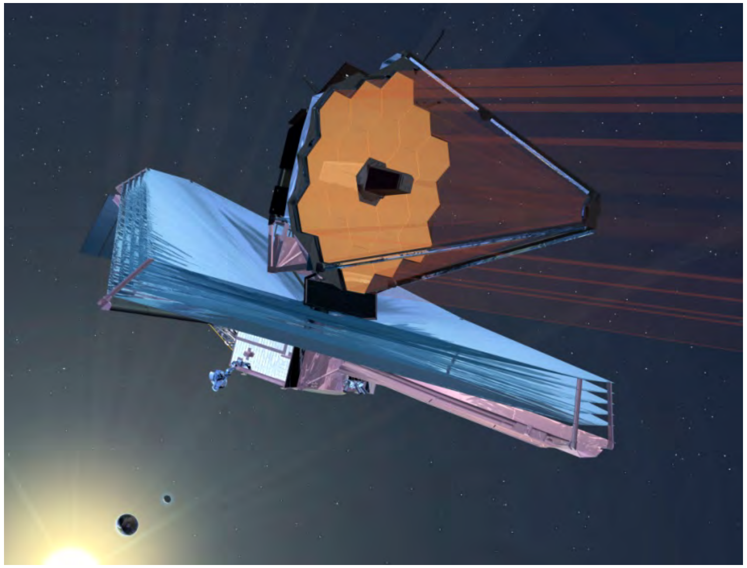
The James Webb Space Telescope
Presentation to SEDS

Carl Starr
JWST Mission Operations Manager
Goddard Space Flight Center

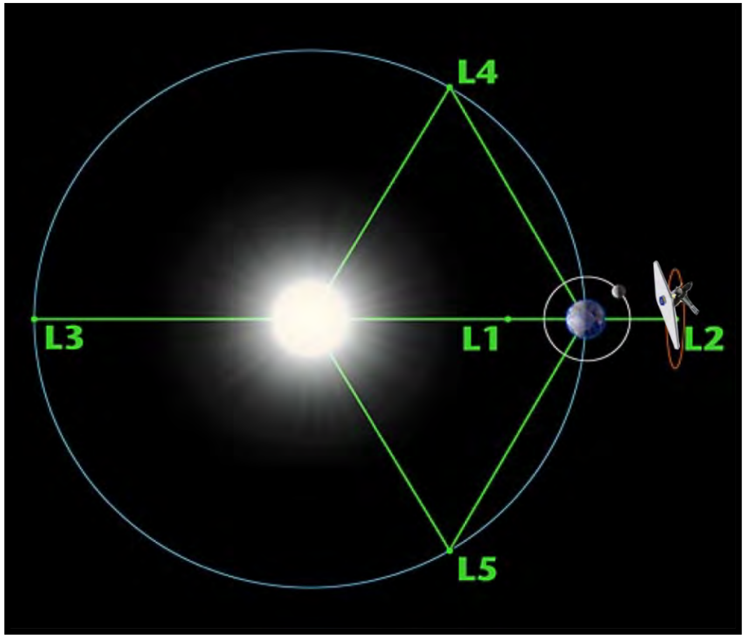
My Career

- I enlisted in the Army in 1986 and served for 12 years.
- In 1997 I went to work in Cambridge, Massachusetts for TRW on the Chandra X-Ray Observatory.
- In 2000 I founded an aerospace engineering company and ran it for 13 years.
- From 2004 to 2014 I ran the day-to-day operations of our Ground Segment and Operations Support engineering team on the James Webb Space Telescope program.
- In October of 2014 NASA hired me directly to be the JWST Mission Operations Manager.
- I work at Goddard Space Flight Center and the Space Telescope & Science Institute (STScI) in Baltimore, Maryland.
- I am responsible for all operations on the telescope once JWST separates from the launch vehicle.
- Recently completed Master of Science in Space Studies at AMU.

JWST Overview: NASA's Successor to the Hubble Space Telescope

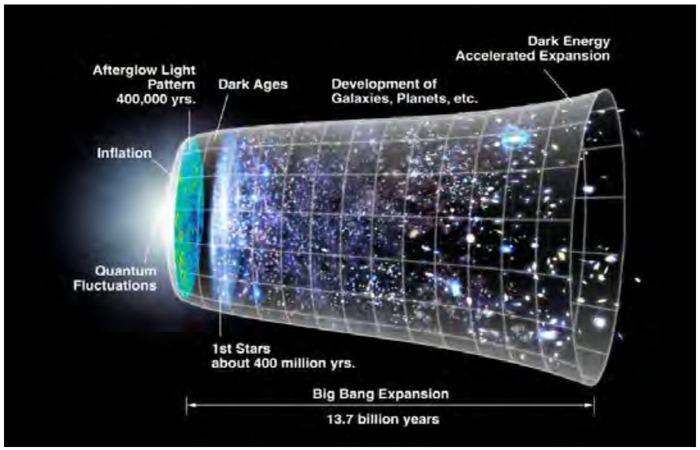


- **Mission Objective: Study the origin and evolution of galaxies, stars and planetary systems by providing Infrared imagery and spectroscopy**
- **JWST Team:**
  - Mission Lead: GSFC
  - International Collaboration with ESA and CSA
  - Prime Contractor: Northrop Grumman Space Technology with Ball Aerospace as Telescope Subcontractor
  - Ground Segment: Space Telescope Science Institute
  - Science Instrument Providers:
    - Near Infrared Camera (NIRCam): University of Arizona
    - Near Infrared Spectrometer (NIRSpec): ESA
    - Mid Infrared Instrument (MIRI): JPL / EC
    - Fine Guidance Sensor / Near Infrared Imager and Slit-less Spectrograph (FGS-NIRISS): CSA
- **Observatory Description:**
  - Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
  - Cryogenic operating temperature telescope and instruments
  - Deployable Sunshield to allow passive cooling of telescope and instruments
  - Launch in Early 2021 to Sun-Earth L2
  - 5-year science mission (10-year goal)



The Science Mission for HST Successor

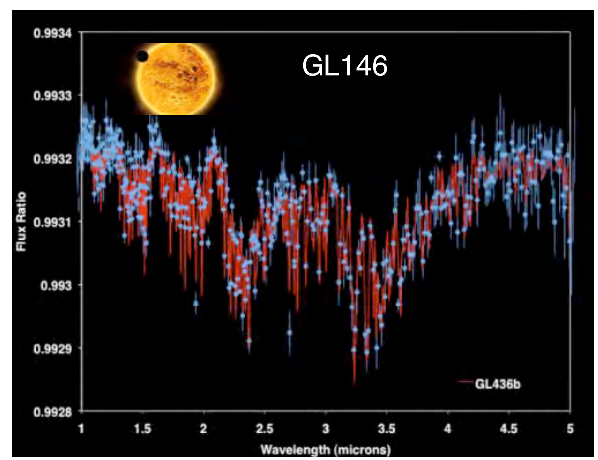
- **Scientists held meetings to determine what kind of telescope should follow HST; they developed 4 science themes that a future observatory should address.**



First Light and Re-Ionization

Assembly of Galaxies

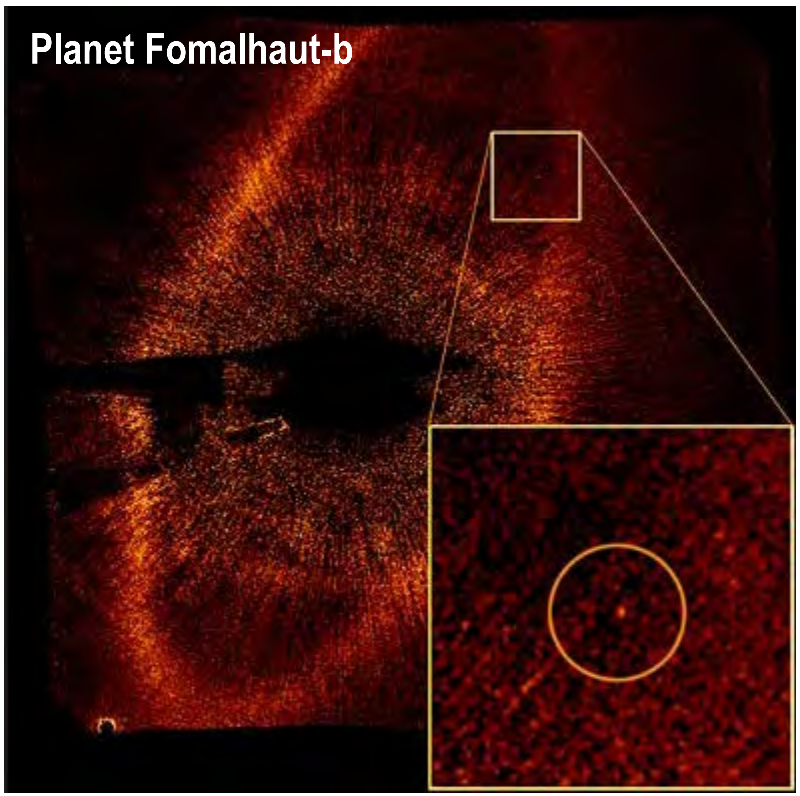
Birth of stars and proto-planetary systems



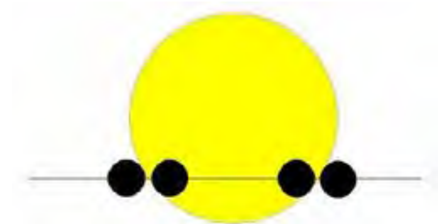
Planetary systems and the origin of life

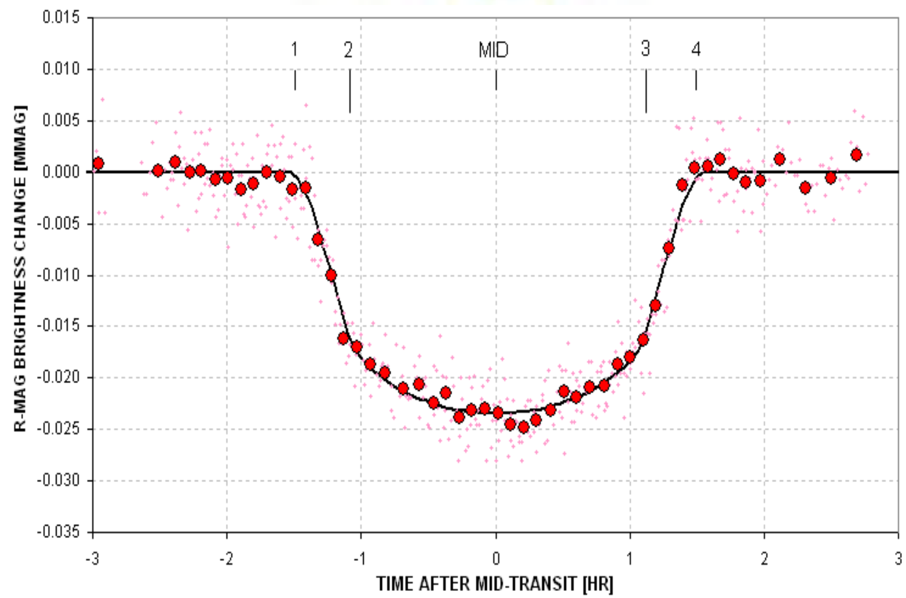
New Question: Exoplanet Science

- **The first exoplanets were discovered around a millisecond pulsar (PSR B1257+12) in 1992 based on timing anomalies. Then in 1992 the first exoplanet was discovered around a main sequence star 51 Pegasi based on radial velocity measurements. Then in 2002 the first exoplanet detection by the transit method was made in 2002, around star OGLE-TR-566 in Sagittarius.**
- **Today we know of approximately 2000 planets around 1300 other stars, and the number is growing everyday.**
  - A planet around the star Fomalhaut (22 LY away) was detected by the Hubble Space Telescope in 2008.
  - Many other planets are being detected as they transit across the face of their stars by missions such as Kepler, which will most likely bring the count up to 3000 before it ends.



Transiting Exoplanet





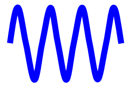
JWST MISSION REQUIREMENTS

What Kind of Telescope Should We Build?

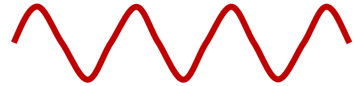
- **Spectral Coverage: (What colors shall we observe?)**
- **Radiometric Sensitivity: (How faint are the objects we want to see?)**
  - Light Collection
  - Sensitivity (Signal to Noise)
  - Stray Light and Temperature
- **Field of Regard: (How much of the sky do we want to see?)**
- **Resolution and Image Quality: (What's the smallest object we want to see clearly?)**

Science Requires an Infrared (IR) Telescope

Hubble Deep Field image shows galaxies out to z~5.



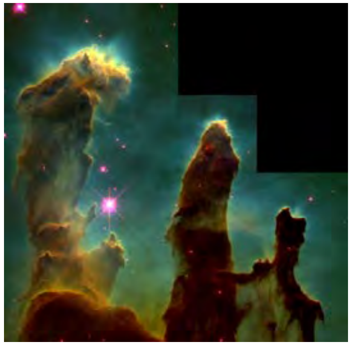
Light emitted by young stars is blue



After traveling 13 billion years thru a universe that has been expanding light waves are stretched and become red or infrared

JWST must operate in the Near Infrared (NIR) wavelengths (0.6 to 5 mircons)

JWST will view the universe at red-shift of 10 or greater to search for the first galaxies



M16 viewed in visible light shows dusty pillars and cocoons. Stars are being born in this dust, but this same dust obscures our view of them.

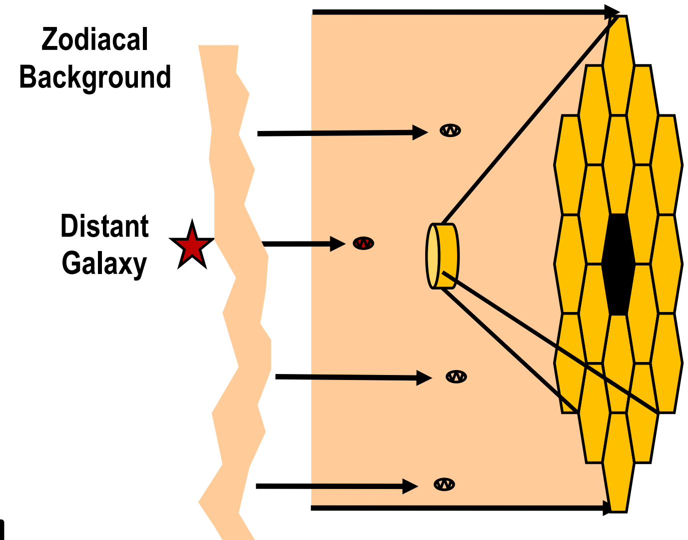
JWST must operate in the Mid Infrared (MIR) wavelengths (5 to 28 microns)

Infrared light can penetrate dust. By observing in the infrared we can see into these dust cocoons. M16 viewed in the IR shows objects hidden by this dust.

Driving Requirements: Radiometric Sensitivity

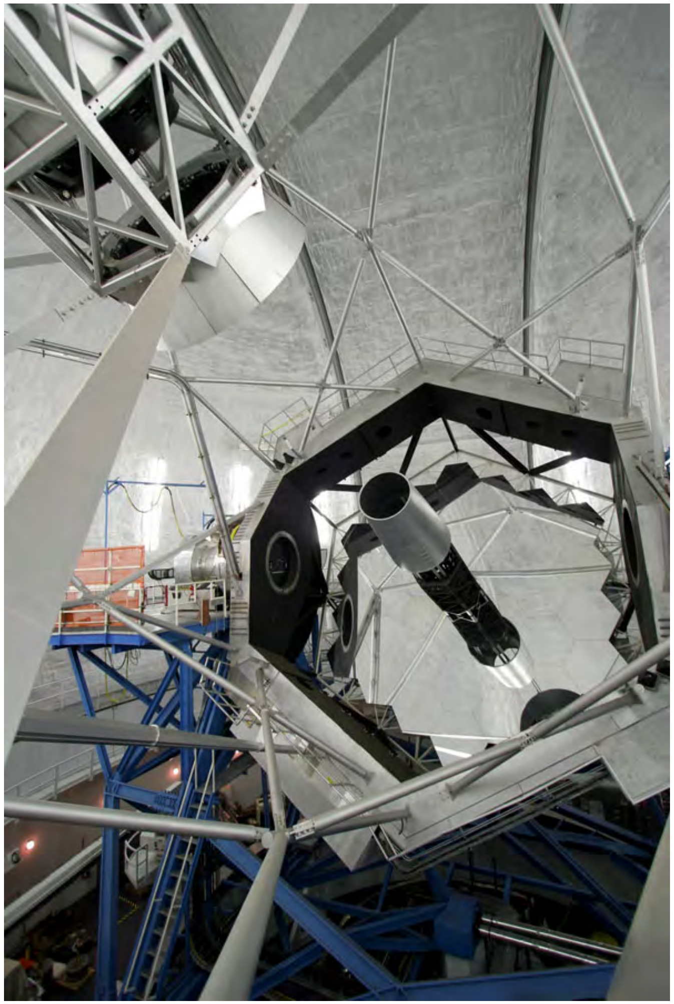
- Sensitivity: Detect 11 nanoJanksy Point Sources with a Signal to Noise Ratio of 10 for exposure time of 10,000 sec.
  - High Signal Collection
    - 25 m^2 Aperture, 6.5 m Diameter
    - Optical Transmission > 52%
    - Detector Quantum Efficiency > 80%
    - Encircled Energy > 59% to 80 mas
  - Low Noise
    - Low Stray Light Levels (Zodi Limited to λ = 10 μm)
      - Cold Optics T < 55 K
    - Low Electronics Noise
      - NIR Detectors Cooled to T < 40 K for 0.1e-/s Dark Currents
      - Total Electrical Noise < 9e-

Infrared Spectrum between 1.4 μm and 2.6 μm, centered at 2.0 μm (R = 1.68)

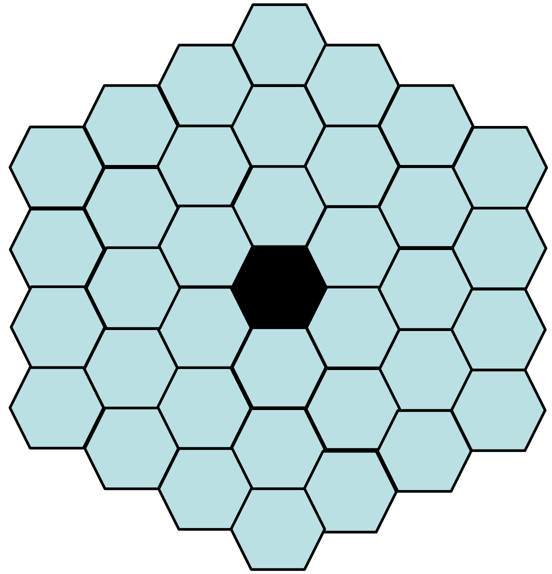


- JWST collects 1 photon per second, and registers one electron every 4 seconds.
- JWST collects 3 photons per second from the natural background and registers 3 electrons from this background every 4 seconds.

Segment Primary Mirror Leverages Keck Technology

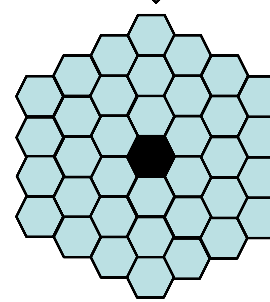


The Keck I Telescope on Maunea Kea Summit in Hawaii

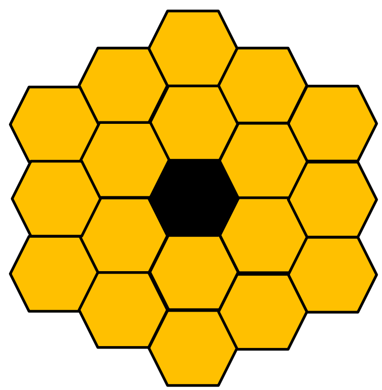


The 10 meter Diameter Keck I Primary Mirror

When one factors in the light lost from the atmosphere, the Keck I Telescope's light collecting power is ~50% less at a wavelength of 2 microns. Therefore its equivalent aperture in space is:



The 5 meter Diameter Equivalent Keck

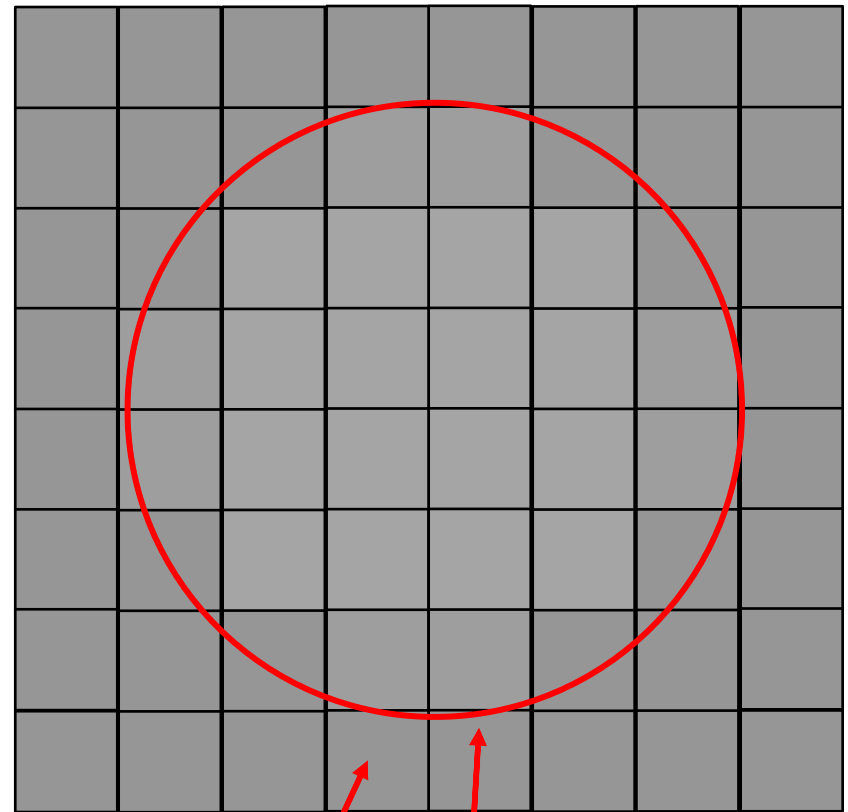


The 6.3 meter Diameter JWST Primary Mirror

How a 10 nanoJanksy Point Source Appears Compared to Anticipated Background

Electron Counts for a 10 nJy Point Source at λ= 2 Micron (R=5) Over 20 pixels For a 10,000 Sec Exposure

	10,000 Sec Exposure	
	Counts	**Variance**
Signal (10 nJy Point Source) (S)	2145	2145
In Field Zodiacal Background (Z)	13396	13396
Observatory Stray Light (B)	14897	14897
Dark Current (D)	1828	1828
	Read Noise	13765
	Total Noise = SQRT(Sum of Variance)	**214.5**

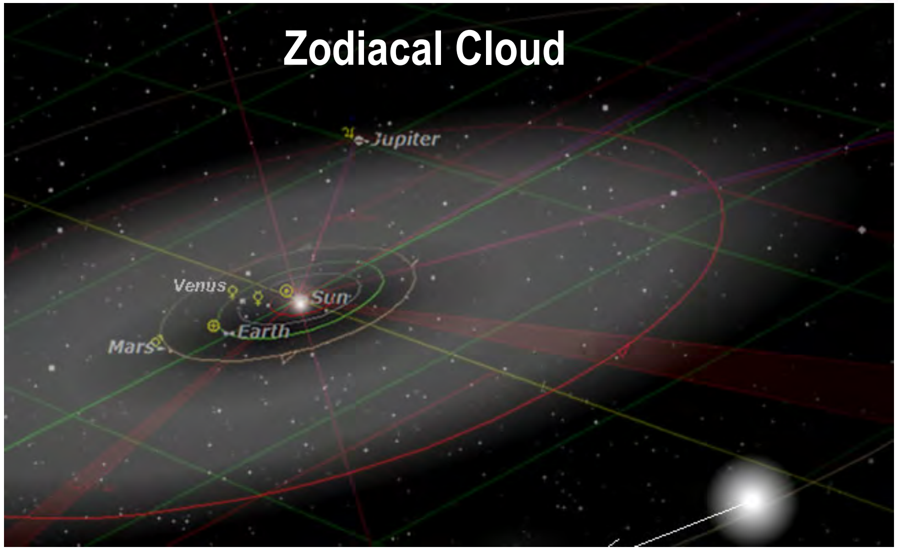


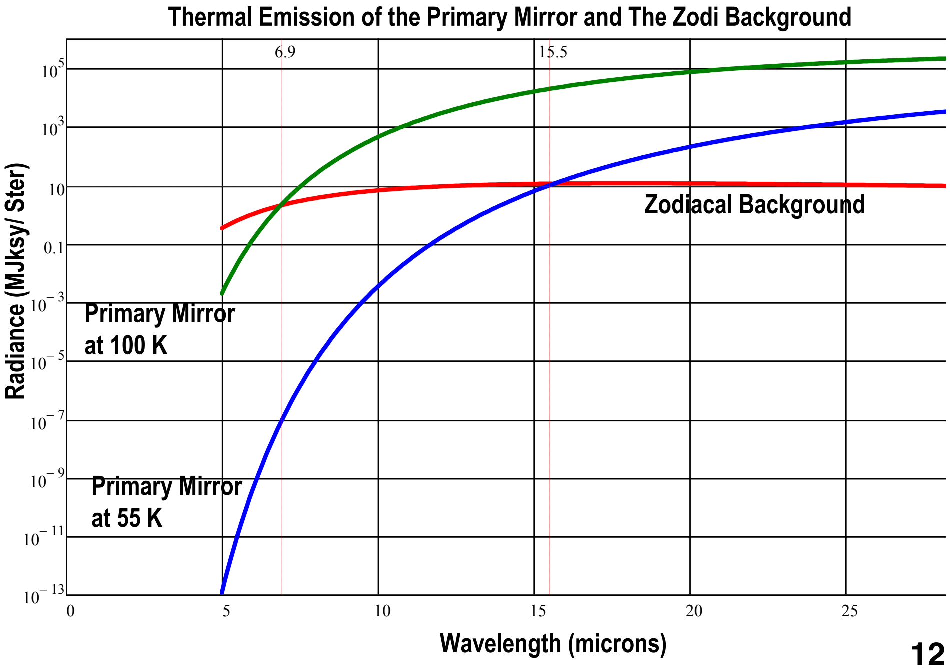
Each Background Pixel Accumulates 1883 Counts

Each Pixel Within the Core of the Point Source Image Accumulates 2017 Counts

Infrared Observatories Must be Very Cold

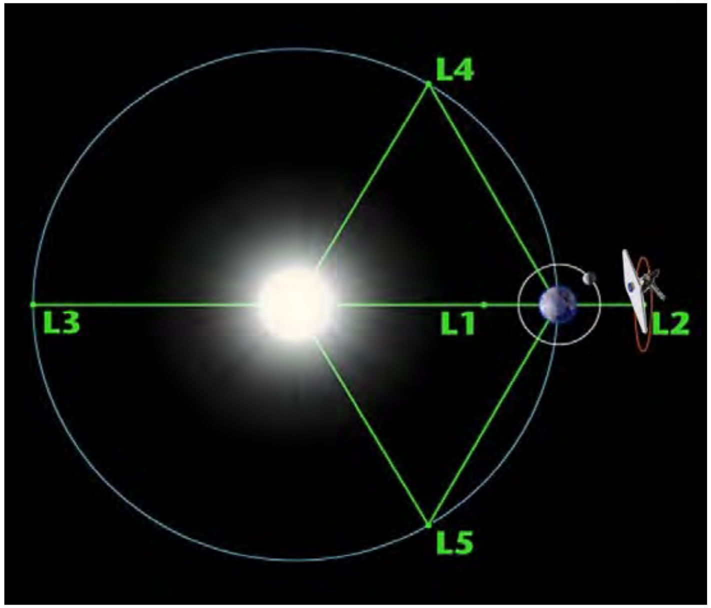
- **The telescope and the instruments glow in the IR. To make sure this glow does not overwhelm the faint signal, both must be cold.**
  - At ambient temperature the primary mirror emits over 350 photons at a wavelength of 2 μm.
- **JWST is designed to emit less IR radiation than the natural Zodiacal background (shown on upper right) out to a wavelengths < 10 μm. This requires optics temperature < 55K (-223° C or -369°F)**
  - The graph on lower right compares the thermal emission of the Primary Mirror to that of the Zodi background vs wavelength.
- **The Science Instrument detectors must be colder to limit their electronic noise. (Dark Current Noise).**
  - The Near Infrared detectors are HgCdTel detectors and must operate colder than 40K.
  - The Mid Infrared detector is Si:As and must operate at 6K.

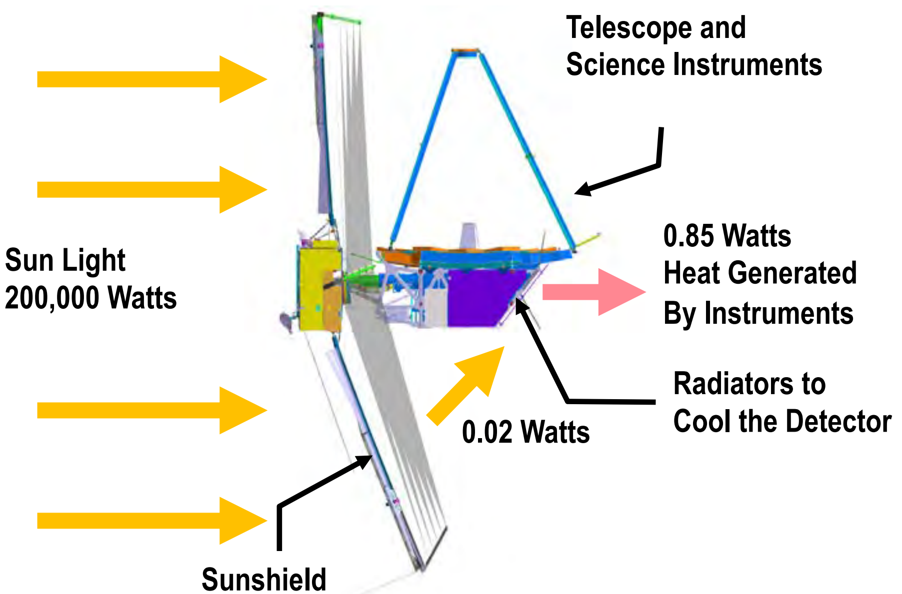




Cooling JWST

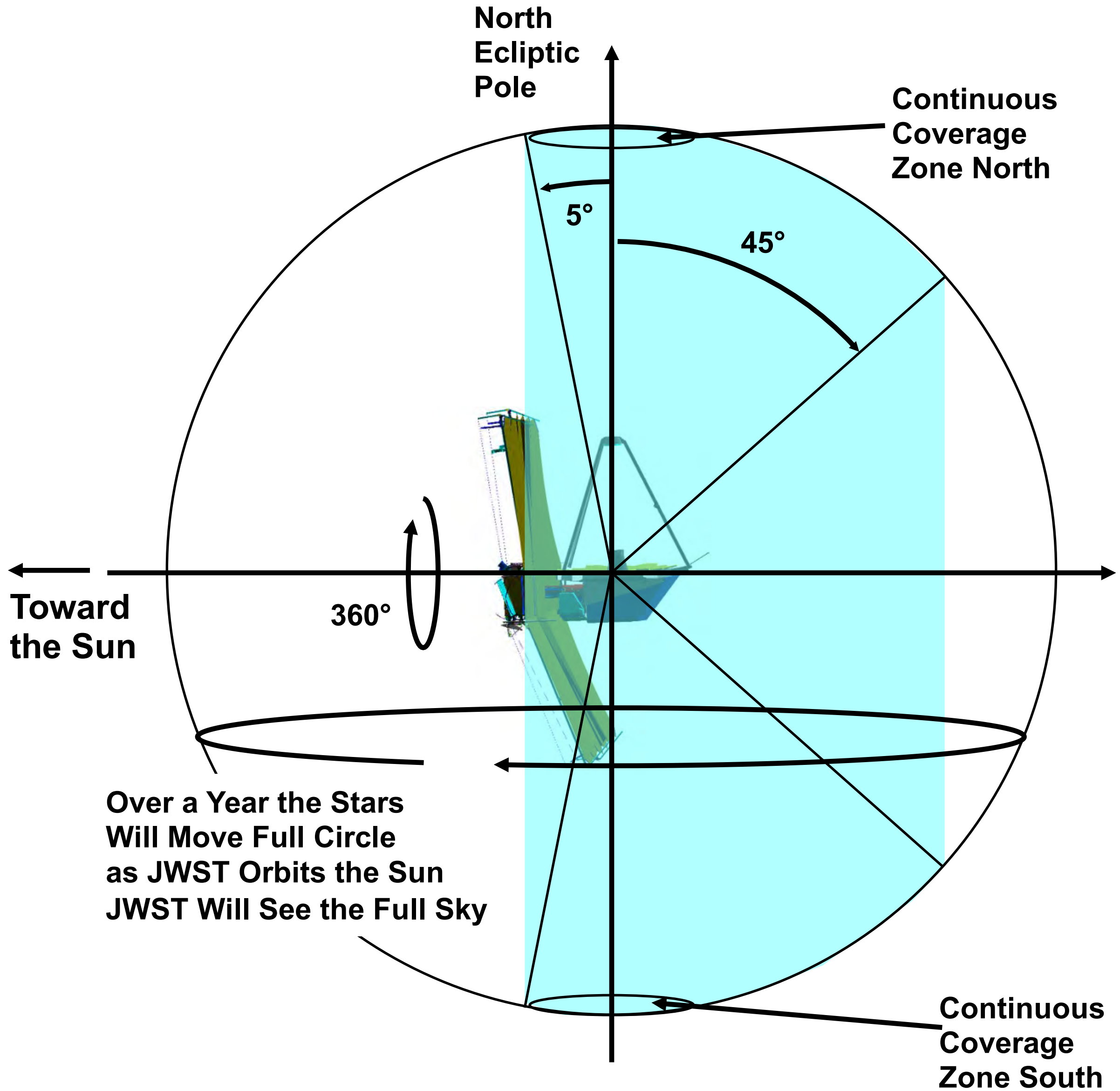
- **A 6-meter telescope and its instruments are too big to refrigerate. Therefore we must allow them to cool down "passively" .**
  - Get it far away from local heat sources, (The Earth, (300K) and the Moon)
  - Keep sunlight off the telescope and instruments
- **Locate the telescope at a point in space called the 2nd Lagrangian Point. This is a stable point 1.5 million km from the Earth opposite the Sun.**
  - The sun, earth and moon are always on the same side of the observatory.
- **A sunshield (umbrella) can shade the telescope from all 3 of these bodies.**
  - This sunshield can also shade the telescope from those electronics that must run hot.
- **The NIR detectors are cooled by dedicated radiators which dump their dissipated power directly to cold space. (Cold Space is 7K)**
- **The MIR detector must be cooled actively by a cryo-cooler to 6K.**





Observatory Celestial Coverage

- The required celestial coverage for the observatory is 35% of the celestial sphere at any given time.
- The sunshield is currently sized to give at least 39%.
- Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide
- The observatory will have full sky coverage over a sidereal year
- There are continuous viewing zones 5° about the North and South Ecliptic Poles
- The observatory will have a roll capability about the telescope boresight of ±5°



JWST Jitter / Pointing Stability

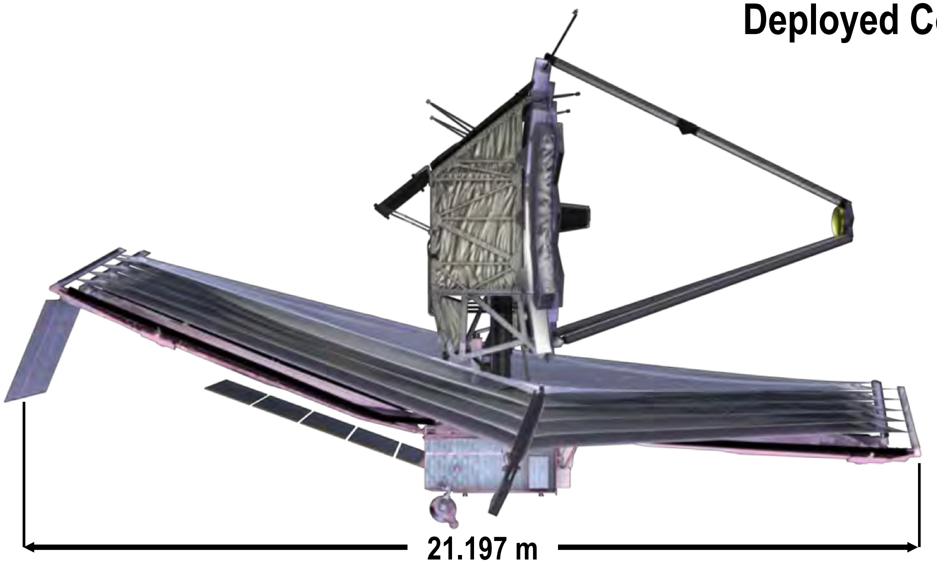
224 miles
(361 km)

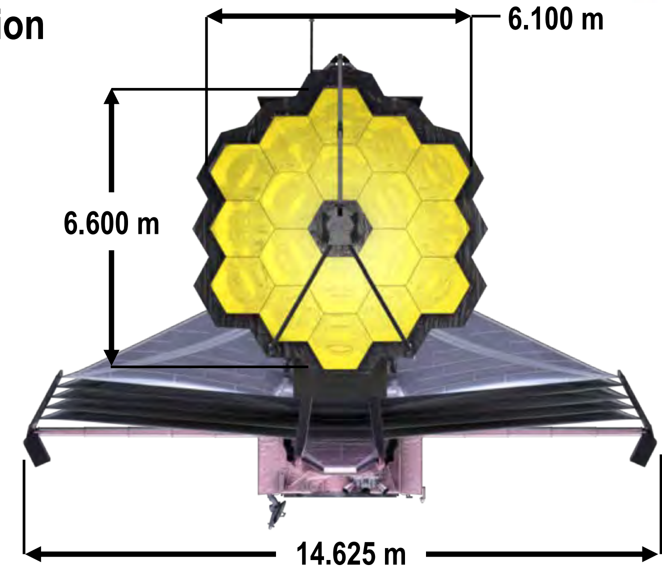
- **JWST is being designed to have pointing stability of 0.007 arcsec.**
- **This means that if JWST was at the Capitol, it could keep a laser beam pointed on a penny on the Empire State Building in NYC**

JWST SYSTEMS DESIGN

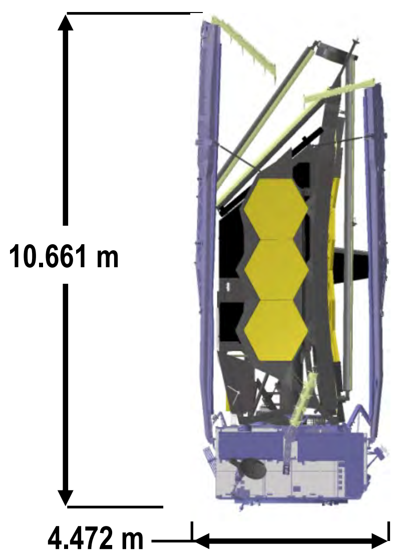
JWST Observatory Summary

Deployed Configuration



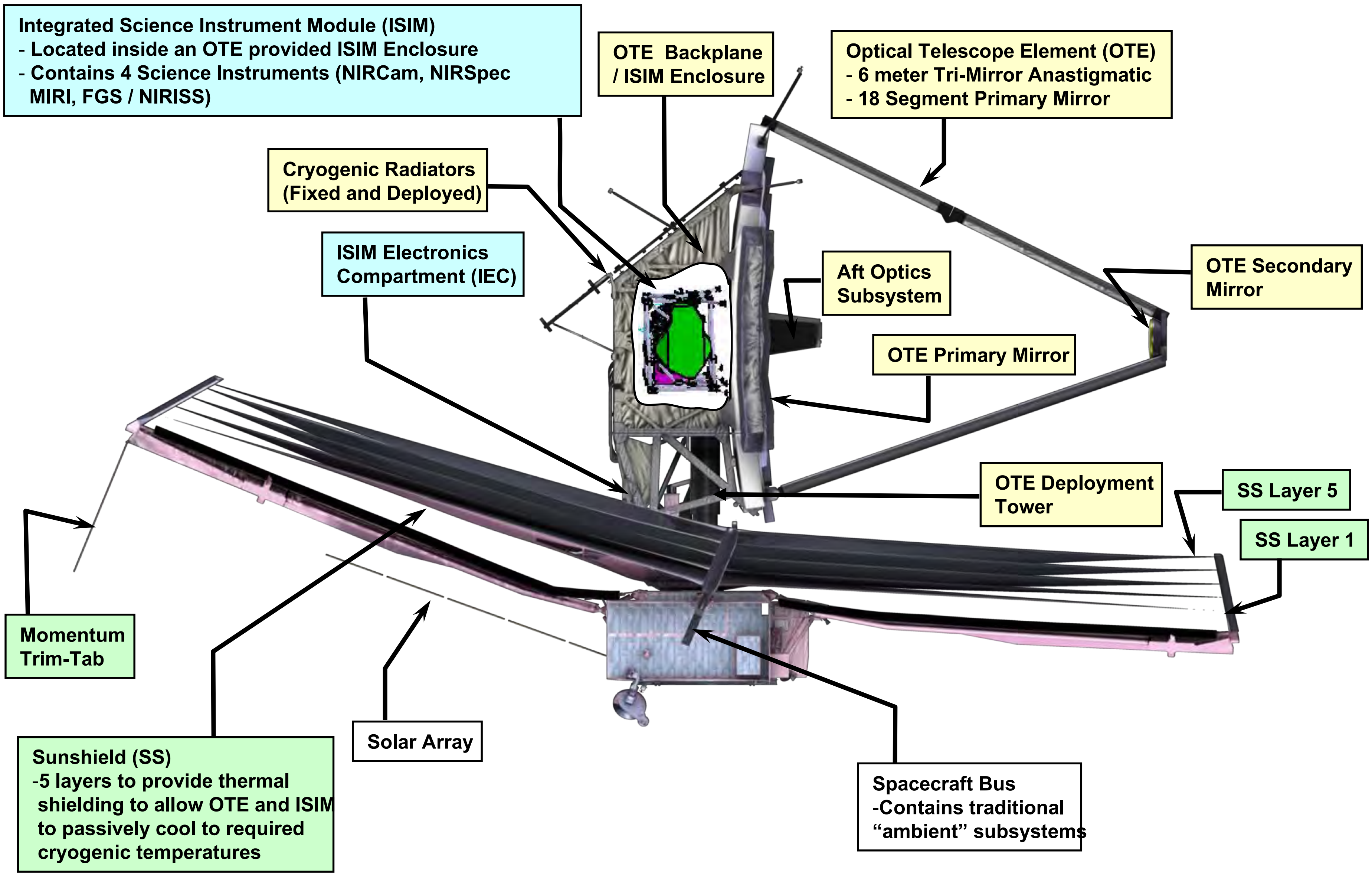


Stowed Configuration

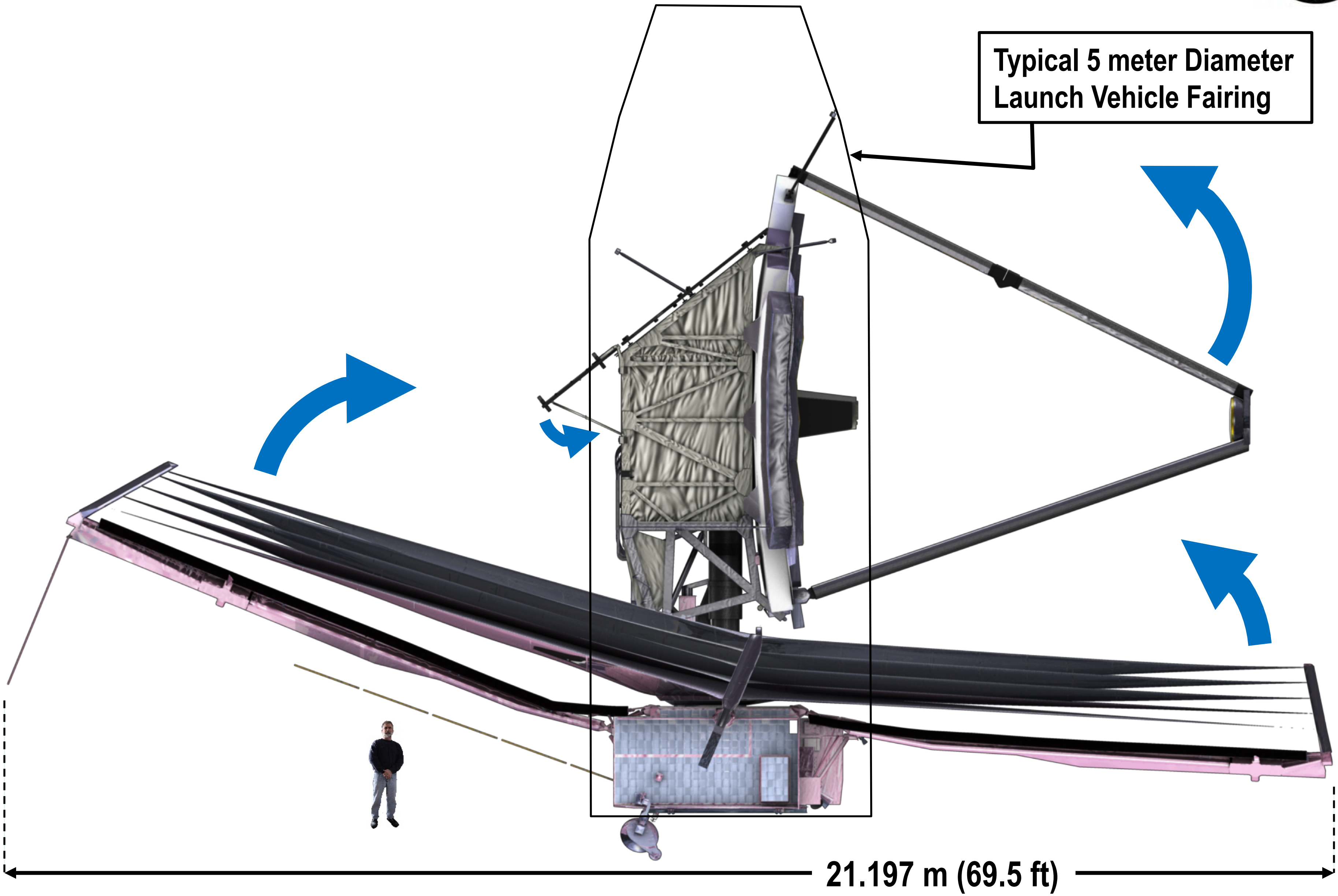


- **Optical Telescope Element (OTE) diffraction limited at 2 micron wavelength.**
  - 25 m^2 , 6.35 m average diameter aperture.
  - Instantaneous Field of View (FOV) ~ 9' X 18'.
  - Deployable Primary Mirror (PM) and Secondary Mirror (SM).
  - 18 Segment PM with 7 Degree of Freedom (DOF) adjustability on each.
- **Integrated Science Instrument Module (ISIM) containing near and mid infrared cryogenic science instruments**
  - The NIRCam SI functions as the on-board wavefront sensor for initial OTE alignment and phasing and periodic maintenance.
- **Deployable sunshield for passive cooling of OTE and ISIM.**
- **Mass: < 6310 kg .**
- **Power Generation: 2000 Watts Solar Array.**
- **Data Capabilities: 471 Gbits on-board storage, 229 Gbits / 12 hours science data.**
- **Science Data Downlink: 28 Mbps.**
- **Life: Designed for 10 years of operation.**

The JWST Observatory Elements and Regions



The JWST Observatory Must Fold-Up to Fit Into the Launcher



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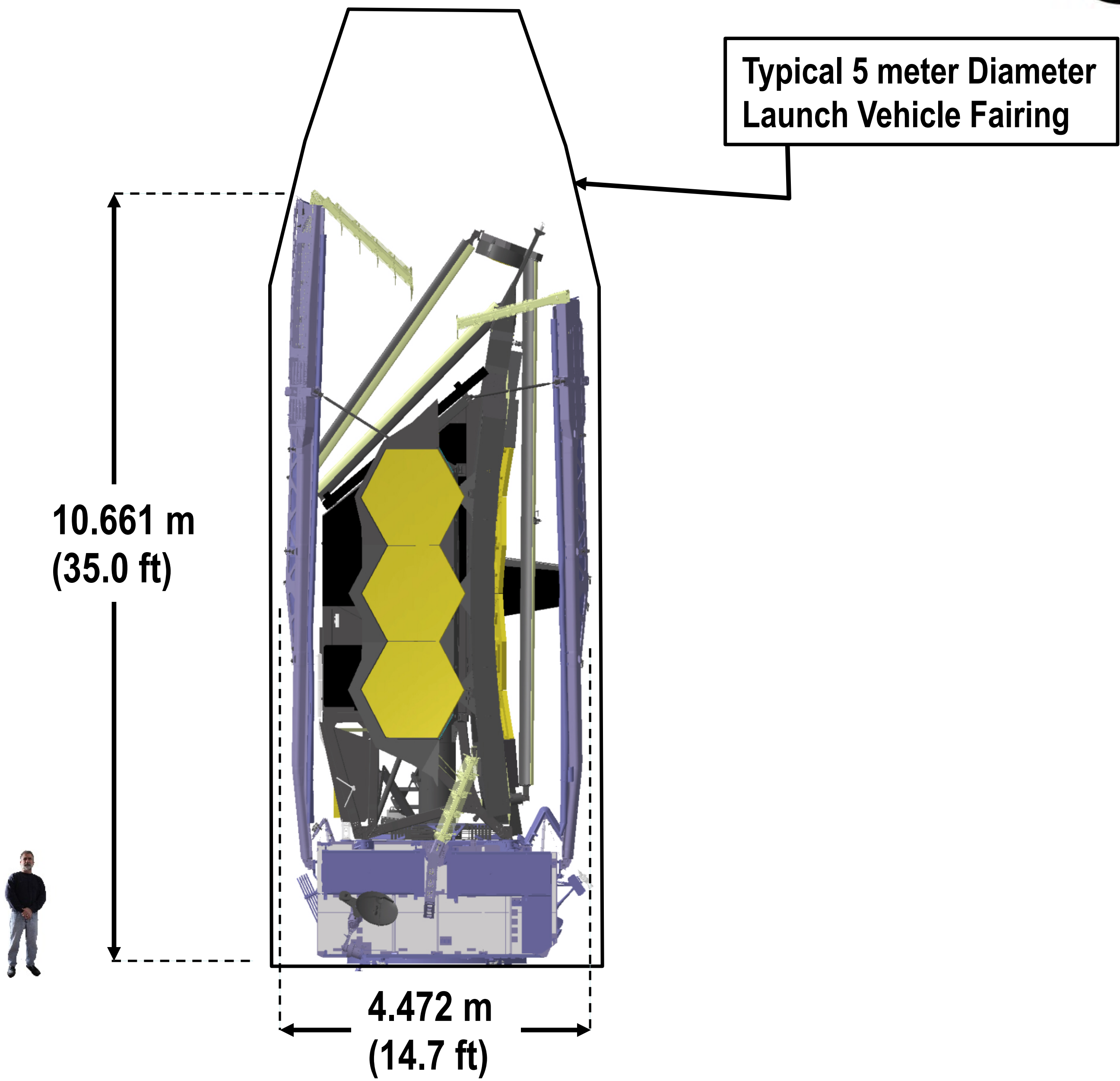
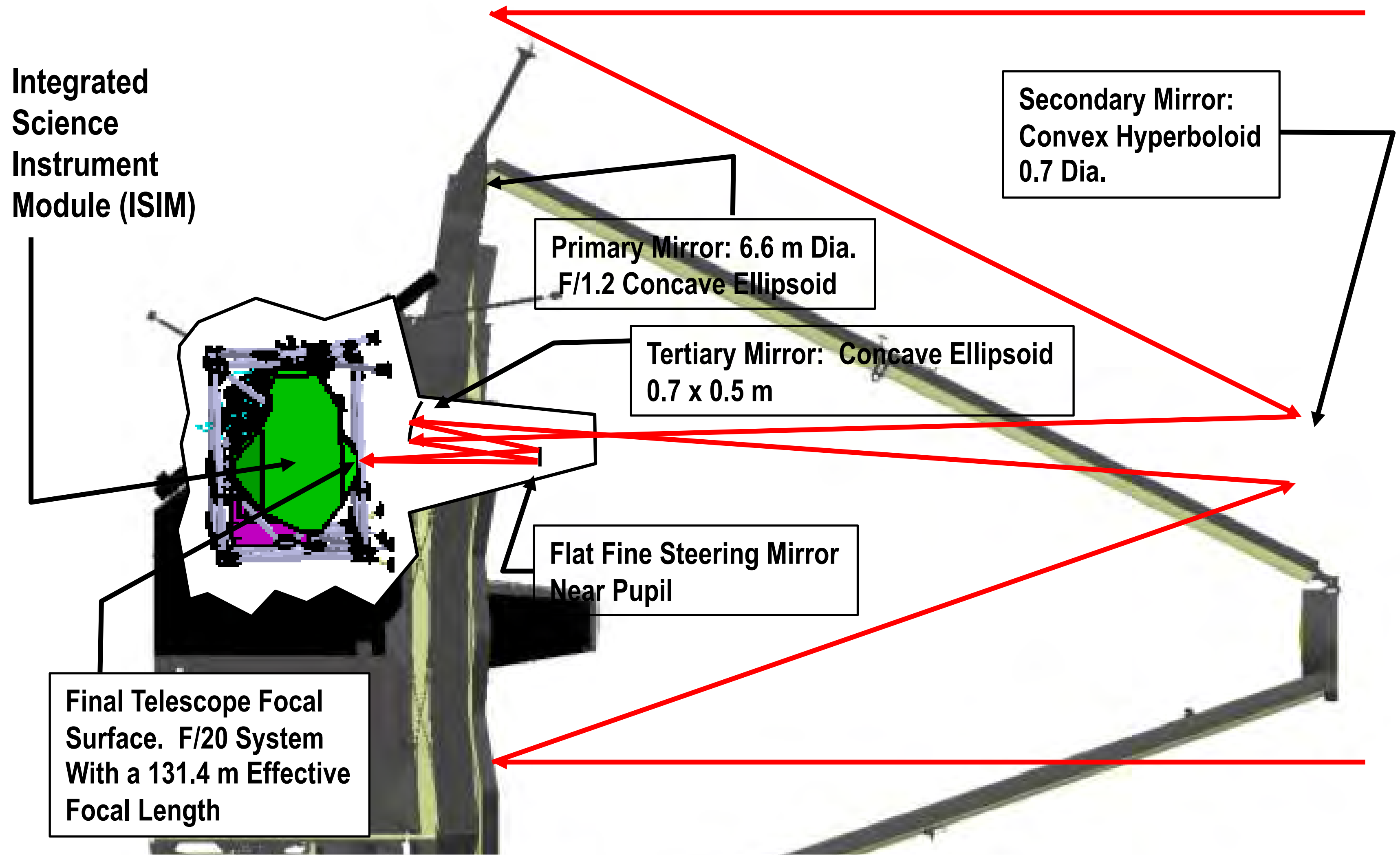
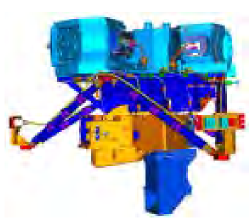
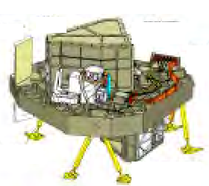


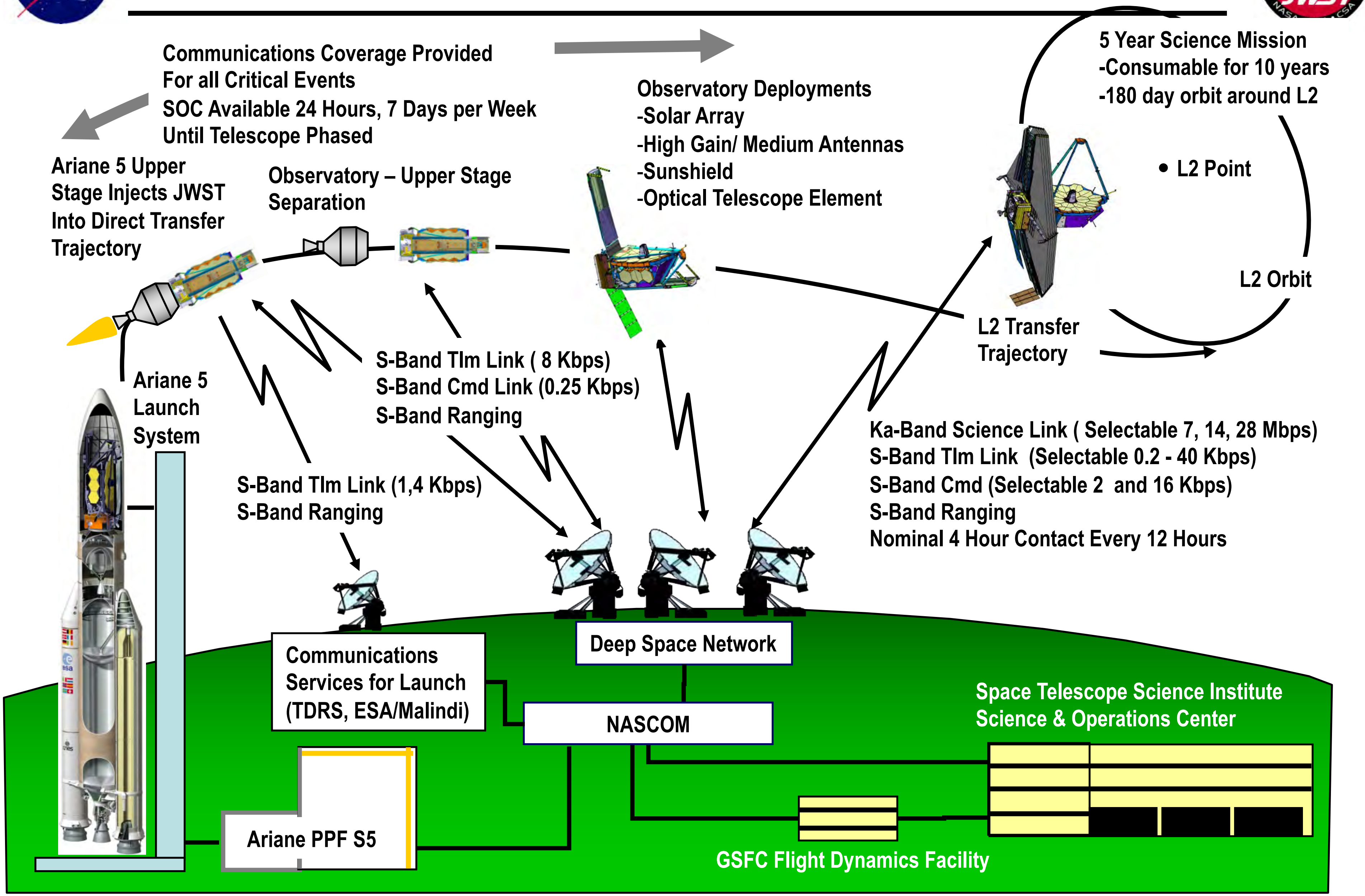
The JWST Tri-Mirror Anastigmatic Telescope



JWST Science Instrument Compliment

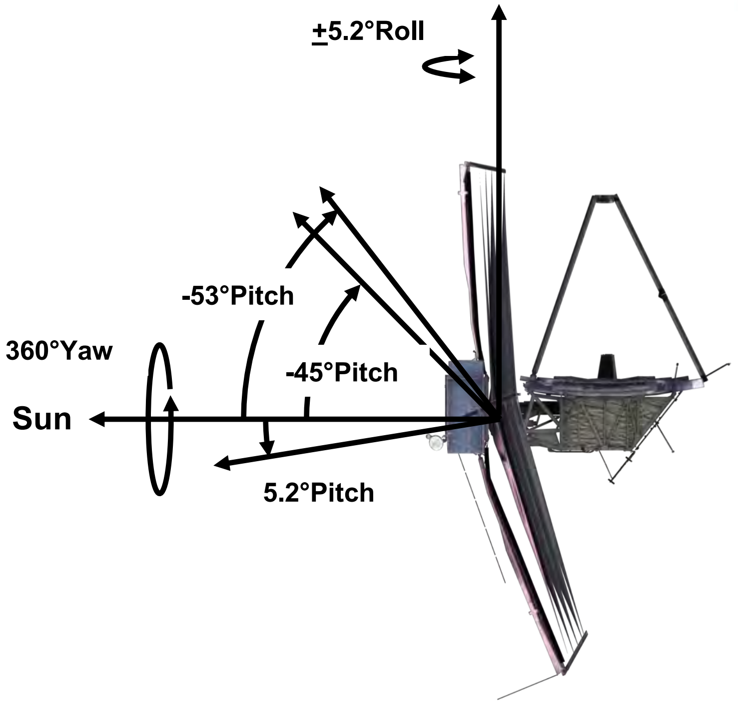
Science Instrument	Science Functions	Design Features and Capabilities
• **NIRCam** • **University of Arizona** 	• Wide field images with low spectral resolution. • Short Wave (SW) channels 0.6 $\mu m < \lambda < 2.3\ \mu m$ • Long Wave (LW) channels 2.4 $\mu m < \lambda < 5.0\ \mu m$ • Special filters for Wave Sensing and Control	• Two redundant modules each with one 2' x 2' SW images and one 2' x 2' LW image • Eight HgCd Te 2048 x 2048 pixels SW detectors and two 2048 x 2048 pixel LW HgCdTe detectors. 18 μm pixel pitch • Refractive optics
• **NIRSPec** • **ESA** 	• Multi-Object spectroscopy, 100 simultaneous spectra • Waveband 0.6 mm < λ < 5.0 mm • Medium to High resolution spectral resolution (R = 100 to 1000)	• Four microshutter arrays each with 171 x 365 programmable slits. Each slit aperture 0.203" x 463" • Total 9.7 sq arcmin FOV • Two 2048 x 2048 pixel LW HgCdTe detectors 18 μm pixel pitch
• **MIRI** • **ESA / JPL** 	• Mid infrared imaging between 5 mm < l < 27 mm • Single slit spectroscopy • High resolution Integral Field Spectroscopy from 4.9 mm < l < 28.8 mm	• 1.4' x 1.9' imager FOV • One 1024 x 1024 pixel Si:As detector for imager • 5" x 0.6" FOV slit spectrometer with one 1024 x 1024 pixel Si:As detector • 7" x 7" FOV Integral Field Spectrometer with 4 channel beam slicer and one 1024 x 1024 pixel Si:As detector
• **FGS / NIRISS** • **CSA** 	• Medium spectral resolution (R=100) NIR imaging • Fine guidance sensing the observatory fine pointing control system	• 2.2' x 2.2' FOV for medium spectral resolution imaging with one 2048 x 2048 pixel LW HgCdTe detector. • Two 2.3' x 2.3' FOV for fine guider using two 2048 x 2048 pixel LW HgCdTe detecors.

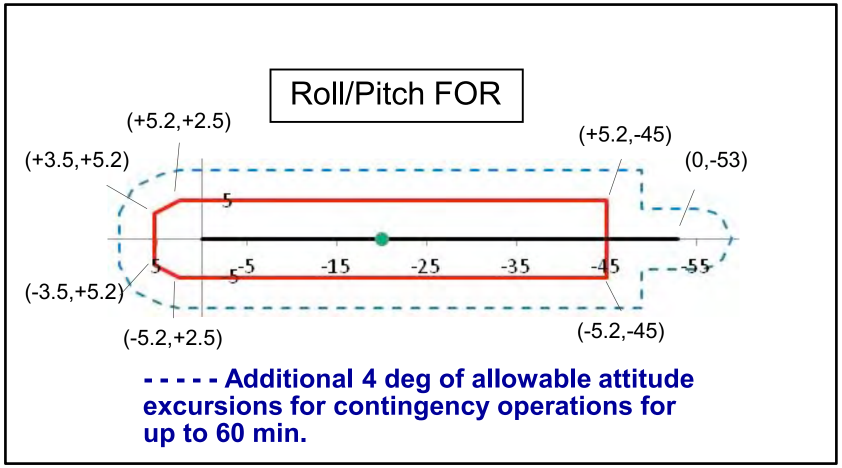
JWST System Architecture



Attitude Constraints from Sunshield Geometry

- The sunshield is designed to shield the OTE / ISIM for Pitch, Roll and Yaw angles shown on the upper right.
    - Pitch limits for science, +5.2°to -45°
    - Pitch limits for station-keeping +5.2°to -53°
    - Roll limits for science ±5.2°
    - Full 360°of Yaw
- Additional guard band of 4° is provided for contingencies for up to 60 minutes.
- The map of Field of Regard (FOR) limits is shown in the lower right.

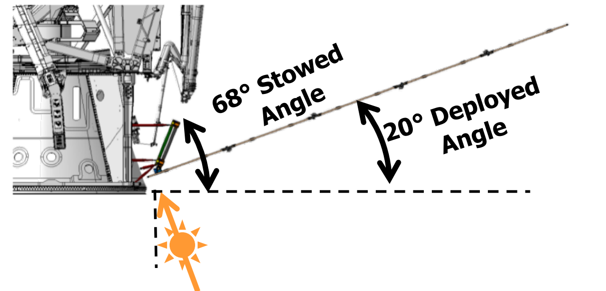




Power Subsystem Features

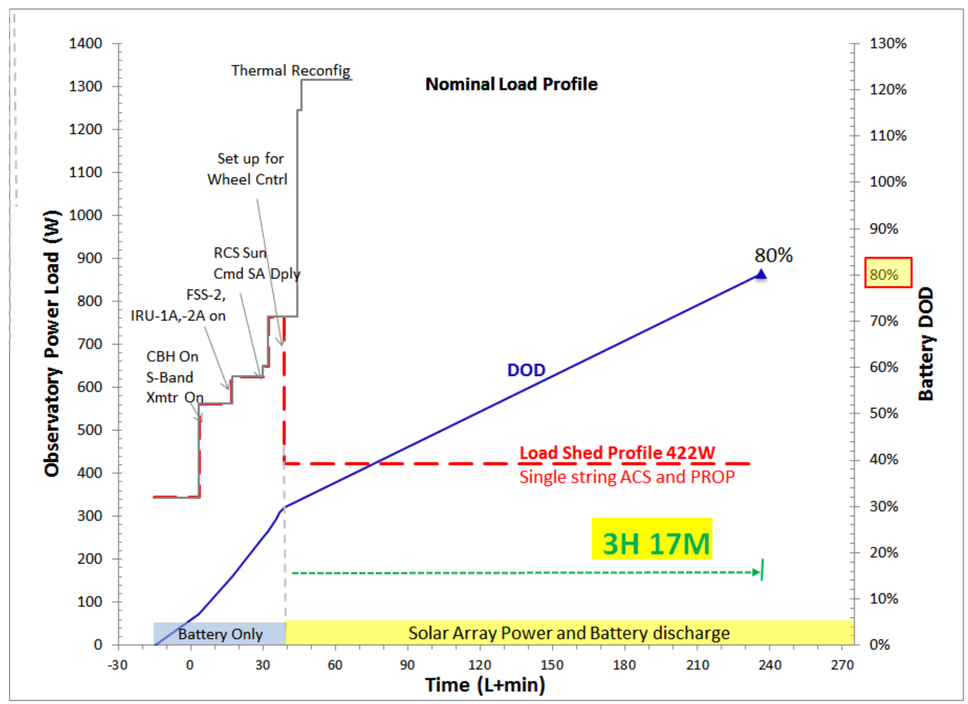
- A 5 panel solar array (SA) providing 2138 watts deployed
- One exposed outer SA panel providing 220 watts stowed
- A 52.8 Amp-hour battery
- The observatory goes to internal power from battery at L-15 min
- The SA is deployed at L+33 min
- If SA deployment is delayed, the battery provides 3 hours and 17 min of power before reaching 80% Depth of Discharge (DOD)
  - Assumes load shedding to power level of 422 watts

Sun-pointing Orientation
sun-pitch -20 °
sun-roll 0 °



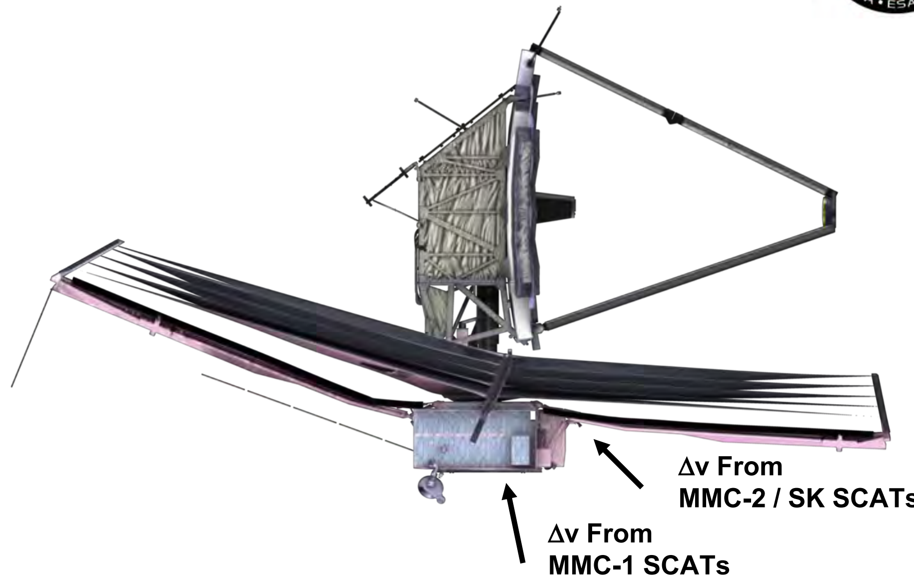
Pointing Error: 4° per axis
Alignment Error: 1° per axis
Stowed SA Offpoint from Sun = 53°

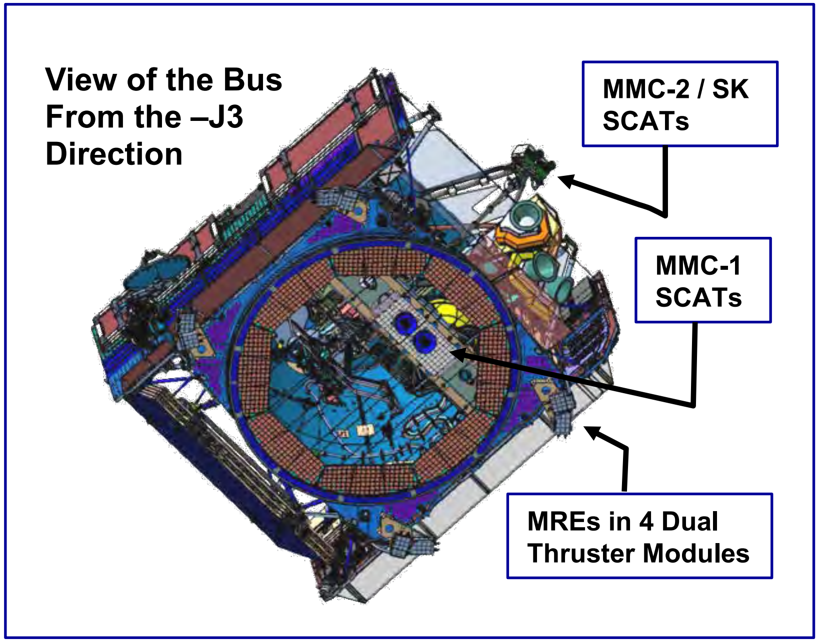
Time Reserve on Battery



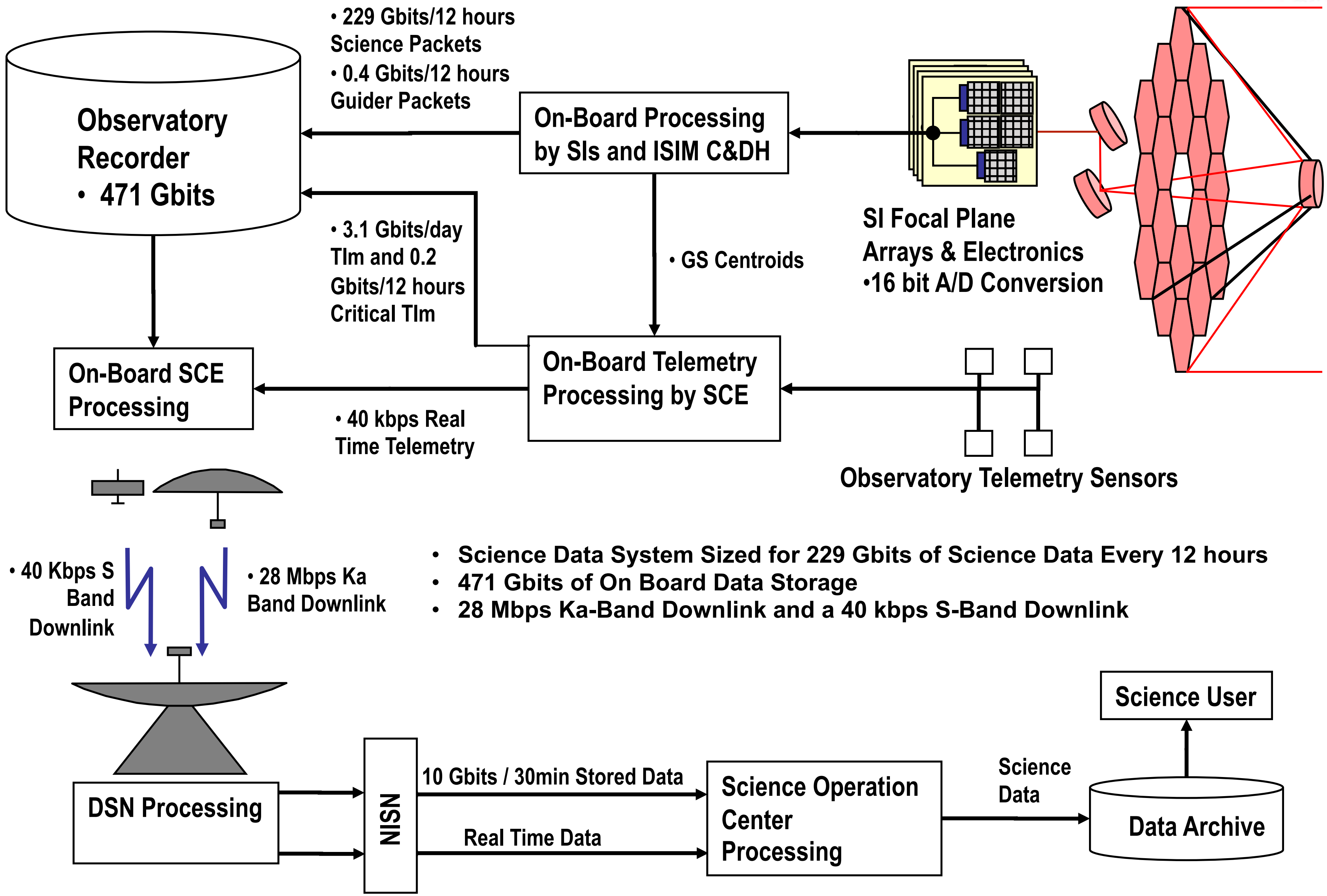
Propulsions System Features

- No thrusters on observatory cold side due to contamination, as illustrated on the right
  - No Δv's in the sunward direction
  - No "thrust-couples" to unload angular momentum in the pitch axis
  - Unloading produces a residual Δv
- Δv maneuvers are provided by two redundant sets of 5 lb Secondary Combustion Augment Thrusters (SCATs)
  - MMC-1 SCATs used for initial Mid Course Corrections (MCCs)
  - MMC-2 / SK SCATs used for final MCC and for station-keeping
- Attitude control, and momentum unloading provided by 1 lb Monopropellant Rocket Engines (MREs)
- Propulsion Subsystem contains tanks for 300 kg of propellant (fuel + oxidizer + pressurant)



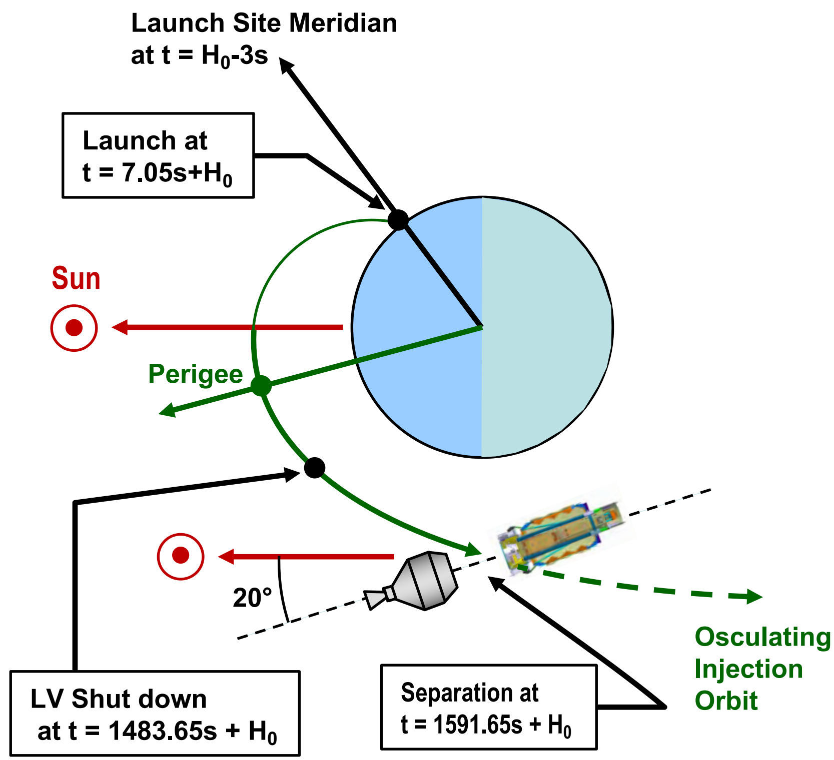


Data Downlink and Storage Capabilities



- Science Data System Sized for 229 Gbits of Science Data Every 12 hours
- 471 Gbits of On Board Data Storage
- 28 Mbps Ka-Band Downlink and a 40 kbps S-Band Downlink

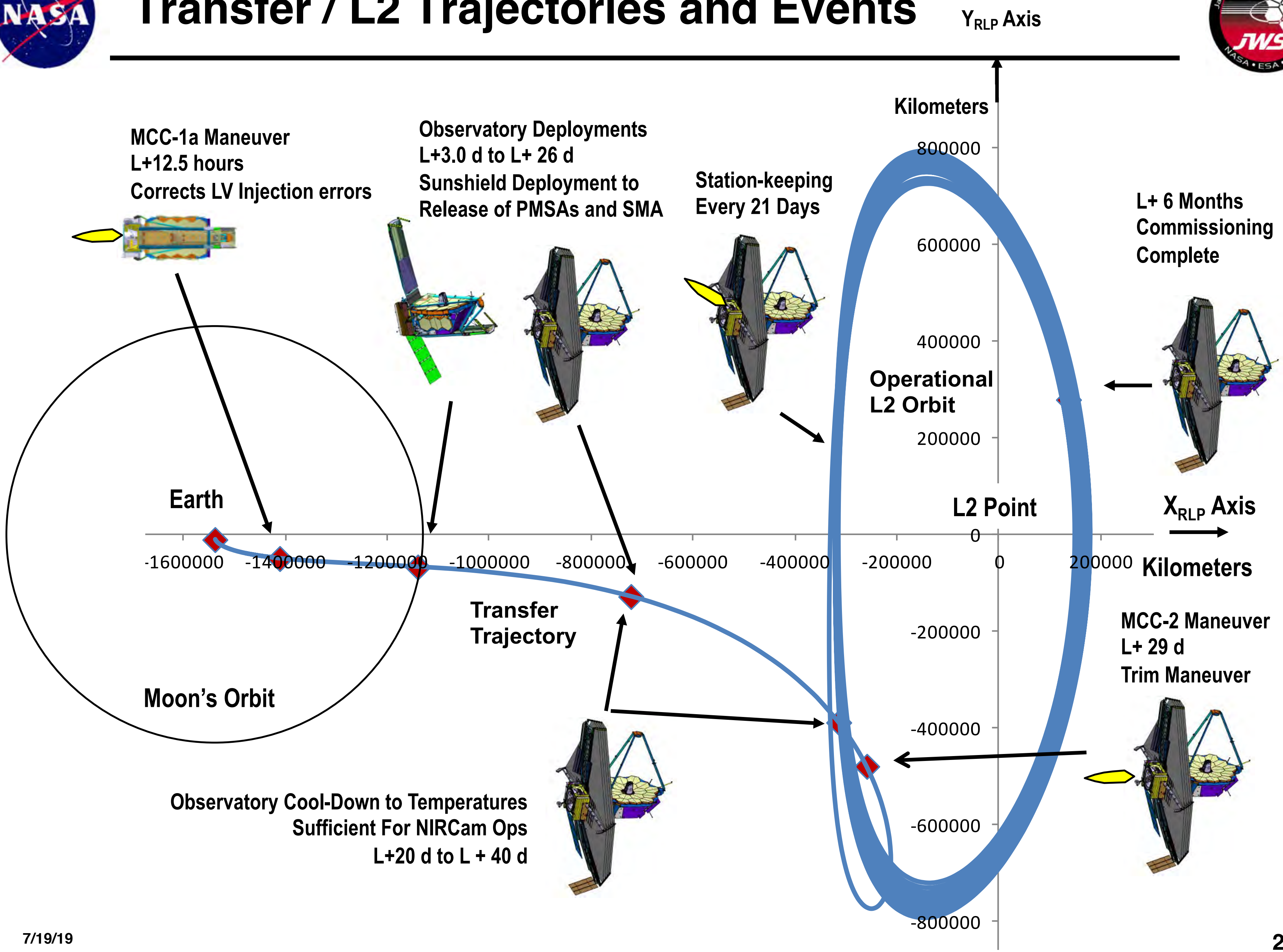
Ascent Trajectory and Events



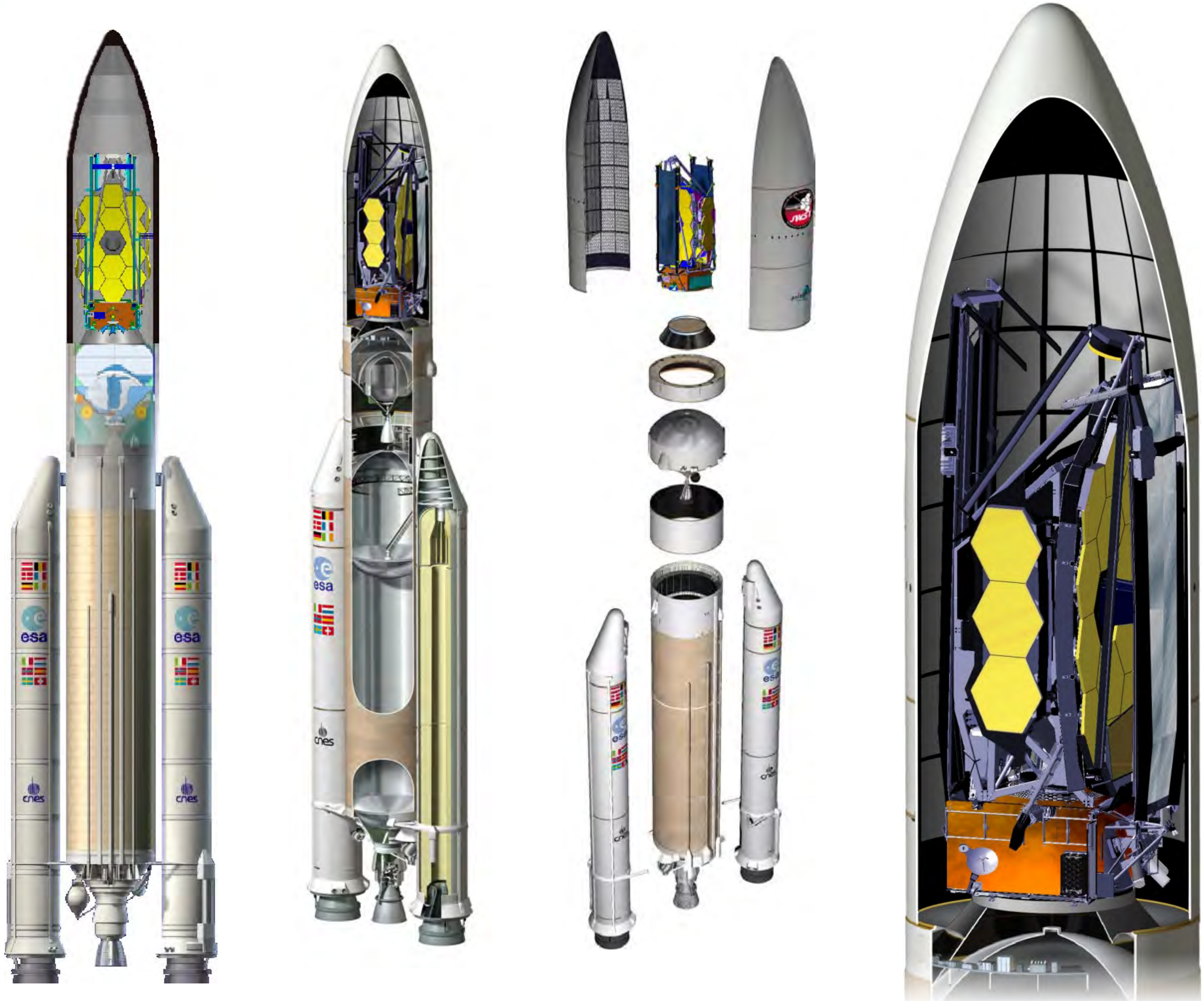
H_0 is the time of ignition of the Vulcain-2 Engine

- The Ariane 5 ascent trajectory is illustrated on the left
  - Vulcain-2 Engine ignition at H0
  - Lift-off at H0+7.05 s
  - JWST Separation at H0+1592 s
- Ariane will use either of two ascent trajectory Flight Programs (FP-2, -3) to inject JWST into its L2 transfer trajectory
  - Two FPs provide 165 valid launch dates between 10-1-2018 and 3-30-2019
  - Launch window times vs date are shown on the following chart
  - The specific FP used depends on the date
- The FPs target an Osculating Injection Orbit documented in the DCI, along with LV dispersions and covariances

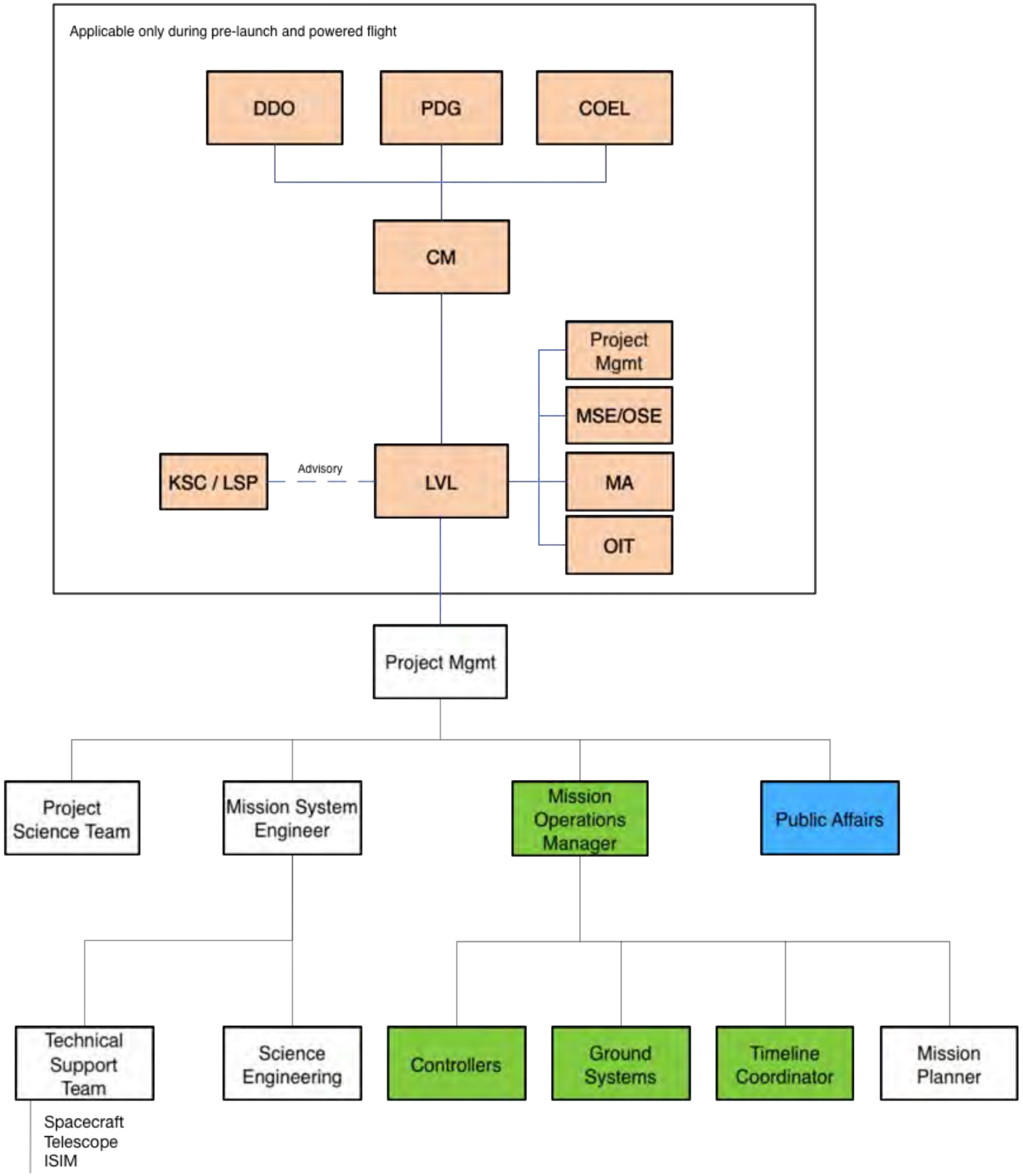
Transfer / L2 Trajectories and Events



Ariane Launch



Pre-launch and Go / No-Go Communications



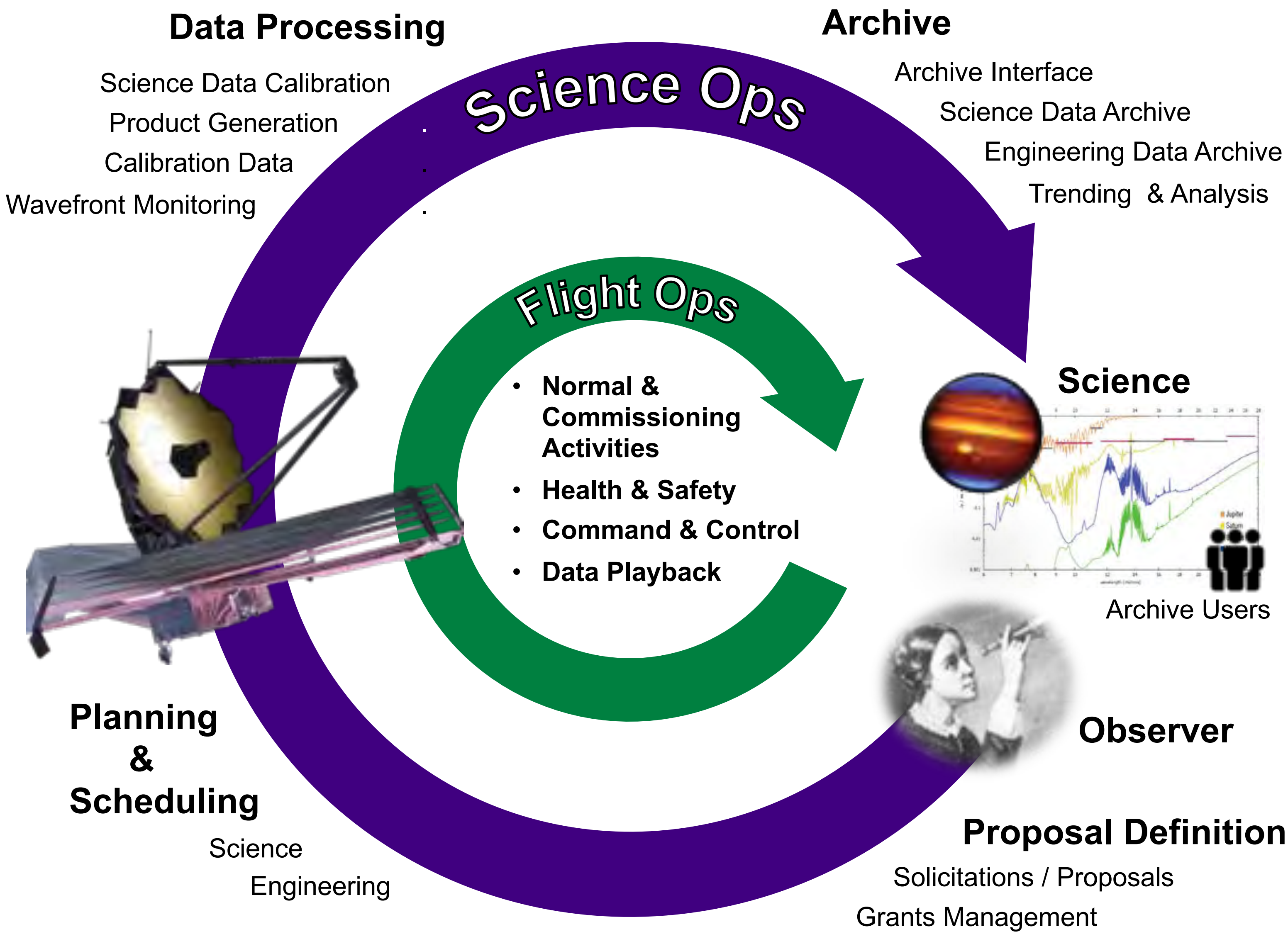
Physical Location

- Flight Control room
- Back room
- Media Center
- Launch Site

LVL	Launch Vehicle Liason
MA	Mission Assurance
OIT	Observatory I&T
CM	Arianespace Mission Director
DDO	Range Operations Director
COEL	Launch Site Operations Manager
PDG	Arianespace Chairman/ CEO
KSC/LSP	Kennedy Space Center Launch Service Program

MISSION OPERATIONS

Science and Flight Mission Operations



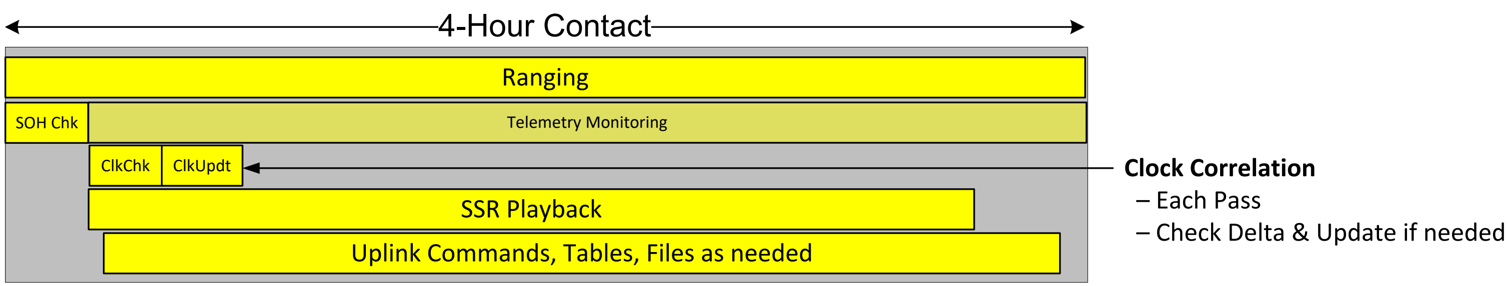
Mission Activities

- **Mission activities are performed to conduct the common functions of the observatory**
  - Well established operations concepts
  - Practiced through rehearsals and other training activities

Activity	Frequency
Contact	Daily x2
Ranging	Each Contact
Data rate changes	As needed
Clock correlation	Each Contact
Recorded data playback	Daily x2
Momentum unloading	As needed
Calibrations	Various
Slews	As needed
Stationkeeping	Every 21 days
OTE temperature collection	3 instances during commissioning; As needed for normal operations
Wavefront Sensing & Control	2 days sense, 14 days correction
Ephemeris updates	Weekly as needed
Contact Schedule updates	Weekly as needed
Observation Plan updates	Weekly as needed

Contact Execution

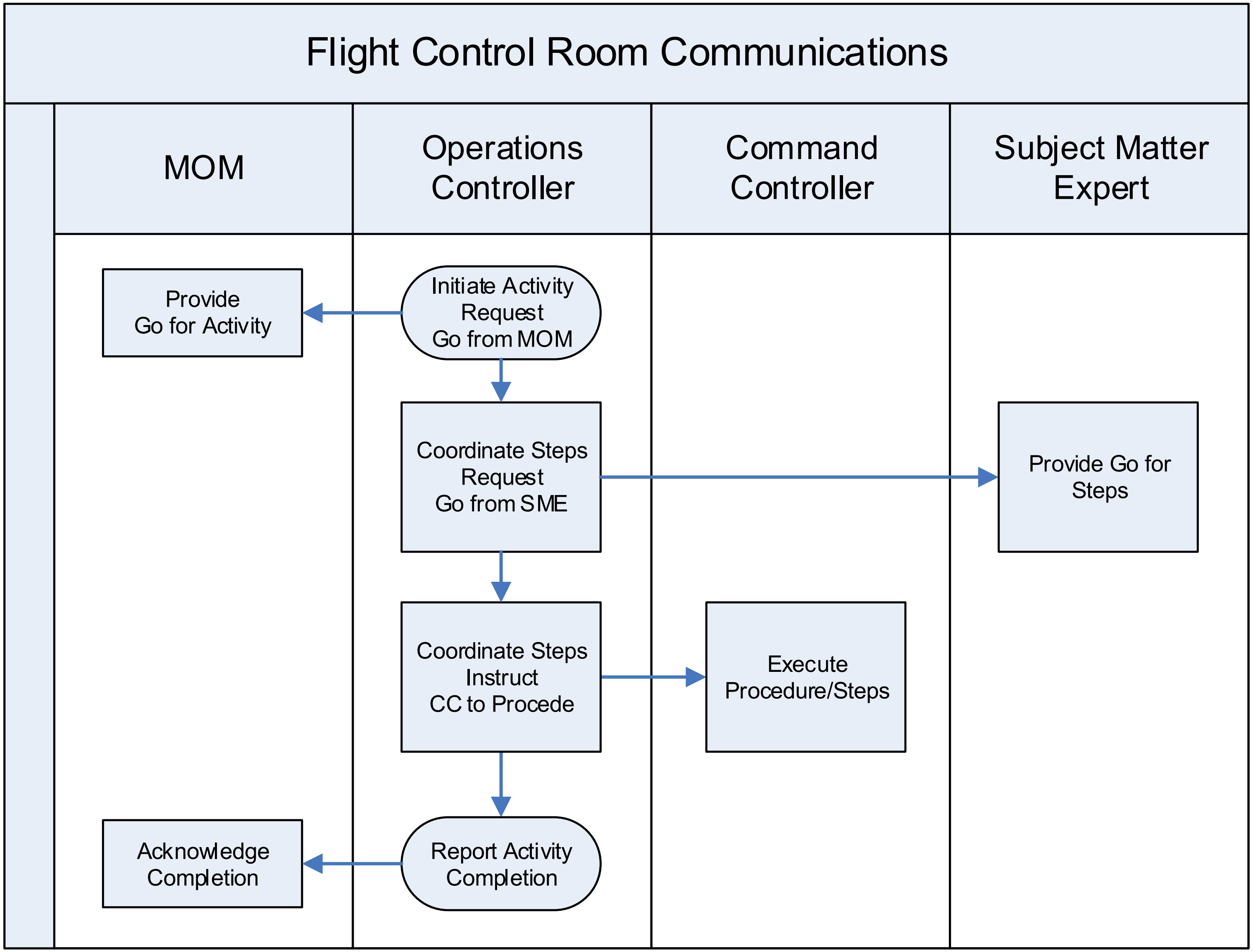
- **Normal Ops: Two 4-hour contacts per day**
- **Real-time Contact Operations**
  - Most activities performed in parallel with science observation



Activity	Parallel w/ OSS	Frequency
SSR Playback	Yes	Every Contact
Clock Correlation	Yes	Every Contact
Ranging	Yes	Every Contact (continuous)
Ephemeris Upload	Yes	Every 7 Days
DSN Contact Schedule Upload	Yes	Every 7 Days
Observation Plan Upload	Yes	Every 7 Days
Mirror Adjustment File Upload	Yes	Every 14 Days
Station Keeping	No	Every 21 Days
FSW Updates	No	As Needed

OSS = Operations Scripts Subsystem
SOH = State of Health

Flight Control Room Communications



Data Rate Transitions & Ranging

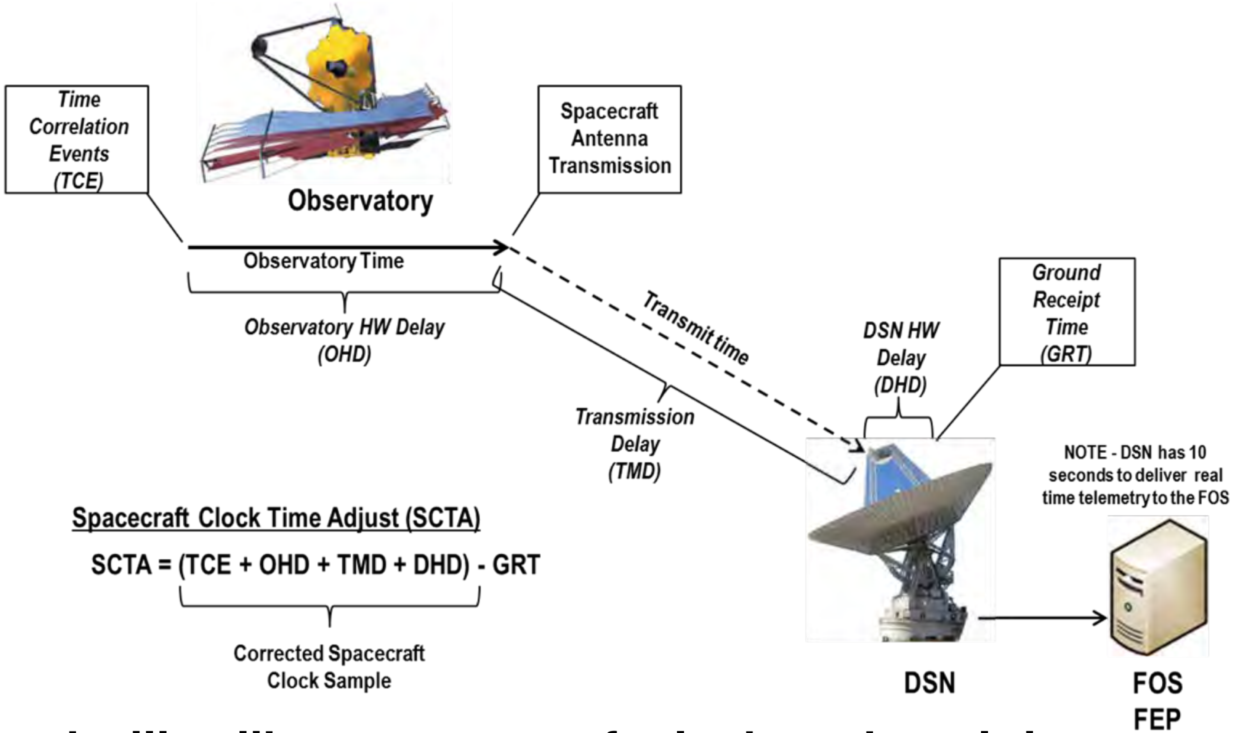
Mode	Asset	Command Data Rate	Telemetry Data Rate	Ranging
Nominal Operations	DSN	16 Kbps	40kbps	Yes
Safe Haven	DSN	250 bps	1Kbps	No
Survival	DSN	250 bps	1Kbps	No

- **Real-time telemetry rate transitions**
  - Only predetermined combinations are allowed, executed via Real-Time Command Procedure (RTCP) to assure proper/repeatable configurations
- **Ranging**
  - Enabled as early as possible (after establishing first contact)
  - Remains enabled continuously and data is collected at each DSN contact
- **Safe Communication Configuration**
  - Safe Haven and Survival disable ranging
  - Safe Comm is a known configuration used for contingencies, similar to launch configuration

Comm = Communication

Clock Correlation

- **Spacecraft clock:**
  - Outputs latched time in telemetry for comparison to Ground Time

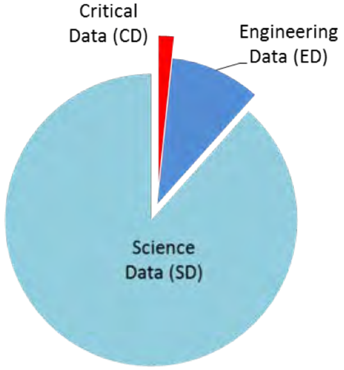


- **Ground will calibrate spacecraft clock each real-time contact**
  - FOS derives the Spacecraft Clock Time Adjust (SCTA) using known/deterministic delays
  - A command procedure determines when/if time needs adjustment

FOS = Flight Operations System
FEP = Front End Processor

Recorded Data Playback (1/3)

- **Critical Data (CD)**
  - Small subset of ED which can be used in support of anomaly resolution and recovery
  - Default partition size: 562 Mb (BOL)
  - File Size (physical): Contents of partition
  - Record rate of 2kbps
  - Time to fill partition: ~78 hours



- **Engineering Data (ED)**
  - State of Health (SOH) data from ISIM (including FGS) and spacecraft (including OTE)
  - Default partition size: 16.5 Gb (BOL)
  - File Size (physical): 140,509,184 bits
  - Nominal record rate of 95kbps (40kbps SC + 55kbps ISIM)
  - Time to fill partition: ~48 hours

- **Science Data (SD)**
  - Image data acquired by ISIM from science instrument focal planes
  - Default partition size: 532.5 Gb (BOL)
  - File Size (physical): 1,040,097,280 bits
  - Peak record rate of ~53Mbps \ average record rate ~2Mbps
  - Memory allocation managed by science instrument schedule to accommodate ~48 hours of science without playback

BOL = Beginning of Life
FGS = Fine Guidance Sensor
Kbps = kilobits per second
Mbps = Megabits per second

Momentum Unloading

- **Nominal Momentum Unloading**
  - Planned and managed by the Proposal Planning System
  - Executed by the Observation Plan

Unload Type	Command Used
Planned Normal	Full MU Command to Zero State
Planned Partial	Partial MU Command
Planned Biased	Full MU Command to Biased State
Autonomous	Full MU Command to Zero State
Real-Time	Full or Partial MU Command
Contingency	Not Commanded

MU = Momentum Unload
ACS = Attitude Control System

Engineering Calibrations

Calibration	One time	Periodic
IRU Calibrations	X	
Star Tracker Misalignment.	X	
Fine Sun Sensor Calibration	X	
Momentum Storage, RWA Cluster Performance	X	
Solar Torque Characterization	X	*
High Gain Antenna / BAGA Calibration	X	
Heater Set Points	X	
JWST First Light or Initial Boresight	X	
Fine Steering Mirror Calibration	X	
Solar Array Data Gather		X
Wave front Sensing Calibration		X
Cryocooler Image Motion Assessment & Cooler Frequency Sweep		X

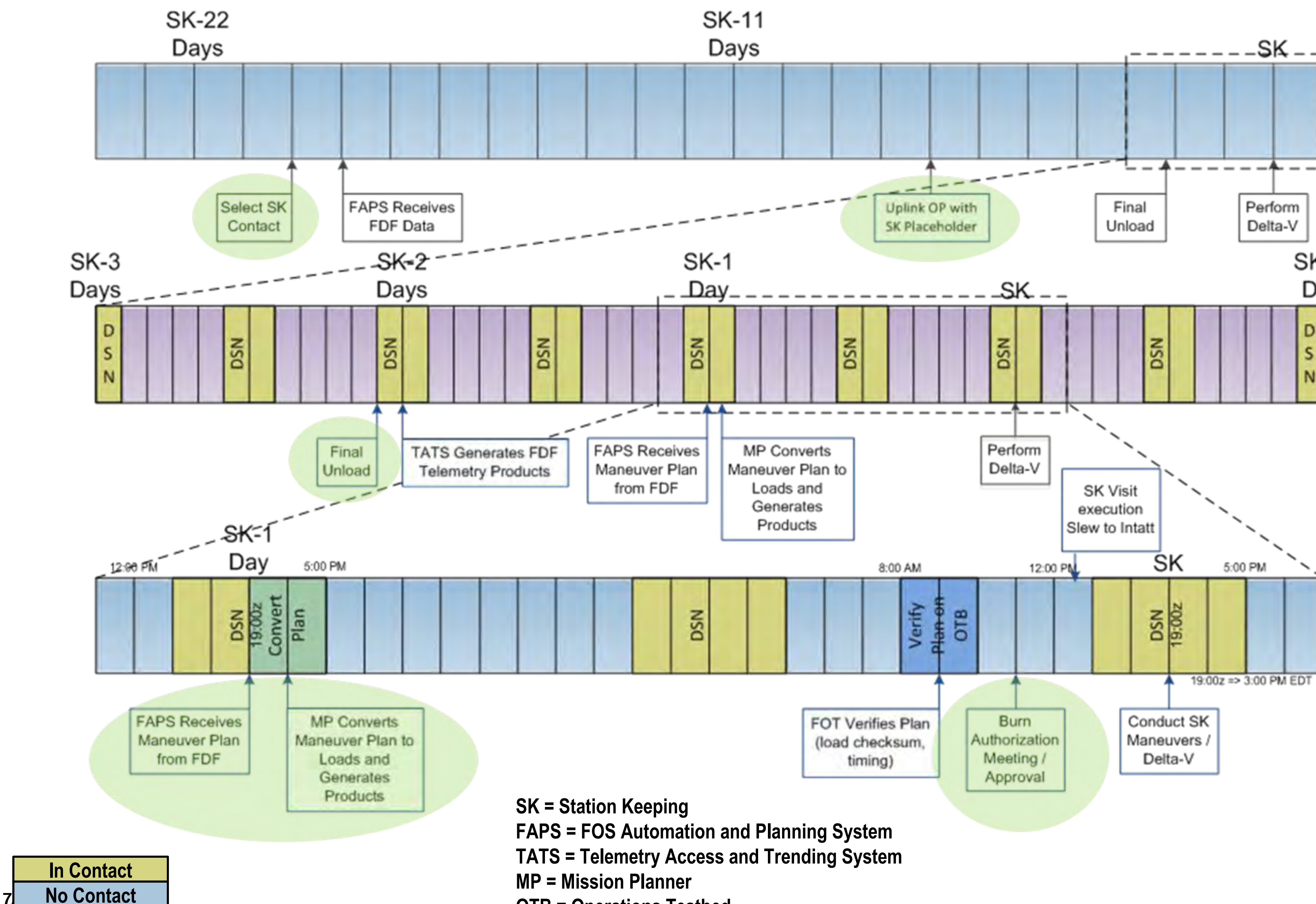
- **One Time calibrations are planned for commissioning**
- **Periodic calibrations will be repeated during normal ops**
  - (*) Solar Torque Calibration is an explicit activity during commissioning but only a periodic collection of data from science attitudes during normal ops

IRU = Inertial Reference Unit
RWA = Reaction Wheel Assembly
BAGA = Bi Axial Gimbal Assembly

Slews

- **Nominal Ops – All slews are managed by OSS Observation Plans and executed by the Attitude Control System (ACS)**
- **Slew**
  - Activity that changes the vehicle pointing to observe a new target at the start of a visit
  - Can be commanded from the ground if needed (used during commissioning)
- **Small Angle Maneuver (SAM)**
  - Activity that changes the vehicle pointing to correct the attitude or to observe a spatial pattern on the sky ($\leq$ 254 arcsec)
  - Also known as “offset maneuvers”

Station-Keeping Timeline



SK = Station Keeping
FAPS = FOS Automation and Planning System
TATS = Telemetry Access and Trending System
MP = Mission Planner
OTB = Operations Testbed

OTE Temperature Collection

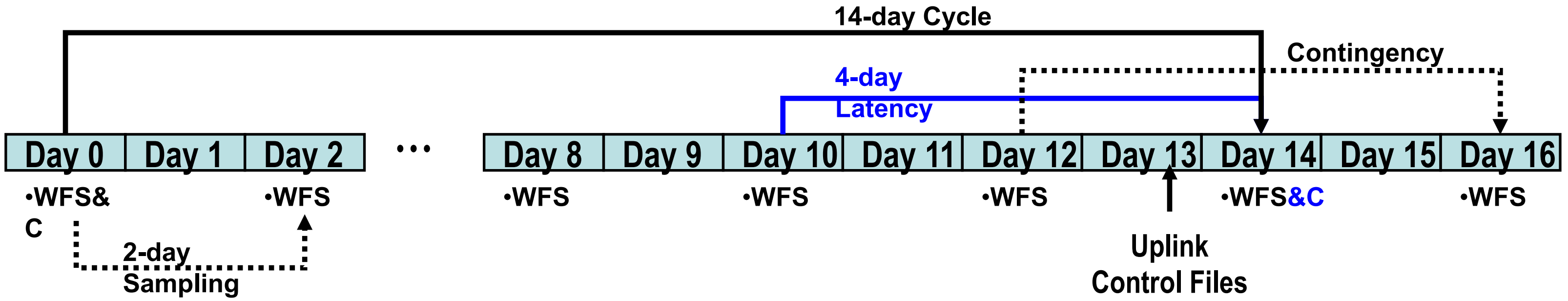
ADU = Actuator Drive Unit
PMSA = Primary Mirror Segment Assembly
WFS&C = Wavefront Sensing and Control

- **OTE temperature measurements**
  - Over 400 temperature sensors
  - ADU is commanded to collect any temperature once per second
- **Commissioning Ops**
  - Ground activates SCS to acquire temperature readings from OTE 3 times during commissioning (1) Before PMSA deployments (2) Before WFS&C begins (3) Before science begins
  - OTE temp data stored to the SSR & played back from ED partition
- **Nominal Ops**
  - Performed as needed based on commissioning recommendations
  - Data used to correlate with and assist in determining the stability of the optics
  - Collection of temperature data will be executed by the observation plan during the slews to targets
  - OSS activates SCSs which have predefined patterns of temperature monitoring regions

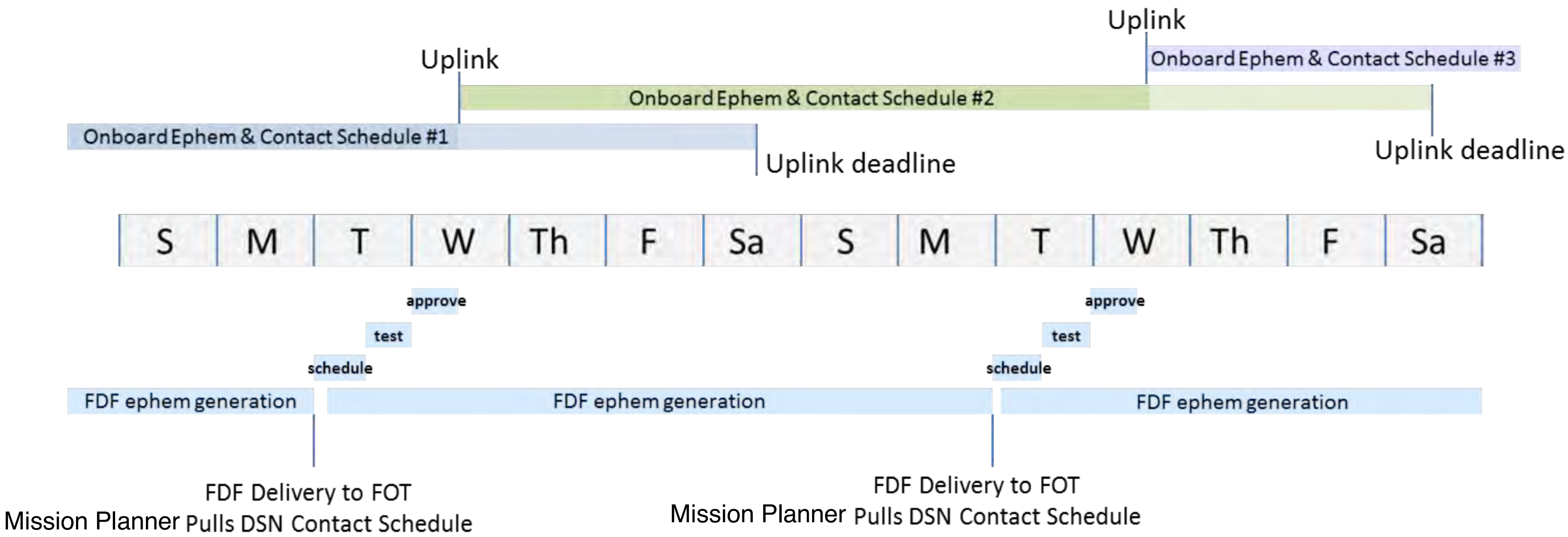
Wave Front Sensing & Control (WFS&C)

- **Wavefront Sensing (WFS) - 2 day cadence**
  - Cadences will be adjusted based on in-flight experience as part of regular calibrations planning

- **Wavefront Control (WFC) - 14 day nominal cadence**
  - Periodic mirror control will continue as needed throughout the lifetime of the mission
  - WFSC team will review & trend results and decide when corrections are necessary



Ephemeris and Contact Schedule Updates



*Every third week the ephemeris uplink will be accompanied by a Station Keeping maneuver

- Both are normal memory loads
- Loaded together with same duration
- Must overlap as S/C performs a continuity check

Observation Plan Updates

- While the Observation Plan is executing, the contents of the plan to be added to, deleted from, displayed, started, and stopped
  - Add to the plan
  - Show the plan
  - Stop plan after visit
  - Stop plan after group
  - Cancel stop
  - Clear the plan
  - Delete visits after
  - Stop the plan

Onboard Plan

Visit C	Visit D	Visit E	Visit F	Visit G	Visit H	Visit I	Visit J	Visit K	Visit L	Visit M	Visit N	EOP

Delete After Visit F

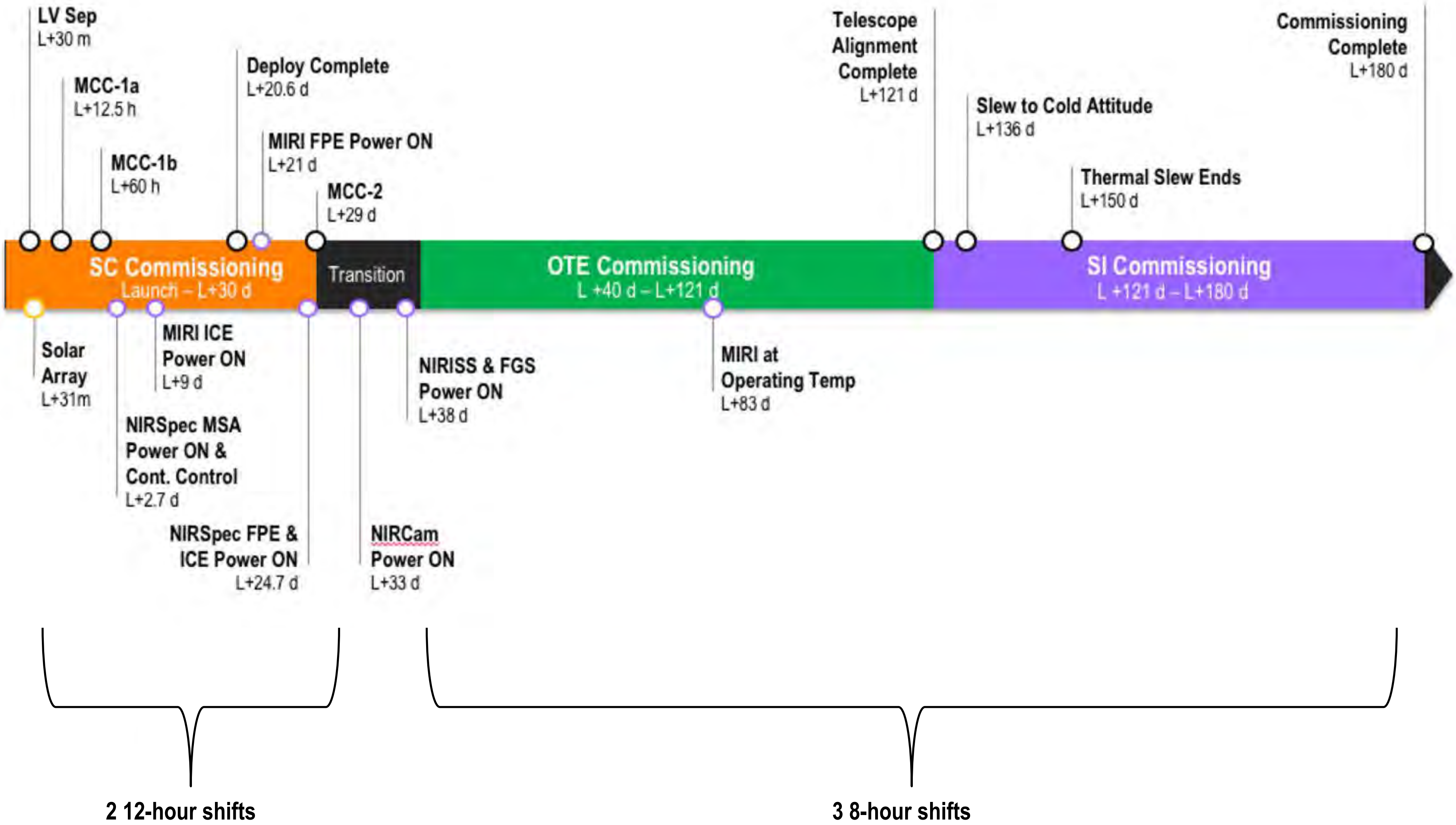
Visit C	Visit D	Visit E	Visit F	EOP

Add to Plan (OP segment file x [O, P])

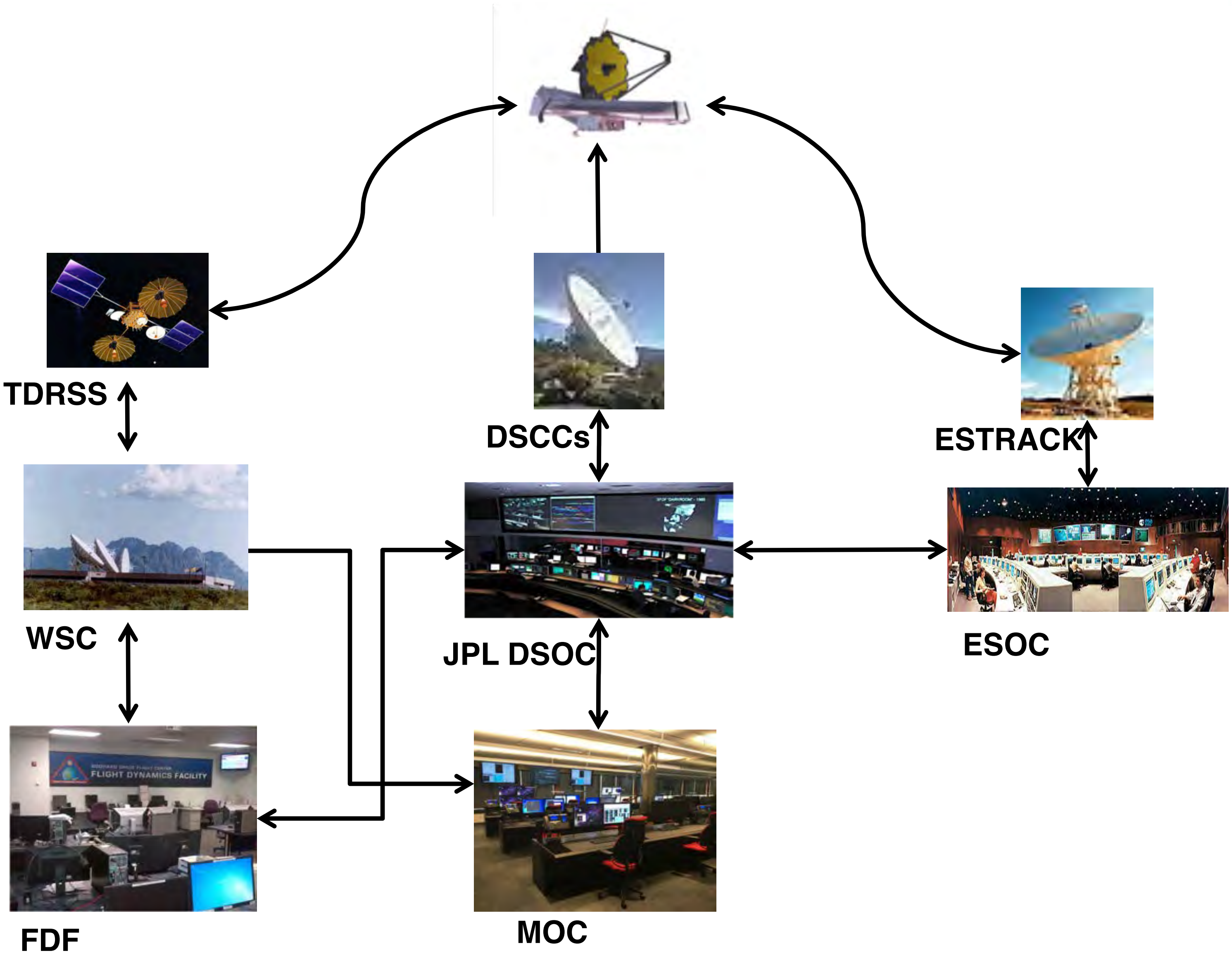
Visit C	Visit D	Visit E	Visit F	Visit O	Visit P	EOP

JWST COMMISSIONING

JWST Commissioning Timeline Overview

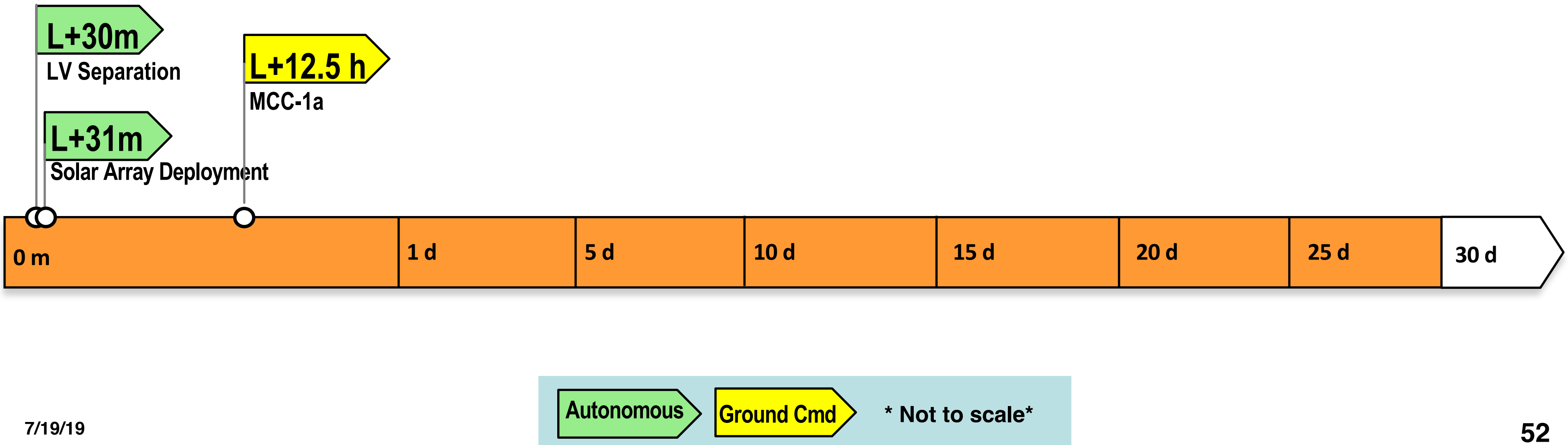


Launch Day Communications with JWST



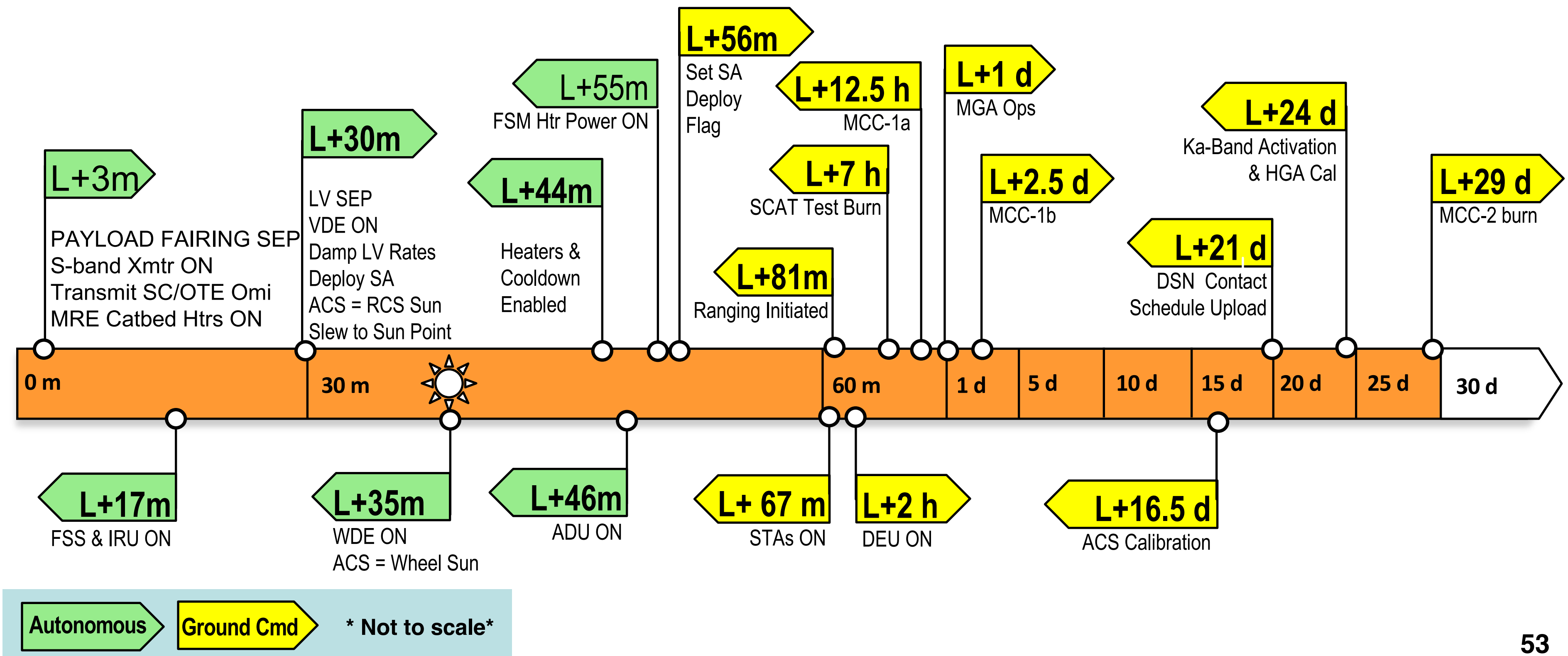
Time Critical Activities

- Time critical activities require successful execution during a precise time window that if missed, may result in either a loss or severely degraded mission
- JWST has the following three time critical activities:
  1. Separation from the Launch Vehicle
     - SCS configures the S/C for rate damping and sun acquisition
     - Autonomous triggered via LV breakwire separation
  2. Solar Array Deployment
     - Establishes a power positive system
     - Autonomously commanded via SCS
  3. First Mid-Course Correction (MCC-1a) Maneuver
     - Trajectory maneuver to get to L2, while preserving delta-V budget
     - Commanded via the ground



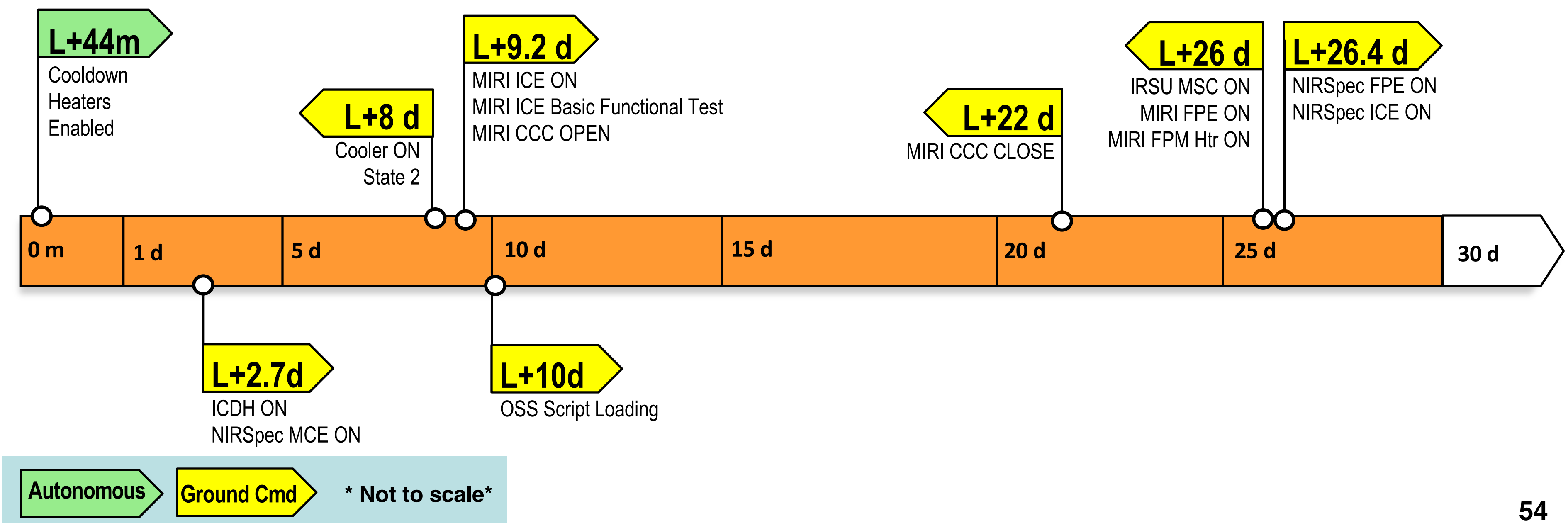
Early Engineering Activities

- **The following components are operational at Launch:**
  - **Computer and solid state recorder (SSR)**
  - **Electrical power subsystem (on battery @ L-15 min)**
  - **S-band receivers**
  - **Propulsion heaters enabled (except catbed Htrs)**
  - **ISIM Remote Sensing Unit (IRSU)**
- **An incremental activation approach used to minimize load on battery**
- **Majority of S/C engineering activities take place within the first 24 hours after Launch**

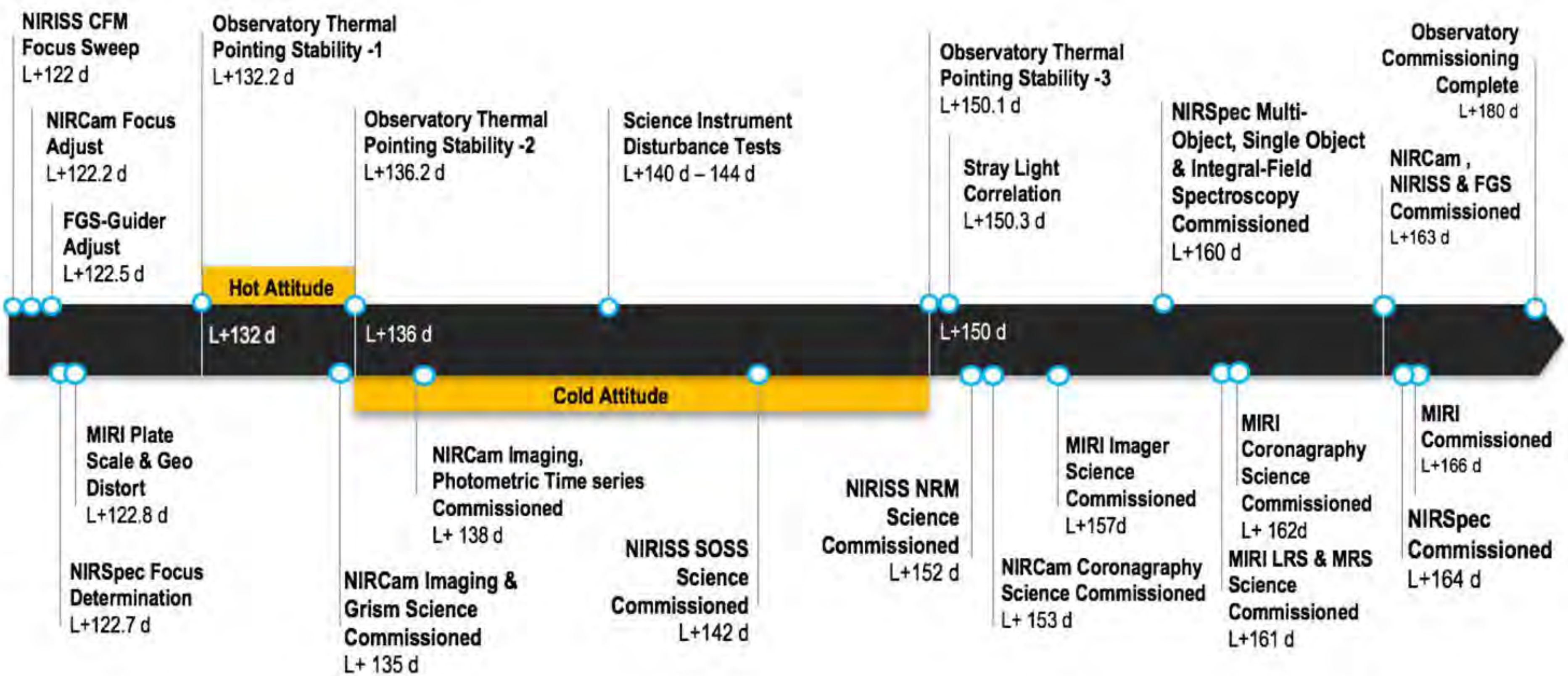


Thermally Driven Activities

- **NIRSpec MSA Temperature:**
  - **> 240K: Power ON ICDH, NIRSpec MCE**
- **MIRI Bench Temperature:**
  - **Between 300-200K Power ON MIRE ICE, ICE Basic Functional Test, Open CCC**
  - **Between 185-180K Close MIRI CCC**
  - **Between 200-160K Power ON IRSU MSC, MIRI Focal Plane Electronics, MIRI Focal Plane Mirror heater**
- **NIRSpec FPA Temperature:**
  - **> 80 K: Power ON NIRSpec FPE, NIRSpec ICE**



Instrument Activities cont.



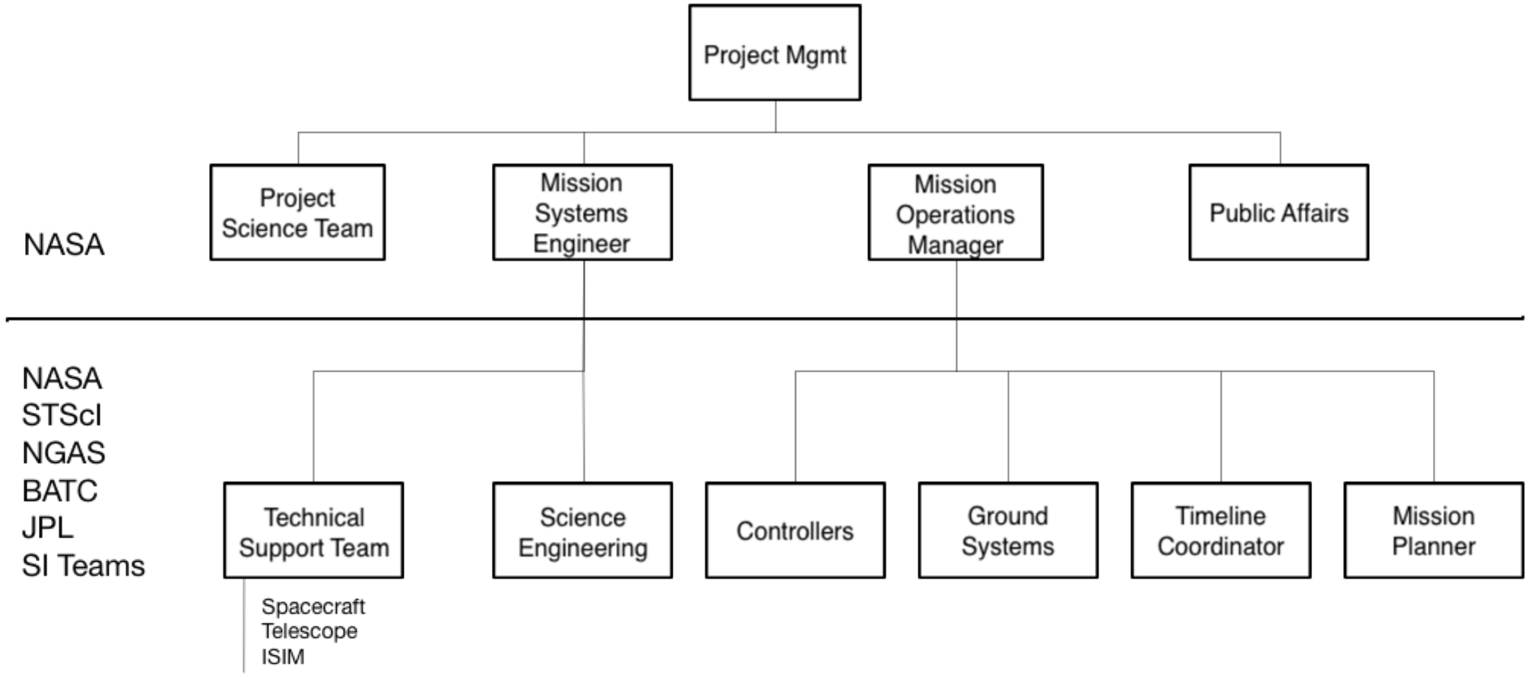
Mission Operations Team

- **Mission Operations Team**
  - Mission Operations Team (MOT) consists of the flight operations team at STScI, instrument teams, GSFC, contractor engineers and project management
  - Members and team leads of the MOT have been identified and assigned to Mission Operations Center (MOC) rooms from which they will support commissioning
  - Currently, the MOT leads are making shift assignments, developing specialist handbooks, and reviewing flight products

Establishing Mission Operations Team (MOT)

- NASA – directs flight operations: pre-launch, commissioning, post commissioning
- STScI – provides flight operations team (FOT), science operations team (SOT), MOC and S&OC resources
- NGAS and BATC – provide the Spacecraft / Sunshield / OTE engineering expertise
- JPL – provides cryocooler support
- SI Teams – provide instrument expertise

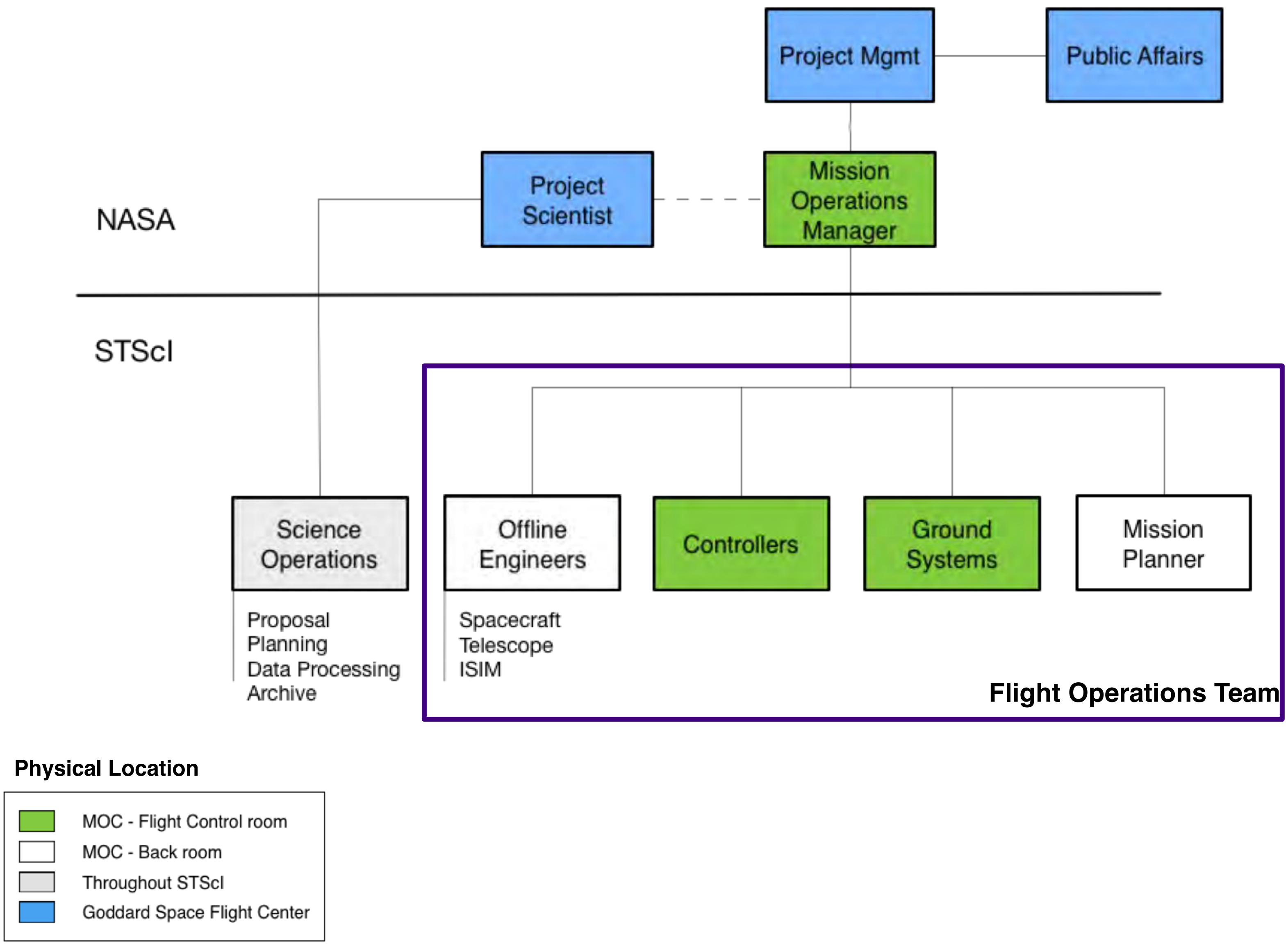
~550 people



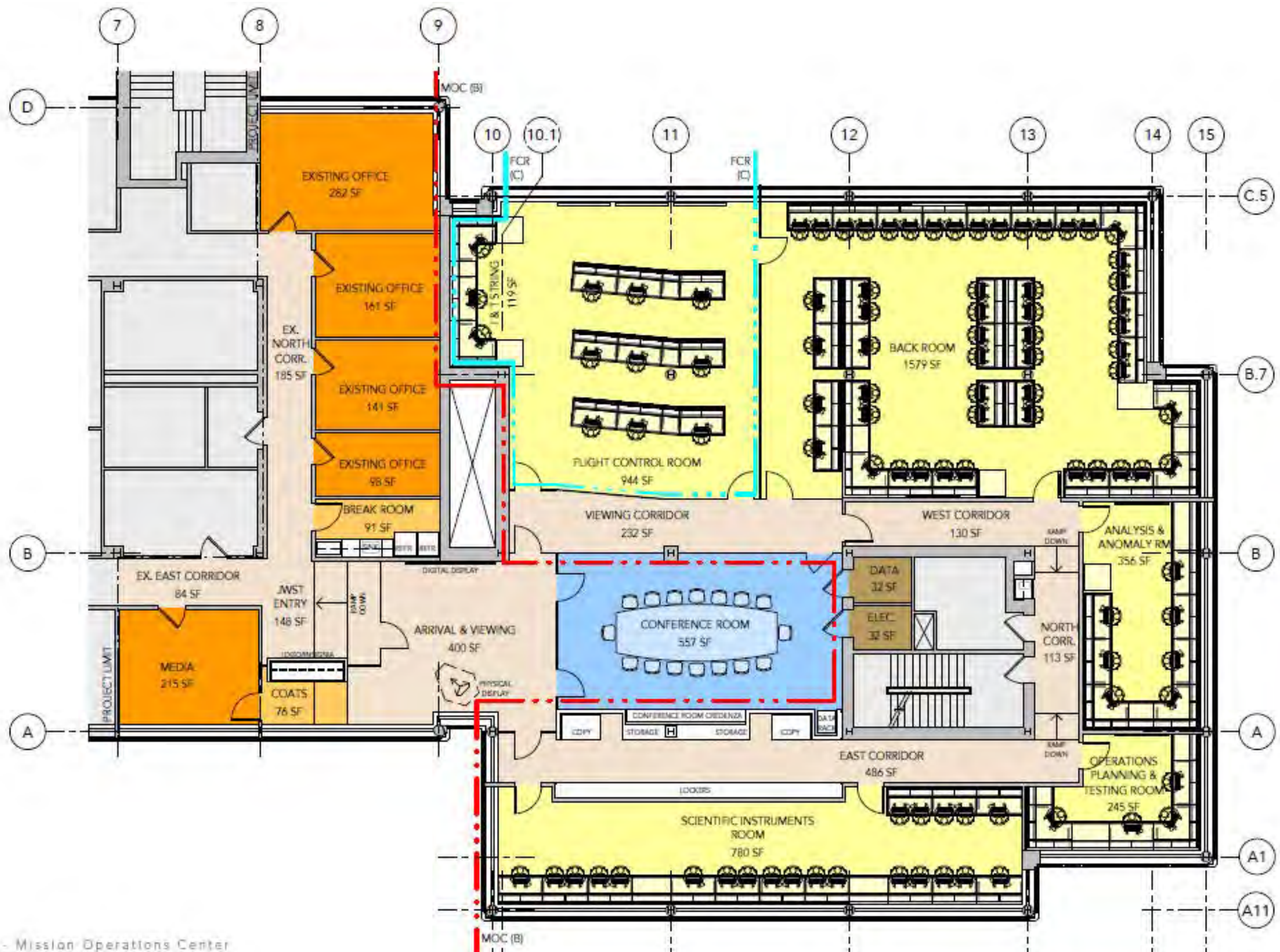
Commissioning Shift Strategy

- **There will be a minimum of 2 people on console per position**
  - Resources are available if MSE requires more support; e.g., deployments
- **We will run 2 12-hour shifts from L-3 days through MCC-2 (L+29 days)**
  - 12 hours on console
  - Purple shift and green shift (identical in capabilities for contingency response)
  - Deployments are conducted on day shifts with purple crew
  - Planning and preparations for next major activities via green crew
- **After MCC-2 activities we move to 3 8-hour shifts**
- **Some teams rotate amongst shifts; e.g., anomaly coordinator**
- **Throughout commissioning, team leads will manage their positions to ensure 2 people are on console at all times**
  - Team leads will rotate their people to ensure ‘fresh’ minds and eyes are on console
  - No one is actually released until the end of commissioning

Operations – Post Commissioning



Mission Operations Center



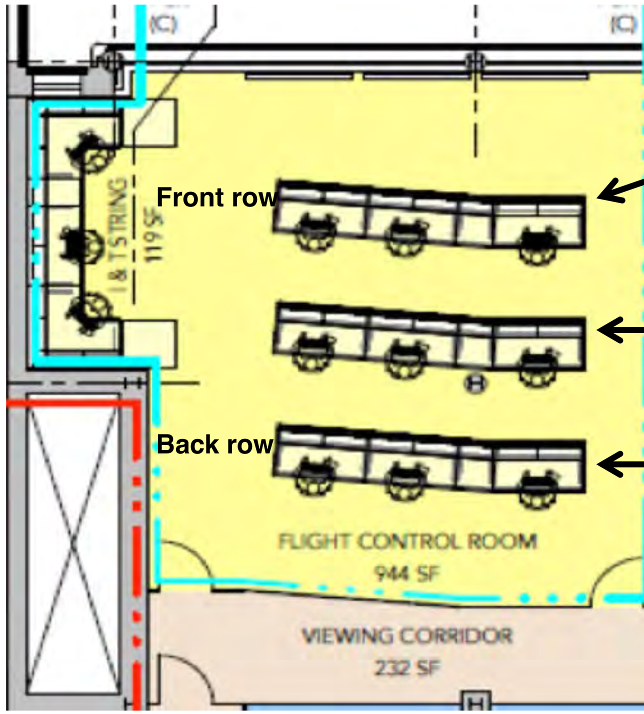
3rd FLOOR PLAN

James Webb Space Telescope - Mission Operations Center
DESIGN DEVELOPMENT FURNISHINGS MEETING
01.07.2015

Read & Company Architects Inc.

Flight Control Room

Monitor
(All interfaces
and bMOC)



Controllers
(Send commands to JWST)

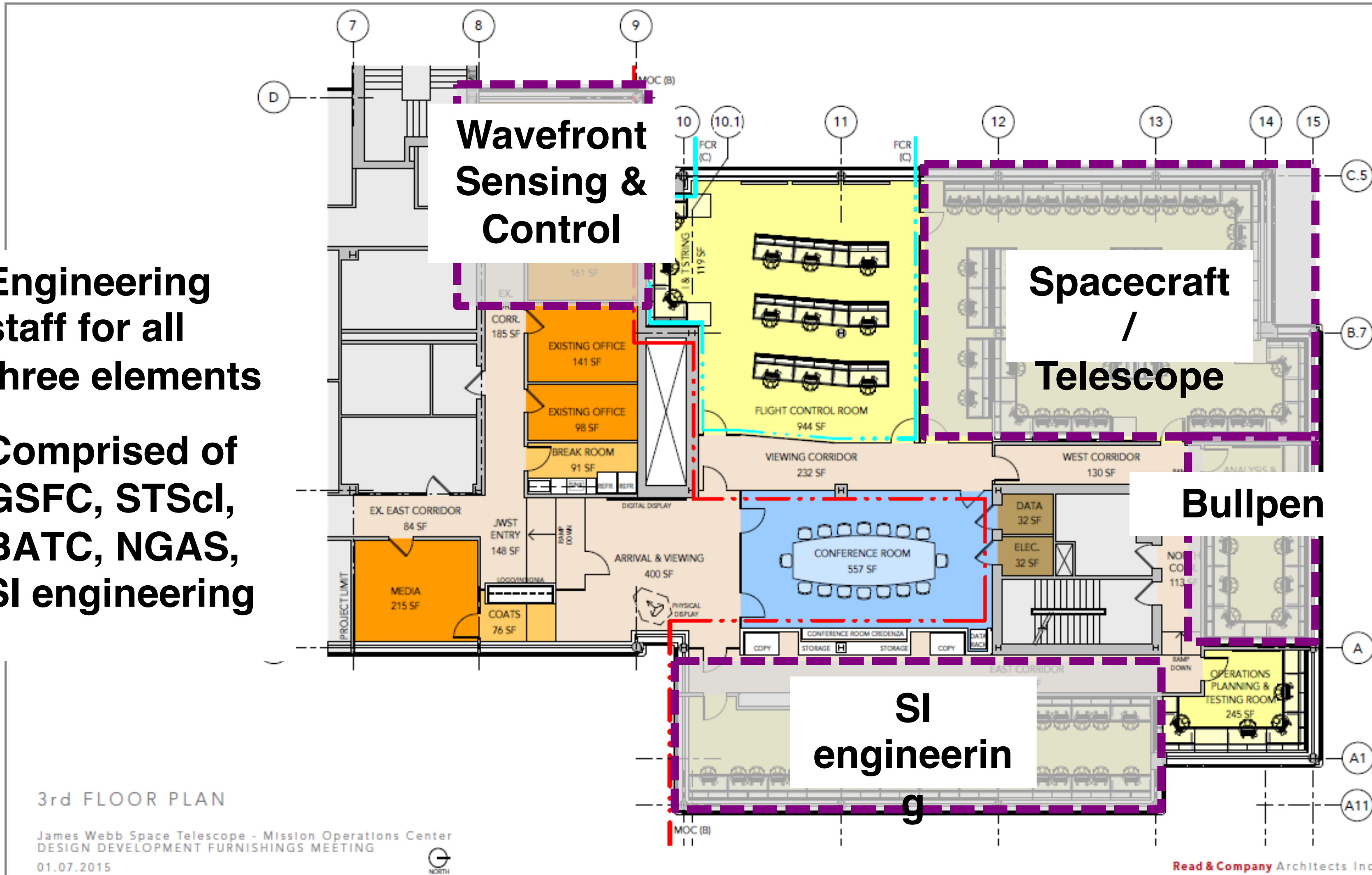
Subject Matter Experts
(Lead commanding of activities)

Mission Operations Manager
(Includes mission planners)

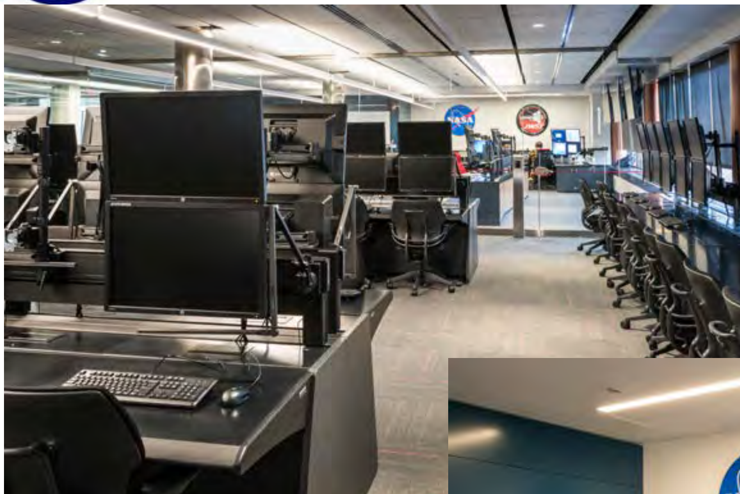
- Commands are sent to the Observatory from the front row
- Subject matter experts and thread leads are in the middle row and lead the execution of activities / telemetry checks with the back room
- Timeline management conducted via the back row

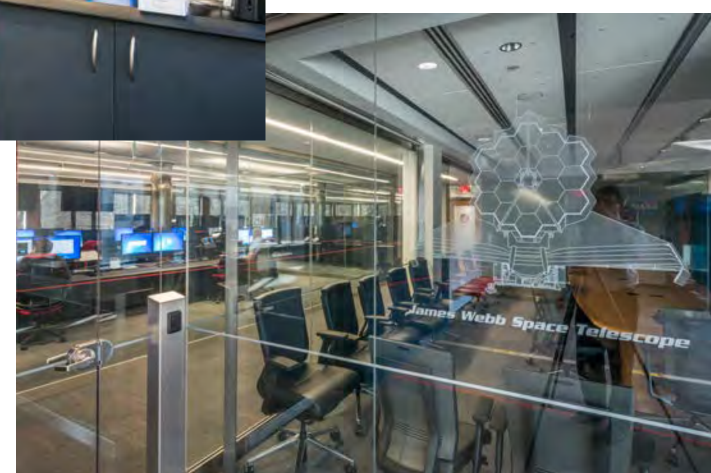
Back Room

- Engineering staff for all three elements
- Comprised of GSFC, STScI, BATC, NGAS, SI engineering



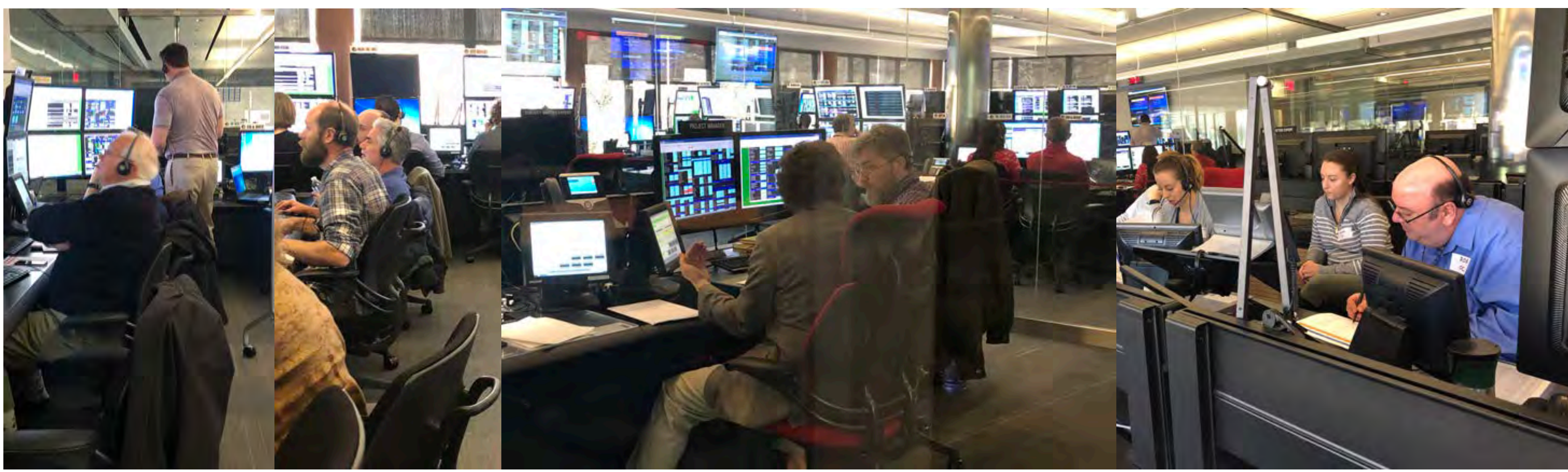
Mission Operations Center (MOC)





Recent Successes

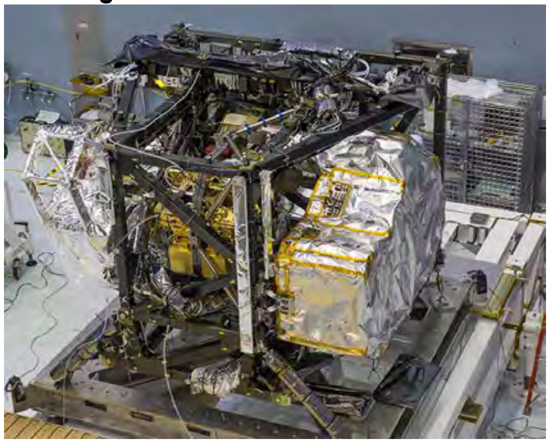
- **Early Commissioning Exercise #2 – March 4th, 5th (~100 people)**
  - Simulates L-1.5 hrs through MCC-1a completion
  - Major anomalies are introduced
  - bMOC is a major participant in the exercise
  - Exercise project management MCC-1a Go/No-Go decision making
  - Exercise anomaly response process & replanning capabilities
  - Introduce eDocs (electronic log-books, on-console handbooks, shift reports, MOC guidebook)
- **Deployment Exercise #1 – March 6th – 8th (~100 people)**
  - Exercise deployment activities through membrane cover release
  - Sustain 24/7 operations at the MOC



JWST PROJECT STATUS

Observatory Status

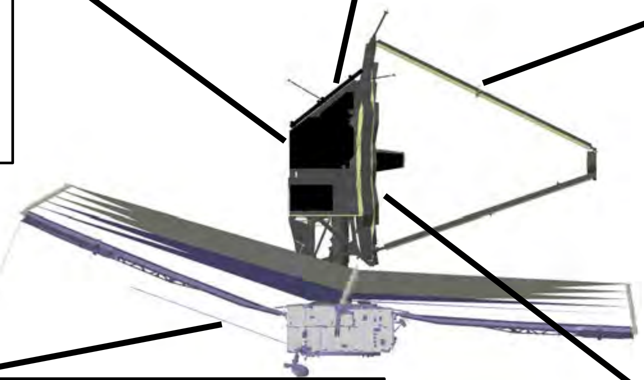
Integrated Science Instrument Module



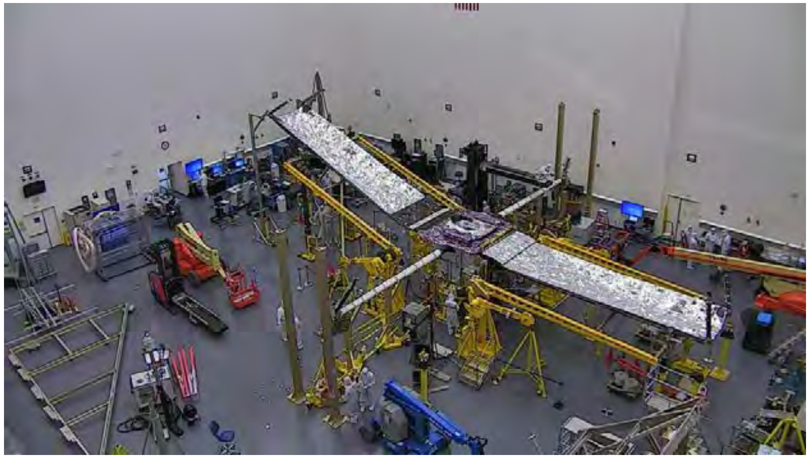
Science Instruments

NIRCam | NIRSpec | FGS/NIRISS | MIRI

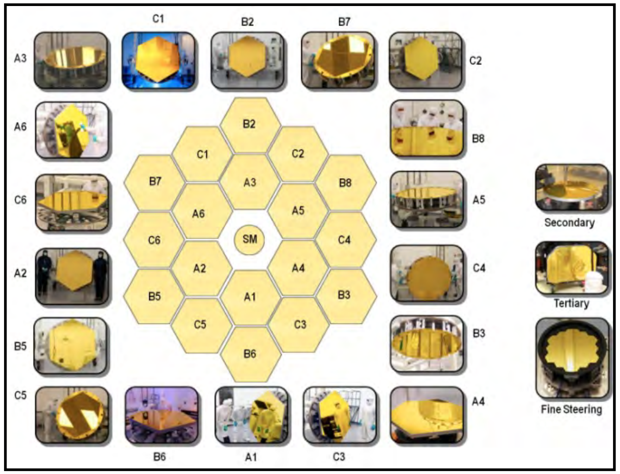
Optical Telescope Element



Spacecraft Bus and Sunshield



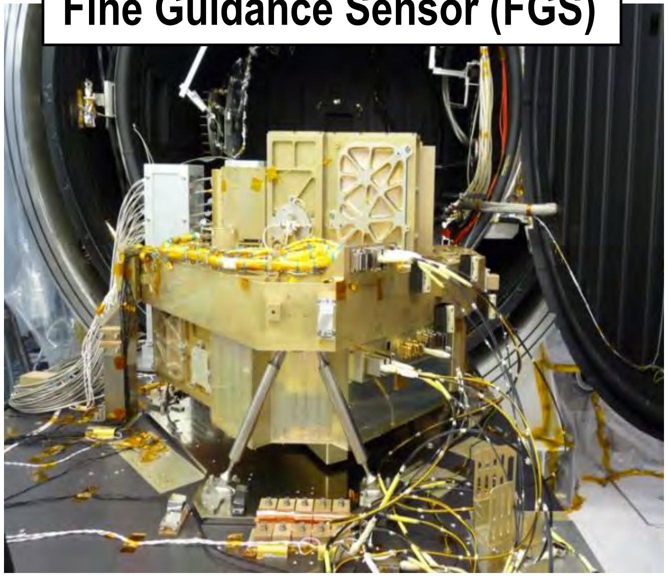
Telescope Optics



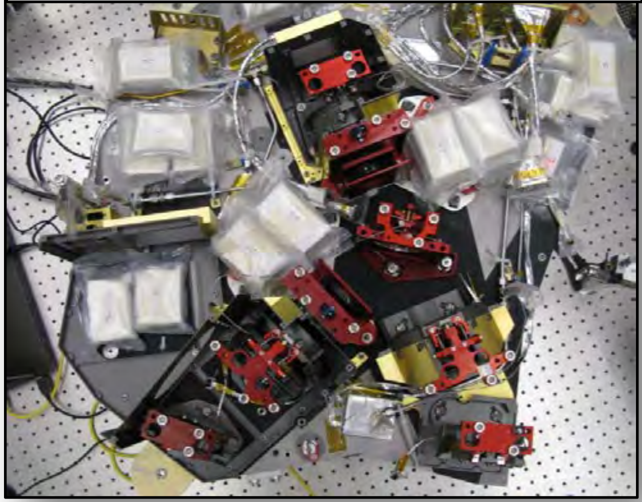
JWST Flight Science Instruments

Mid Infrared Instrument (MIRI)

Fine Guidance Sensor (FGS)

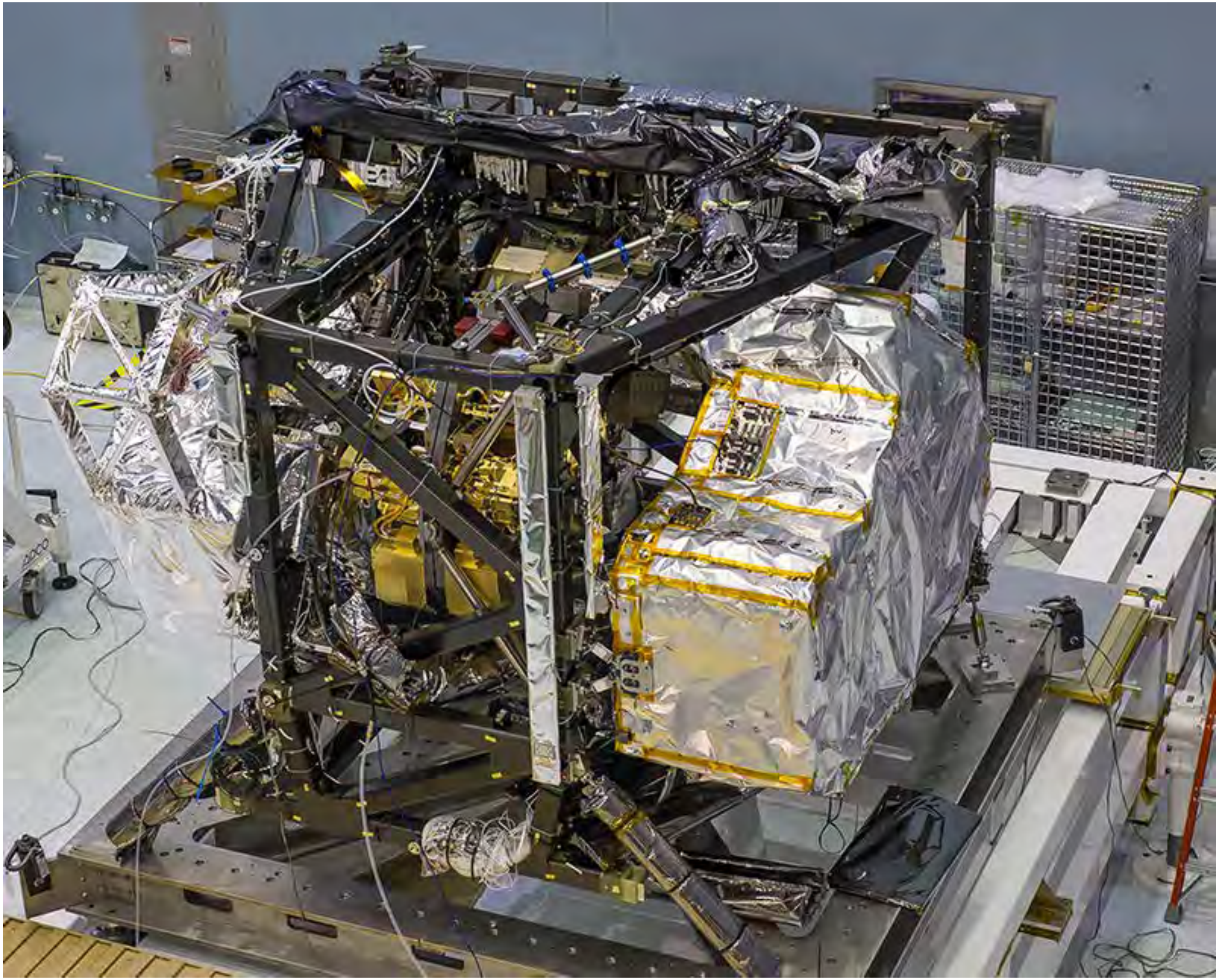


Near Infrared Camera (NIRCam)



Near Infrared Spectrometer (NIRSpec)

The Integrated Science Instrument Module (ISIM)



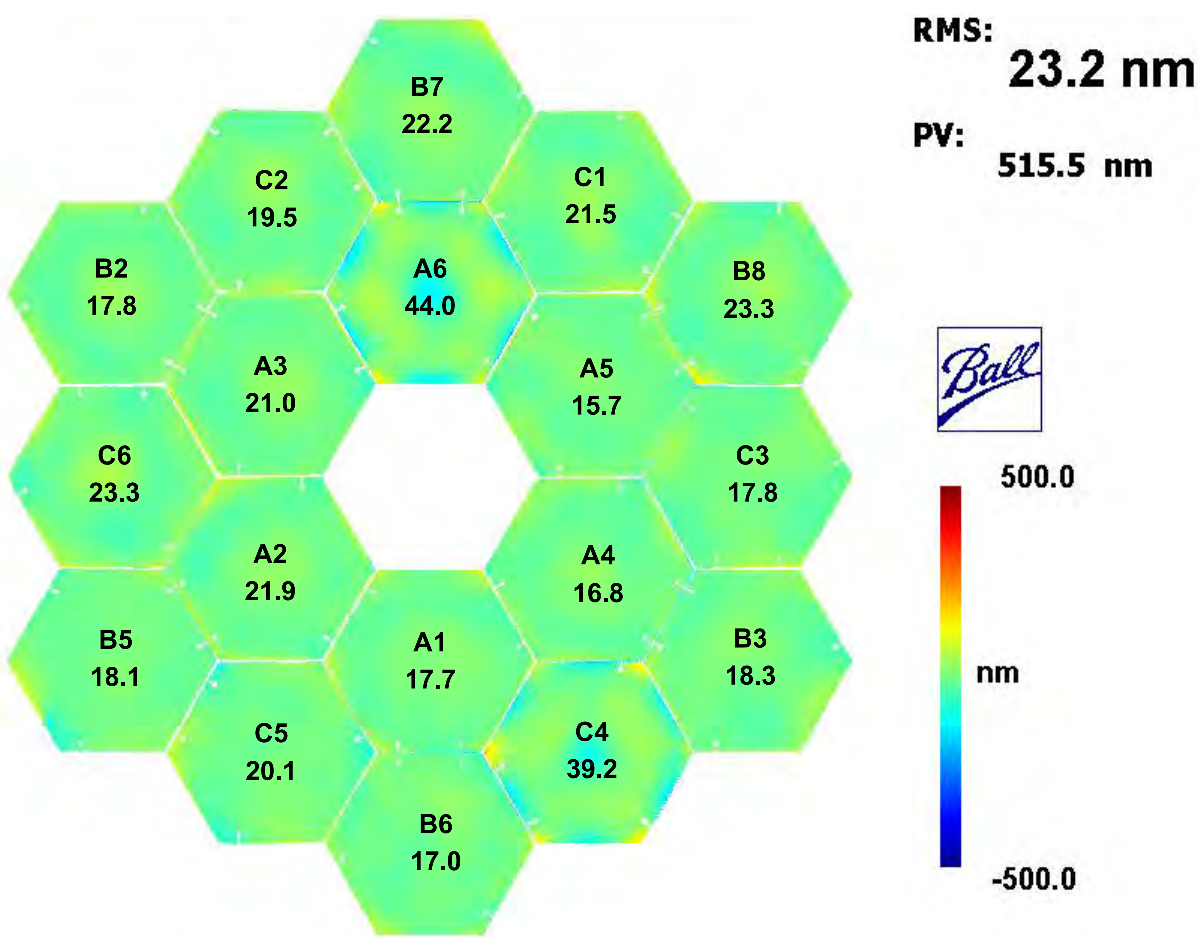
Six PMSAs in the XRCF Cryo Test

Viewers look on from the Gallery as the test stand is removed from the carriage in preparation for removal of the PMSAs, packing and return to BATC.

Composite Cryogenic "Total Surface Figure"

	Total Figure XRCF Measurement	Very High Freq Sub Aperture Tinsley Measurement	Metrology Uncertainty
A1	17.7	2.9	8.0
A2	21.9	3.4	8.0
A3	21.0	5.8	8.0
A4	16.8	3.2	8.0
A5	15.7	5.0	8.0
A6	44.0	4.5	8.0
B2	17.8	5.7	8.2
B3	18.2	4.2	8.2
B5	18.0	3.9	8.2
B6	17.0	4.0	8.2
B7	22.2	4.3	8.2
B8	23.3	4.6	8.2
C1	21.5	5.1	8.2
C2	19.5	6.0	8.2
C3	17.8	3.2	8.2
C4	39.2	5.0	8.2
C5	20.1	4.2	8.2
C6	23.3	5.4	8.2
Weighted RMS	23.2*	4.6	8.1

Requirement = 25.8 nm rms
Total Measurement + Uncertainty = 25.0 nm rms



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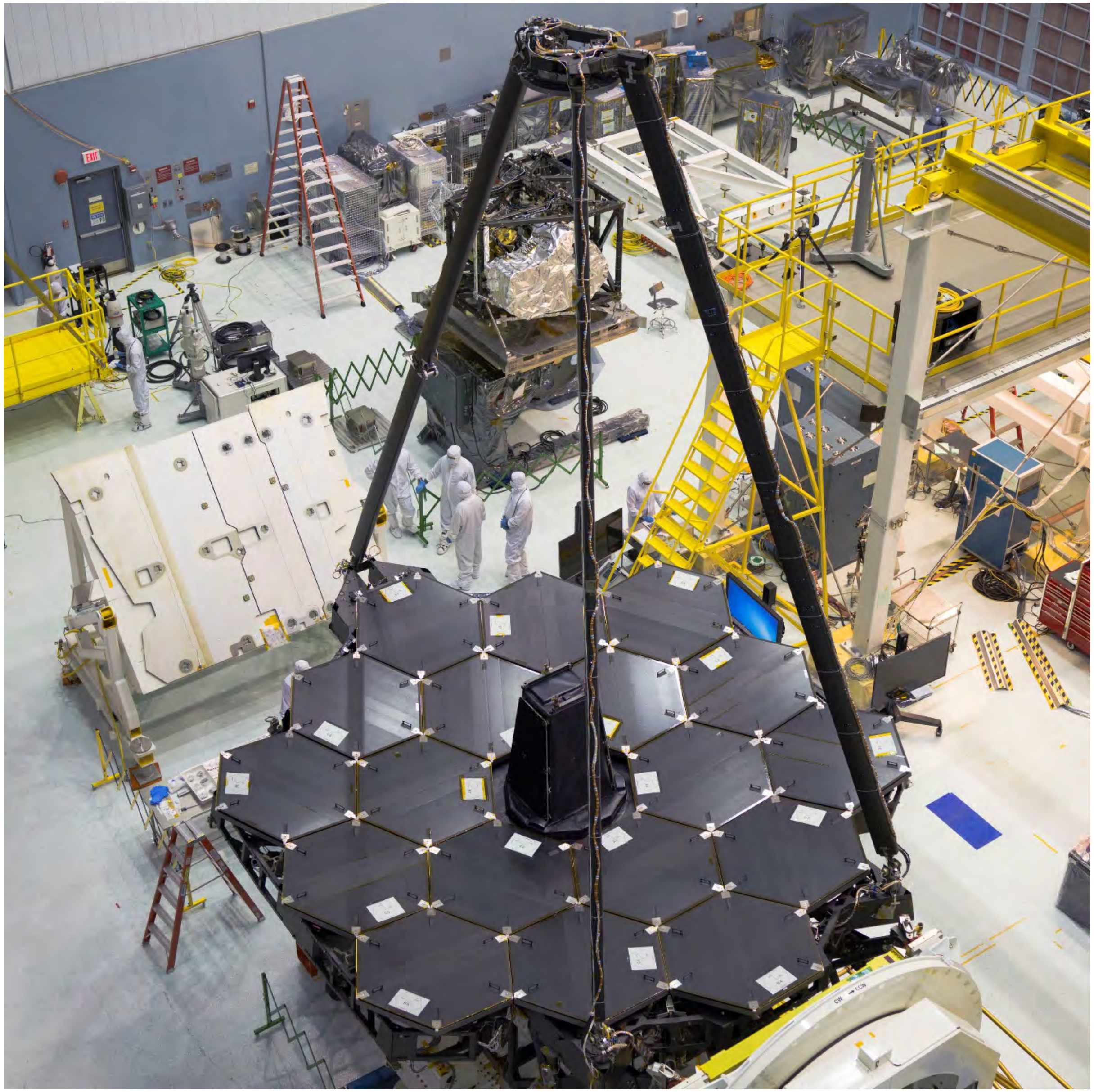
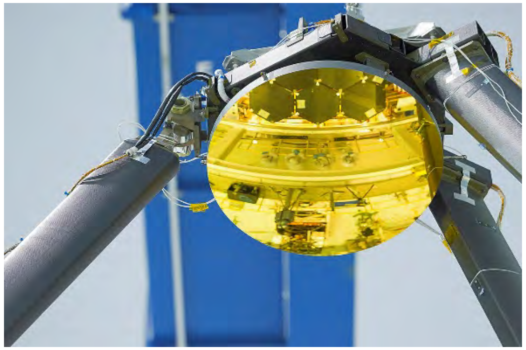
Optical Telescope Element Structure

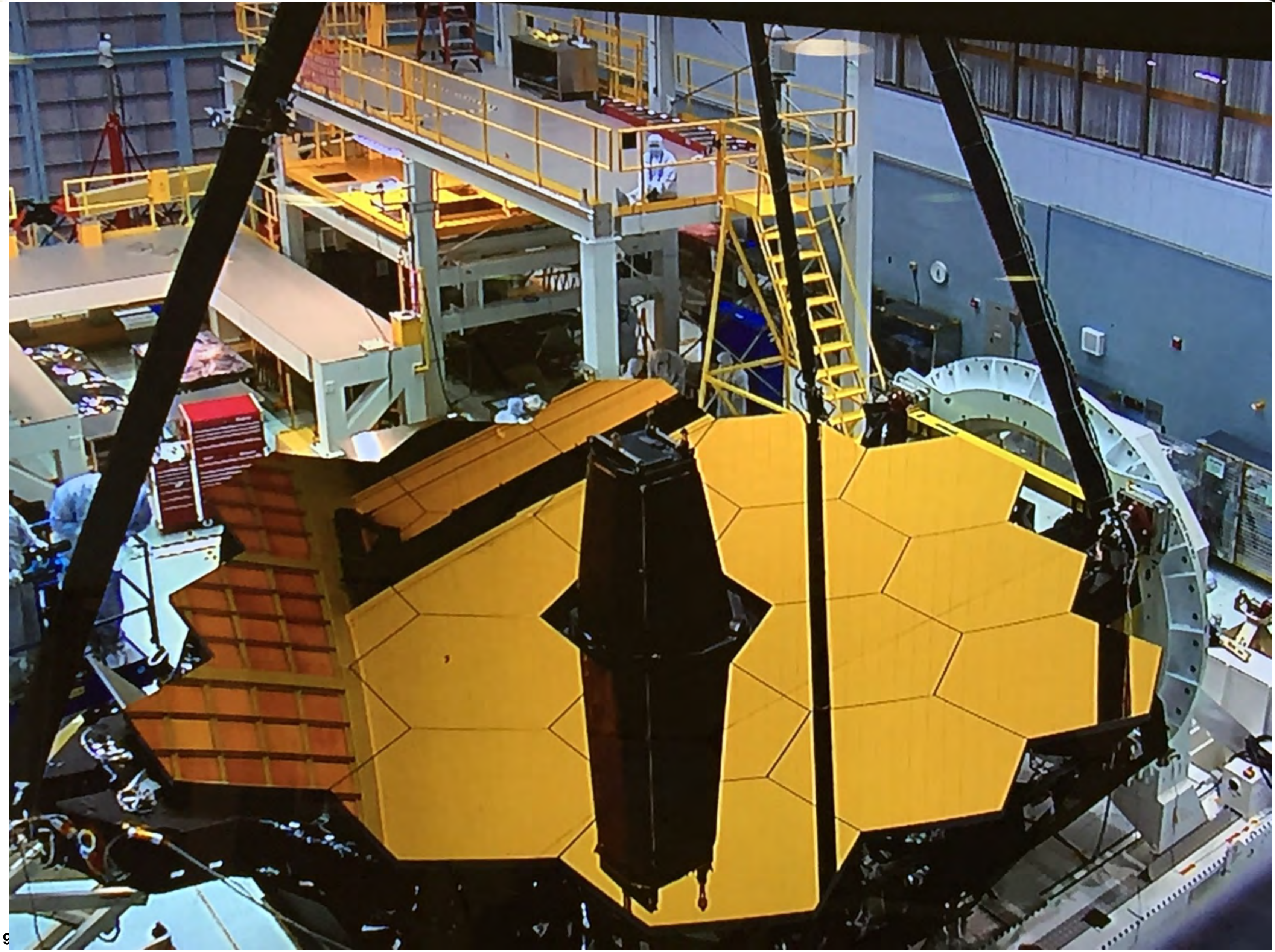
Optical Telescope Element Assembled



- The Optical Telescope Element just after its assembly at GSFC.
- Primary Mirror Segments facing with protective dust covers
- Secondary Mirror shown below facing down.

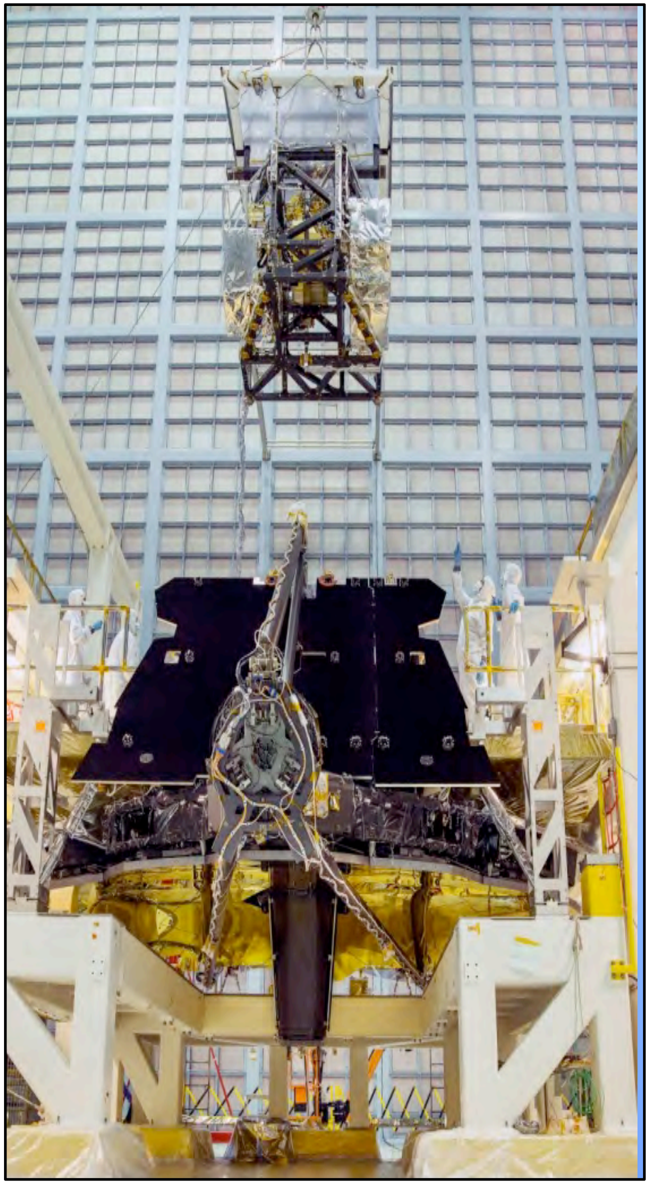


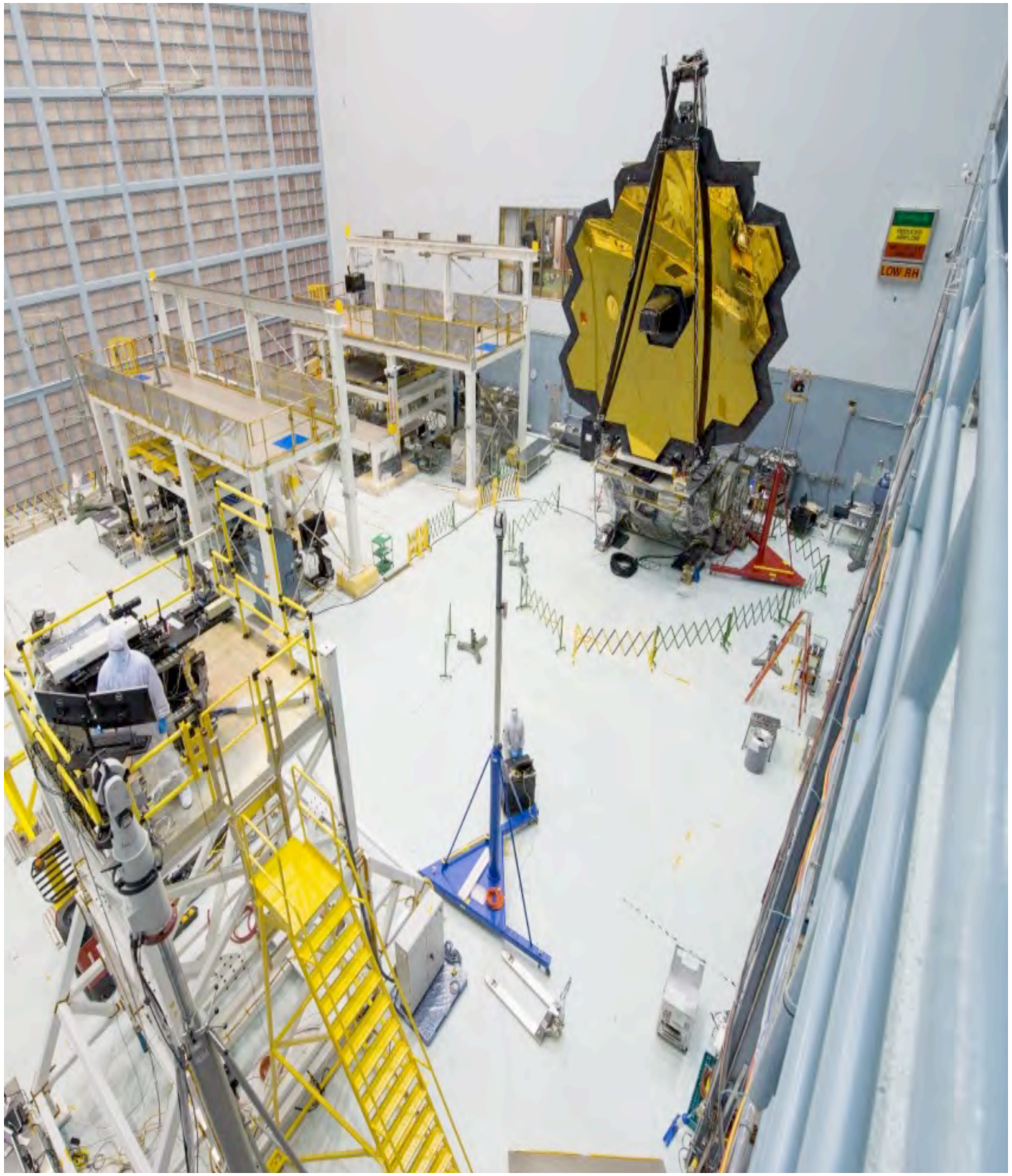
The JWST Primary Mirror Uncovered



The JWST Telescope in the GSFC Clean Room

ISIM – OTE Integration into the OTIS



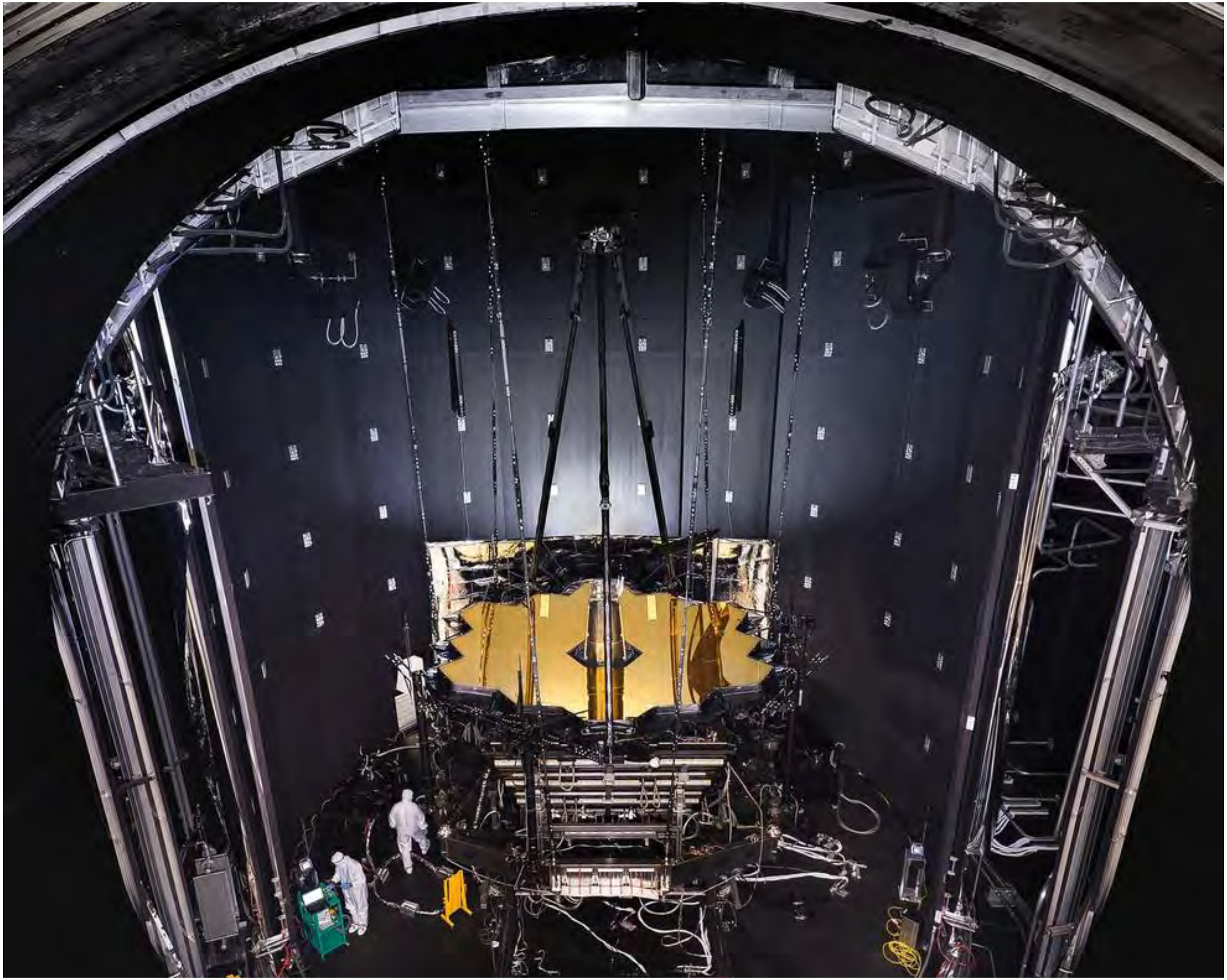


Covering OTIS for Vibro – Acoustics Testing at GSFC

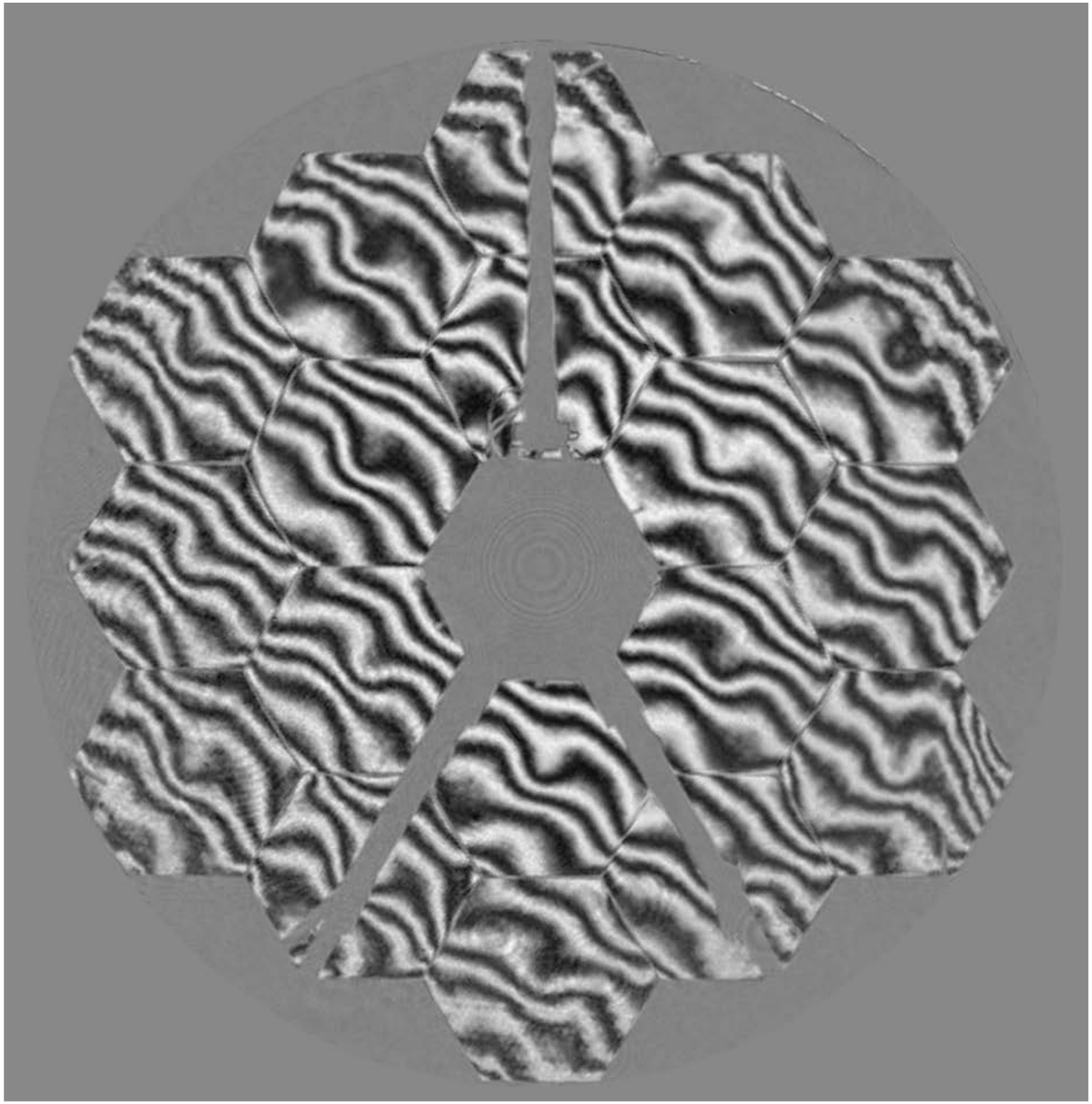
OTIS Mechanical Environment Test Results

[redacted]

JWST In the JSC Chamber A Prior to Chamber Close-Out



Phased and Aligned Primary Mirror Interferogram



Membrane Shape Measurements

- Template Layer 5 in test stand at full tension (3 x flight load) for shape measurements

80

Sunshield Status

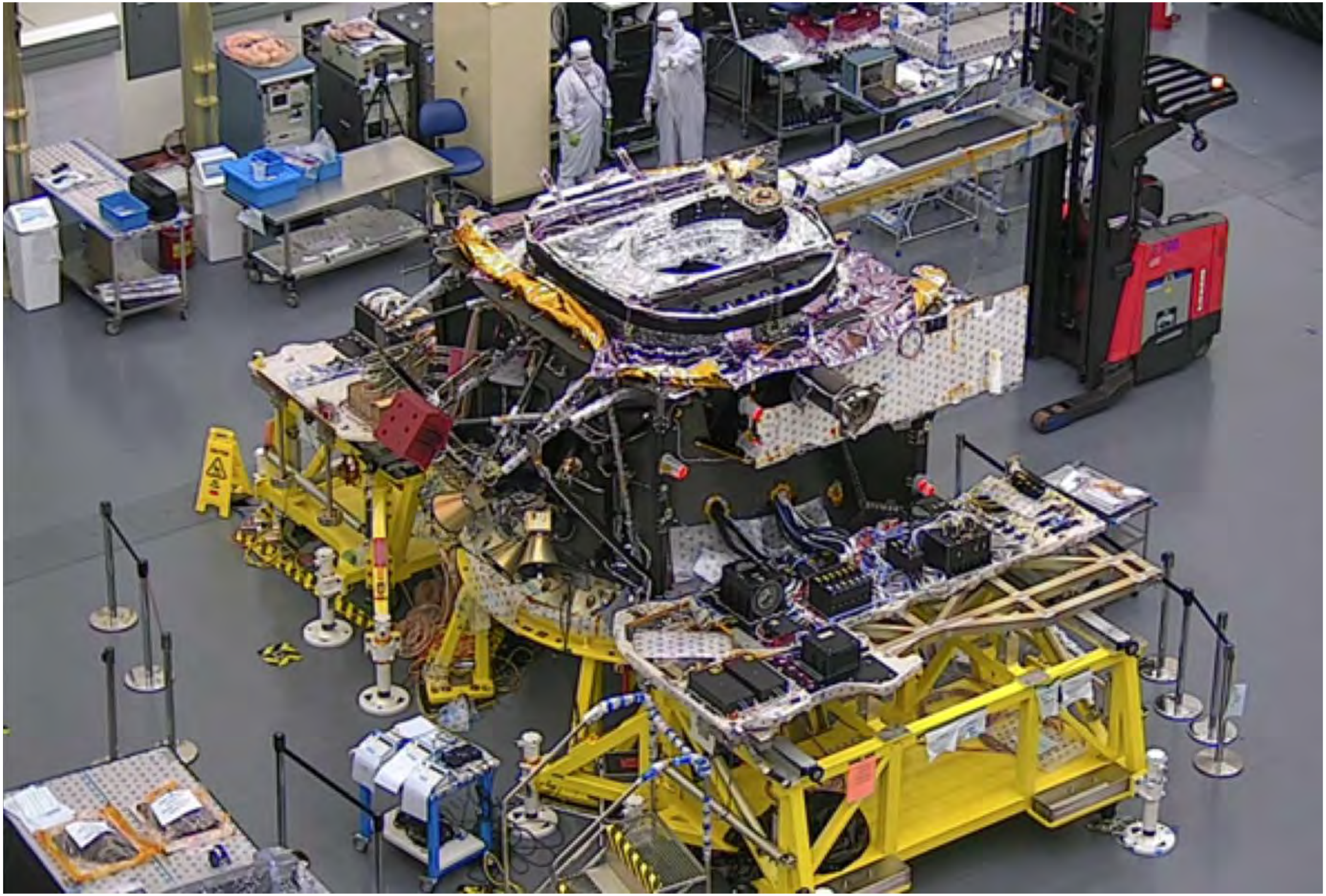
- **Sunshield Membranes shown to the right , delivered to NGAS for integration into the Spacecraft Element.**

- **Flight Unitized Pallet Structure (UPS) Assemblies shown below, completed for integration into the Sunshield.**

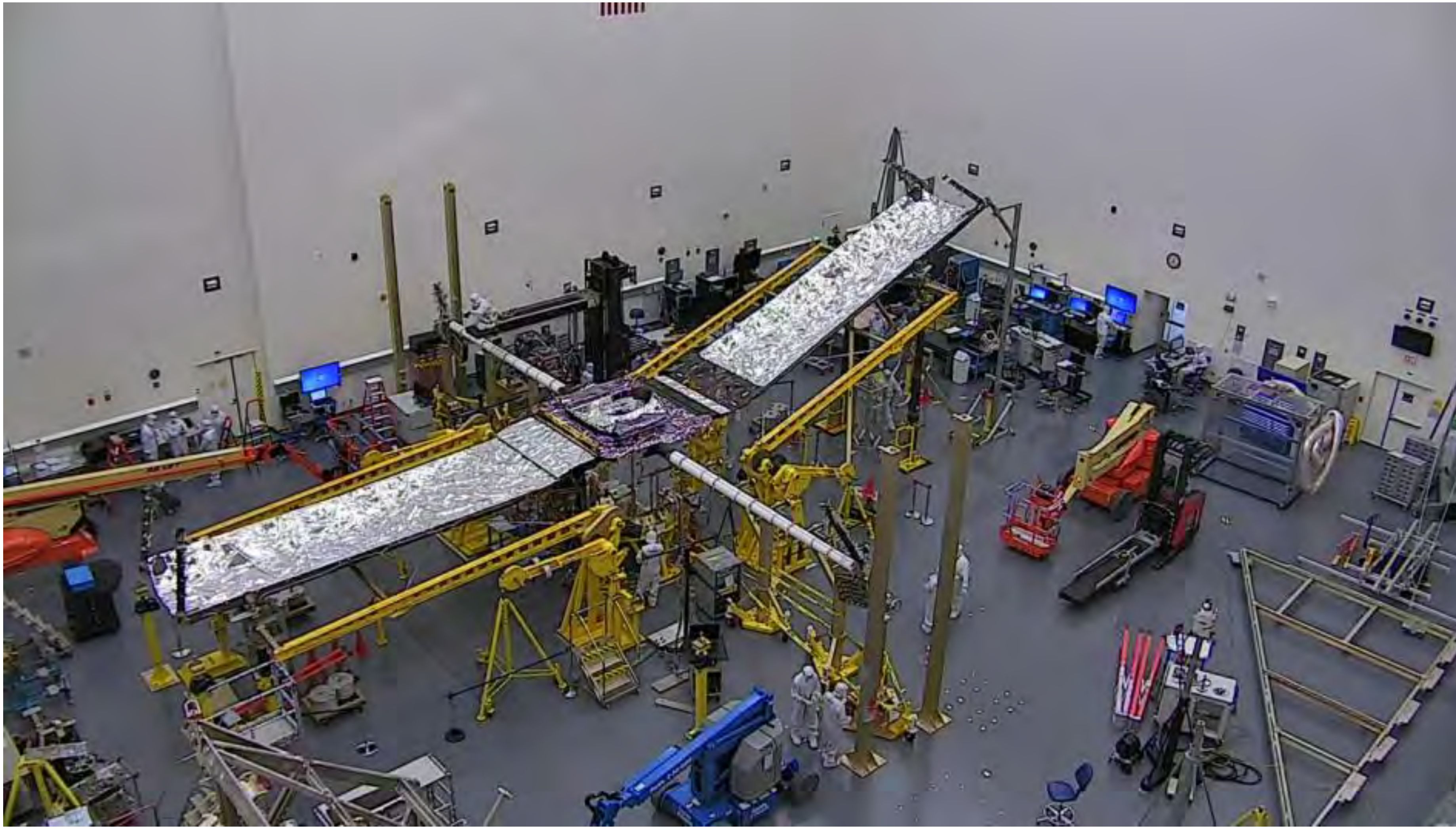
Aft UPS at conclusion of phase 1 manufacturing

Flight Layer 3 - Lowering into shipping crate

The JWST Spacecraft Bus



Spacecraft Bus and the Sunshield Structure



The Telescope and Spacecraft Element Side by Side at NGAS

CONCLUDING THOUGHTS

Telescopes Then and Now

- In 1970 when most of the senior scientists and engineers on JWST were growing up, the Mount Palomar Telescope was the largest telescope in the world.
- Located in hills of San Diego County California.
- Its massive primary mirror was 5.1 meters in diameter.
- It weighed in at 545 tons or 495,000 kg

- Forty five years later, we are making JWST which will be bigger than Palomar.
- Located beyond the moon, 1.5 million kilometers from the Earth.
- Its primary mirror will be 6.1 meters in diameter.
- JWST will weigh 6310 kg, (~1 /100 of the Palomar Telescope)

Summary

- **The James Webb Space Telescope will be one of the premier astronomical tools of the next decade. It will address some of our most fundamental questions.**
  - First Stars and Galaxies, Star Formation, Solar System Evolution and Search for Habitable Exoplanets.
- **It is truly a first of its kind space observatory and has offered the Systems Engineering Team some very unique and difficult challenges.**
  - Cryogenic Design of a Large Space Observatory
  - Complex On-Orbit Deployments
  - Verification by Analysis
- **JWST will re-write the books on astronomy AND engineering of future space observatories.**
- **I consider myself very lucky to be a part of this Team and this Program, and to have the pleasure of sharing our work with you.**