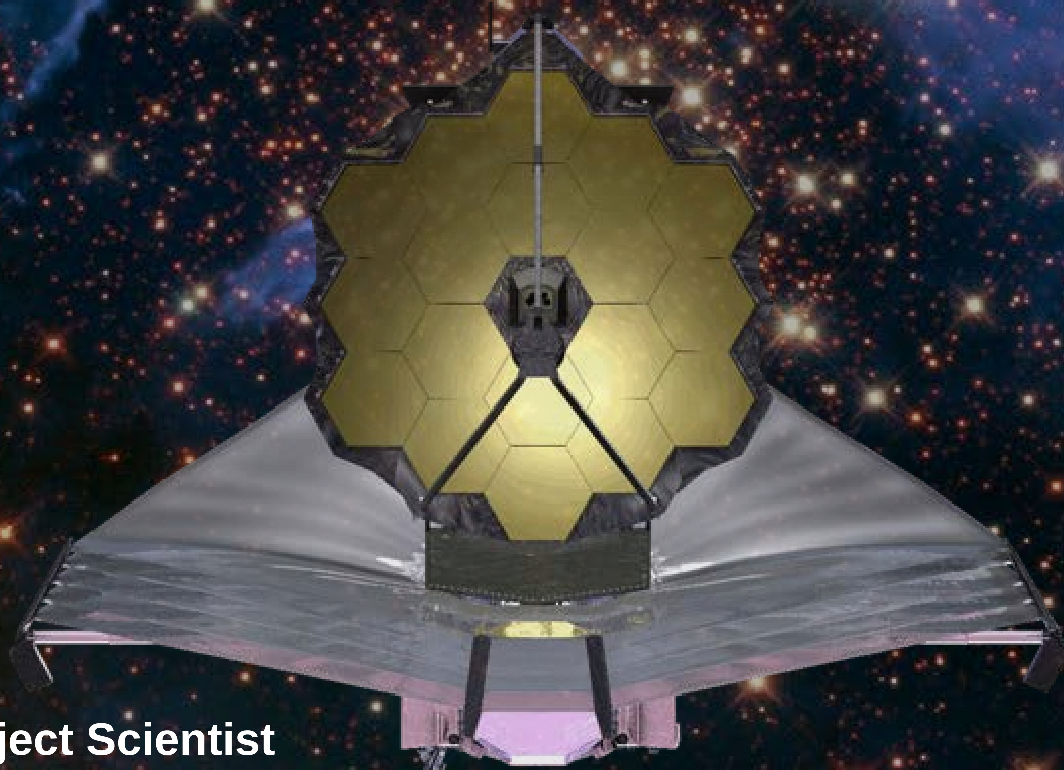
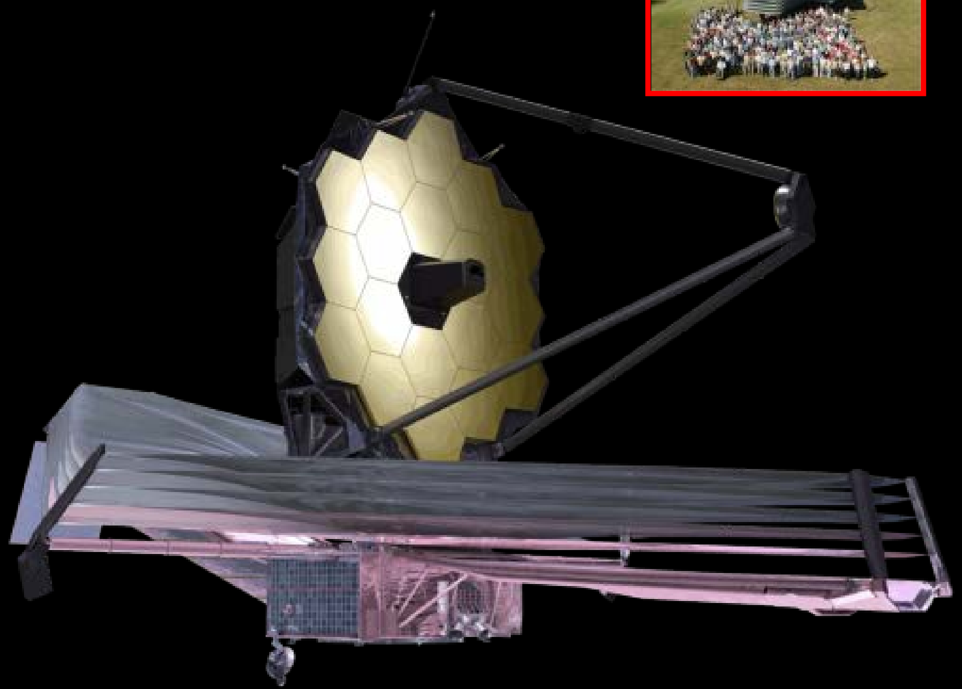
James Webb Space Telescope: Why are we building it like this?



John Mather
JWST Senior Project Scientist
NASA's Goddard Space Flight Center

on behalf of 7 billion current Earthlings, ~10,000 future observers, ~ 1000 engineers and technicians, ~ 100 scientists worldwide, 3 space agencies

James Webb Space Telescope



Organization

- Mission Lead: Goddard Space Flight Center
- Senior Project Scientist: Dr John Mather
- International collaboration: ESA & CSA
- Prime Contractor: Northrop Grumman Aerospace Systems
- Instruments:
  - Near Infrared Camera (NIRCam) – Univ. of Arizona
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) & Near IR Imaging Slitless Spectrometer – CSA
- Operations: Space Telescope Science Institute

Description

- Deployable infrared telescope with 6.5 meter diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission requirement (10-year propellant lifetime)

Science Requirements Sources

- Alan Dressler HST & Beyond Report, 1996
- Volunteers + 3 competitively selected Science Working Groups
- “Design Reference Mission” voted on by SWG
- Science Requirements Document
- HQ Level 1 Requirements
- Science Assessment Team (external review)

Endorsements matter!

- Dan Goldin, 1996 AAS meeting: “I see Alan Dressler here. All he wants is a four meter optic that goes from a half micron to 20 microns. And I said to him, "Why do you ask for such a modest thing? Why not go after six or seven meters?”” (standing ovation after speech)
- 2000 Decadal Survey, top priority
- 2010 Decadal Survey built around it

Choice of International Responsibilities

- ESA spacecraft bus (like Herschel, Planck, Gaia missions), *rejected* by standing review board (interface too complex)
  - Substitute: Ariane 5 launch vehicle (rejected by O'Keefe, accepted by Griffin)
- ESA offered Near IR Spectrometer (NIRSpec) and European Consortium offered mid IR instrument (MIRI)
- NASA decided on JPL/European partnership for MIRI
- CSA offered Fine Guidance Sensor and Tunable Filter Imager (TFI)
  - TFI became Near IR Imaging Slitless Spectrometer
- NASA does everything else: S/C, telescope, operations, ISIM, NIRCam, microshutters, detectors, cooler, etc.

The James Webb Space Telescope

JWST Launch

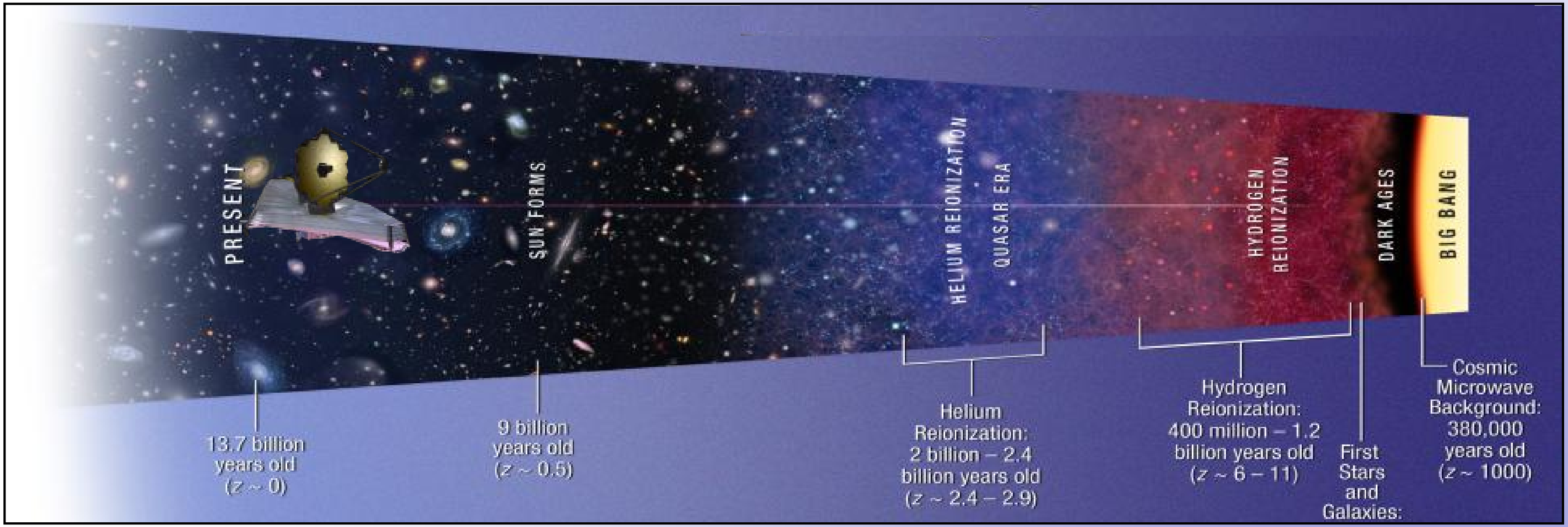
- Launch vehicle is an Ariane 5 rocket, supplied by ESA
- Site will be the Arianespace's ELA-3 launch complex near Kourou, French Guiana

Arianespace – ESA - NASA

The James Webb Space Telescope

JWST Science Themes – The End of the Dark Ages

JWST Questions
1.) What are the first galaxies?
2.) When did reionization occur?
3.) What is the Universe's reionization history?
4.) What sources caused reionization?



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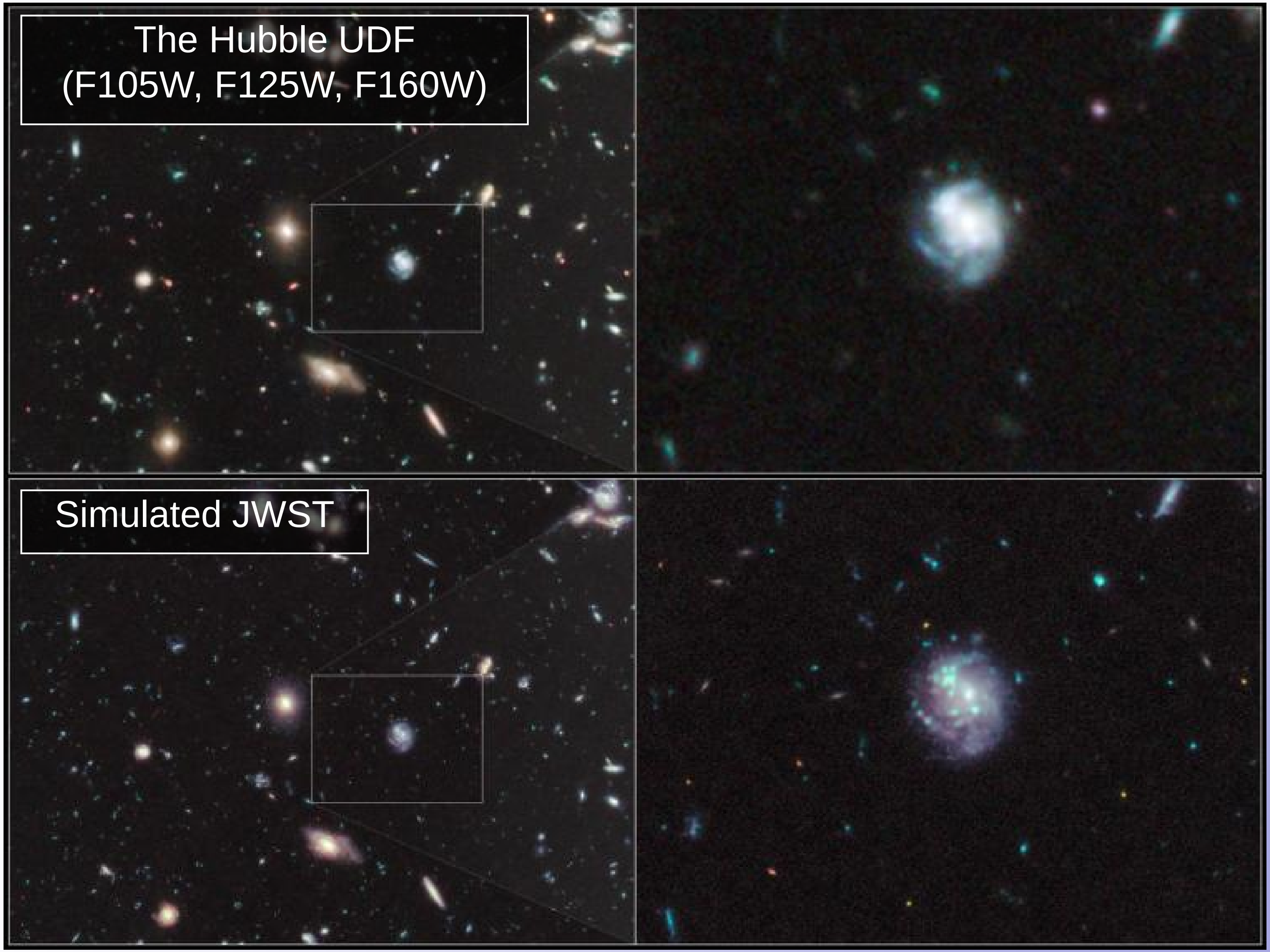
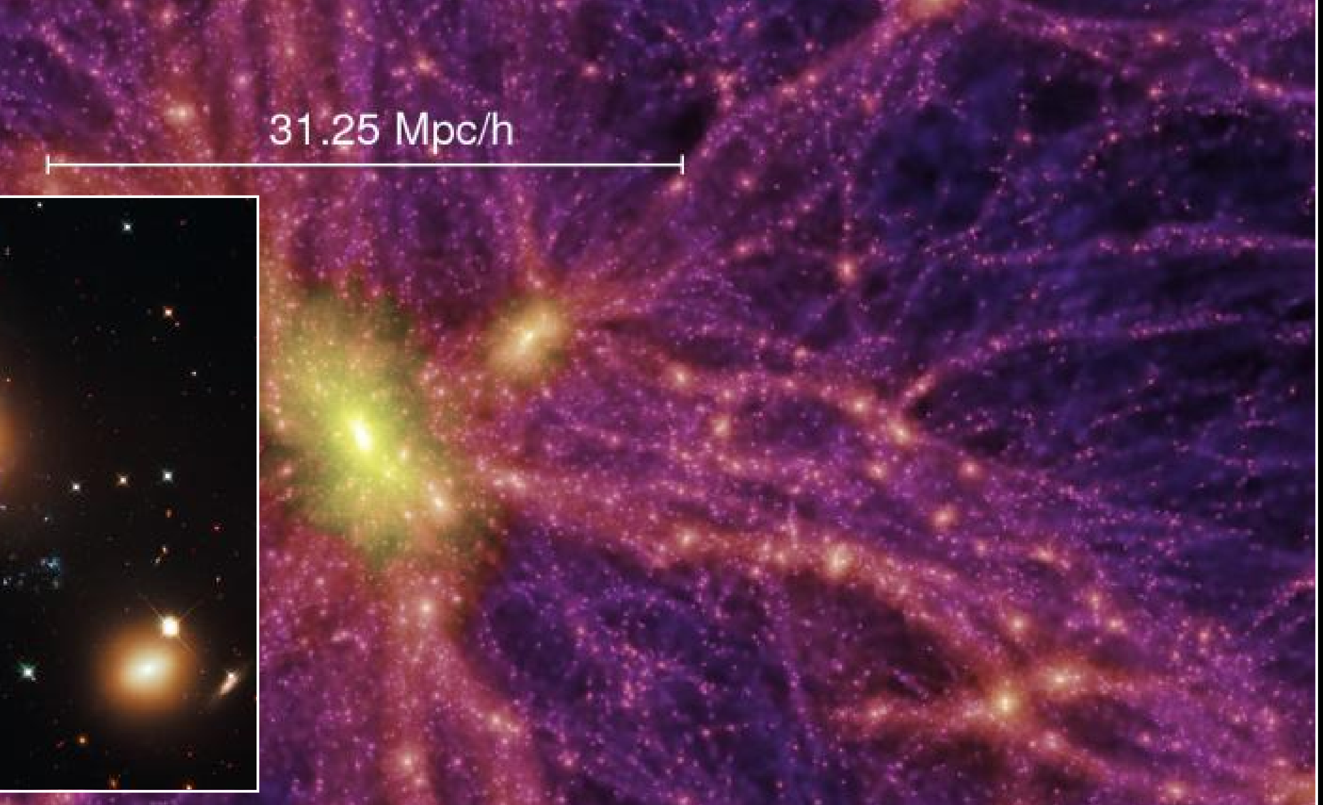
JWST Science Themes – The End of the Dark Ages



→ JWST will have higher angular resolution than Hubble for deep fields

The James Webb Space Telescope

JWST Science Themes – The Assembly and Evolution of Galaxies



JWST Questions

1.) Where and when did the hubble sequence form?

2.) Do hierarchical formation models and global scaling relations explain diverse galaxy morphologies and their cosmic evolution?

3.) How did the heavy elements form?

4.) What role do ULIRGs and AGN play in galaxy evolution?

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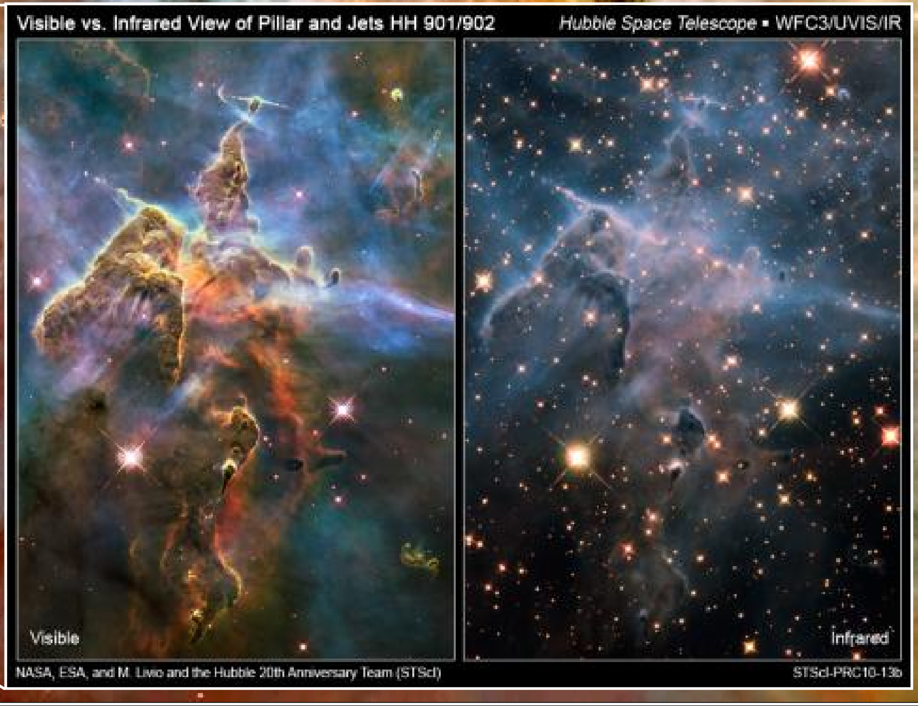
JWST Science Themes – The Birth of Stars and Planetary Systems

The power of high-res ir imaging
(Hints from WFC3)

The Carina Nebula



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<u>JWST Science Themes – The Birth of Stars and Planetary Systems</u>

- Lifting the Curtain on Star Formation (optical)

The James Webb Space Telescope

<u>JWST Science Themes – The Birth of Stars and Planetary Systems</u>

- Lifting the Curtain on Star Formation

<u>JWST Questions</u>

1.) How do clouds collapse and form stars and planets?

2.) How does environment affect star formation?

3.) How does feedback from star formation affect environment, and trigger new star formation?

4.) How are chemical elements produced and recirculated?

5.) What is the stellar and substellar IMF, to and beyond the H-burning limit?

6.) How does the IMF depend on environment (age, metallicity, binarity)?

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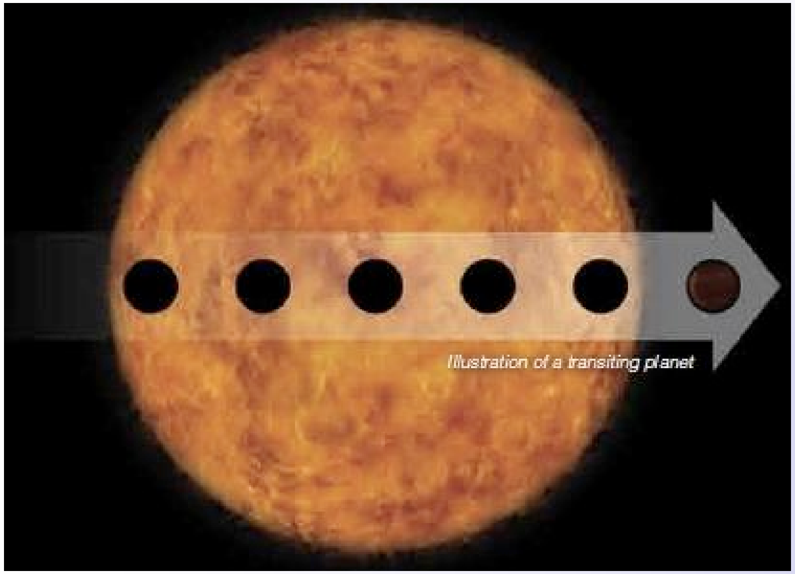
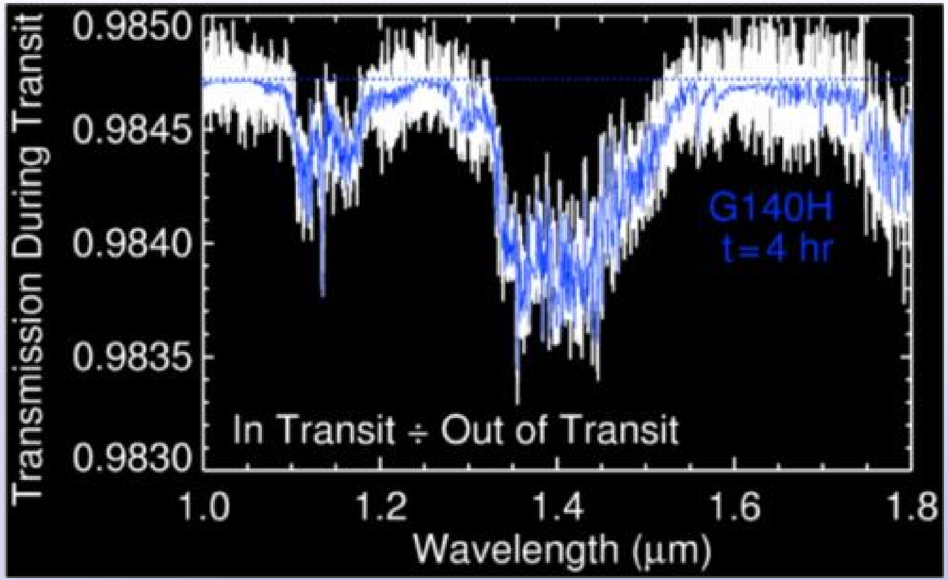
JWST Science Themes – The Origins of Life





Atmospheric transmission spectrum (4 hours) for HD209458-like Kepler source using NIRSpec (R=3000).
Simulation from J. Valenti

JWST Questions

1.) How do planets Form?
2.) What are the properties of circumstellar disks like our solar system?
3.) What criteria should be used to establish habitable zones?
4.) Is there evidence for liquid water on exoplanets?

→ JWST will detect water in habitable zone super Earths

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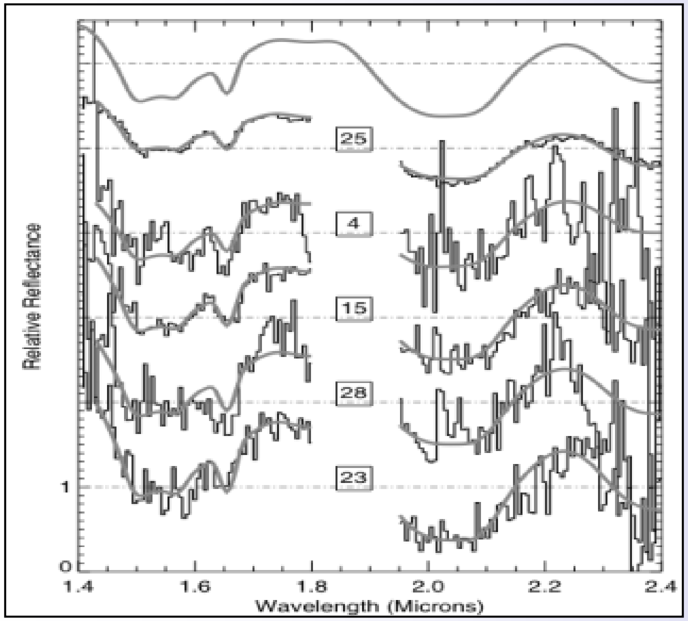
Artist's impression of a binary KBO

The Outer Solar System

1.) NIRSpec will measure IR spectra for all known Kuiper Belt Objects (KBOs).

2.) Spectral features from water ice will be mapped at redder wavelengths than currently possible, revealing surface mineralogy.

3.) The Chemical compositions of these objects will provide clues to the nature of the solar nebula. This in turn provides insights on the early formation and evolution of the solar system.



NIRC spectra of water ice features in Haumea collision family objects

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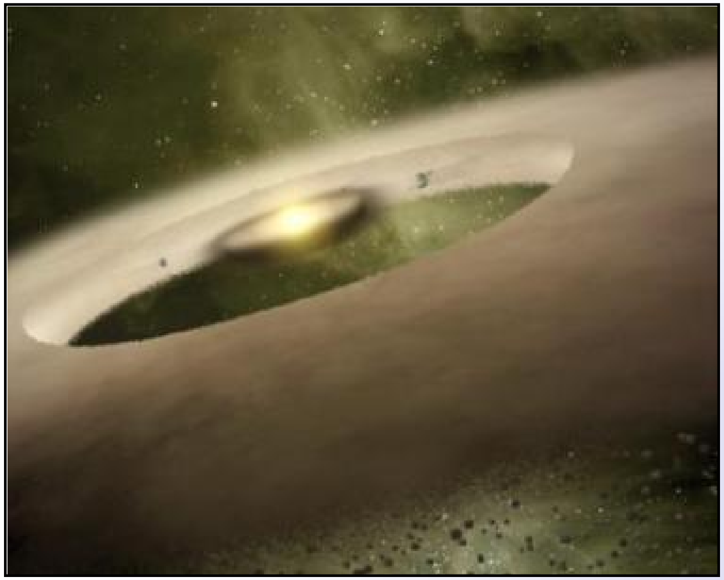
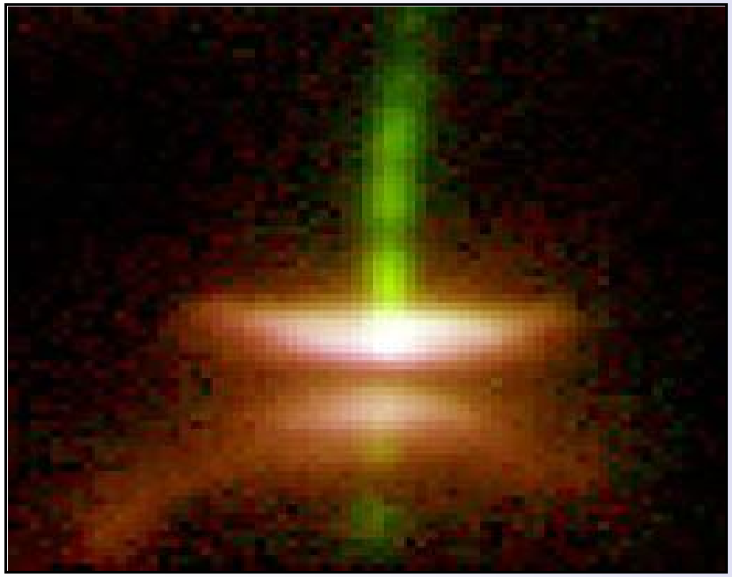


Protoplanetary Disks

1.) Resolve structure in the nearest disks at >30 AU scales with TFI and MIRI Coronography

2.) Measure dust settling characteristics as a part of planetesimal build up

3.) Trace gaps and asymmetries produced by embedded protoplanets



HH 30 edge-on disk with NIRSpec/MIRI IFU FOV

4.) Delineate gas content and parent populations

5.) Measure radial dependency of gas chemistry

6.) Probe mass inflow and outflow

7.) Measure statistics of disk properties vs stellar mass and environment

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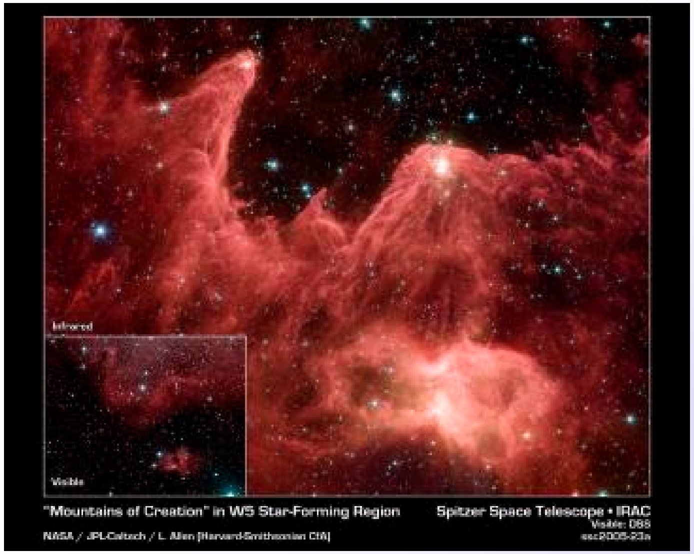


Bow shock around the Galactic O-type runaway star ζ Ophiuchi

Massive Stars: Formation

1.) How do hot, massive stars emerge from their dust-obscured natal cocoons?

2.) How does their presence affect the formation of other stars?

Massive Stars: Feedback

3.) How does the evolution of massive stars shape their galactic environments?

4.) How does metallicity effect massive star evolution?

Massive Stars: Circumstellar Structure

5.) What causes circumstellar nebulae to form around LBV and WR stars?

6.) How is mass lost from these stars?

7.) How are their outflows structured?

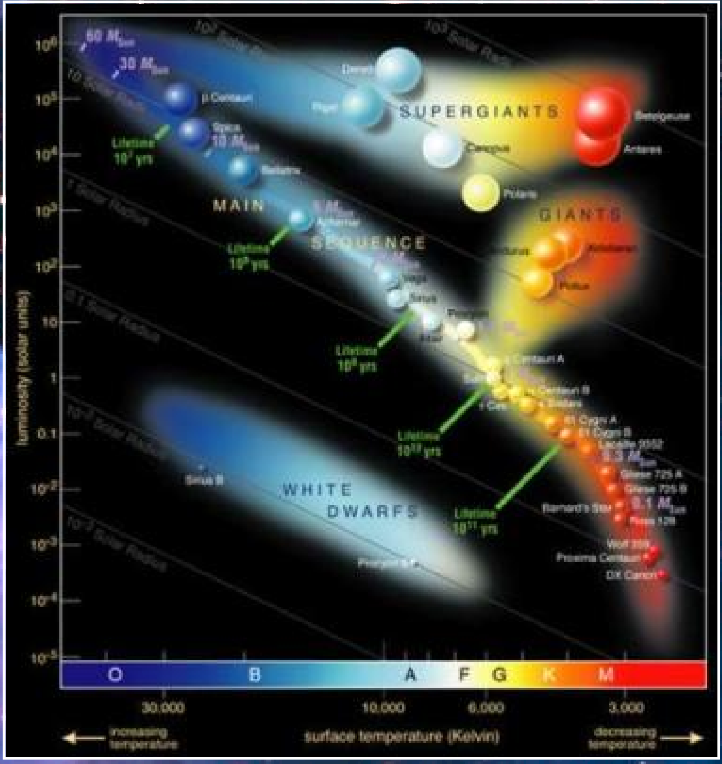
The James Webb Space Telescope

Resolved Stellar Populations – Local Group

1.) NIRCam and TFI Imaging plus NIRSpec MOS spectroscopy of star forming regions and Milky Way components will provide age and abundances distributions, testing formation and assembly models.

2.) Use near-IR imaging to complete a stellar inventory of nearby populations, by measuring stars from the brightest giant phases to low mass dwarfs.

3.) MIRI imaging and spectroscopy will penetrate extincted regions to discover and characterize T_{eff}, log(g), and mass for stars down the hydrogen burning limit, and into sub-stellar regimes.



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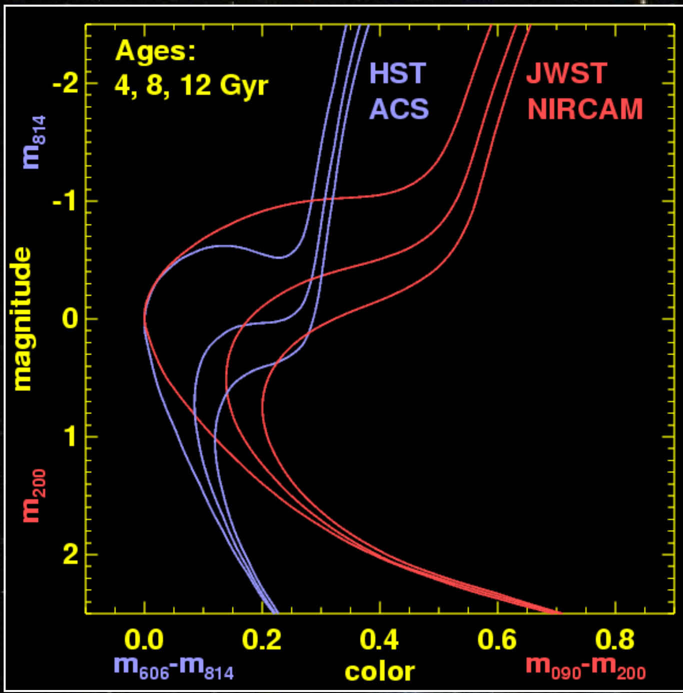


Resolved Stellar Populations – Local Volume

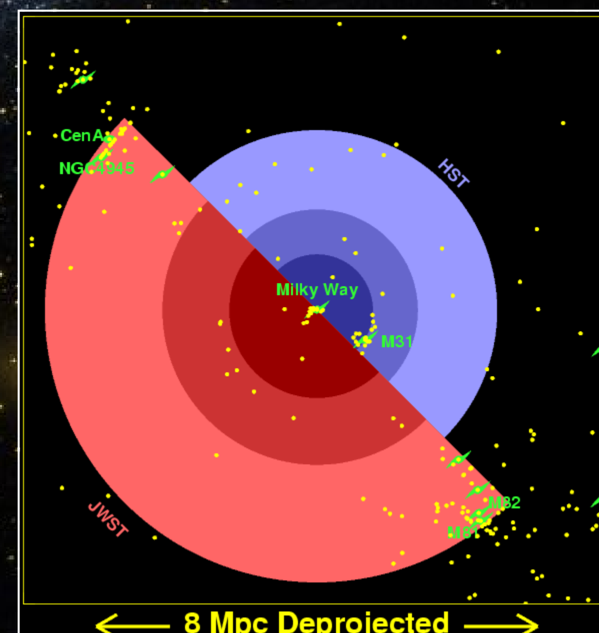
1.) Photometry will reach faint main sequence stars like our Sun in galaxies outside the local group. Extended star formation periods will be efficiently measured with filters well-separated in wavelength.

2.) Relative to HST Imaging, JWST/NIRCAM will have superb sensitivity over a broad wavelength range, be diffraction limited, and have a larger field of view. This will yield deep near-IR CMDs with excellent age discrimination.

3.) A view of the nearby universe, with galaxies at their true distances. Concentric circles correspond to hypothetical observing programs of 10, 100, and 1000 hours.

4.) At a given distance, JWST will be nearly six times faster than HST for this type of work.

5.) For a given exposure time, JWST can explore galaxies about 50% further away than those available to HST.



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Transient Objects

1.) Explore the nature of exotic transients through increased sensitivity and resolution (GRBs, Sne, tidal disruption events, unknown objects, …).

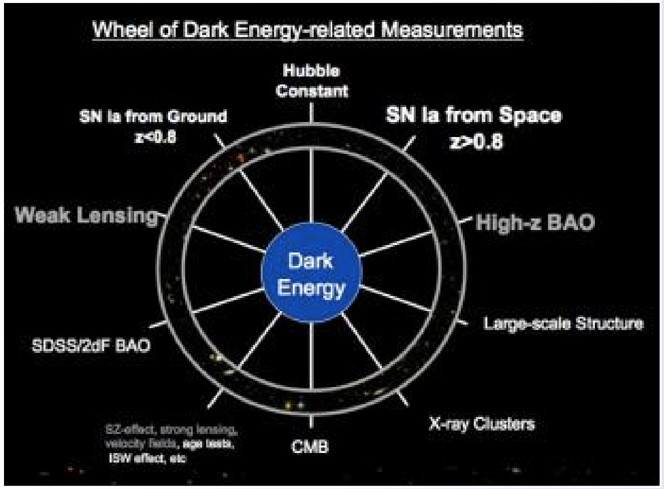
2.) Measure the nature of Dark Energy through IR light curves of SNe.

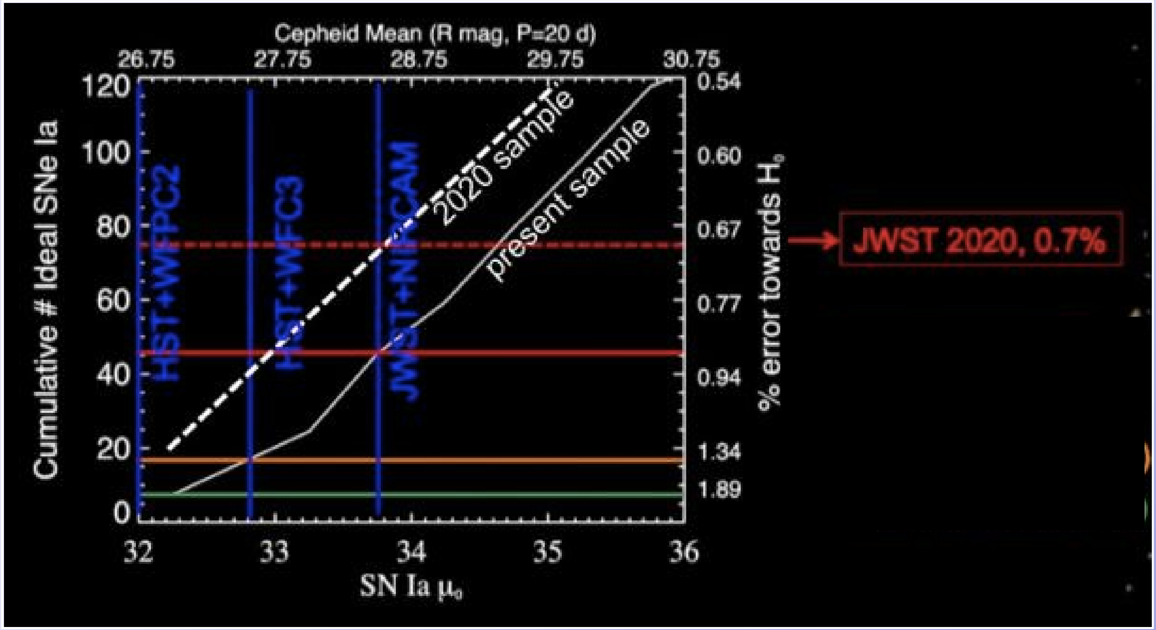
3.) Measure the SNe rate at high-z and probe its connection with the star formation rate and galaxy morphology.

The James Webb Space Telescope

<u>Dark Energy and Dark Matter: The acceleration parameter of the Universe</u>

1.) Leverage multiple techniques to minimize systematic errors.
2.) wide field surveys will find targets.
3.) Measure very distant supernovae (standard candles?)
4.) SNe rest frame IR light curves – may be better standard candles?
5.) directly measure effects of dark matter from distorted geometry of distant objects, masses of galaxies and clusters to high-z, rotation curves, etc…
6.) Map cosmic archeology at high-z (prior to acceleration, formation of clusters).
7.) Measure Cepheid variables in galaxies with known maser distances.





→ JWST will constrain Dark Energy through exquisite measurements of H_O

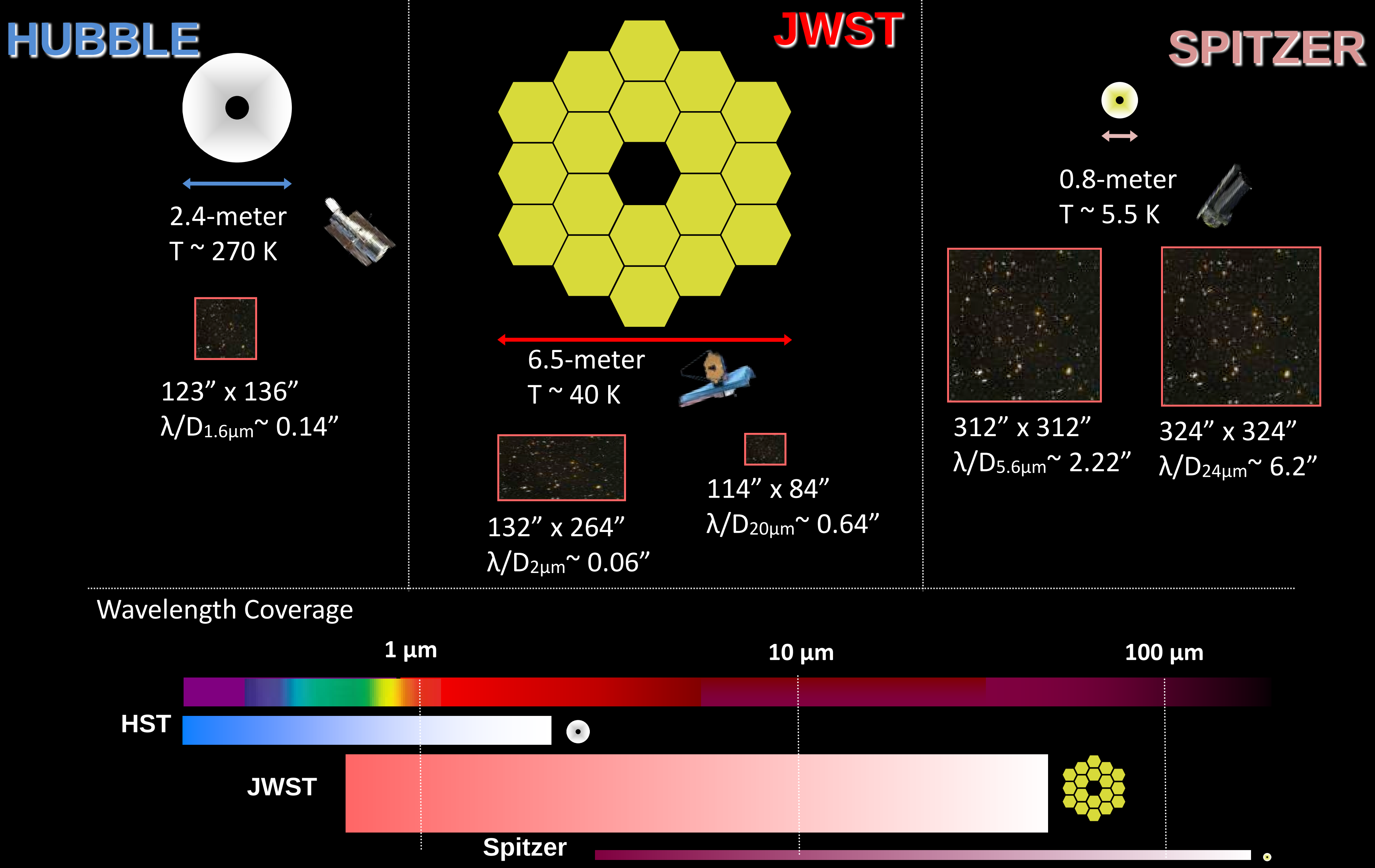
Why Infrared?

- Unexplored area: in 1996, had IRAS, COBE , HST, Compton GRO results, ISO just launched, but not yet Chandra, Spitzer, WISE, Herschel
- Can't do (most of) IR from ground – air absorbs and emits, telescope glows
- IR comes from distant (redshifted) universe – HST can't see far enough or faint enough to see first galaxies, supernovae, etc.
- IR comes from cool objects (protostars, planets, dust grains) and shows new science
- IR penetrates dust clouds, revealing stars being born

Why so big?

- Top targets *very* faint, based on extrapolating from Hubble (sub-nanoJansky, 31^{st} magnitude)
- Wave diffraction → $\delta\theta = 1.22\ \lambda / d$, need telescope size proportional to wavelength to get image as sharp as HST
- Long term ambitions – observe other Earths!
  - Master segmented mirrors, deployments
- Ground-based competition (already had 10 m diameter Keck, planning several 30 m size!)

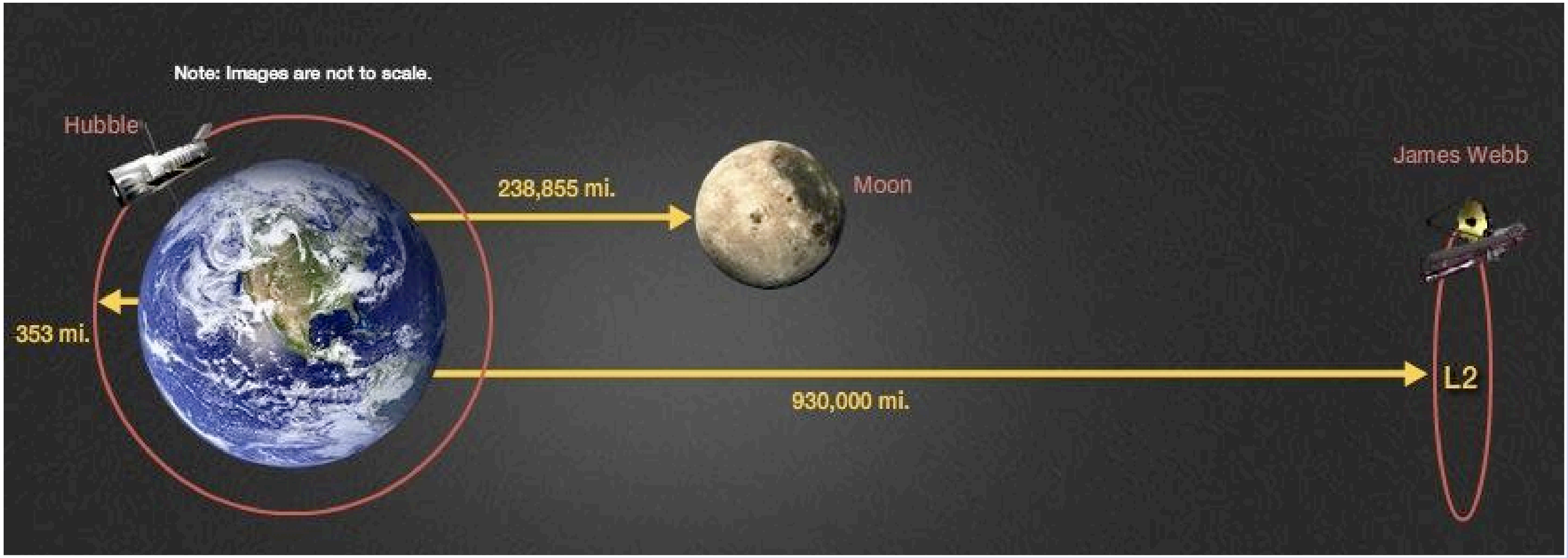
JWST and its Precursors



Sun-Earth L2 orbit required

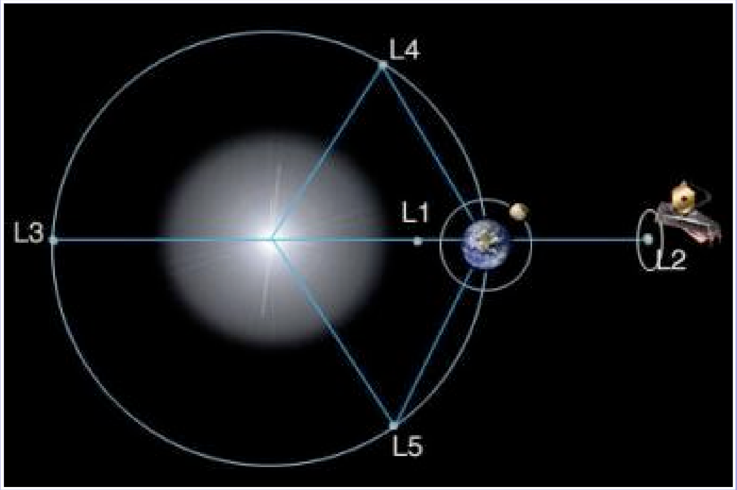
- Low Earth orbit prevents deep cooling – Sun & Earth always changing directions, sometimes telescope is between them
- COBE orbit (polar Sun-synchronous) might work, but limited to 10 minute observations for most of sky
- Geo-synch orbit flies through electron zones, can't take long exposures either
- Escape orbit limits lifetime, data rate
- *S-E L2 is just right: boundary between Earth and Solar orbits, 1,000,000 miles away, Sun and Earth always in same direction, single umbrella is enough, no harder to reach than geo-synch*
- Must go direct – only one trip through radiation belts → no lunar flyby

The James Webb Space Telescope



JWST Orbit

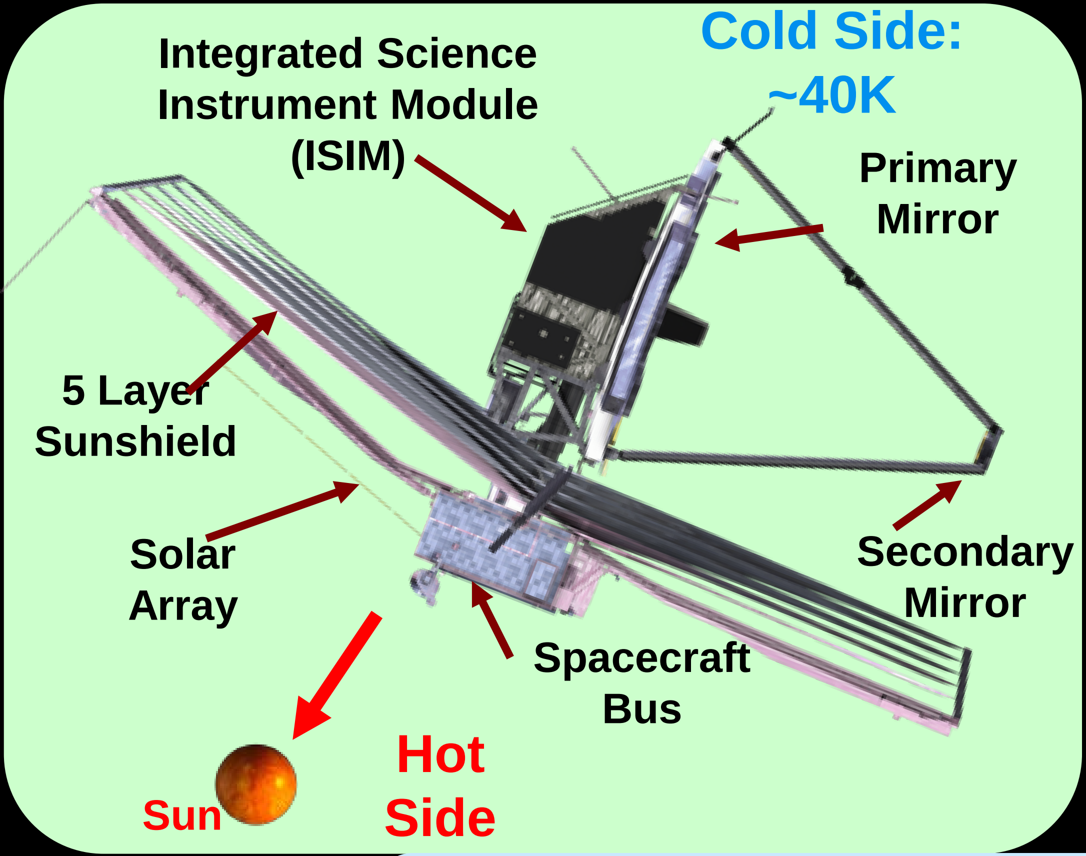
- JWST will orbit Sun-Earth L2 Lagrange point, 1.5 million km from Earth



No user-serviceable parts inside

- In 1996, no servicing availability for L2 orbit
- Expensive and heavy to provide full modularity
- But: modularity would enable easier I&T
- Now, it's the law! (for missions after JWST)
- Remote possibility: servicing robot could attach to JWST's interface ring, but nothing was designed for access
- JWST is fragile and hazardous to astronauts

HOW JWST WORKS

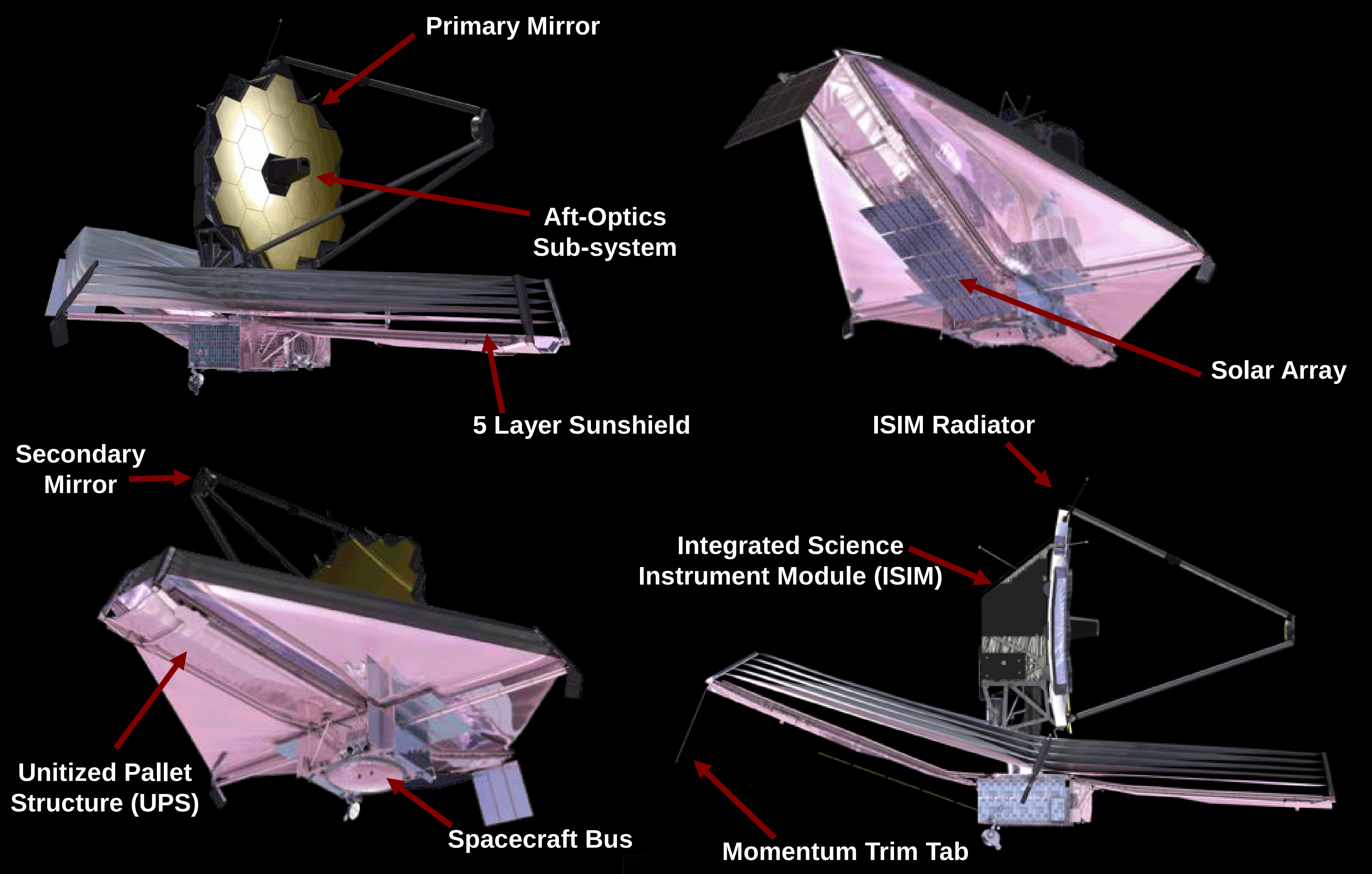


JWST is folded and stowed for launch

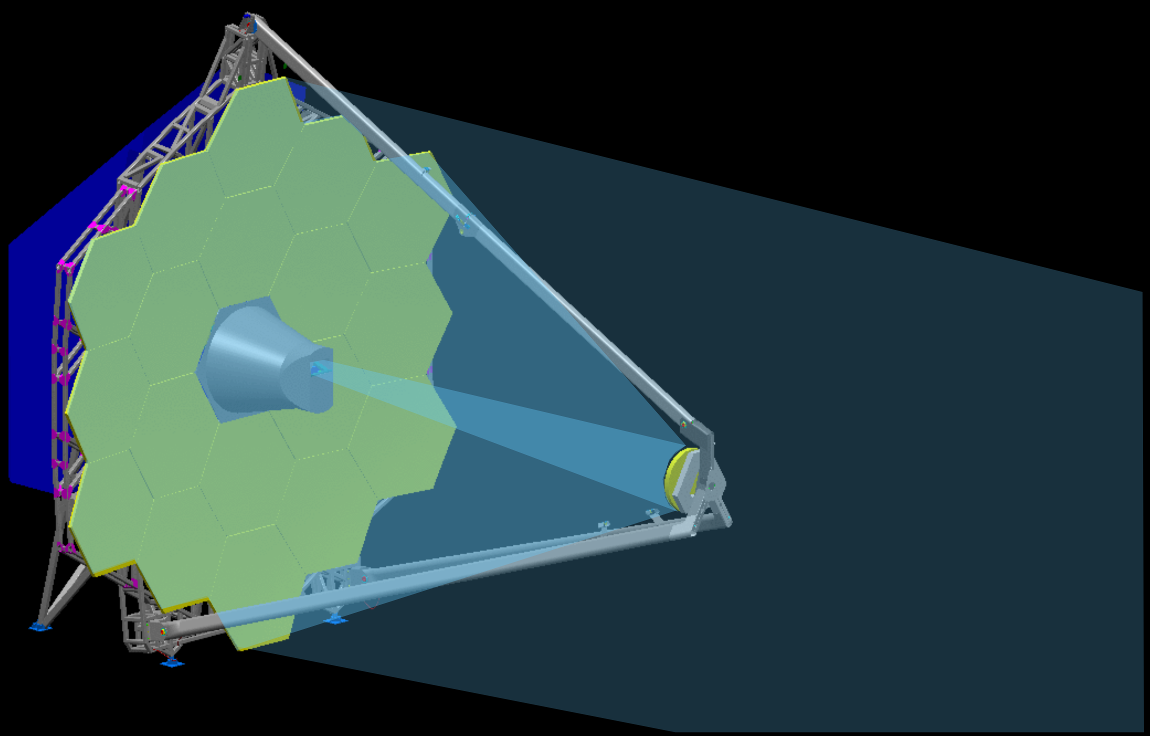
Observatory is deployed after launch

JWST Orbits the 2nd Lagrange Point (L2)

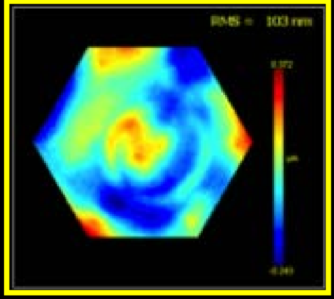
JWST Design: Key Features



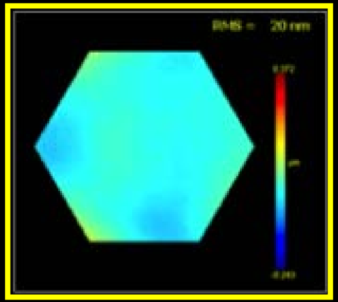
JWST's Telescope Design



- 18 primary mirror segments
- 6 degrees of freedom + ROC
- Beryllium mirrors
- 40 K operation
- <u>Cryo-polishing required</u>
- Long lead time fabrication



Ambient Surface



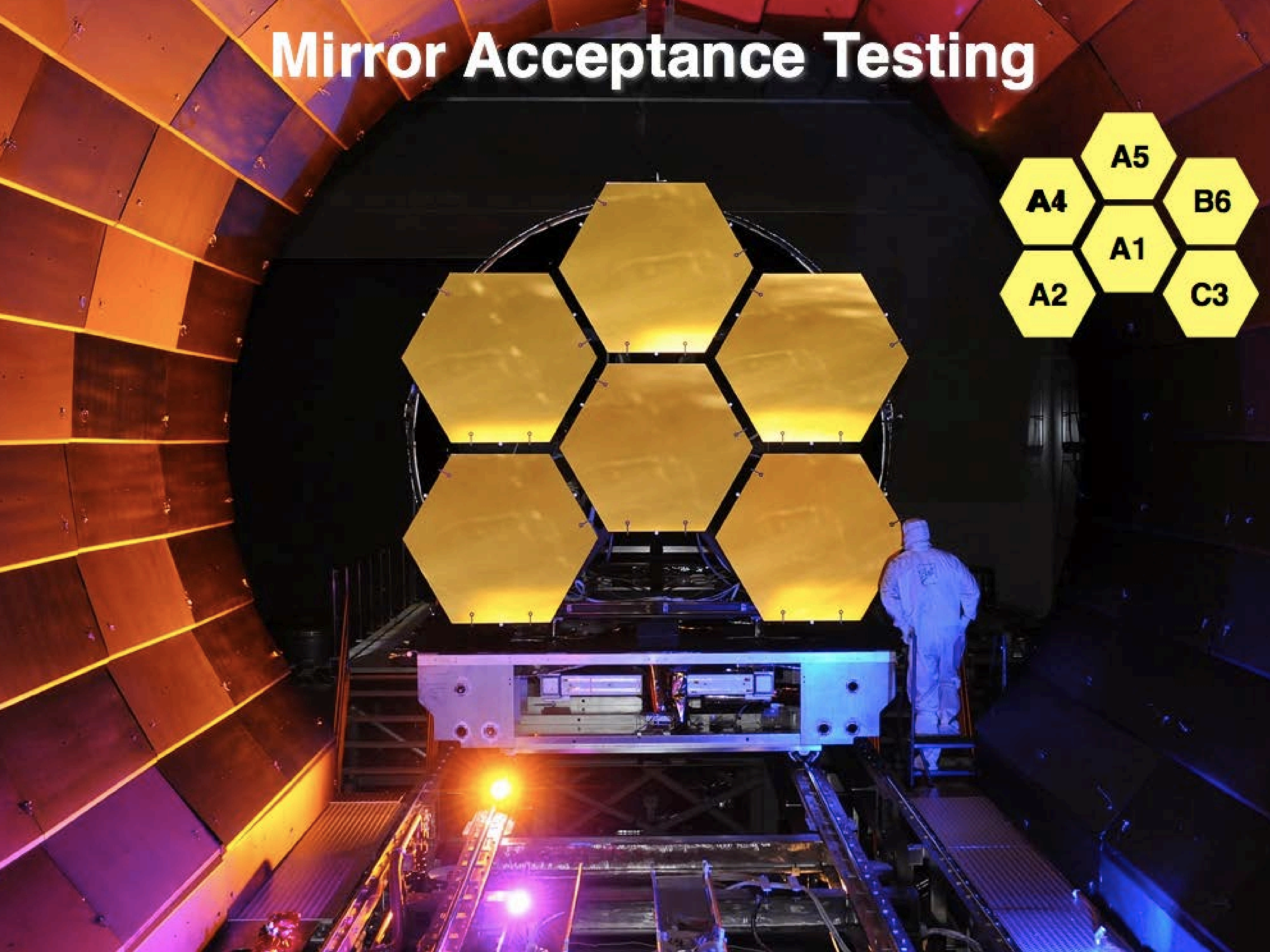
Cryo Surface

- *Elliptical* f/1.2 Primary Mirror (PM)
- *Hyperbolic* Secondary Mirror (SM)
- *Elliptical* Tertiary Mirror (TM) images pupil at *Flat* Fine Steering Mirror (FSM)
- Diffraction-limited imaging at ≥ 2 μm [150 nm WFE @ NIRCam focal plane]

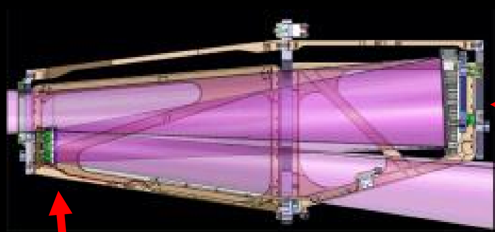
Beryllium Mirrors only choice

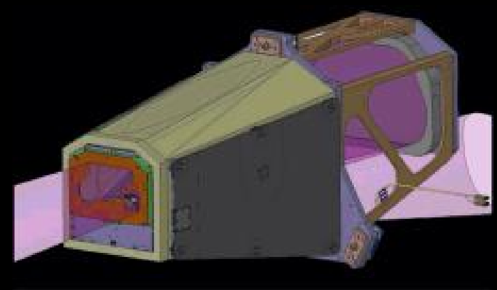
- NRO/DoD/NASA sponsored competitions
- 12 contracts
- Beryllium, aluminum, thin glass shell on actuators, thin glass shell on ribs and actuators, thin glass shell bonded to carbon fiber ribs, ULE sheets on honeycomb spacers, etc.
- Only Be met thermal distortion specs (shrinkage OK, competing designs distorted too much)
- Only available in US, only 1 machine shop (Axsys) and 1 polishing shop (Tinsley), must follow OSHA regs (berylliosis hazard from powder)
- Gold coating (~ 1 oz) for IR reflectivity

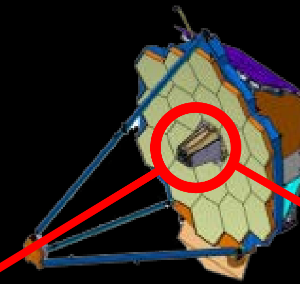
Mirror Acceptance Testing



Aft-Optical System Optics Complete







Aft optics and optical bench complete

Tertiary Mirror

Fine Steering Mirror

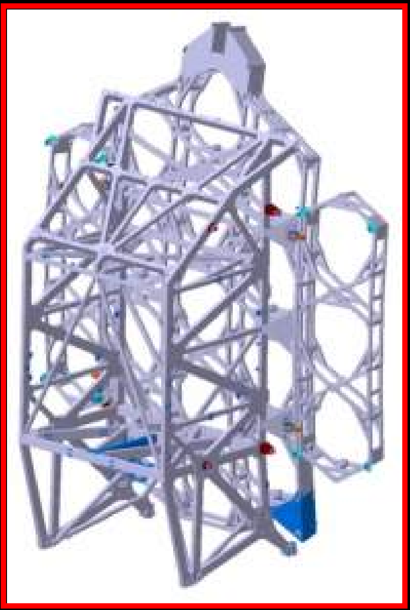
AOS in cryo-test

Huge Shrinkage Challenges

- Each material is different: at room T, Aluminum shrinks 22 ppm/K, Be 11.5, etc. Shrinkage *much* greater than optical tolerances
- Can't use single material throughout – strength, stiffness, cost, expertise, vendor selection, etc. issues
- Implications:
  - Focus after cooling, must allow for huge contraction
  - Differential contraction stresses at joints
  - Internal stresses in composite materials & adhesives
  - Many (hexapod) kinematic mounts

Primary Mirror Backplane

- Pathfinder backplane (central section) is complete
  - Primary use is verification of test procedures at JSC
- Flight Backplane center section is also complete



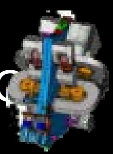
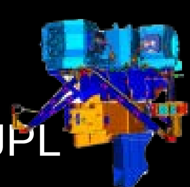
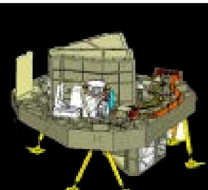
Flight backplane

Pathfinder

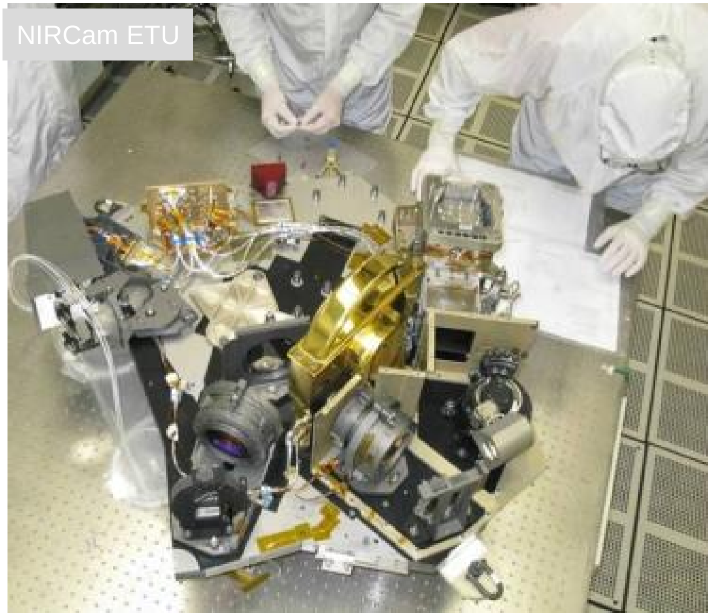
Choice of Instruments & Detectors

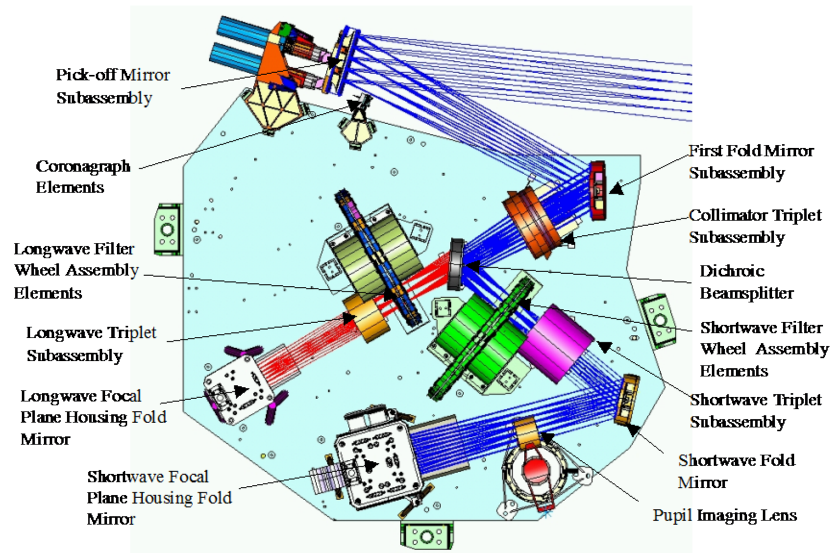
- Don’t do what other equipment can do from the ground → $\lambda > 1.7$ µm is prime; low to medium spectral resolution ($\lambda/\delta\lambda < 3000$)
- Do be general purpose (detect *and* characterize, with cameras and spectrometers)
- Do be driven by scientific objectives, and:
- Be driven by detector availability: InSb (visible to 5 µm at ~ 30 K), HgCdTe (visible to adjustable cutoff out to 5 µm at ~ 40K), Si:As (5 to 28 µm at 7 K)

JWST Instrumentation

Instrument	Science Requirement	Capability
NIRCam Univ. Az/LMATC 	Wide field, deep imaging ‣0.6 µm - 2.3 µm (SW) ‣2.4 µm - 5.0 µm (LW)	Two 2.2’ x 2.2’ SW Two 2.2’ x 2.2’ LW Coronagraph
NIRSpec ESA/Astrium 	Multi-object spectroscopy ‣0.6 µm - 5.0 µm	9.7 Sq arcmin Ω + IFU + slits 100 selectable targets: MSA R=100, 1000, 3000
MIRI ESA/UKATC/JPL 	Mid-infrared imaging ‣ 5 µm - 27 µm Mid-infrared spectroscopy ‣ 4.9 µm - 28.8 µm	1.9’ x1.4’ with coronagraph 3.7”x3.7” – 7.1”x7.7” IFU R=3000 - 2250
FGS/NIRISS CSA 	Fine Guidance Sensor 0.8 µm - 5.0 µm Near IR Imaging Slitless Spectrometer, ‣1.6 µm - 4.9 µm	Two 2.3’ x 2.3’ 2.2’ x 2.2’ R=700 with coronagraph

NIRCam will provide the deepest near-infrared images ever and will identify primeval galaxy targets for the NIRSpec



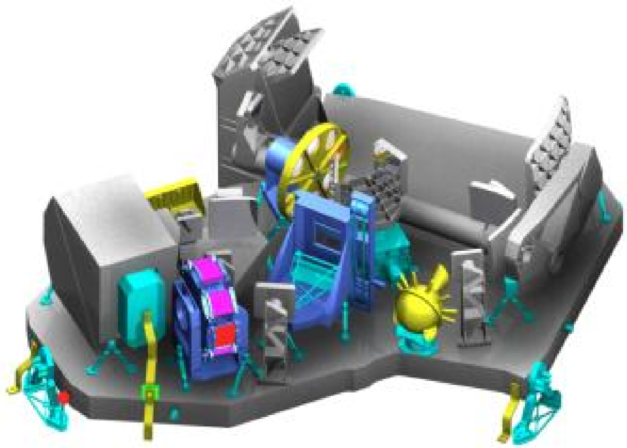


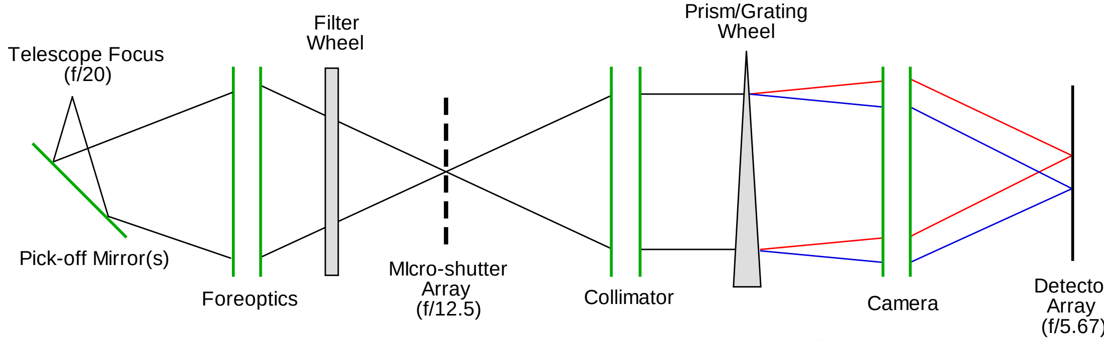
- Developed by the University of Arizona with Lockheed Martin ATC
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 4, 10, 100 (filters + grism), coronagraph
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns, coronagraph
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 10 detectors, 40 K passive cooling
  - Refractive optics, Beryllium structure
- Supports OTE wavefront sensing

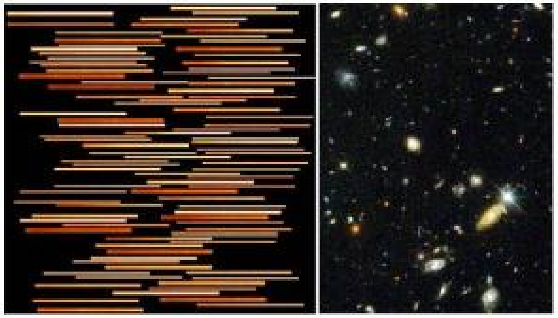
Choice of Near IR Spectrometer

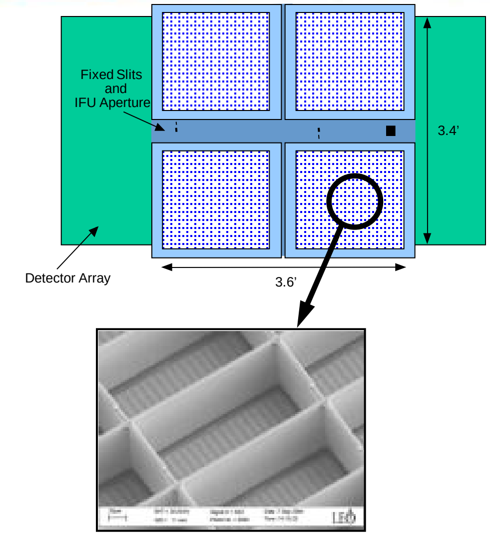
- Traditional*: single slit grating spectrometer*, one object at a time, not good enough at all!
- Inspiration: ground-based equipment can do hundreds at once
- Inspiration: Texas Instruments DLP with micromirrors to select desired galaxies
- New technology required*: microshutter array* (H. Moseley & team, GSFC) endorsed by Science Working Group
- Alternatives: Integral Field Unit *(field slicer*, Fourier transform, lenslet array)
- ESA/Astrium design: MSA + field slicer + single slits

The NIRSpec will acquire spectra of up to 100 galaxies in a single exposure



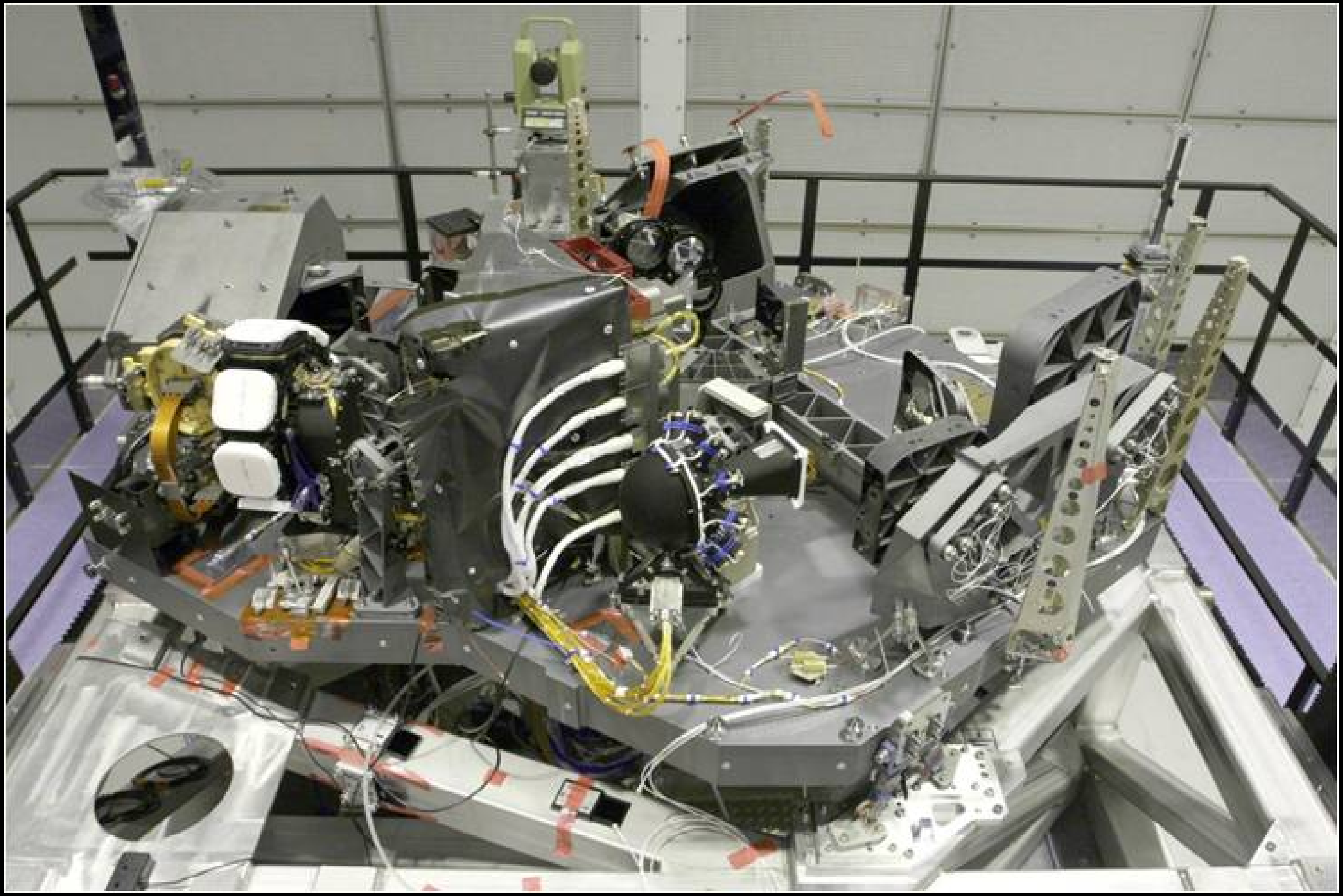




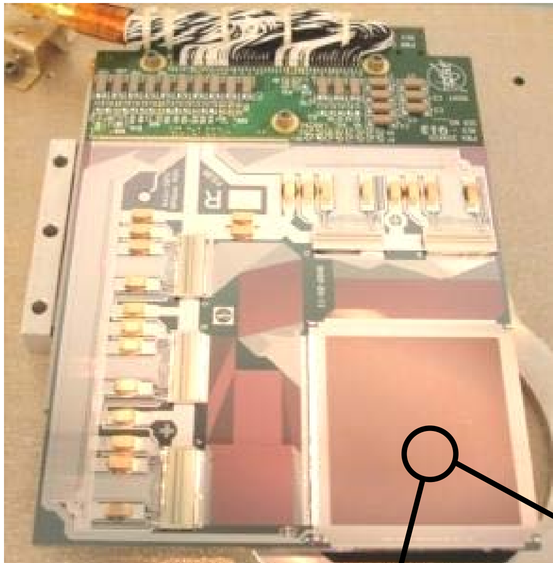


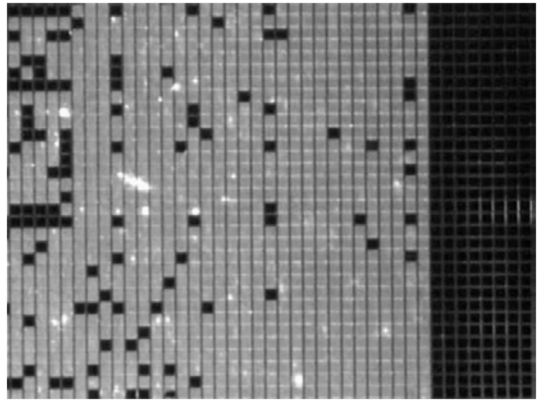
- Developed by the European Space Technology Center (ESTEC) with Astrium GmbH and Goddard Space Flight Ctr
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
    - Aperture control:
      - Programmable micro-shutters, 250,000 pixels
      - Fixed long slits & transit spectroscopy aperture
      - Image slicer (IFU) 3x3 arc sec
  - Detector type: HgCdTe, 2048 x 2048 format, 2 detectors, 37 K passive cooling
  - Reflective optics, SiC structure and optics

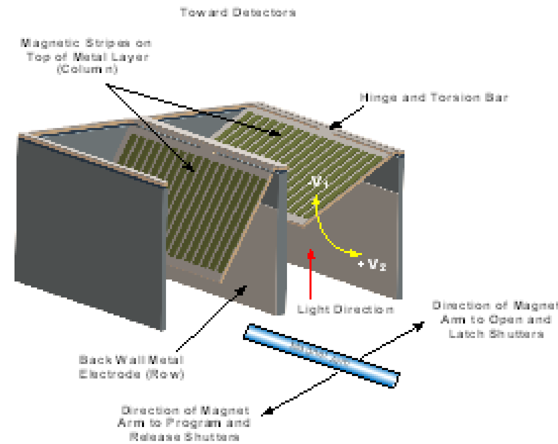
FLIGHT NIRSpec

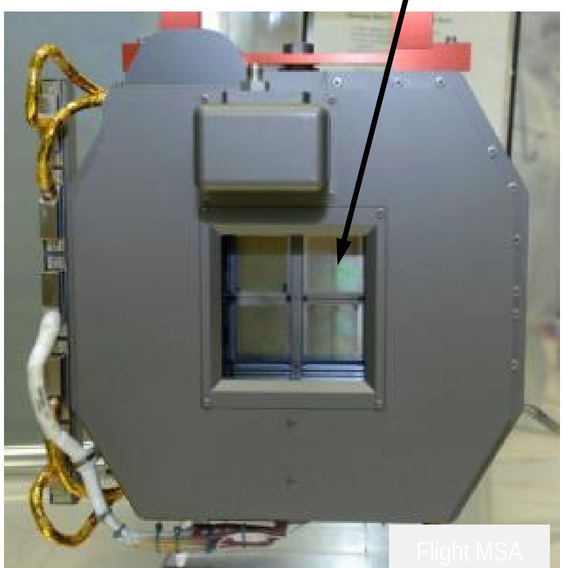


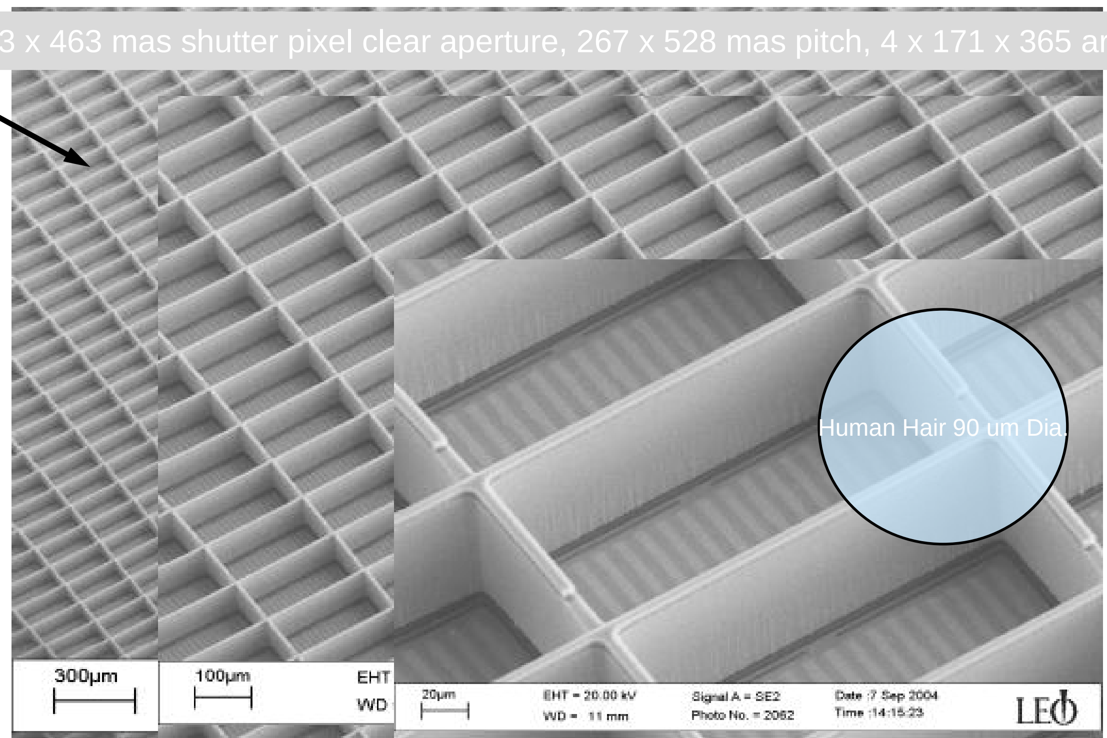
Aperture control: 250,000 programmable micro-shutters System at TRL-8 and delivered to ESA June 2010





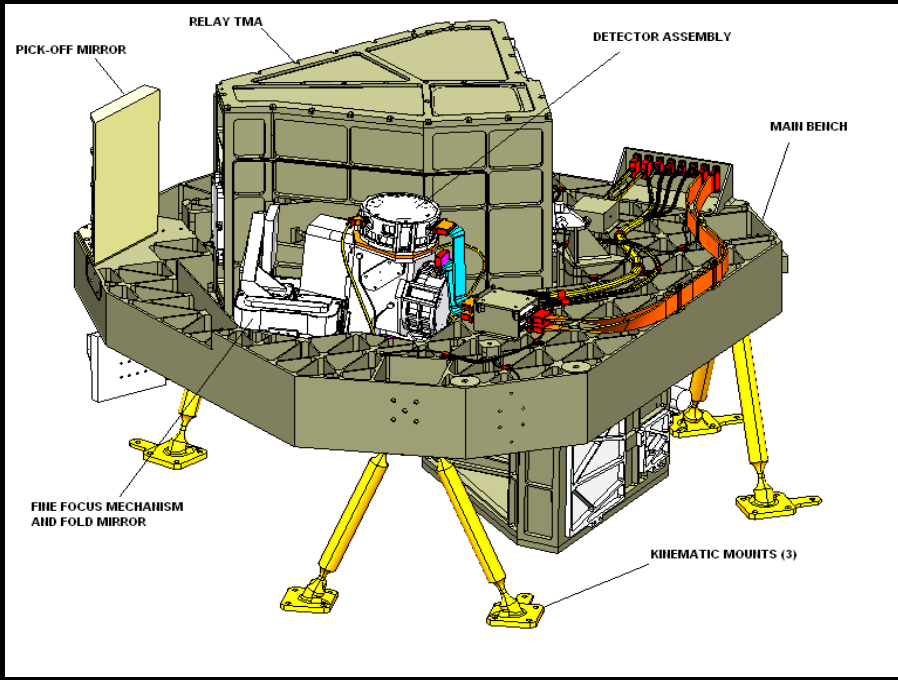


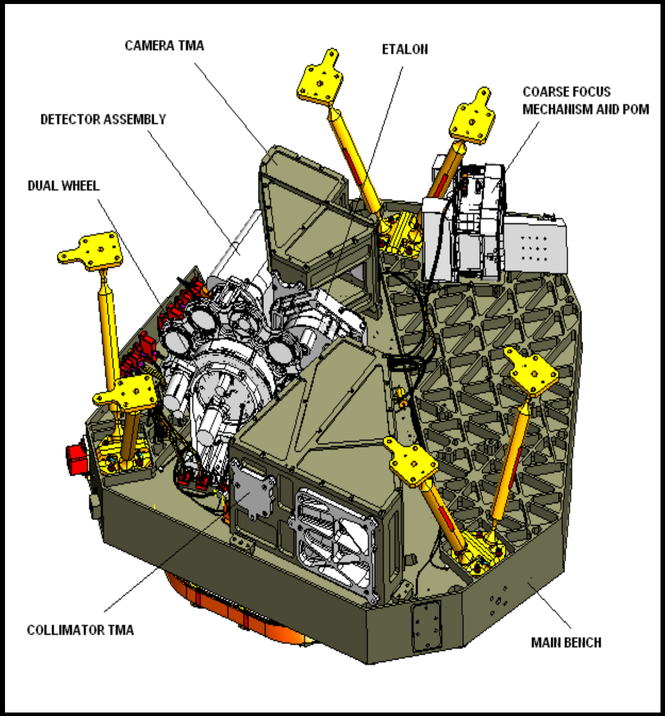




Flight MIRI has been delivered

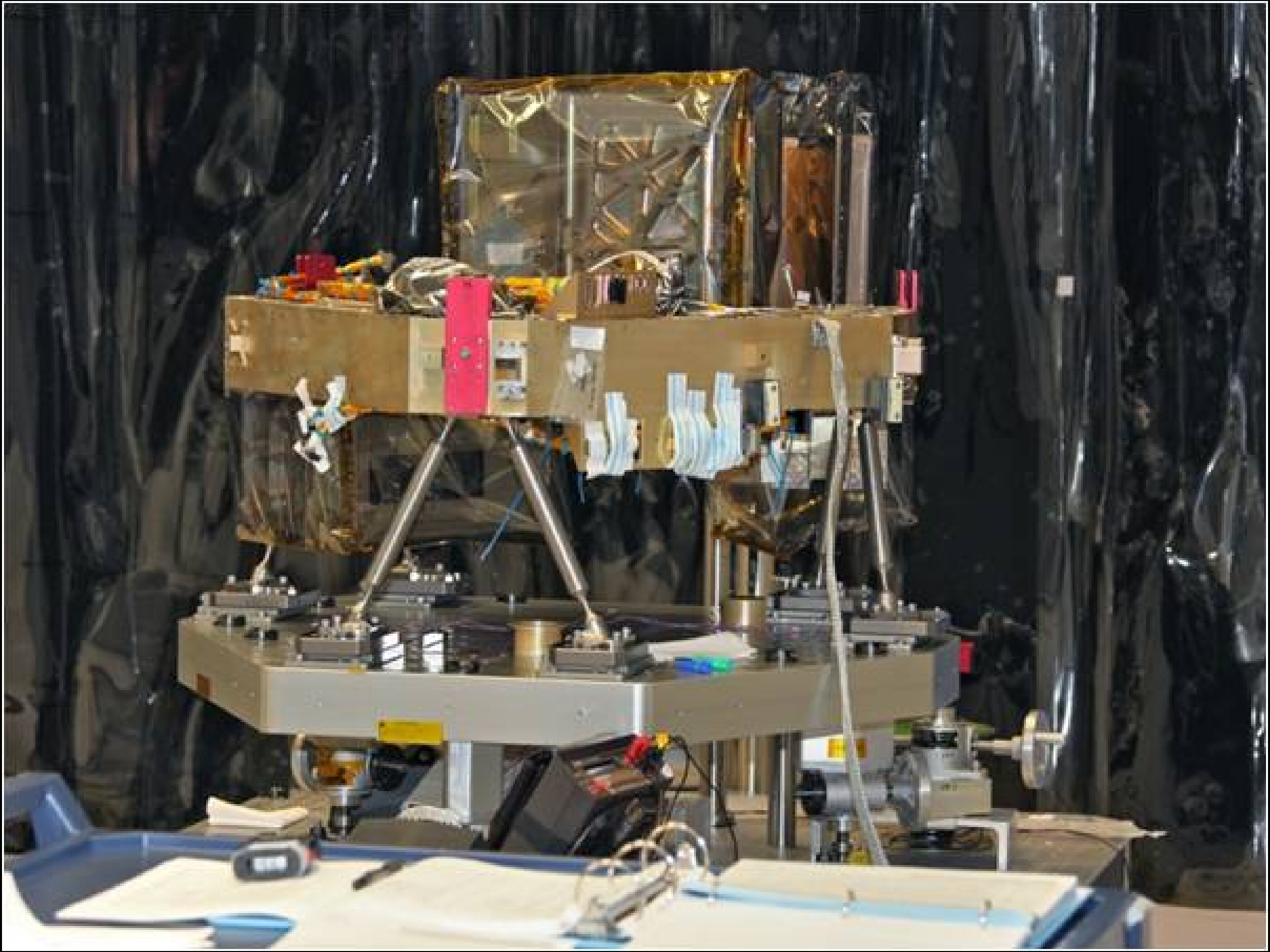
FGS/NIRISS have been delivered, provide pointing control & imaging spectroscopy





- Developed by the Canadian Space Agency with ComDev
  - Operating wavelength: 0.8 – 4.8 microns
  - Spectral resolution: Broad-band guider and R=100 science imagery
  - Field of view: 2.3 x 2.3 arc minutes
    - R=700 imagery with near IR Imaging Slitless Spectrometer and coronagraph
  - Angular resolution (1 pixel): 68 mas
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 3 detectors, 40 K passive cooling
  - Reflective optics, Aluminum structure and optics

Flight Fine Guidance Sensor



Choice of MIRI Cooler

- Need 7K to enable mid IR detectors
- In 1996, only solid H2 coolers available
  - Heavy, limited life, hazardous!!
- NASA sponsored cooler development competitions for multiple future missions
  - Winner: Northrop Grumman pulse tube design with gaseous helium compressor
    - No design lifetime limitation
    - Much lighter weight
    - But: vibration source, requires power

Choice of Fine Pointing Control

- 3-axis control required, ~0.007 arcsec precision
- Like HST: gyros (short term precise sensing), external star trackers (arcsec level), reaction wheels (to push against), fine guidance sensor at telescope focal plane
- Unlike HST: add Fine Steering Mirror (at image of primary mirror), remove Magnetic Torquer (very small magnetic field at L2), replace mechanical gyro with HRG (no moving parts)

Choice of Propulsion

- HST orbit was raised by Shuttle missions
- JWST orbit unstable, needs maintenance every few weeks (saddle-shaped pseudo-potential)
- JWST must manage solar pressure torques
- Use small and very small thrusters, with N_2H_2, or N_2H_2 + oxidizer; must damp fuel slosh, can't use polymer balloon
- All thrusters on *warm* side of spacecraft
  - Can't thrust efficiently *towards* Sun

Choice of Sunshield Design

- Need 4 layers, to let heat get out (angled design)
- Need 5th one to allow for margin, and damage by dust particles (micrometeorites)
- Sun Protection Factor 1,000,000
- Solar radiation pressure force 2 P/c ~ 1 millinewton (weight of 0.1 gram on Earth, P = intercepted power), would tumble over telecope in 1 day if not balanced over center of mass → shield almost symmetrical, wedged like boat bottom for stability
- Also provides *contamination* control: if photons can't go from hot to cold, neither can (neutral) atoms; everything but He and H_2 condenses on telescope or MIRI instrument

Rigid Body Pointing

- Considered articulating telescope behind sunshield, to enable wider range of angles from Sun
- But: No scientific requirement
- Better *is* enemy of good enough; if it's not required, it's forbidden (Mather's principle of management)

Robotic Assembly

- Considered robotic assembly concepts
- Not needed for this size telescope: hinges, cables, actuators, and motors are good enough (= robots with zero IQ)
- Would be valuable if volume were the limiting resource instead of mass
- Maybe next time! (or, maybe we can get a bigger rocket?)

RF communications good enough

- Data rate not very high: comparable to HST
- Range ~ 50x greater (HST goes via TDRSS) but still OK via Deep Space Network (larger dishes)
- Considered optical comm, but would have had to develop it ourselves – now more mature – and provide at least 2 ground stations in new locations (e.g. desert in Chile)

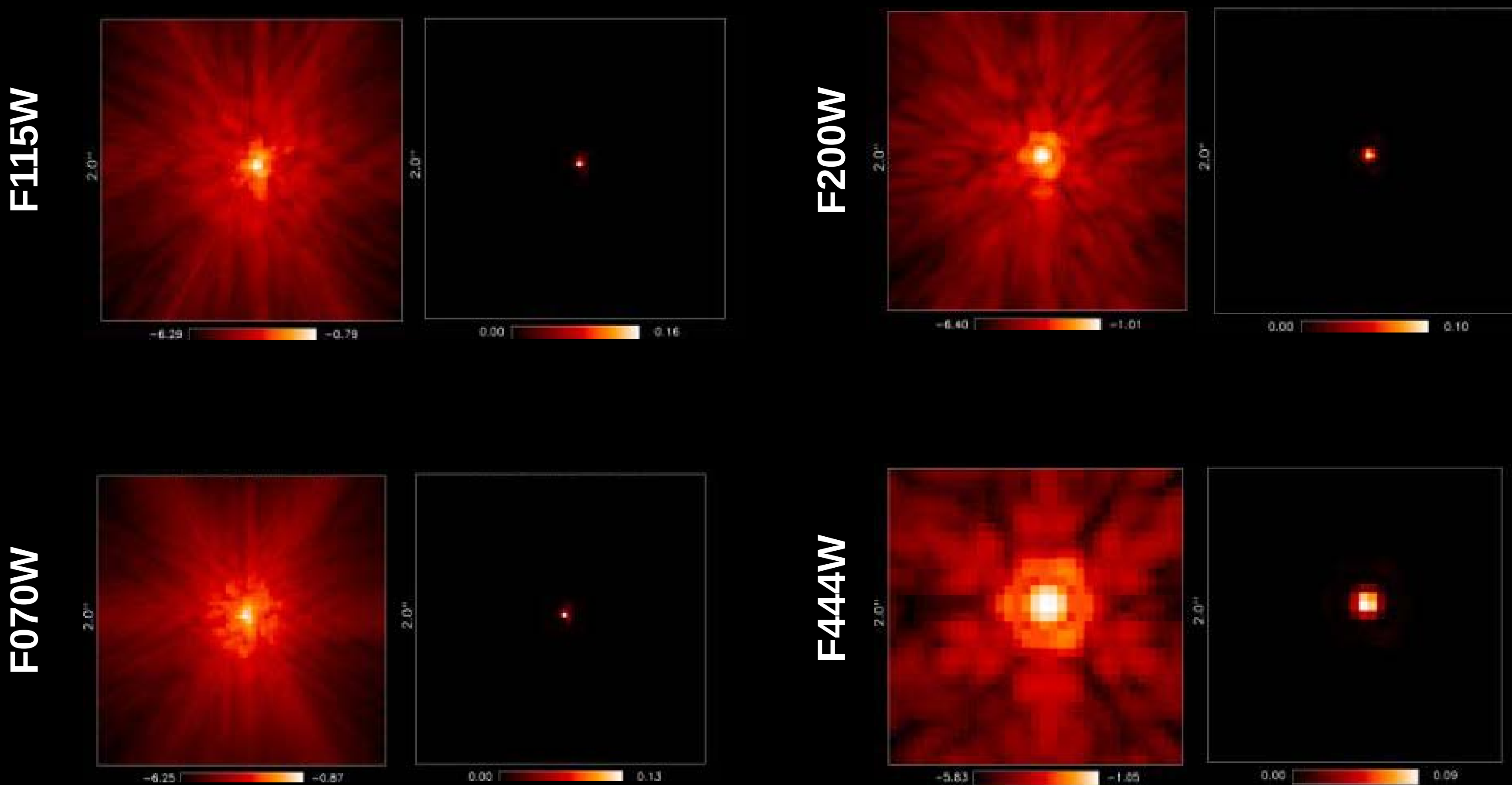
Focusing Algorithms

- Basic method developed for HST repair mission, selected from competition, improved for JWST by JPL team (D. Redding et al.), and continued development by BASD, GSFC
  - Take photos of bright star in focus and out of focus with NIRCam
  - Process in computer to get error map, using least-squares fit, and diffraction theory
- Must precede by coarse adjustments
- Proven on scale model testbed – BASD, GSFC

Testbed Telescope

- 1/6 scale model with all the same adjustments
- Proves that all the adjustment procedures work as expected

Predicted Image Quality



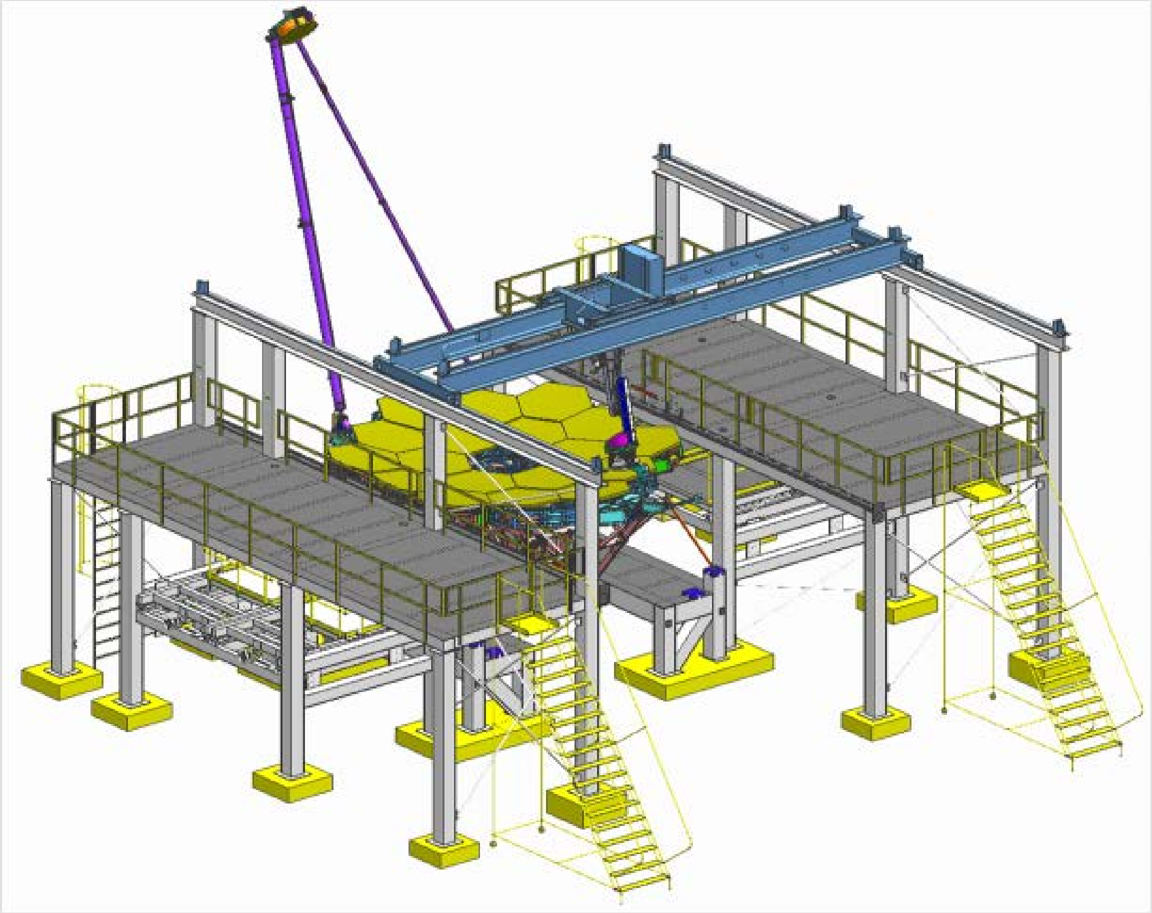
Log Scale

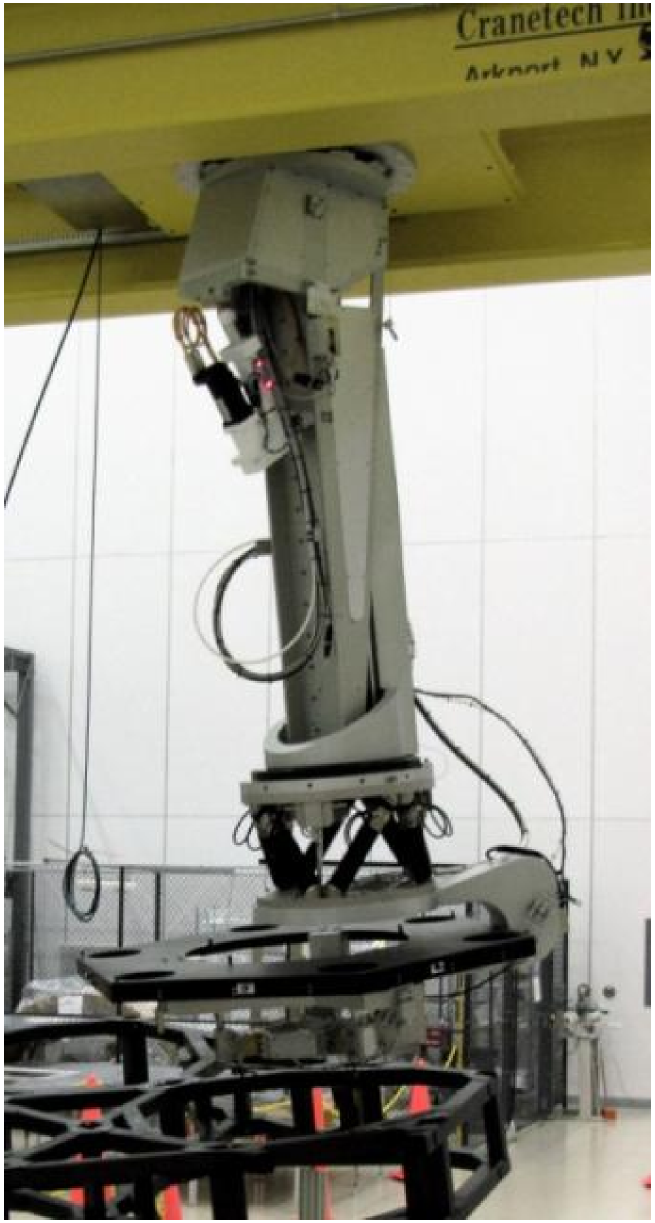
Linear Scale

Ground Based Testing

- Lesson learned from HST: test everything important in 2 ways, make sure they agree
  - HST primary *was* tested 2 ways, they didn't agree, people believed the *wrong* but *precise* measurement without finding the reason for disagreement!
- JWST too big for total end-end simulation with traditional autocollimator or external collimator
- Prove primary mirror adjusts right, using interferometers at center of curvature
- Prove end-end imaging with light source in instrument module, sent out to 3 sub-aperture flats, to reflect back into instruments

Optical Telescope Element will be integrated on this alignment stand using the machine at right for primary mirror segment installation

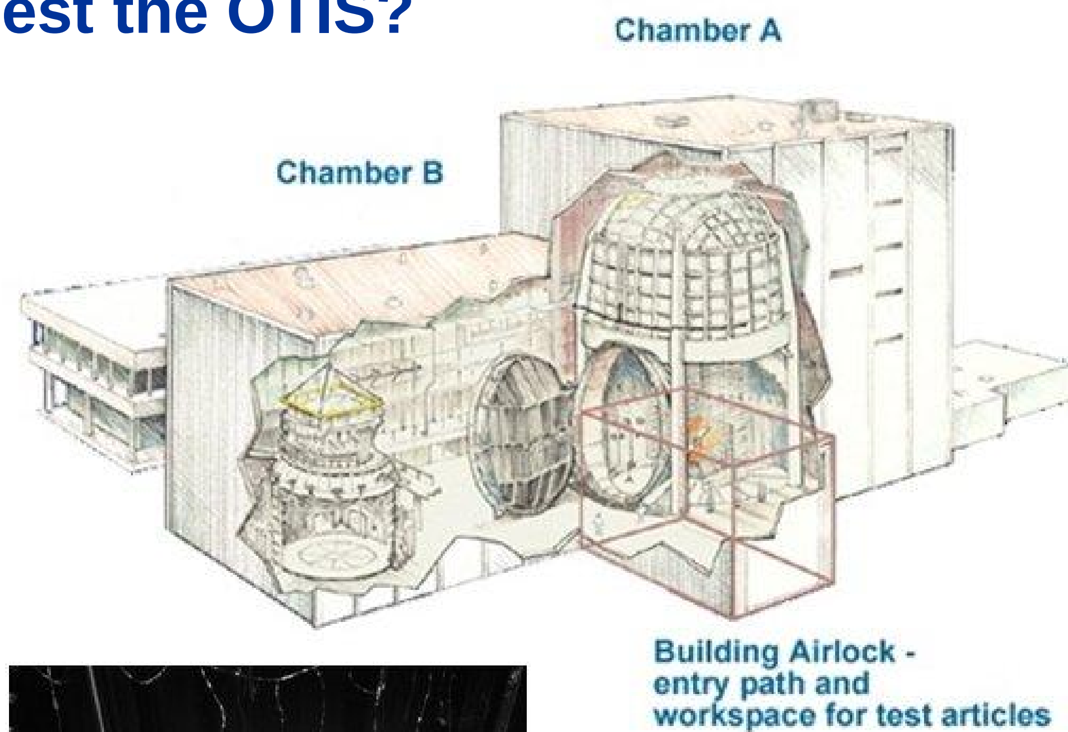


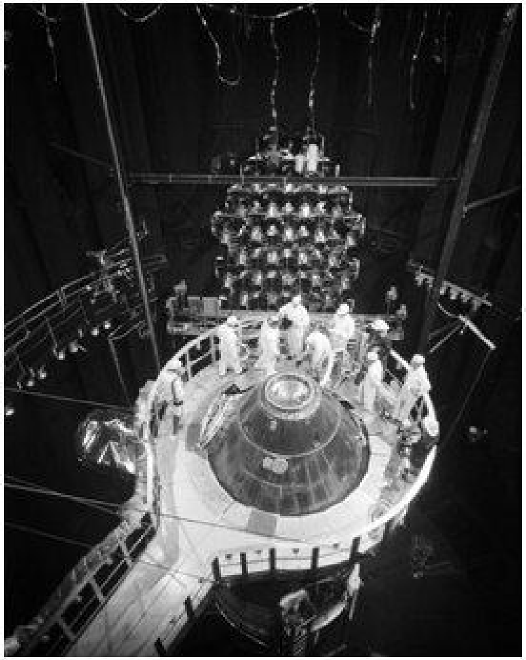


followed by attachment of the ISIM to make OTIS – scheduled for 2016

Where to Cryo-Test the OTIS?

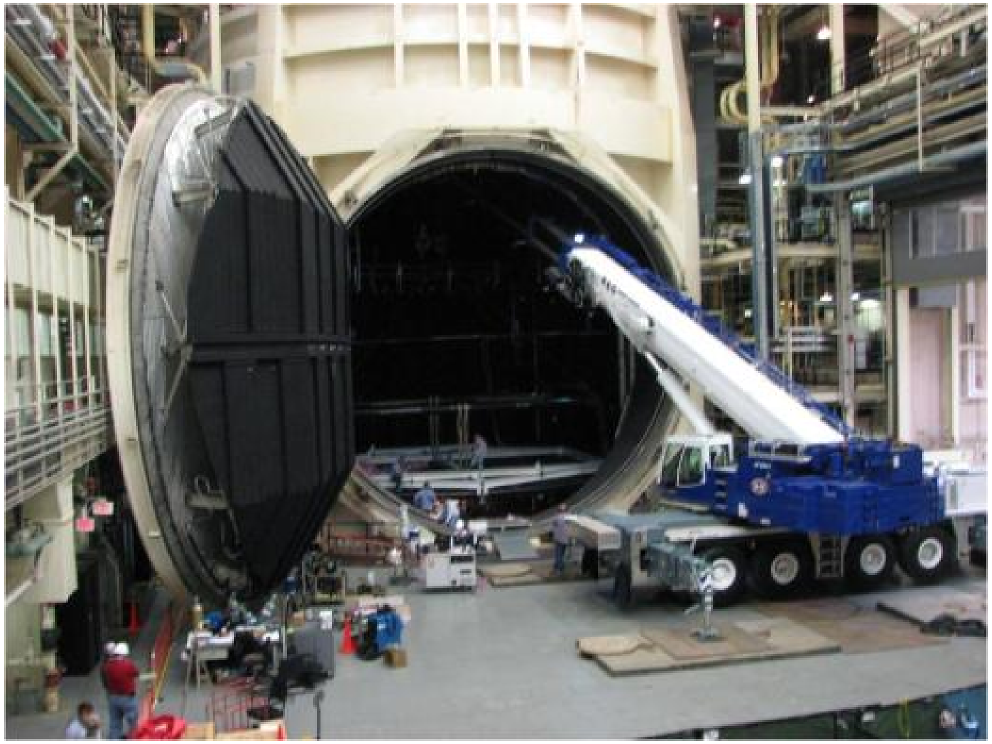
Off to JSC to a giant National Historic Landmark vacuum chamber from the Apollo era





JSC Upgrades Are Complete

Refurbishment for deep cryogenic operation is done



Including the installation of the GHe shrouds and refrigeration system for taking JWST to its flight operating temperature

JSC Chamber A fits perfectly!

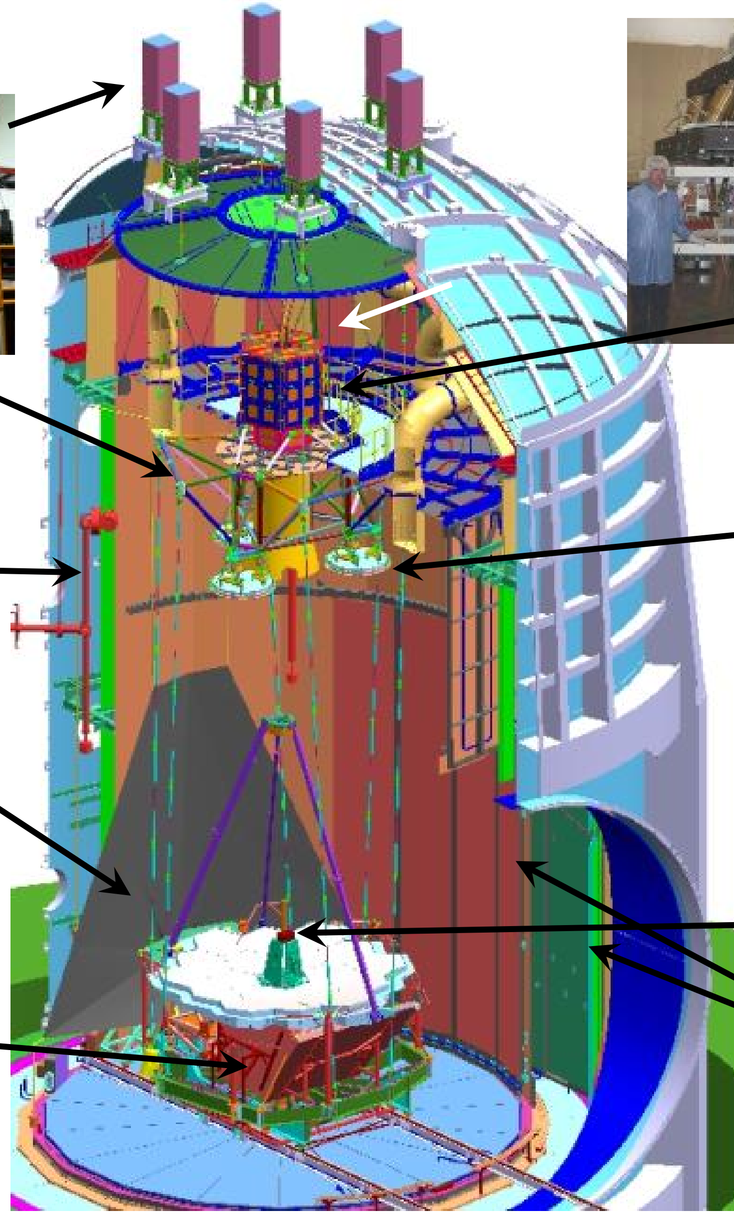
Chamber Isolator
1st unit tested

Suspension Subsystem

Photogrammetry Windmills

Space Vehicle Thermal Simulator (SVTS) w/ cryo-cooler and electronics

Hardpoint Offloader Support System



Center of Curvature Optical Assembly (COCOA)
Well into its I&T

3 Autocollimating Flat Mirrors
1st unit complete.
Units 2 & 3 polished

AOS Source Plate

LN2 and Helium Cryogenic Shrouds and “barn door”

I wish…

- That we had adjustments on *all* the mirrors in the telescope
  - The one that can't be adjusted, has to be proven *stable* and *correct!*
  - Very difficult to do! Even more difficult than adjustments and actuators
  - Next time!

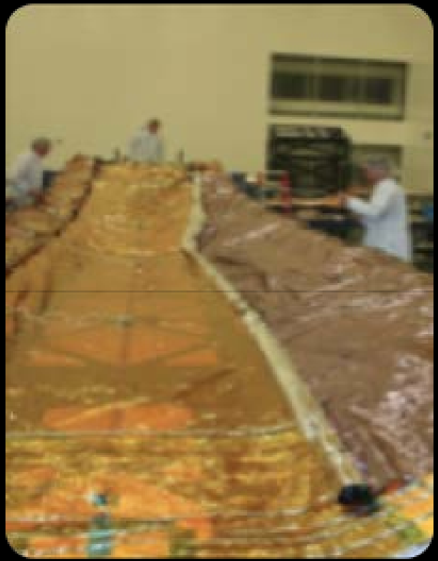
I wish…

- That there were cryo-electronics capable of driving longer cables
- Our instrument box is on the back of the telescope, the “Coleman lantern” in the cold area
- Very difficult thermal engineering job
- Next time: find or invent the needed cable drivers early!

40K is cold enough for telescope

- Thermal emission very low out to 10 µm
  - Still low enough out to 28 µm
- HgCdTe detectors at 5 µm work well enough at 40 K
  - Can have passive cooling
- Enables mid IR instrument cooled actively to 7 K inside with pulse tube cooler

Sunshield Deployment



Sunshield cover test

1/3rd scale thermal test

UPS Deployment/clearance tests

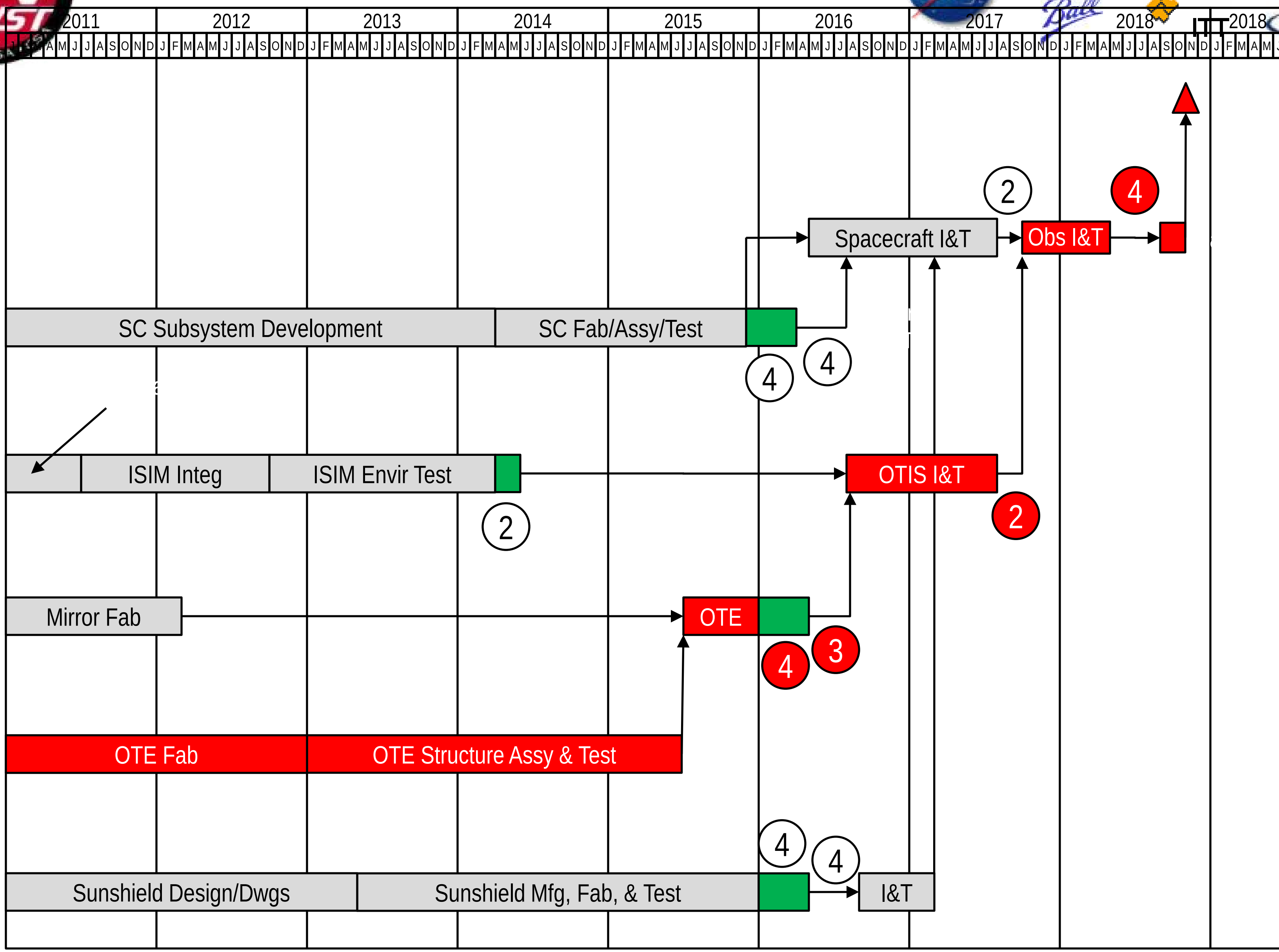
Membrane fold tests

Sunshield alignment

Sunshield deployment tests

3D Shape Measurement: Layer 3

- Layer 3 template membrane is being used to verify 3D shape and alignment tolerances: Layers, 5, 4, 2, and 1 will be tested next year
- Next step is hole-punching. Designed to verify release pin hole alignments on five folded membranes


2011
2012
2013
2014
2015
2016
2017
2018
2018
Spacecraft I&T
Obs I&T
SC Subsystem Development
SC Fab/Assy/Test
ISIM Integ
ISIM Envir Test
OTIS I&T
Mirror Fab
OTE
OTE Fab
OTE Structure Assy & Test
Sunshield Design/Dwgs
Sunshield Mfg, Fab, & Test
I&T
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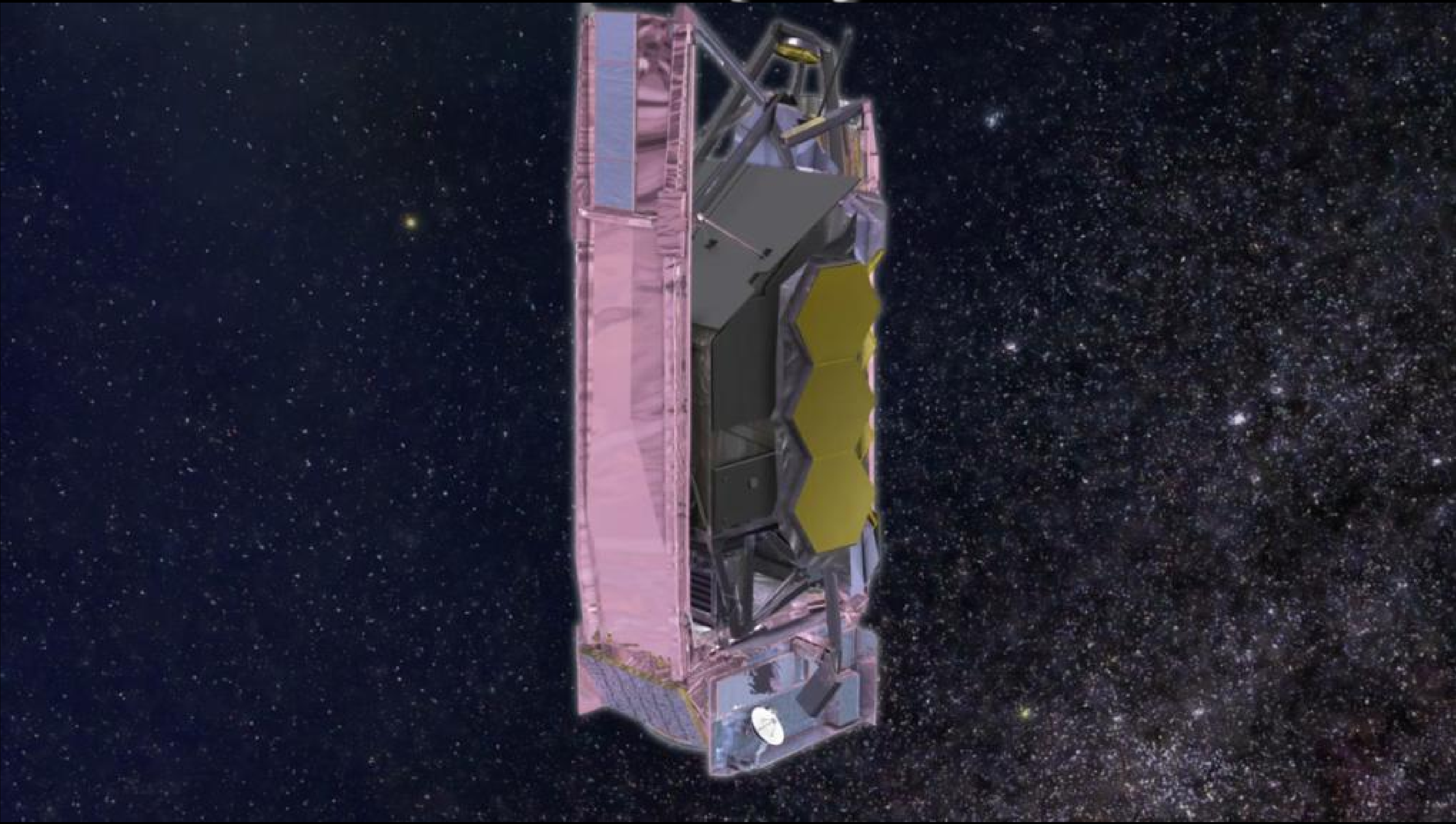
4

JWST Deployment



Want to Learn More about JWST?

Gardner et al. 2006,
Space Science Reviews, 123/4, 485
http://jwst.nasa.gov/scientists.html

2011 Conference
Webcast and Charts
http://webcast.stsci.edu
“Webcast Archives”

White Papers:

JWST in Decadal Survey
Solar System Objects
Dark Energy
Transiting Planets
Coronagraphy
Planetary Systems
Stellar Pops
Star Formation
Galaxy Assembly
First Light
Astrobiology
Scientific Capabilities

Science White Papers
http://www.stsci.edu/jwst/science/whitepapers/

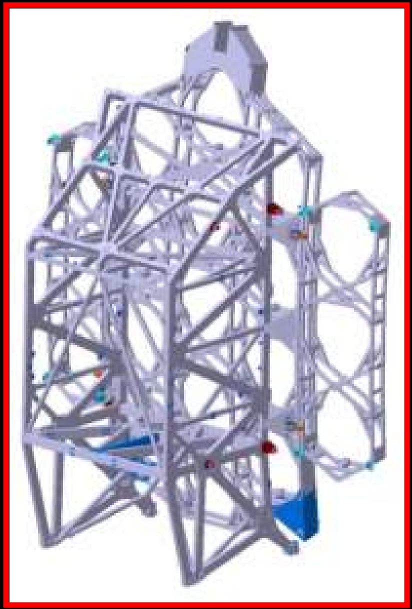
JWST FAQ for Scientists:
http://jwst.gsfc.nasa.gov/faq_scientists.html

The End

- Questions?

Primary Mirror Backplane

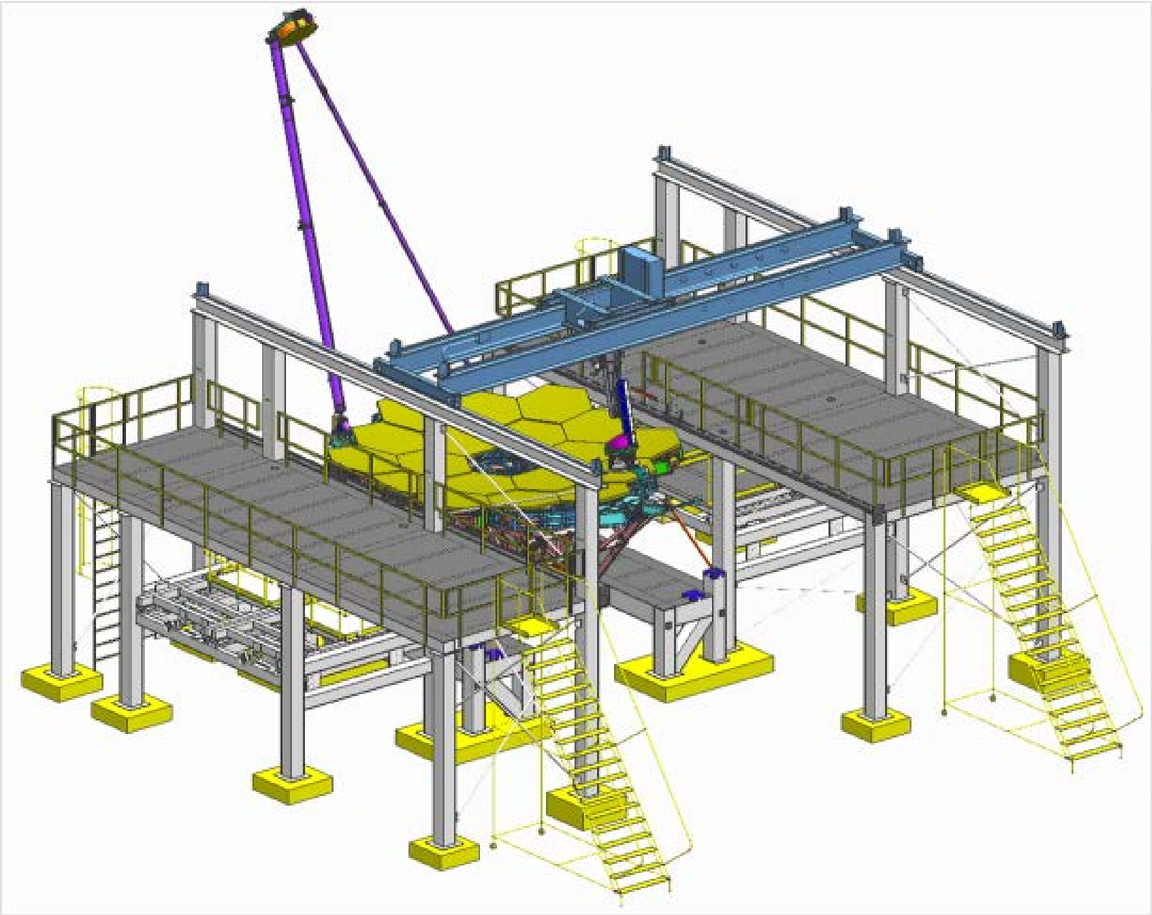
- Pathfinder backplane (central section) is complete
  - Primary use is verification of test procedures at JSC
- Flight Backplane side sections under construction

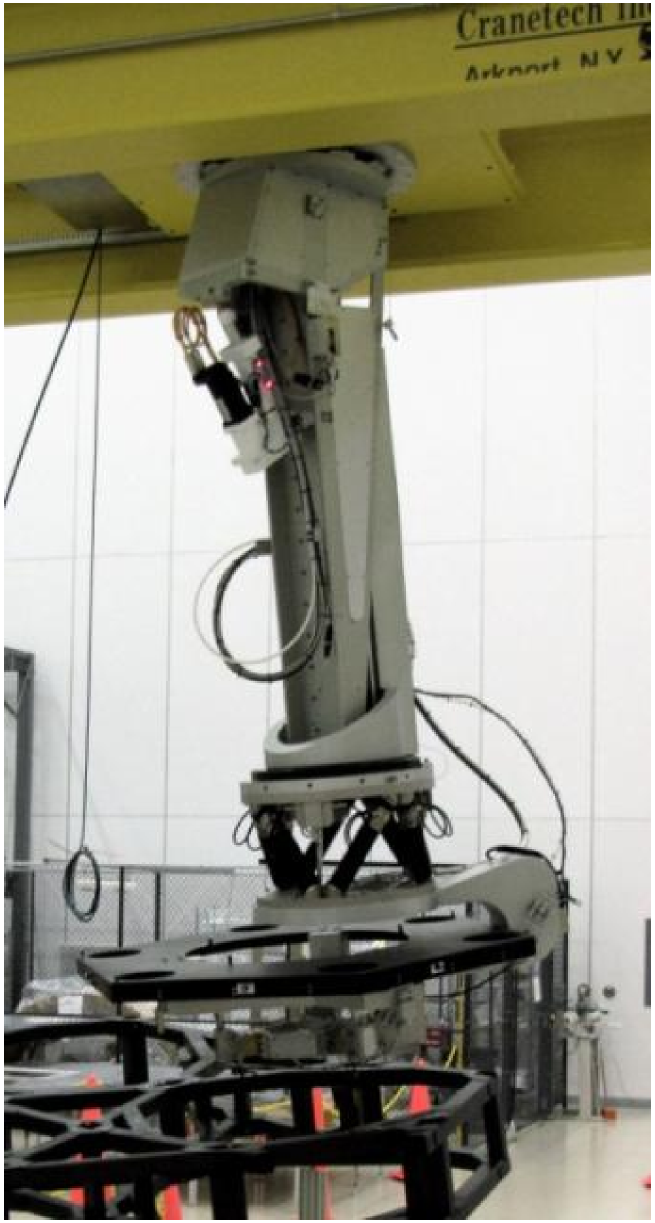


Flight backplane center section complete

Pathfinder

Optical Telescope Element will be integrated on this alignment stand using the machine at right for primary mirror segment installation



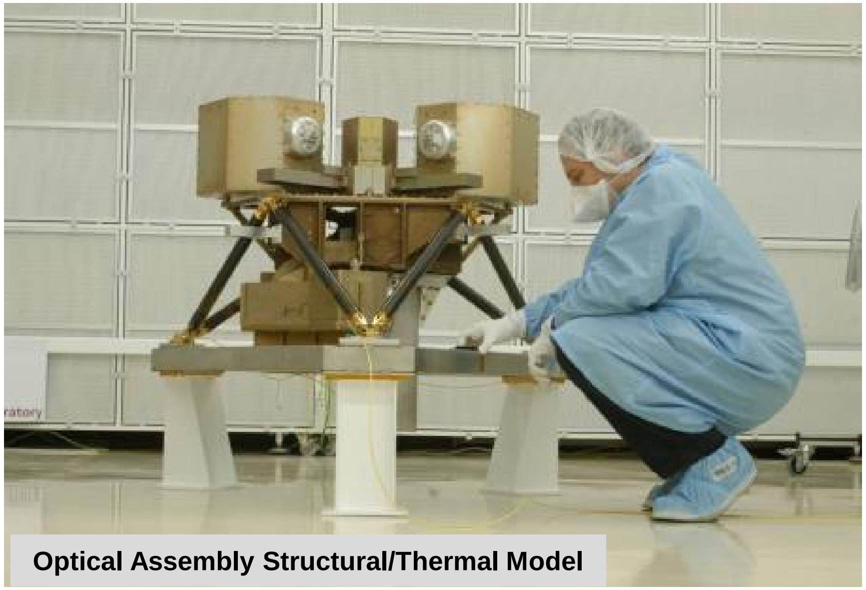


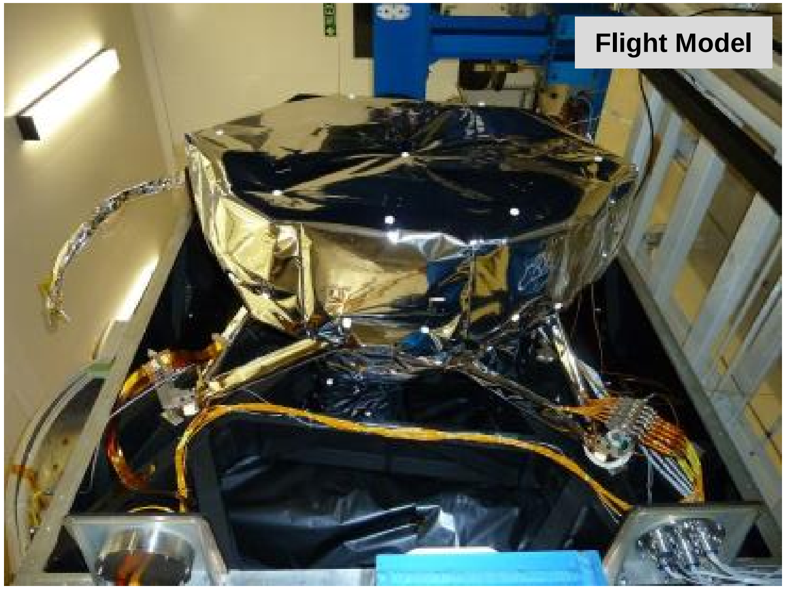
followed by attachment of the ISIM to make OTIS – scheduled for 2016

MIRI is on schedule for delivery during 2012

Flight MIRI on test fixture

The MIRI instrument will detect key discriminators that distinguish the earliest state of galaxy evolution from more evolved objects

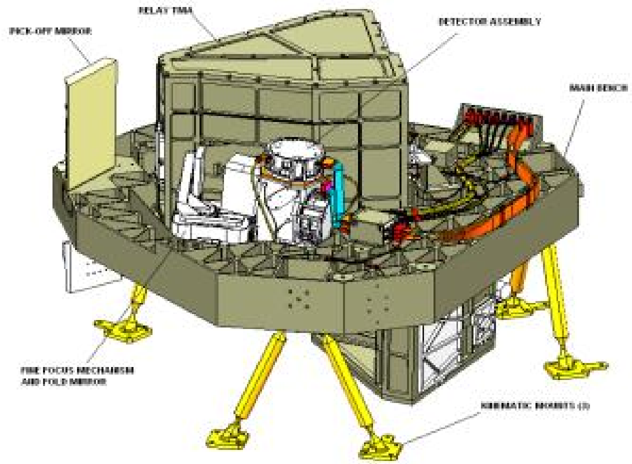

Optical Assembly Structural/Thermal Model

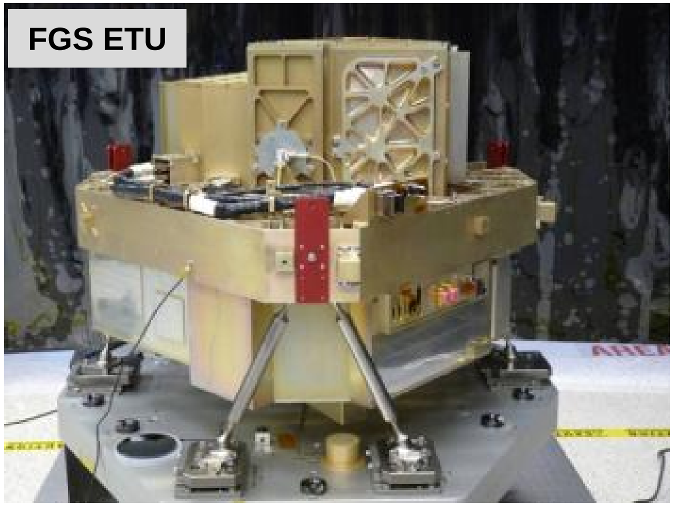

Flight Model

- Developed by a European Consortium and JPL
  - Operating wavelength: 5 - 29 microns
  - Spectral resolution: 5, 100, 2000
  - Broad-band imagery: 1.9 x 1.4 arc minutes FOV
  - Coronagraphic imagery
  - Spectroscopy:
    - R100 long slit spectroscopy 5 x 0.2 arc sec
    - R2000 spectroscopy 3.5 x 3.5 and 7 x 7 arc sec FOV integral field units
  - Detector type: Si:As, 1024 x 1024 pixel format, 3 detectors, 7 K cryo-cooler
  - Reflective optics, Aluminum structure and optics

Flight unit cryo-vacuum testing successfully completed during July 2011

The FGS-Guider and NIRSS provide imagery for telescope pointing control & spectroscopy for Ly-α galaxy surveys and extra-solar planet transits

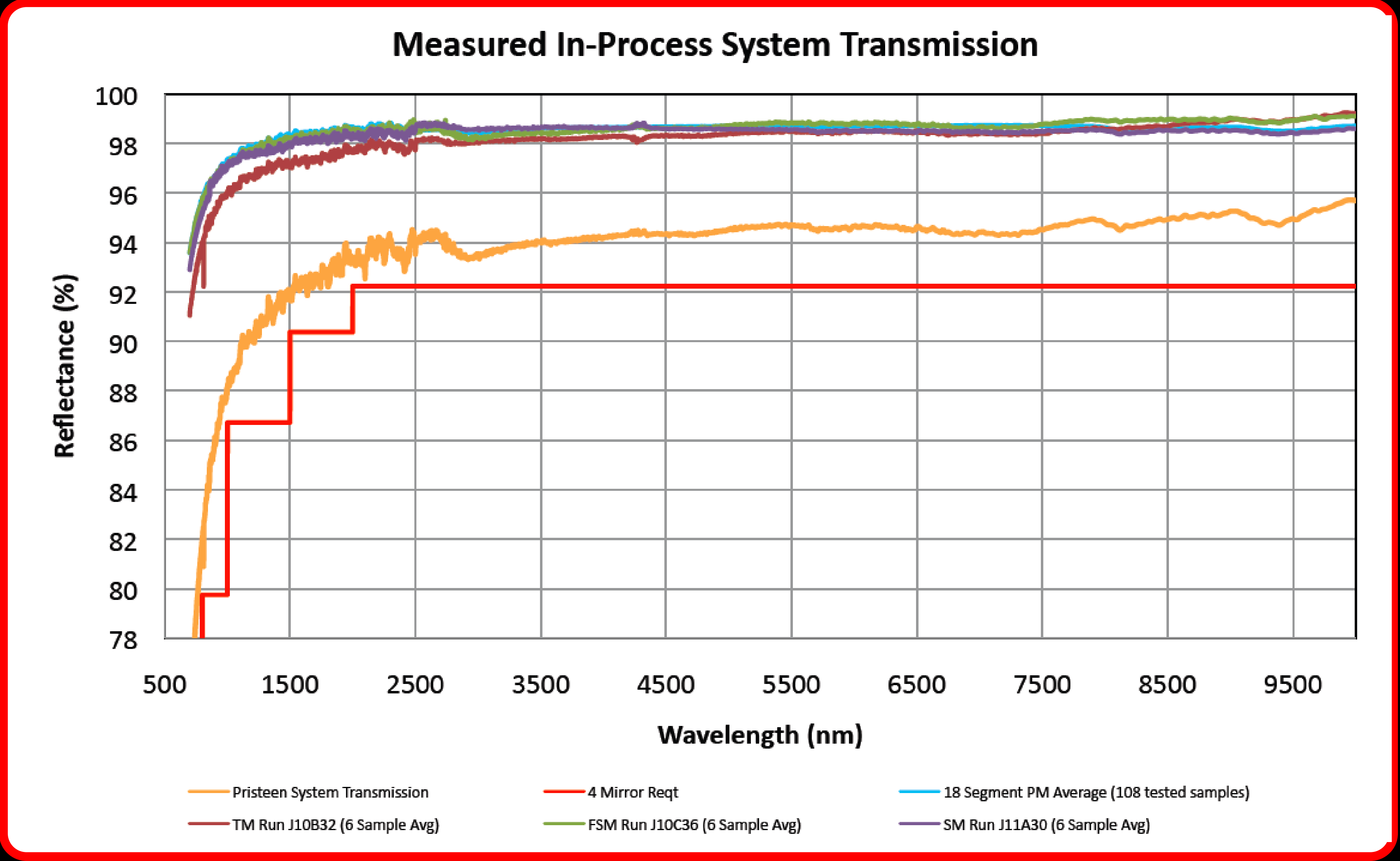




- Developed by the Canadian Space Agency with ComDev
  - Broad-band guider (0.6 – 5 microns)
  - Field of view: 2.3 x 2.3 arc minutes
  - Science imagery:
    - Slitless spectroscopic imagery (grism)
      - R ~ 150, 0.8 – 2.25 microns optimized for Ly alpha galaxy surveys
      - R ~ 700, 0.7 – 2.5 microns optimized for exoplanet transit spectroscopy
    - Sparse aperture interferometric imaging (7 aperture NRM) 3.8, 4.3, and 4.8 microns
  - Angular resolution (1 pixel): 68 mas
  - Detector type: HgCdTe, 2048 x 2048 pixel format, 3 detectors
  - Reflective optics, Aluminum structure and optics

Mirror Reflectivity

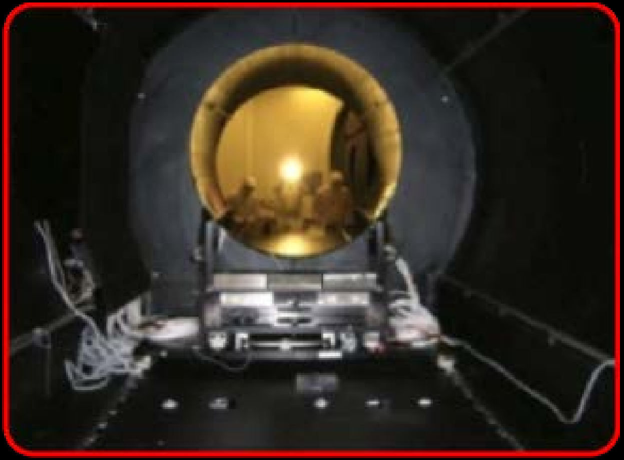
- Measured reflectivity of newly coated mirrors (i.e. pristine)

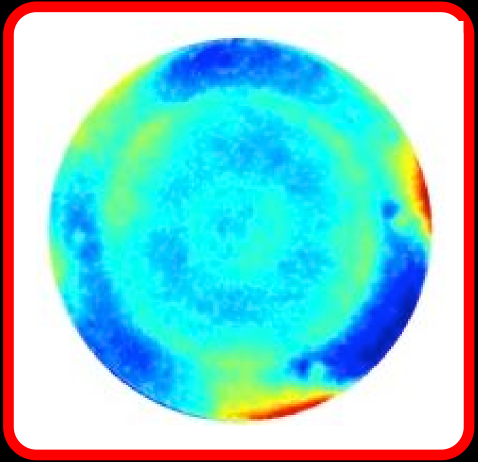


Flight Mirrors: Cryo-Performance

- Preliminary Surface Figure Error (SFE) for OTE optical elements
  - Preliminary as-built cryo-measured surface figure error (SFE)

Mirror	Measured (nm RMS SFE)	Uncertainty (nm RMS SFE)	Total (nm RMS SFE)	Requirement (nm RMS SFE)	Margin (nm RMS SFE)
18 Primary Mirrors (composite)	23.7	8.1	25.0	25.8	6.4
Secondary	14.5	14.9	20.8	23.5	10.9
Tertiary	17.5	9.4	19.9	23.3	11.9
Fine Steering	14.7	8.7	17.1	17.5	3.7

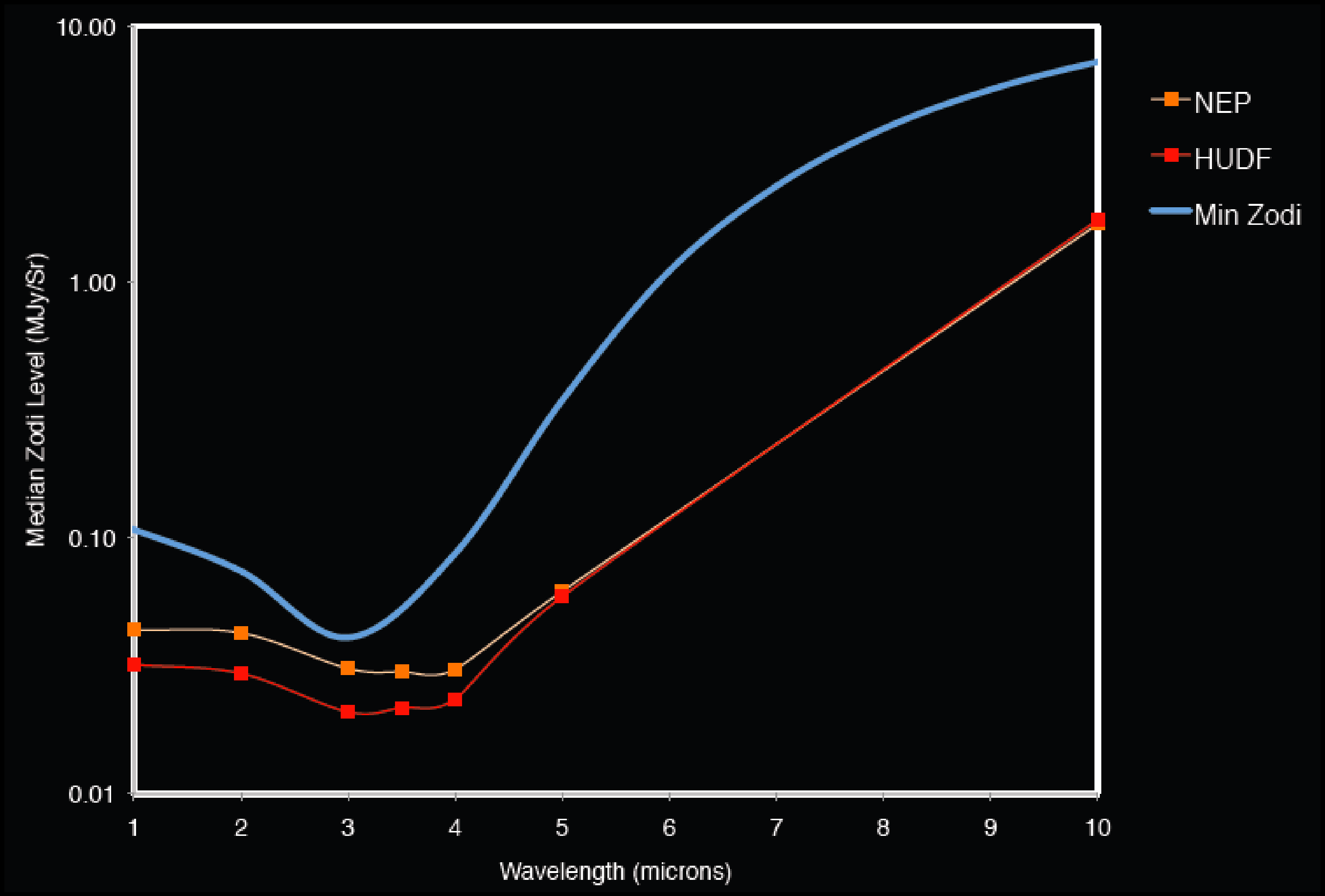




Secondary Mirror

Sky Background

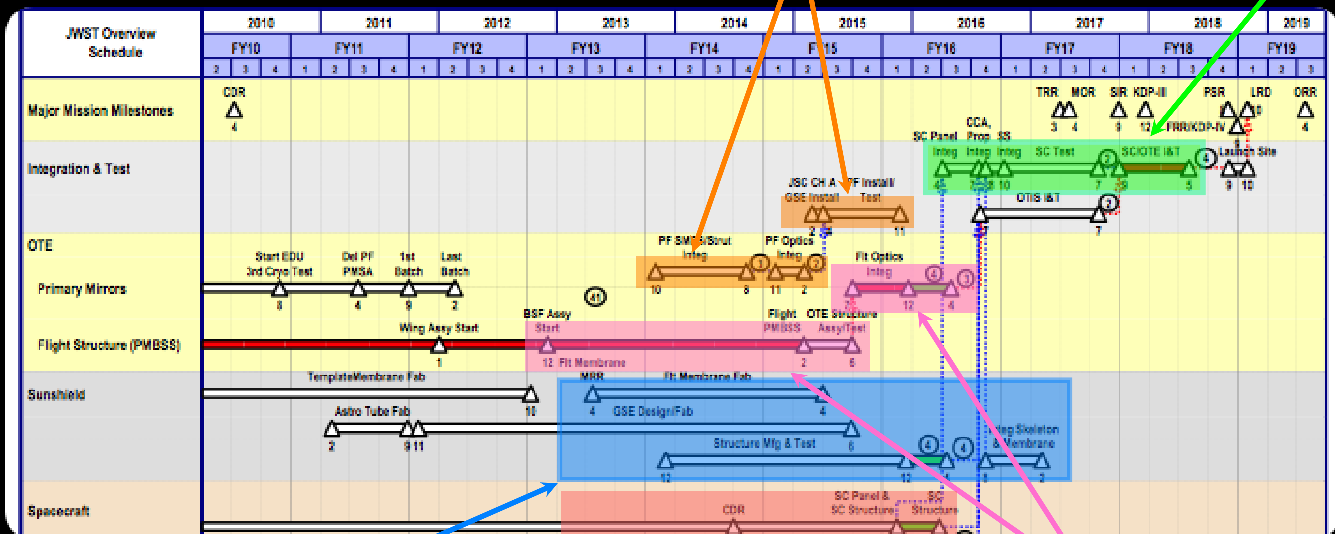
- JWST should be zodi-limited at λ < 10 µm
- Background levels will include contribution from stray light



Observatory Schedule

Pathfinder backplane/SMSS
- integration & test

Telescope/Sunshield/Spacecraft
- integration & test



Sunshield Flight Membrane fabrication:
- Sunshield structure integration and test

Primary Mirror Support Structure:
- Assembly completion and cryo-test
- Mirror population

Spacecraft
- Design, fabrication & subsystem integration

JWST Schedule

- Key Events for 2012

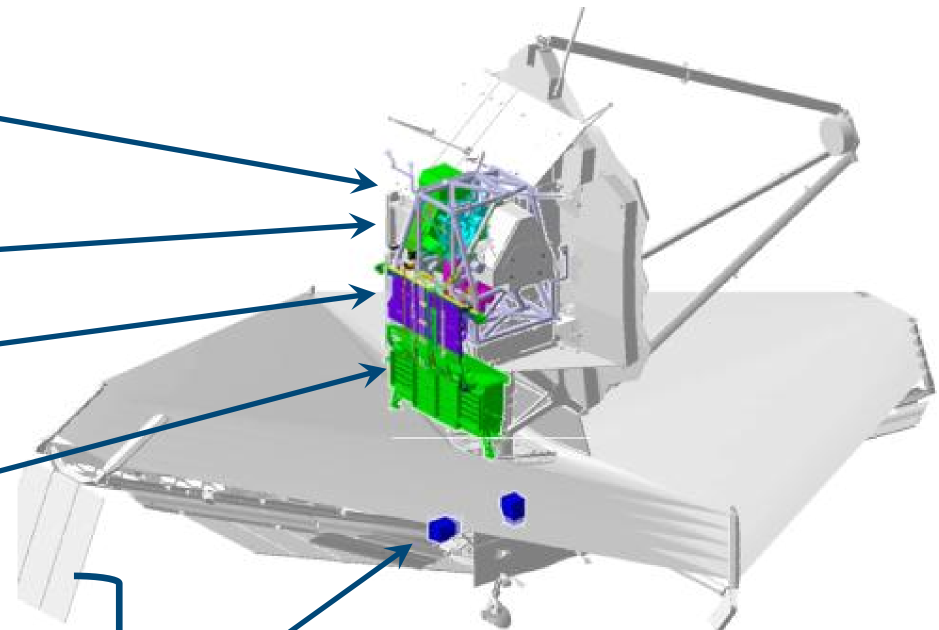
Month	Milestone	Comments
Oct '11	Begin construction of 140,000-lb robotic facility to build segmented main mirror at GSFC	Assembly began 10/4
Nov '11	Complete electronics simulator model for Integrated Science Instrument Module ("ISIM") Deliver tools for software development environment and verification	Completed 11/15 Completed 10/27
Dec '11	Install Helium shroud floor at Johnson Space Center thermal vacuum chamber ("JSC TVC") Determine root cause of NIRSpec optical bench flaw	Completed 10/26
Jan '12	Conduct Critical Design Review for Spacecraft-to-Optical Telescope Element vibration isolation system Finish building Center of Curvature Optical Assembly ("COCOA") for testing primary mirror in JSC TVC Review preliminary requirements for ground structure for spacecraft equipment panels Complete Aft Optic System integration and alignment Update Program Plan and Program Commitment Agreement to reflect replan	
Feb '12	Complete assembly and initial testing of main mirrors at Marshall Space Flight Center Install Helium shroud walls at JSC TVC	
Mar '12	Complete assessment of System Engineering Team thermal margins Deliver ISIM computer #2 to ISIM integration and testing Complete analysis of JSC TVC telescope testing equipment plans	
Apr '12	Receive Flight Mid-infrared Instrument (MIRI) from Europe, first of the telescope's four science instruments	



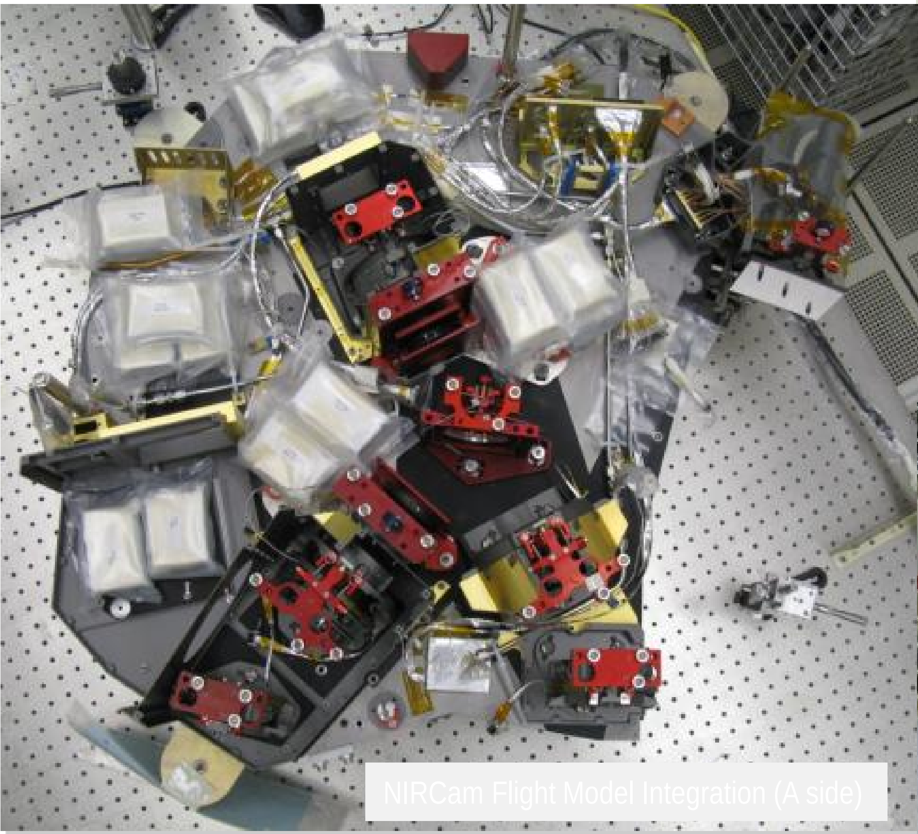

ISIM is the science instrument payload of the JWST

- ISIM is one of three elements that together make up the JWST space vehicle
  - Approximately 1.4 metric tons, ~20% of JWST by mass
  - Completed CDR during 2009

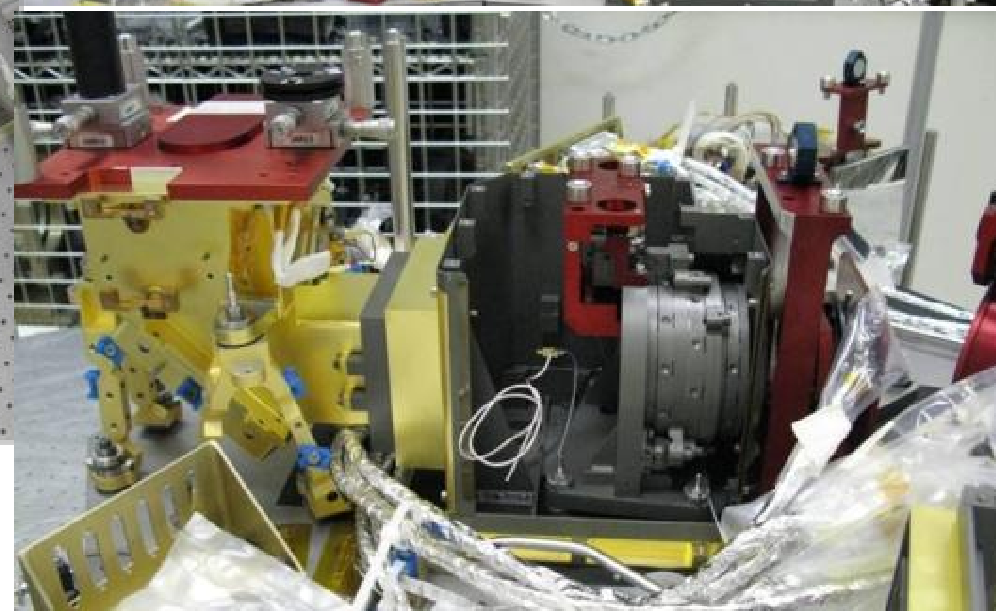
- The ISIM system consists of:
  - Four science instruments
  - Nine instrument support systems:
    - Optical metering structure system
    - Electrical Harness System
    - Harness Radiator System
    - ISIM electronics compartment (IEC)
    - ISIM Remote Services Unit (IRSU)
    - Cryogenic Thermal Control System
    - Command and Data Handling System (ICDH)
    - Flight Software System
    - Operations Scripts System



NIRCam is on schedule for delivery during 2012

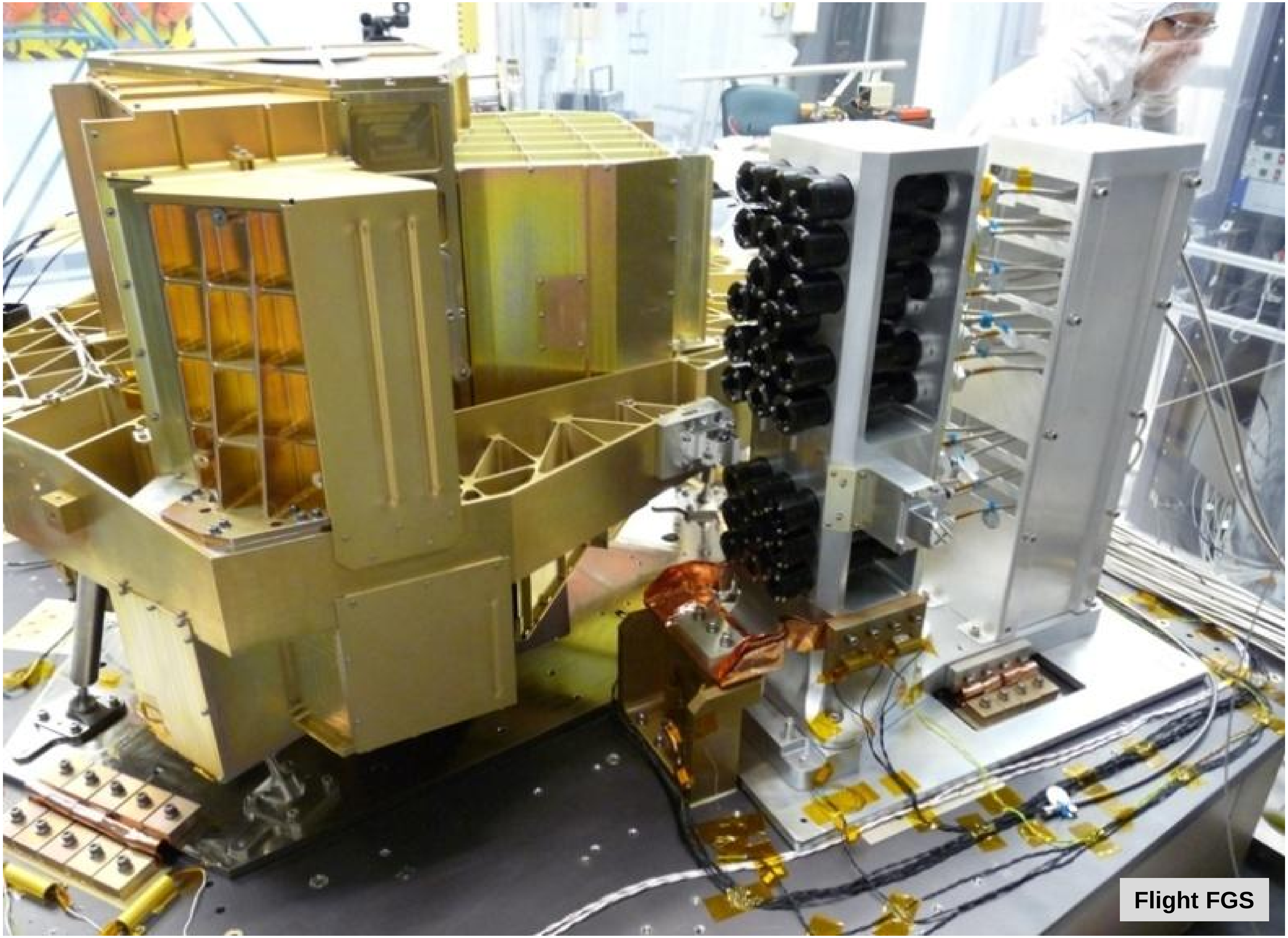

NIRCam Flight Model Integration (A side)


NIRCam Flight Model Integration (A side)



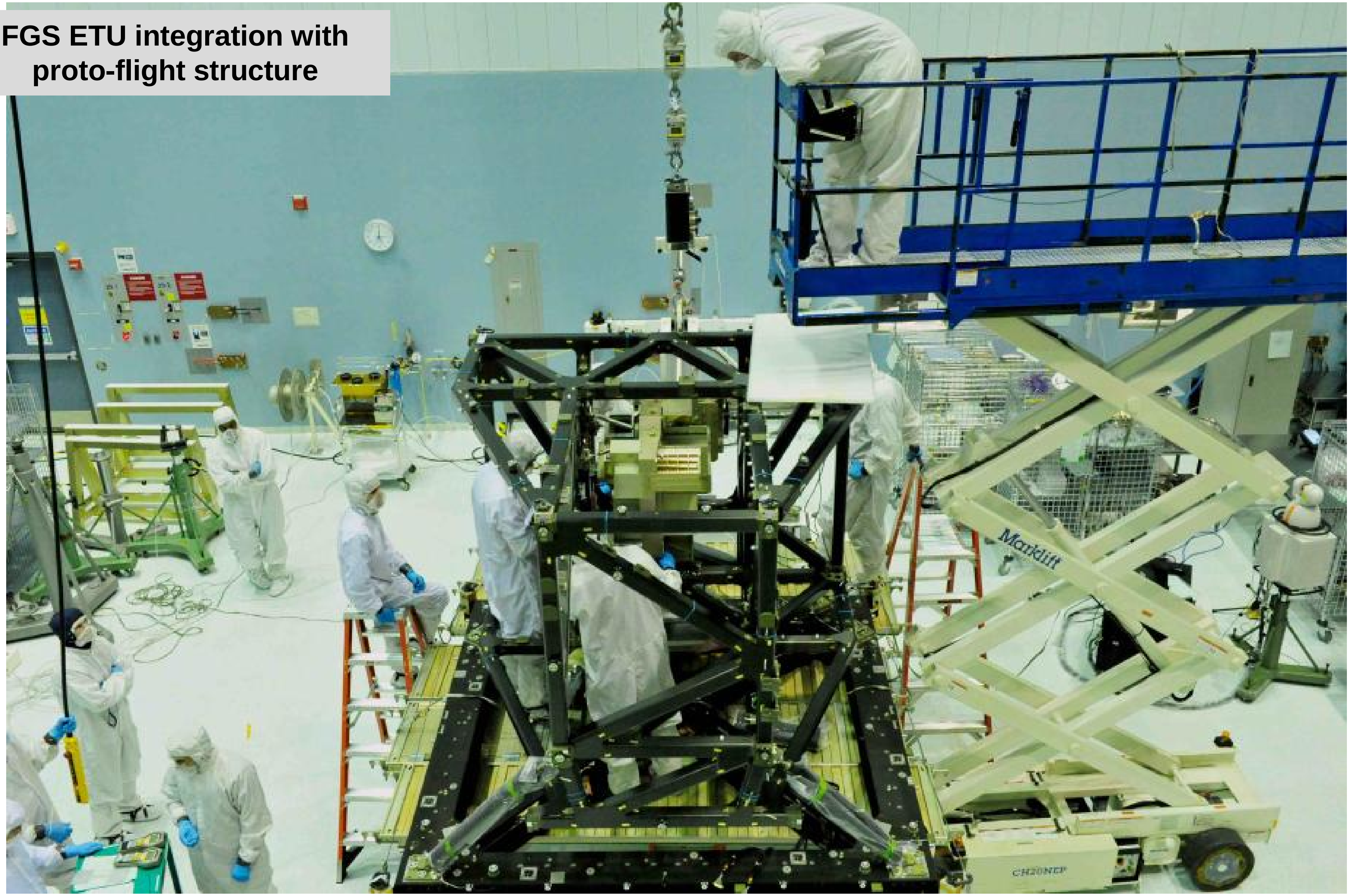
NIRSpec delivery expected during 2012

FGS is on schedule for delivery during 2012



ETU SI integration with ISIM structure proceeding well

FGS ETU integration with proto-flight structure



Integration and Test of the James Webb Space Telescope

- As is typically the case, I&T for JWST is a hierarchical process
  - Lower level elements, developed and tested in parallel
  - Integrated into higher level assemblies and tested again
    - **Subsystems → Science Instruments**
    - **Four Science Instruments + Electronics + Structure… → ISIM**
    - **ISIM + OTE → OTIS**
    - **OTIS + Spacecraft → Observatory**
  - Verify performance requirements at the appropriate level of assembly
  - Try to catch problems at the lowest level possible (easiest to fix)
  - Provide independent cross-checks at the higher levels to confirm nothing went wrong in assembly
- For an observatory as complex as JWST
  - There's a lot of I….
  - There's a lot of T….
- *Here are some highlights….*

ISIM I&T has already begun; SI integration will be a highlight, starting with 1st delivery in the spring of 2012.

Test installation of MIRI Structural Thermal Model

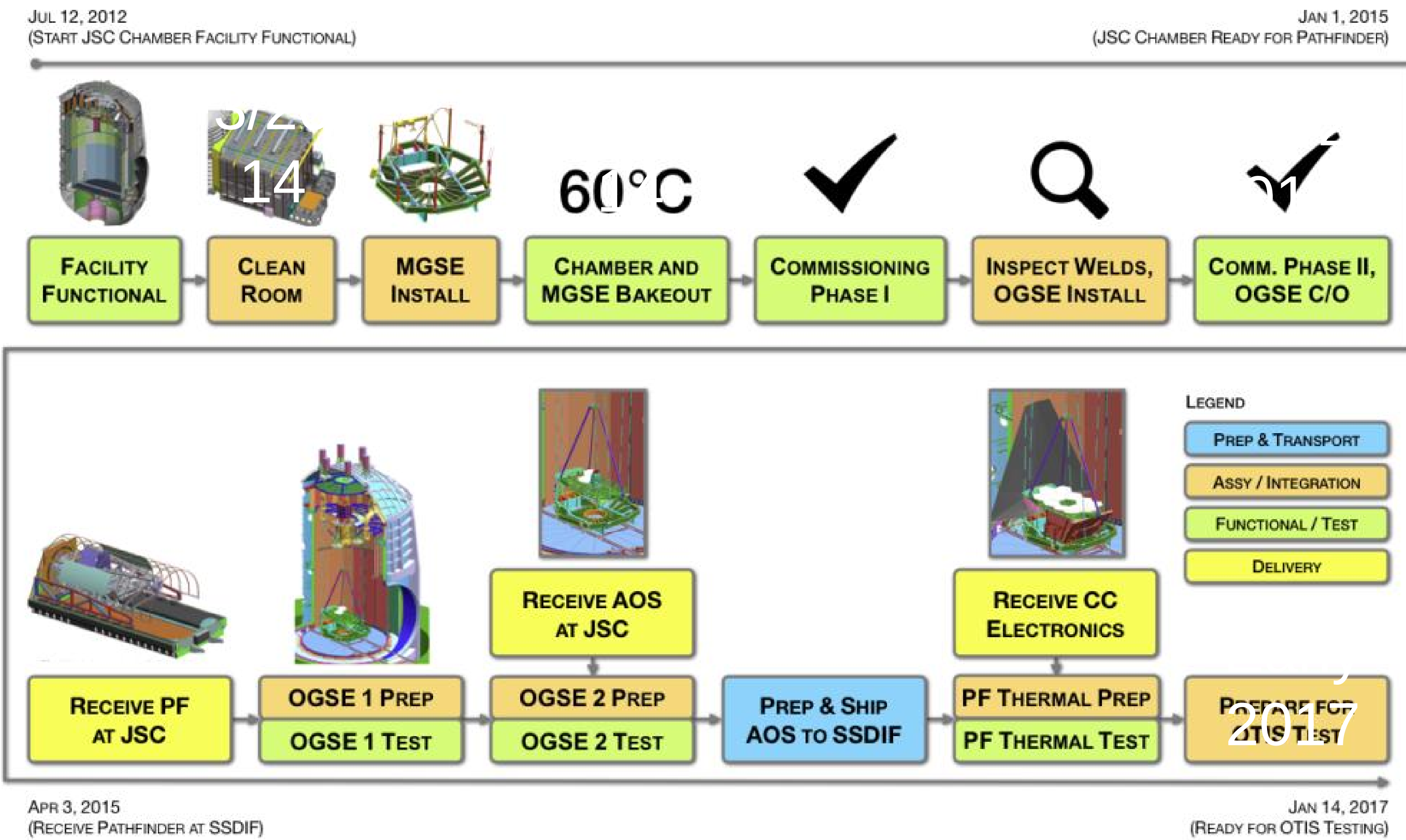
Key Aspects of the ISIM Cryo-Vac Program

- The principal goals
  - Verify parfocality, coalignment, pupil alignment of SI's
  - Cross-check image quality against OSIM
  - Verify wavefront sensing capabilities of the SI's, obtain necessary calibrations
  - Validate thermal performance and correlate thermal model
  - Verify performance with ISIM electrical systems, non-interference of SI's with each other
  - Test some of the operational scenarios
- At least two, and probably three ISIM cryo-vacs are planned
  - Two bracketing the rest of the ISIM environmental test program to confirm optical and thermal stability of the system against vibe/acoustics
  - Regression cryo-vac after likely replacement of NIR detectors
- First scheduled to begin in 2013

Key Aspects of the JSC OTIS Cryo-Vac Program

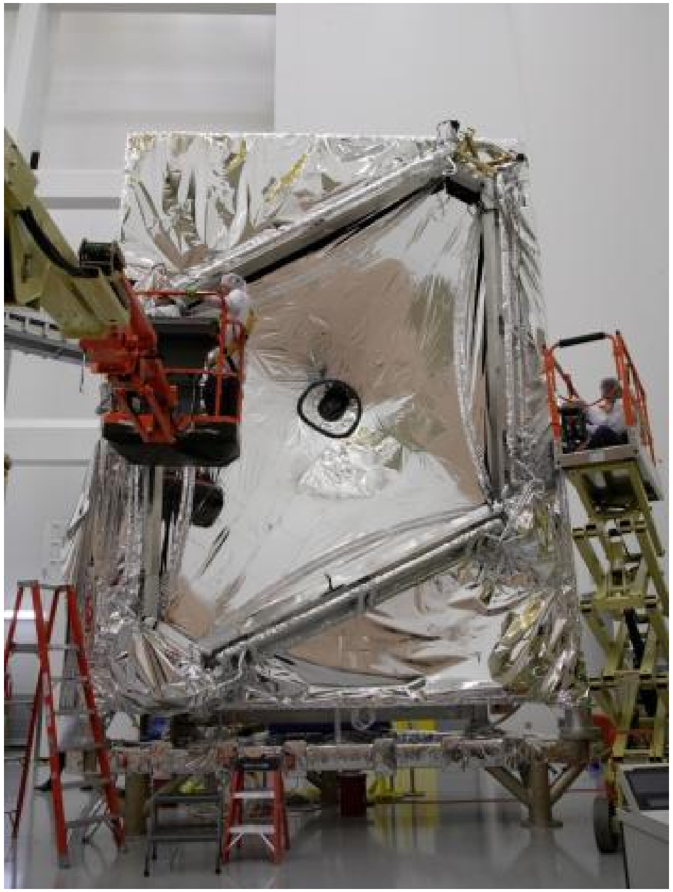
- Optical goals
  - Verify critical fixed alignments – ISIM to AOS
  - Verify co-alignment to within budgeted actuation range for active primary and secondary mirror
  - Verify optical performance stability against expected thermal transients
  - Cross-checks of lower level testing
- Thermal goals
  - Provide the thermal conditions required to perform electro-optical-mechanical and thermal hardware verification, including MIRI cryo-cooler end-to-end performance
  - Collect thermal balance point data that is used to correlate and validate the OTE/ISIM thermal flight model (highly sensitive to workmanship)
- Electrical, operational goals
  - Proper electrical operation of flight systems, cross-strapping, redundancy
  - Demonstration of key operations, e.g. Wavefront Sensing & Control, parity checks of guiding functions
  - Day-in-the-life operational script testing
- A critical overall goal is model validation

JSC Test Facilities, GSE, Procedures Validated w/Many Activities Before Flight OTIS Arrives



Sunshield and Rest of Spacecraft Progress On Their Own I&T Path

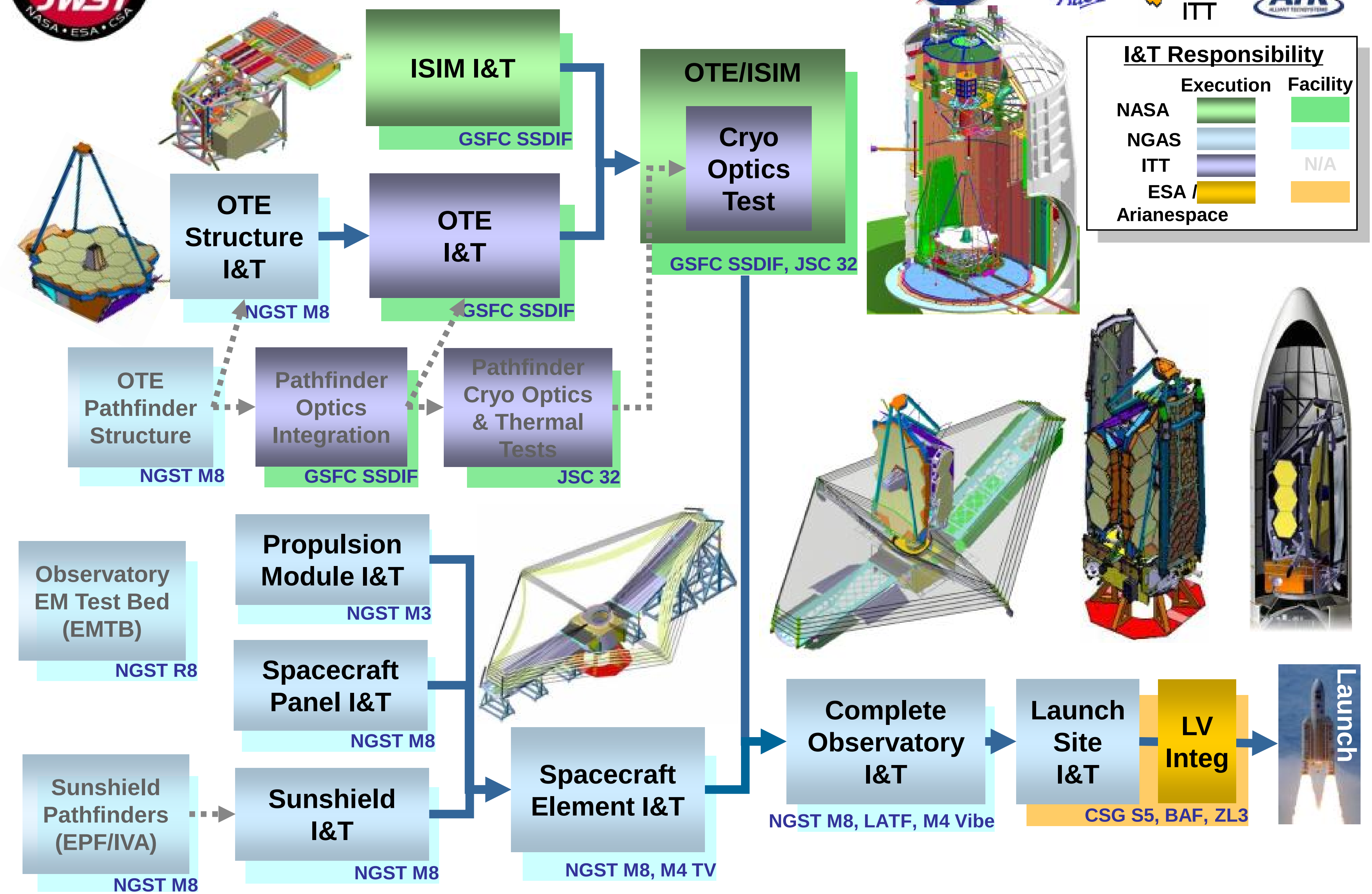
- 1/3rd scale sunshield test completed successfully for thermal model validation



- Template sunshield membranes currently in work

- *Everything meets up at NGAS a year before launch for Observatory I&T*

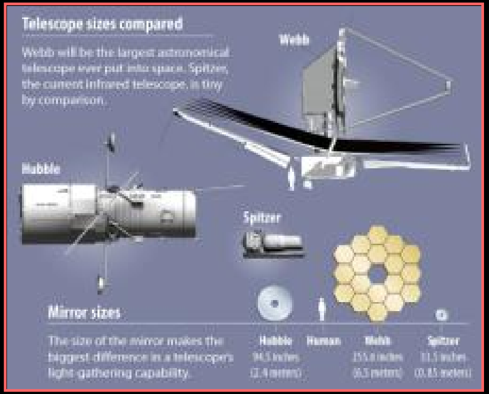
I&T Flow Overview and Responsibilities



Key Design Drivers

Sensitivity;

- Detection of First Galaxies



Aperture

- Collection area 25 m^2
- Diffraction limited @ 2 µm

Low Backgrounds

- Cryogenic observatory
- Passive cooling

Stowable/Deployable Architecture

- Telescope stowed for launch

The James Webb Space Telescope

James E. Webb (1906 – 1992)

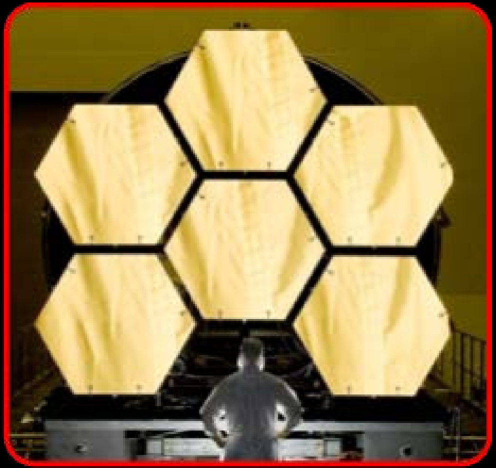
- Second Administrator of NASA (1961 – 1968)
- Oversaw first & Second manned spaceflight programs (Mercury, Gemini)
- Oversaw Mariner and Pioneer planetary exploration programs
- Oversaw Apollo program: On time, On budget! (he asked for enough!)
- Supported space science at NASA and universities

Telescope Mirrors Gold Coated

Flight Mirrors: Cryo-Performance

- Preliminary Surface Figure Error (SFE) for OTE optical elements
  - Preliminary as-built cryo-measured surface figure error (SFE)

Mirror	Measured (nm RMS SFE)	Uncertainty (nm RMS SFE)	Total (nm RMS SFE)	Requirement (nm RMS SFE)	Margin (nm RMS SFE)
18 Primary Mirrors (composite)	23.7	8.1	25.0	25.8	6.4
Secondary	14.5	14.9	20.8	23.5	10.9
Tertiary	17.5	9.4	19.9	23.3	11.9
Fine Steering	14.7	8.7	17.1	17.5	3.7



Primary Mirror

MIRI flies British Airways to USA

Minister Paradis Unveils the Made-in-Canada Technology That Will Direct the World's Most Powerful Space Telescope

Longueuil, Quebec, July 25, 2012 — Today, the Honourable Christian Paradis, Minister of Industry and Minister responsible for the Canadian Space Agency (CSA), unveiled Canada's contribution to the James Webb Space Telescope, successor to the Hubble Space Telescope. The CSA is contributing a two-in-one instrument that will direct the telescope precisely, allowing it to study stars and planets forming in other stellar systems. The highly advanced, made-in-Canada technology will be delivered to NASA for integration into the Webb telescope on July 30.

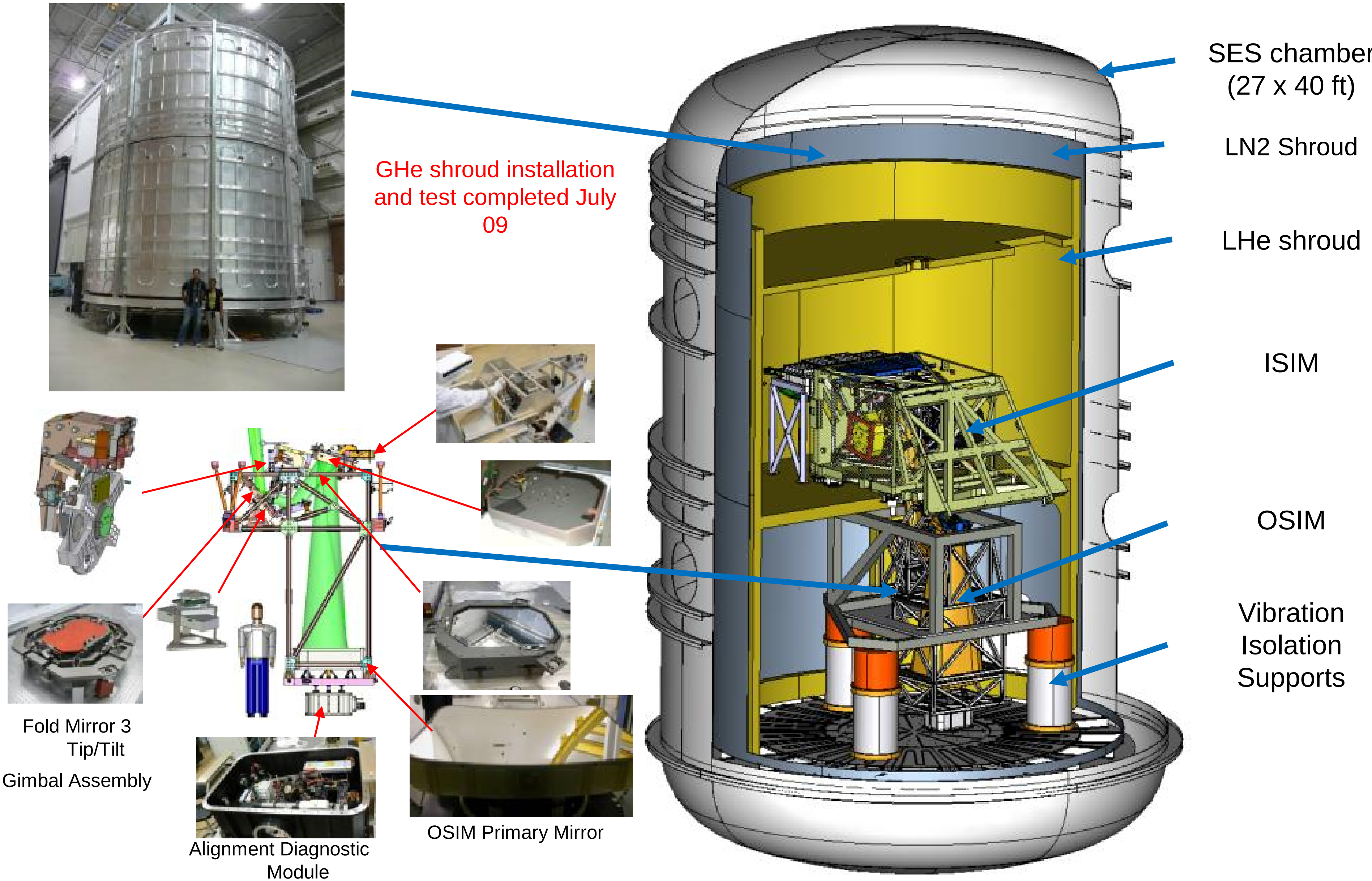
NIRCam *Environmental Testing to Begin*

- **Palo, Alto, CALIF., April 16, 2012** – Lockheed Martin [NYSE: LMT], under a contract from the University of Arizona (U of A), has completed assembly of the Near Infrared Camera (NIRCam) Instrument Modules. NIRCam is the prime near-infrared imaging instrument for NASA's James Webb Space Telescope (JWST). The work was done at the Lockheed Martin Space Systems Advanced Technology Center (ATC) in Palo Alto, where environmental testing is about to begin. U of A and Lockheed Martin are responsible for the NIRCam instrument design (Optical, Mechanical, Structural, Thermal, Electronic, Precision Mechanisms and Control Software), the instrument control and focal plane electronics and software. Delivery of the NIRCam instrument to the NASA Goddard Space Flight Center is expected to occur in late summer 2012.

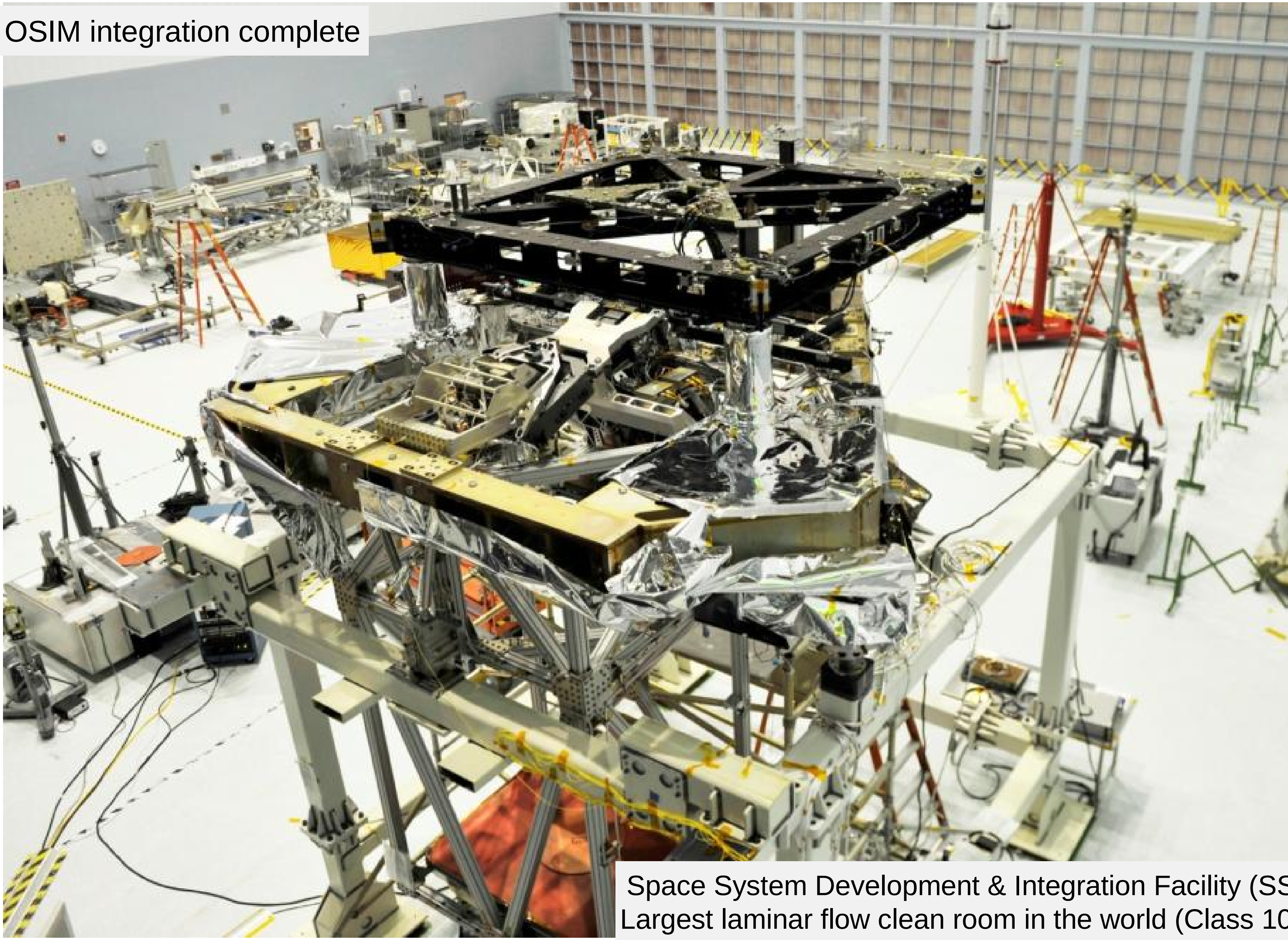
Test Unit SI integration with ISIM structure worked well

MIRI ETU integration with proto-flight structure

ISIM will be tested at ~35 K in the GSFC SES chamber using a cryogenic telescope simulator (OSIM)



OSIM certified for cryo-vac in 2012



OSIM integration complete

Space System Development & Integration Facility (SSDIF)
Largest laminar flow clean room in the world (Class 10,000

Ambient Optical Alignment Stand for OTE & OTIS assembly recently installed in the SSDIF clean room