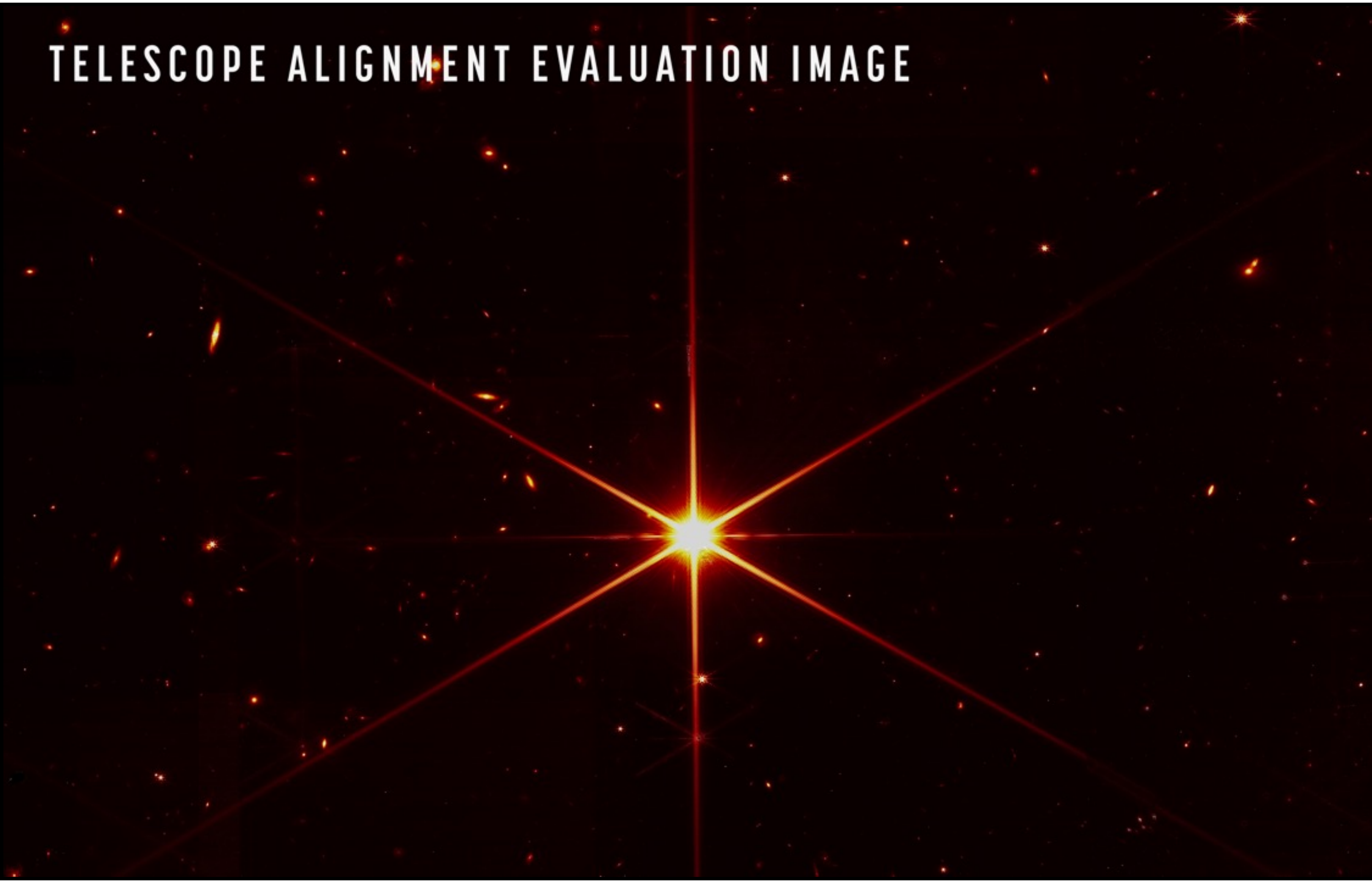
Telescope Alignment

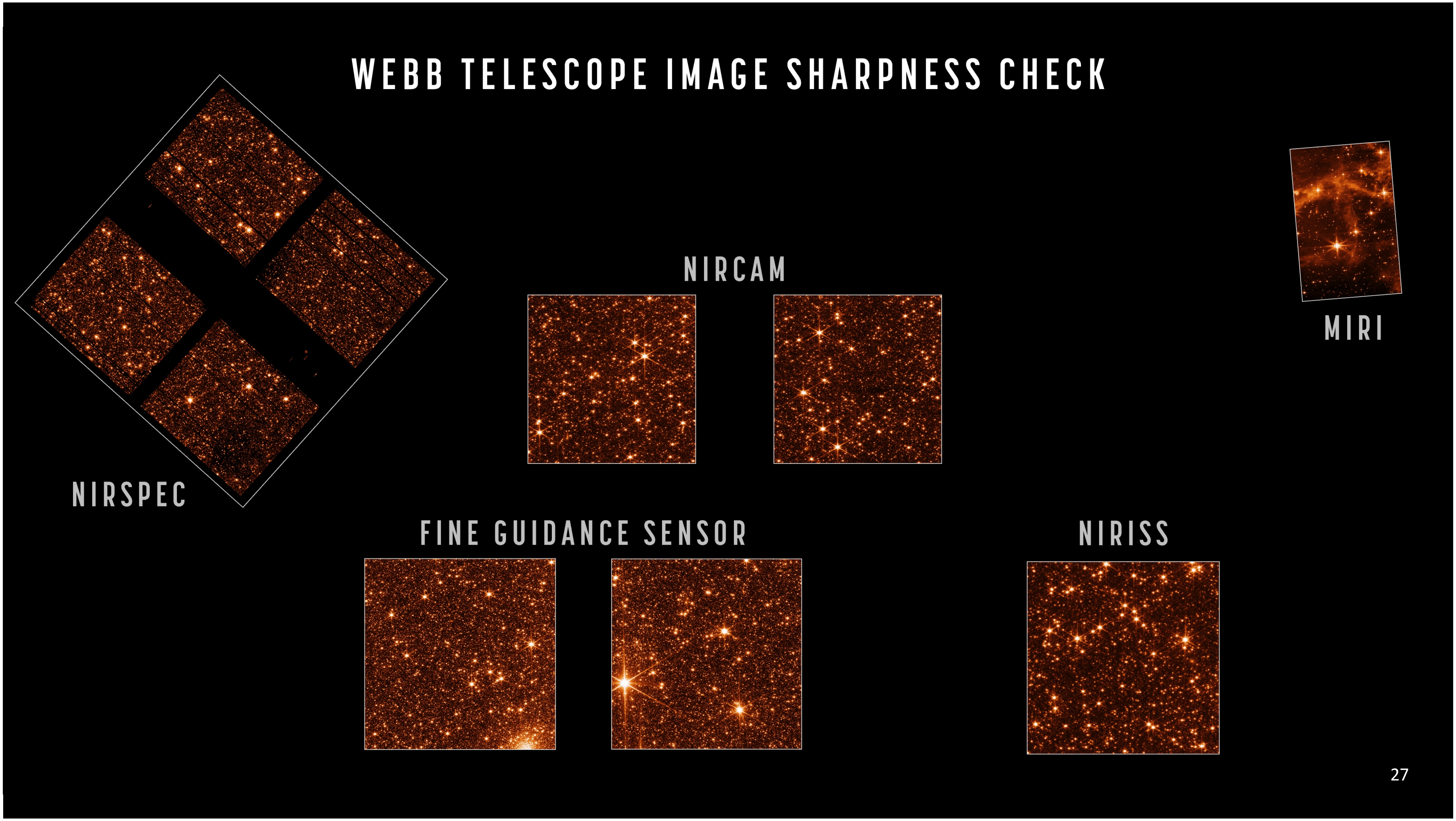


Science Instruments



TELESCOPE ALIGNMENT EVALUATION IMAGE




WEBB TELESCOPE IMAGE SHARPNESS CHECK
NIRSPEC
NIRCAM
MIRI
FINE GUIDANCE SENSOR
NIRISS

Operations

Science:

- Observations are competitively-selected in a blind process
  - Proposals solicited in annual numbered “cycles”
  - Cycle 1 observations (including Early Release Observations) have been selected and planned
- Observations get programmed and scheduled and uploaded to Webb in weekly batches, executed quasi-autonomously
- Raw science data downloaded ~daily in multi-hour sessions via Deep Space Network (DSN) Ka-band facilities
- Data and findings become public

Engineering:

- Telemetry down and commanding up, via DSN S-band

“Webb is a marvelous machine. It is a remarkable engineering achievement full of scientific potential and promise. It has been built to explore the frontiers of cosmology and astronomy, from observing the end of the cosmic dark ages to ‘sniffing’ the atmospheres of exoplanets around nearby stars to perhaps detecting the chemistry that makes life possible as we know it.

But its greatest discoveries will likely be answers to questions that have yet to be asked or imagined.”

-Paul Geithner