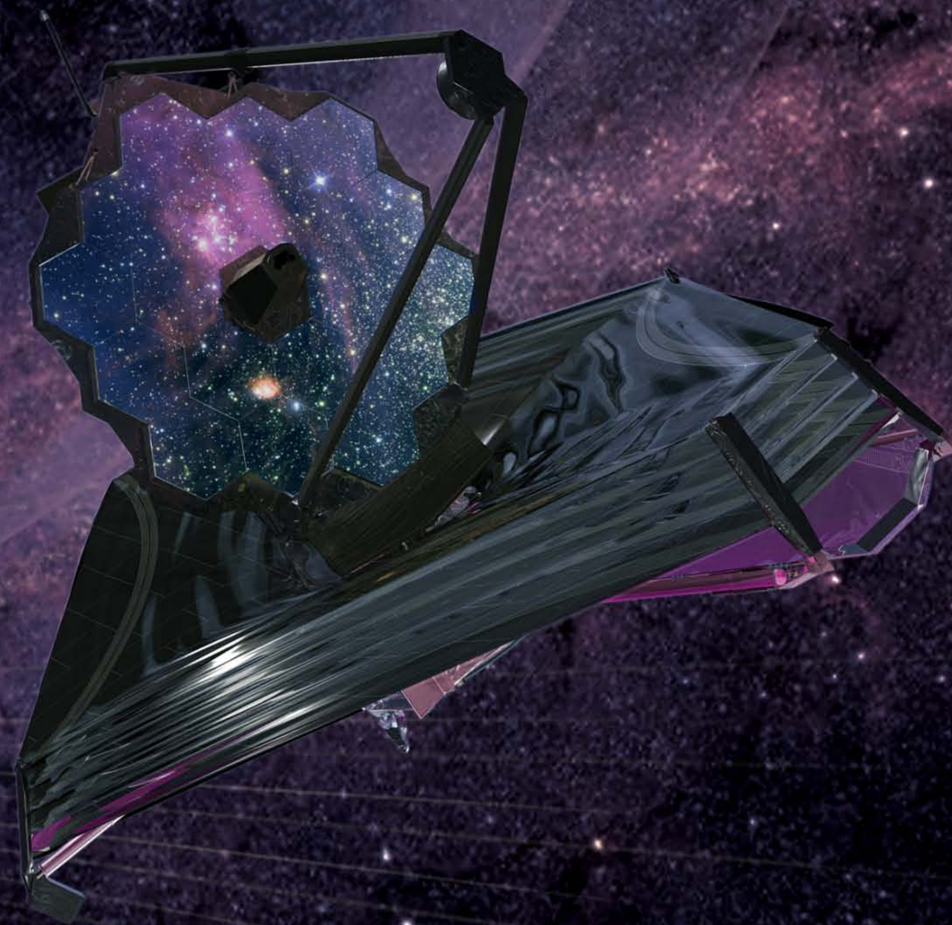
# The James Webb Space Telescope Mission




**Matt Greenhouse**
JWST Project Office
NASA Goddard Space Flight Center

11 September 2012

# JWST is a general astrophysics mission for use by the international astronomical community

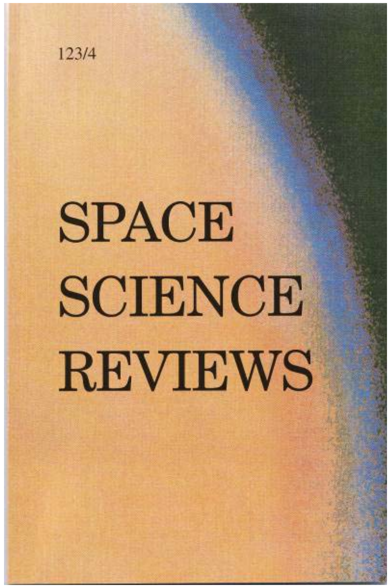
- Often described as the successor to the Hubble Space Telescope, the JWST will serve astronomers world-wide in much the same way:
  - Science & mission operations managed by the Space Telescope Science Institute
- The science investigations performed by the JWST will be determined by the General Observer community.
  - Observing time allocated through annual peer-reviewed proposal cycles
- Four science themes have been defined by a succession of international community working groups to guide engineering development of the JWST:

Identify the first bright objects that formed in the early Universe, and follow the ionization history.

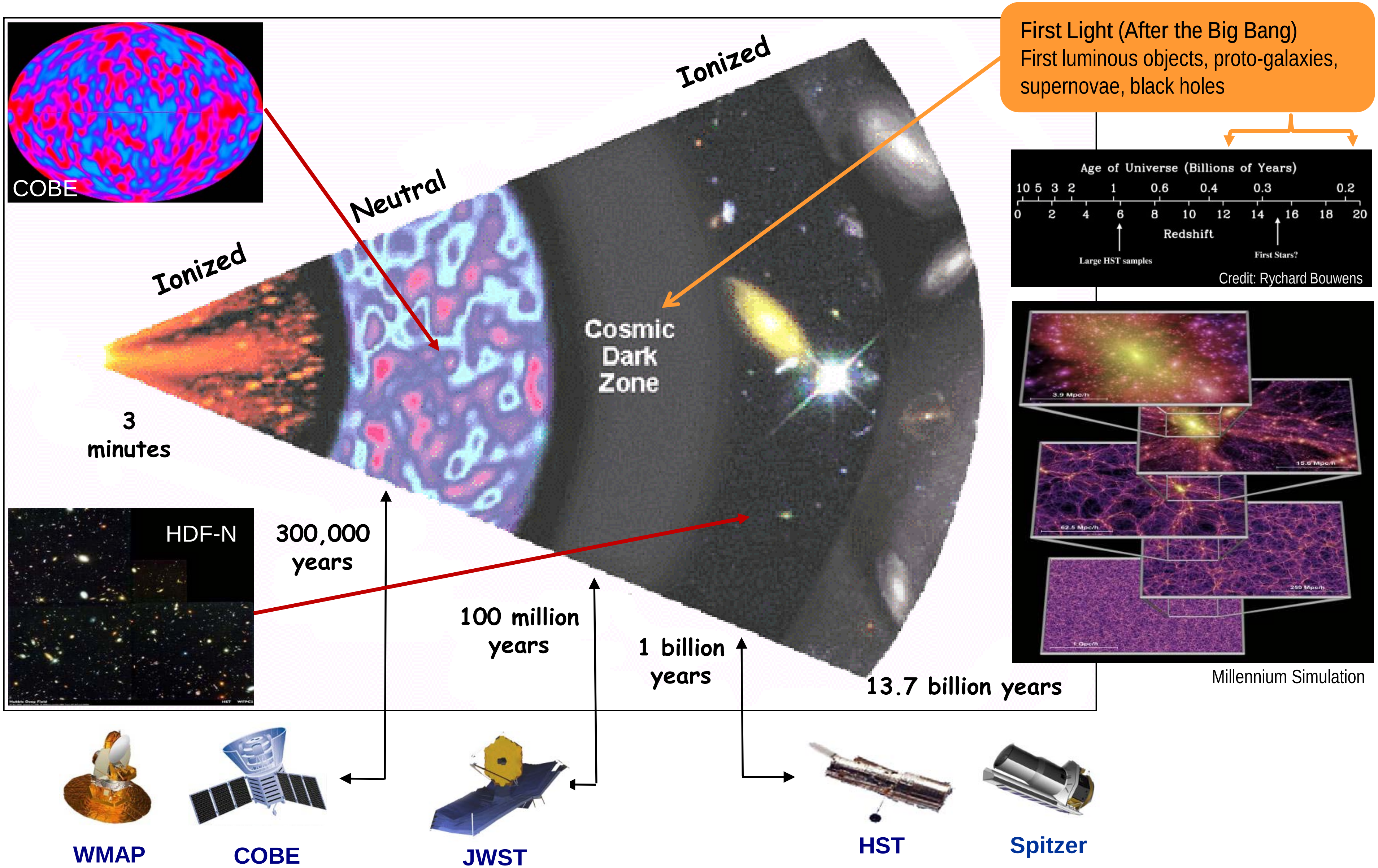
Determine how galaxies and dark matter, including gas, stars, metals, overall morphology and active nuclei evolved to the present day.

Observe the birth and early development of stars and the formation of planets.

Study the physical and chemical properties of solar systems (including our own) and where the building blocks of life may be present.

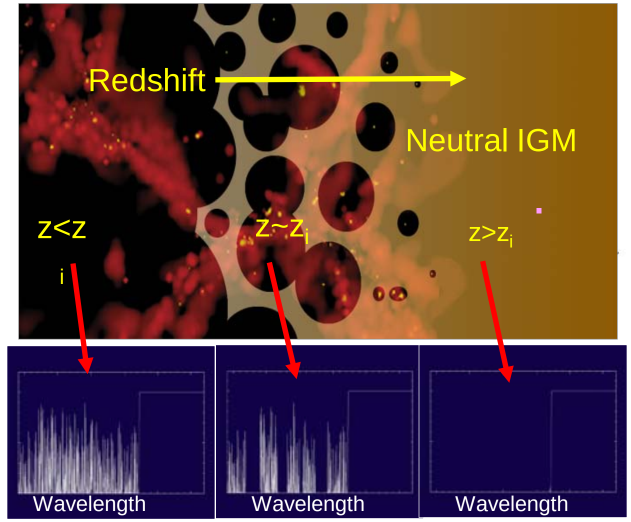


# JWST is designed to observe formation of the first galaxies

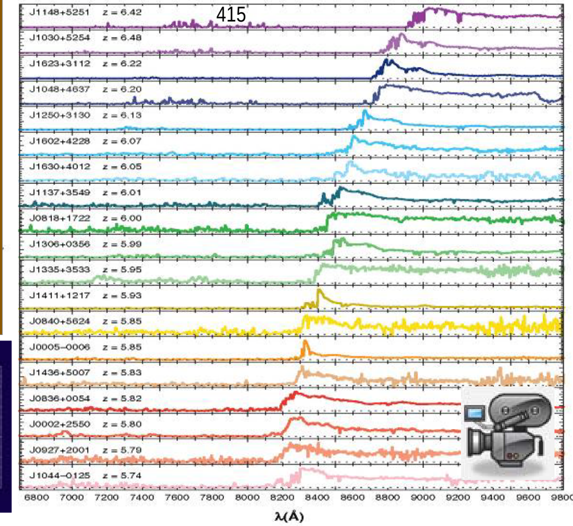


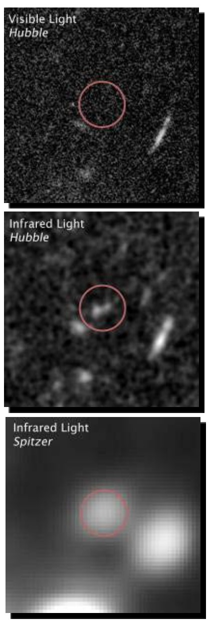
# Key questions about the galaxy formation era:

- How did black holes form and interact with their host galaxies?
- What is the nature of the first galaxies?
- When did re-ionization of the inter-galactic medium occur?
- What caused the re-ionization?

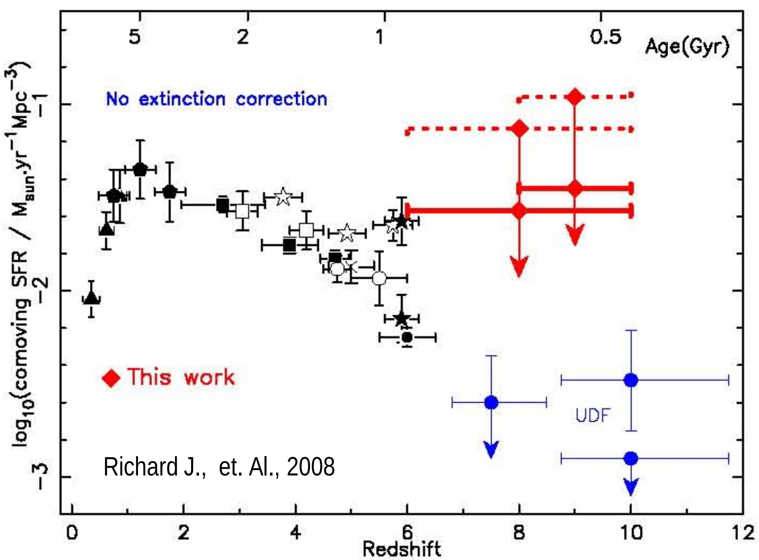



Fan, Carilli & Keating 2006, ARAA, 44, 415




z = 7.6 (Bradley & Illingworth 2008)

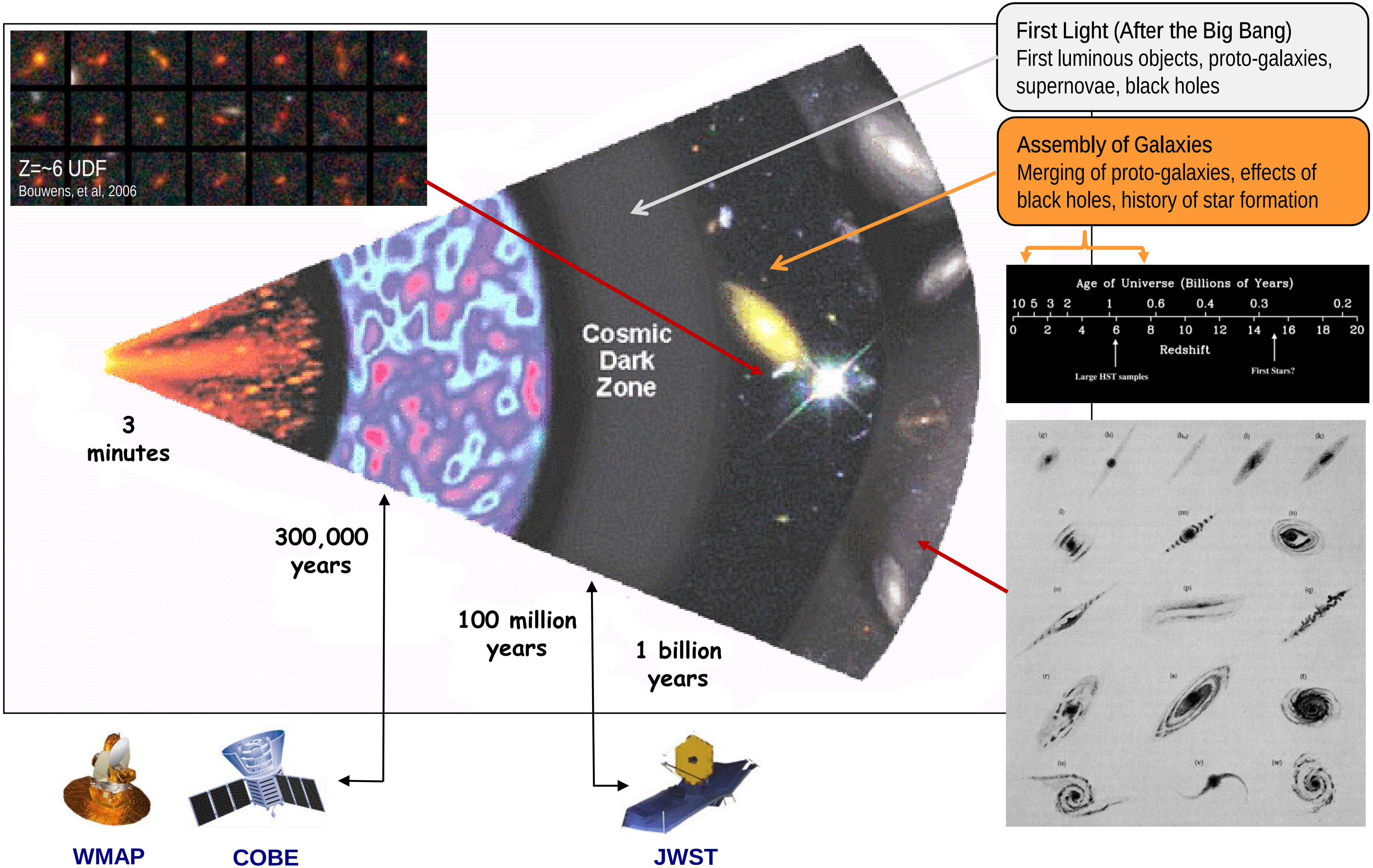



Key Enabling Design Requirements:

- Deep near-infrared imaging survey (1nJy)
- Near-IR multi-object spectroscopy
- Mid-IR photometry and spectroscopy

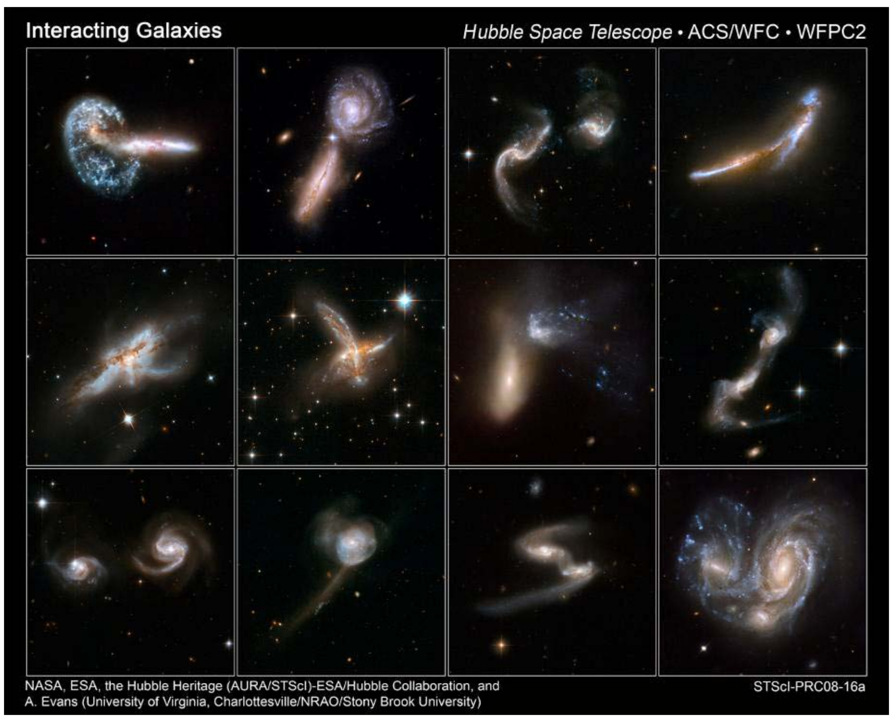
| Redshift z | $m_{AB}$ | Fν (nJy) | Lyman Break wavelength |
|---|---|---|---|
| 0 | | | 0.12 μm |
| 10 | 30.3 | 2.8 | 1.34 μm |
| 15 | 30.9 | 1.6 | 1.95 μm |
| 20 | 31.3 | 1.1 | 2.55 μm |

# JWST is designed to observe the evolution of galaxies

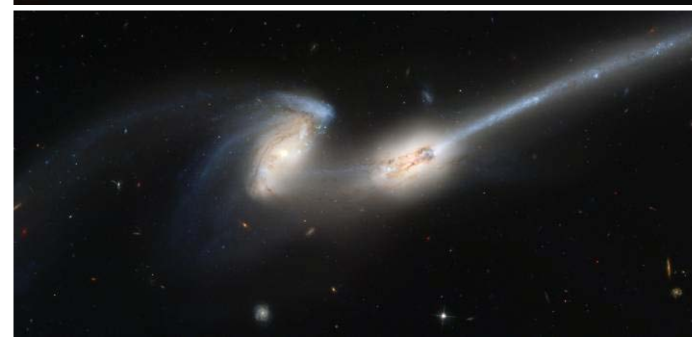


# Key questions about galaxy evolution:

- When did the Hubble Sequence form?
- What role did galaxy collisions play in their evolution?
- How is the chemical evolution of the universe related to galaxy evolution?
- What powers emission from galaxy nuclei?



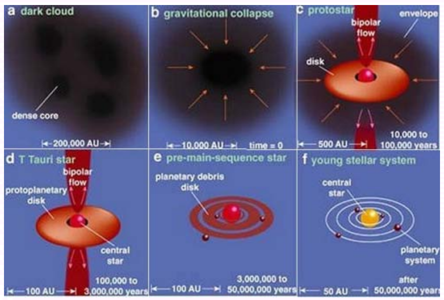




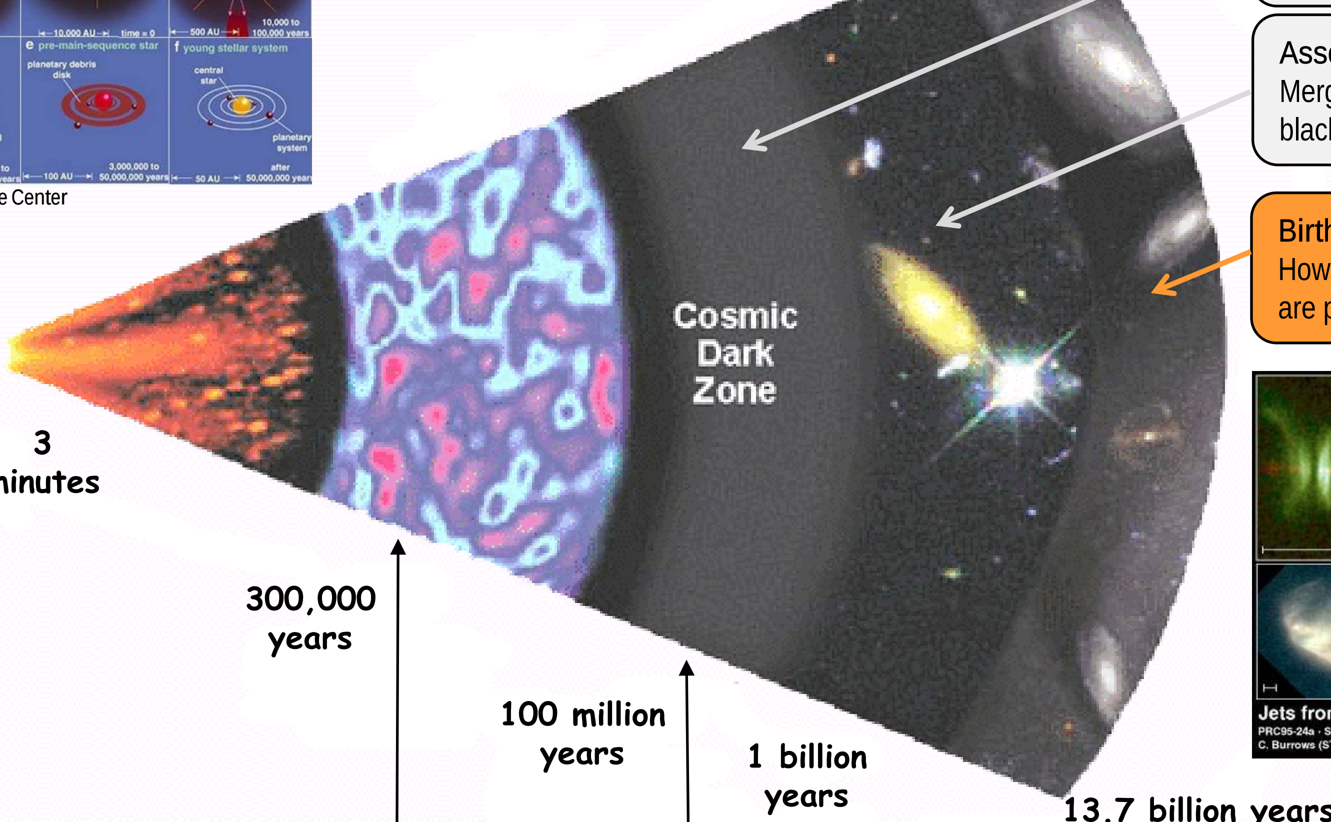
Key Enabling Design Requirements:

- Wide-area near-infrared imaging survey
- Low and medium resolution spectra of 1000s of galaxies at high redshift
- Targeted observations of galactic nuclei

# JWST will observe how stars form in our galaxy



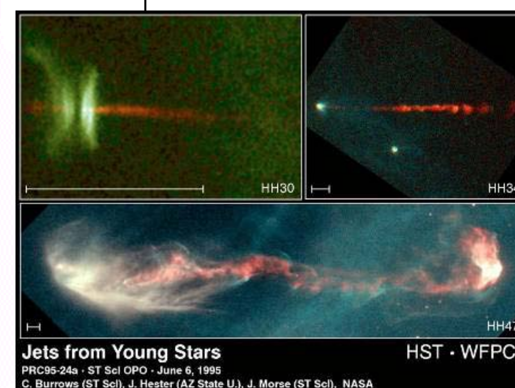

Spitzer Science Center




**First Light (After the Big Bang)**
First luminous objects, proto-galaxies, supernovae, black holes

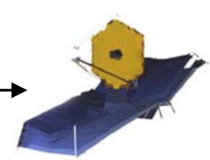
**Assembly of Galaxies**
Merging of proto-galaxies, effects of black holes, history of star formation

**Birth of Stars and Planetary Systems**
How stars form and chemical elements are produced




WMAP

COBE



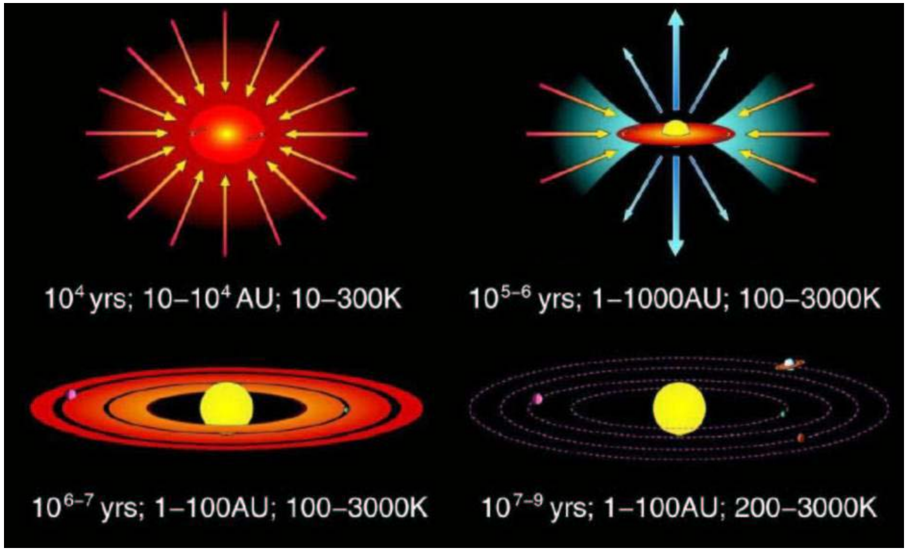
JWST

# Key questions about star formation:

- How do molecular clouds collapse?
- How does environment affect star-formation?
  - Vice-versa?
- What is the mass distribution of low-mass stars?
- What do debris disks reveal about the evolution of terrestrial planets?

Deeply embedded protostar

Circumstellar disk




Agglomeration & planetesimals

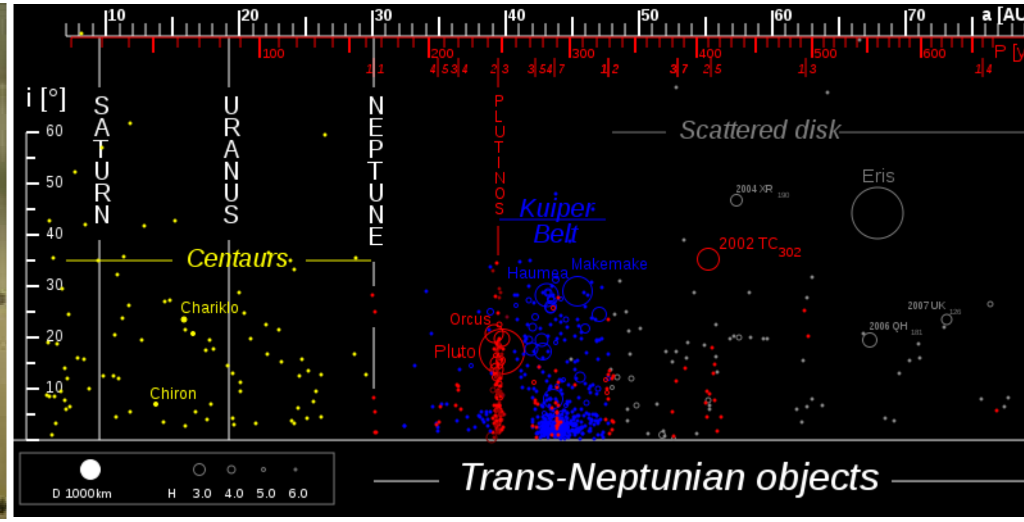
Mature planetary system

The Eagle Nebula as seen in the near-infrared

**Key Enabling Design Requirements:**

- High angular resolution near- and mid-IR imagery
- High angular resolution imaging spectroscopy

# JWST will observe how planetary systems form and evolve

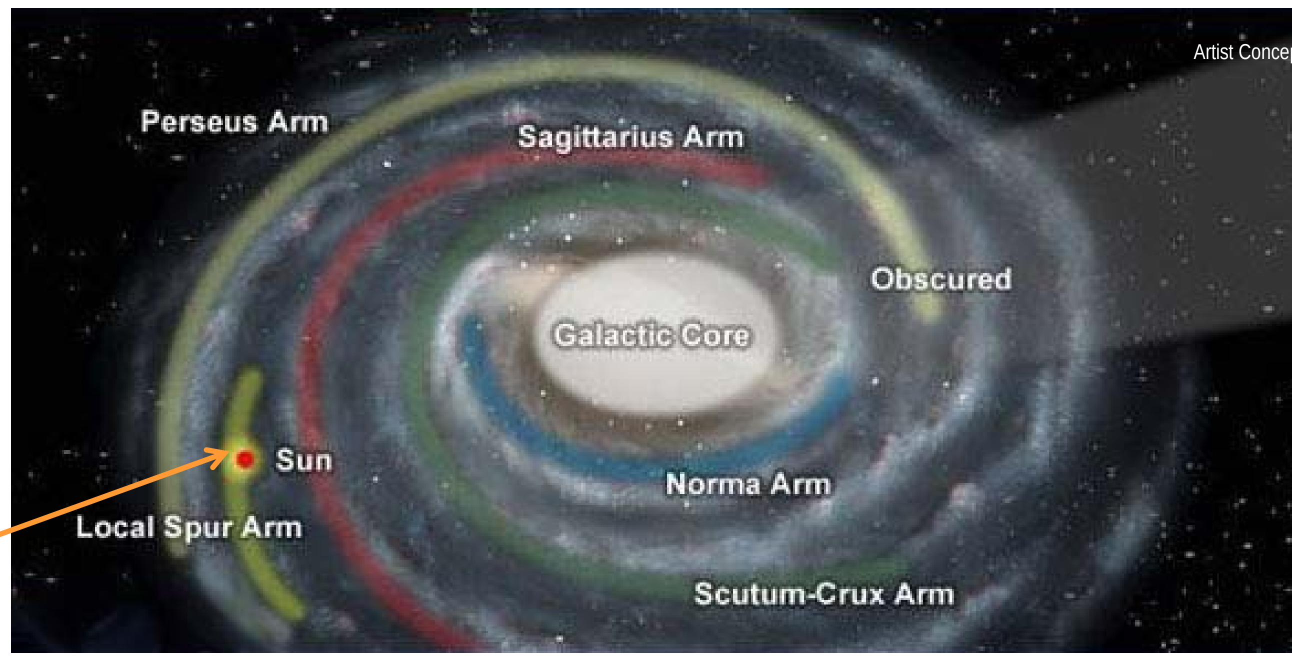




First Light (After the Big Bang)
First luminous objects, proto-galaxies, supernovae, black holes

Assembly of Galaxies
Merging of proto-galaxies, effects of black holes, history of star formation

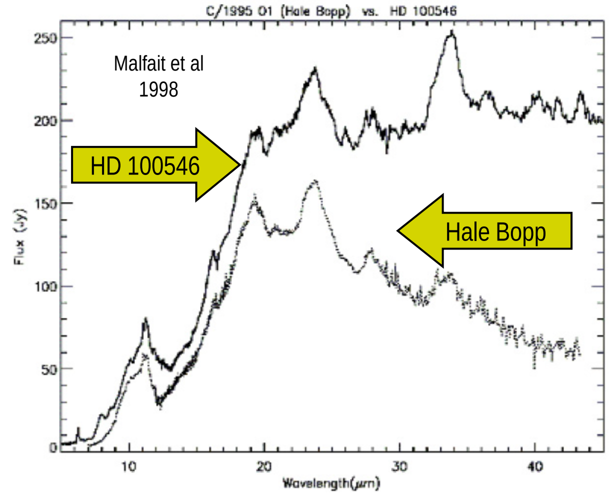
Birth of Stars and Planetary Systems
How stars form and chemical elements are produced

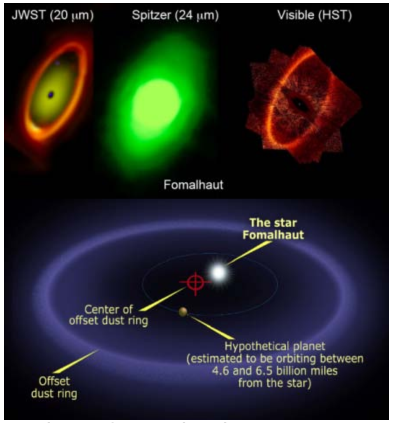
Planetary Systems & Origins of Life
Formation of planets



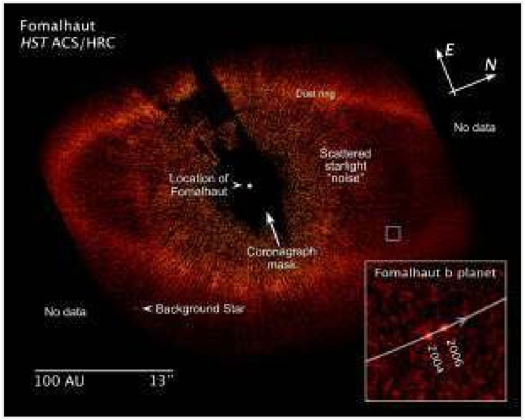
# Key questions about planet formation:

- How do planets form?
- How are circumstellar disks like our Solar System?
- How are habitable zones established?



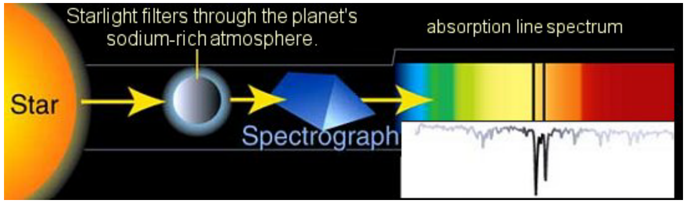

Kalas, Graham & Clampin 2005

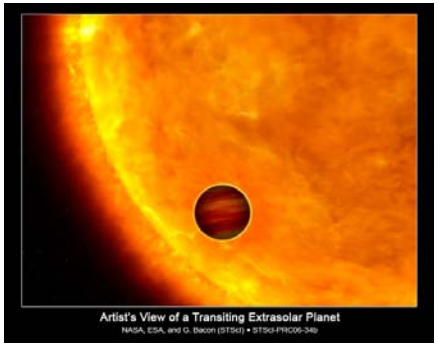


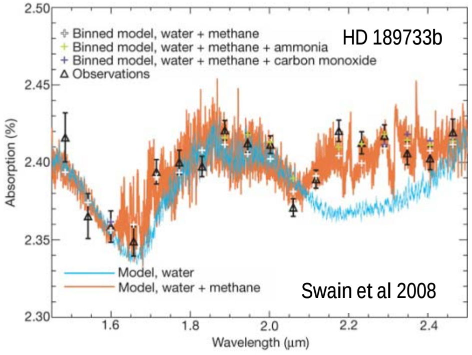

Kalas et al 2008

## Key Enabling Design Requirements:

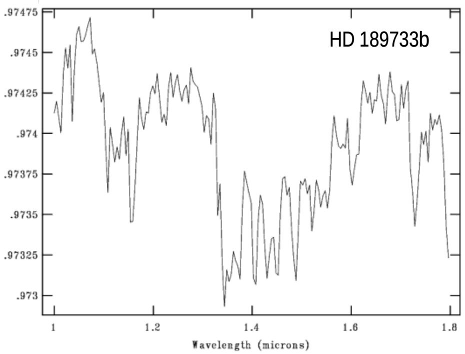
- Near- and mid-IR coronagraphic imagery
- Near- and mid-IR spectroscopy
- High cadence sub-array imagery & spectroscopy

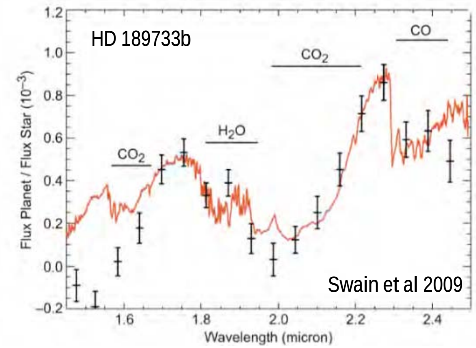



JWST simulation: Greene 2009



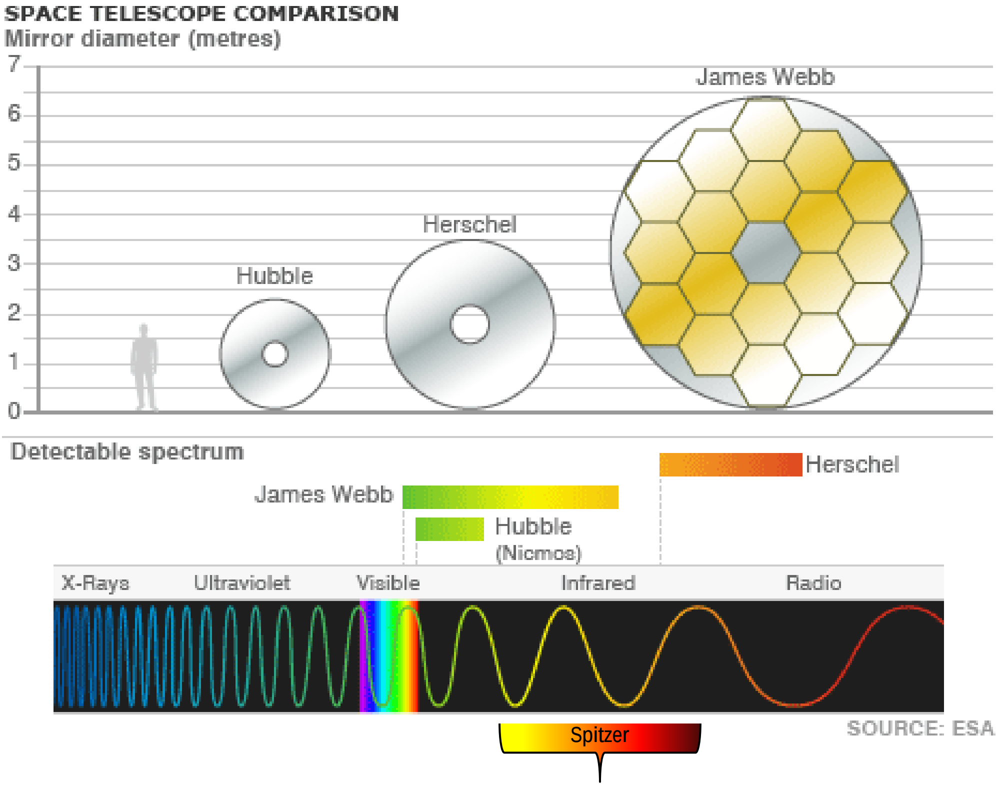
# JWST requires the largest cryogenic telescope ever constructed

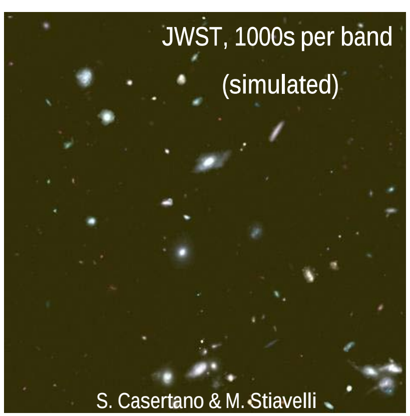
**To observe the early universe, the JWST mission requires:**

- 7X the light gathering capability of the Hubble Space Telescope
- similar angular resolution in the near-infrared spectrum
- wavelength coverage spanning the optical to mid-infrared spectrum

**As a consequence, the observatory requires:**

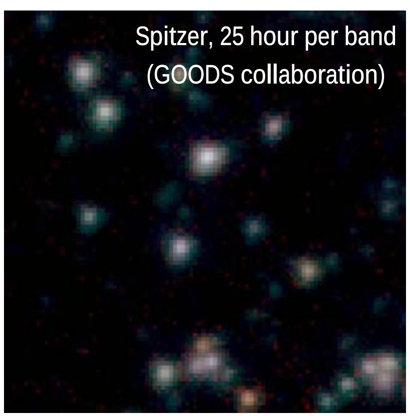
- a primary mirror that is larger in diameter than available rocket fairings
- a high stability 40-50K cryogenic operating temperature



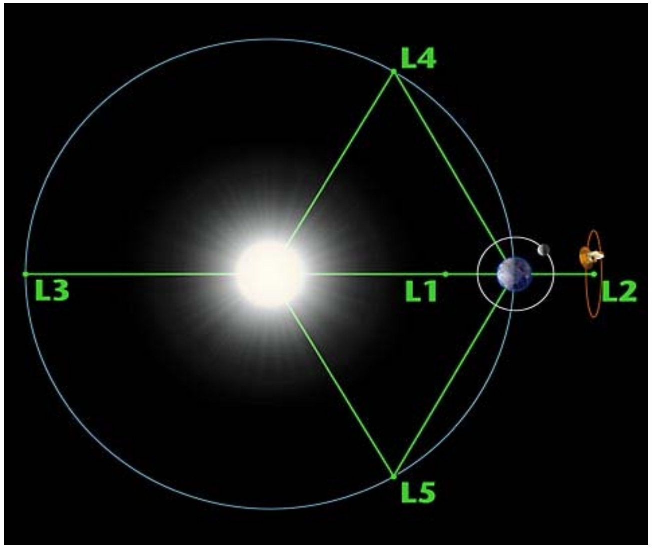

1’x1’ region in the UDF

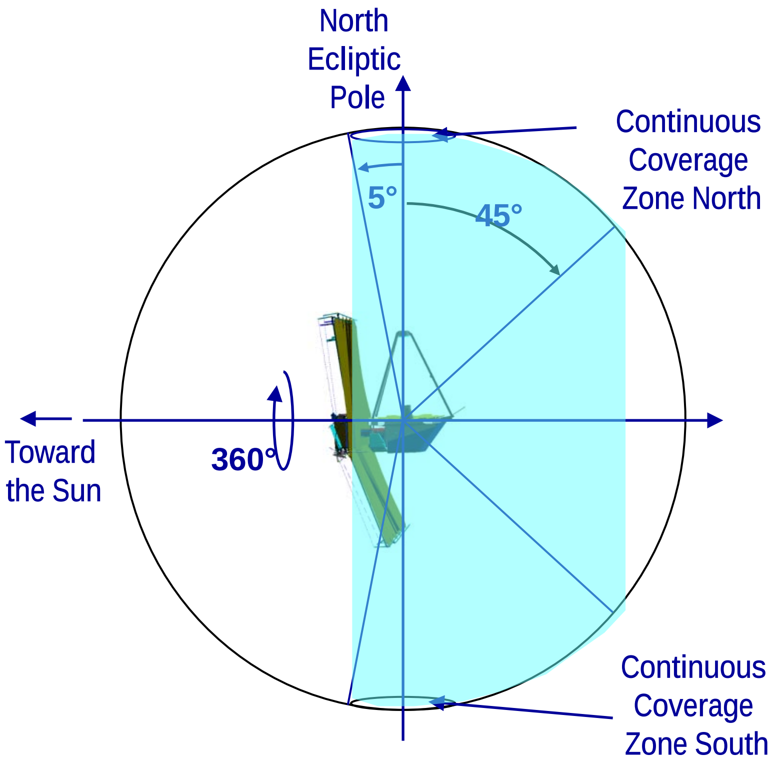
3.5 to 5.8 um



# The JWST will be placed in orbit about the Sun-Earth L2 point approximately 1.5 million km from Earth

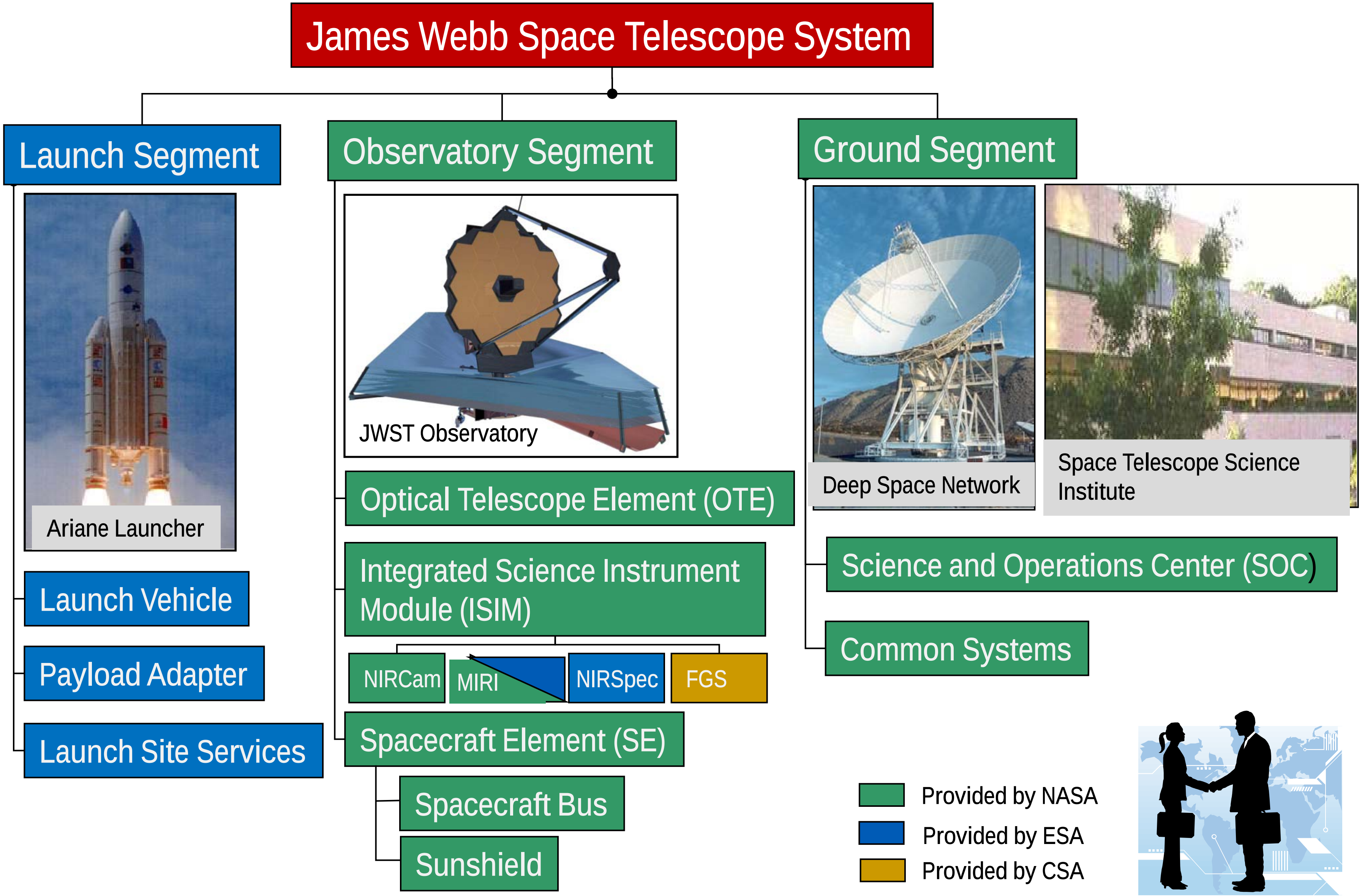
- An L2 point orbit was selected for JWST to enable passive cryogenic cooling
  - Station keeping thrusters are required to maintain this orbit
  - Propellant sized for 11 years (delta-v ~ 93 m/s)
  - ~100 day direct transfer trajectory




- The JWST can observe the whole sky while remaining continuously in the shadow of its sunshield
  - Field of Regard is an annulus covering 35% of the sky
  - The whole sky is covered each year with small continuous viewing zones at the Ecliptic poles

# The JWST program is a multi-agency partnership

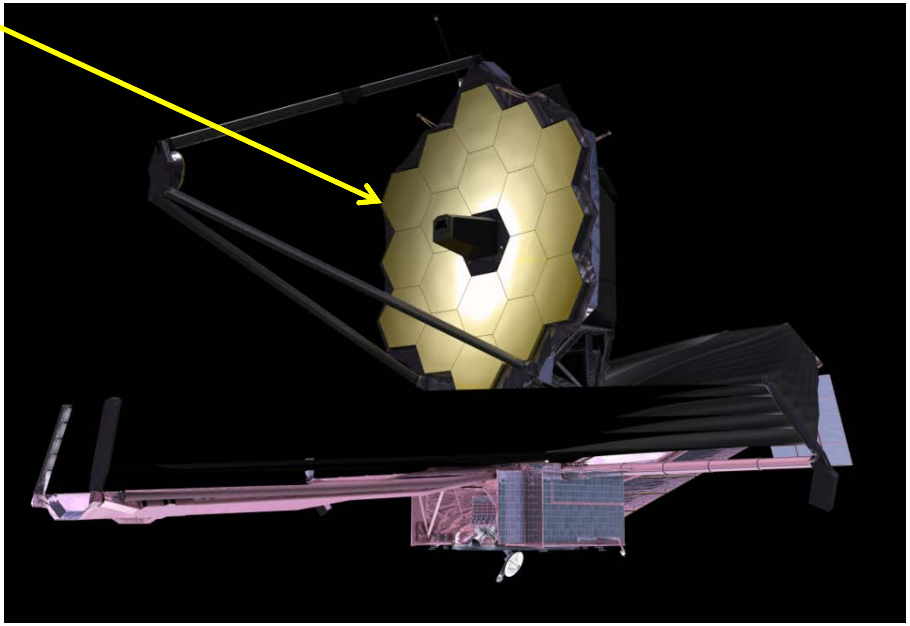


# The JWST space vehicle consists of three elements

**Optical Telescope Element (OTE)**
Collects star light from distant objects

**Integrated Science Instrument Module (ISIM)**
Extracts physics information from star light

**Spacecraft**
Attitude control, telecom, power & other systems



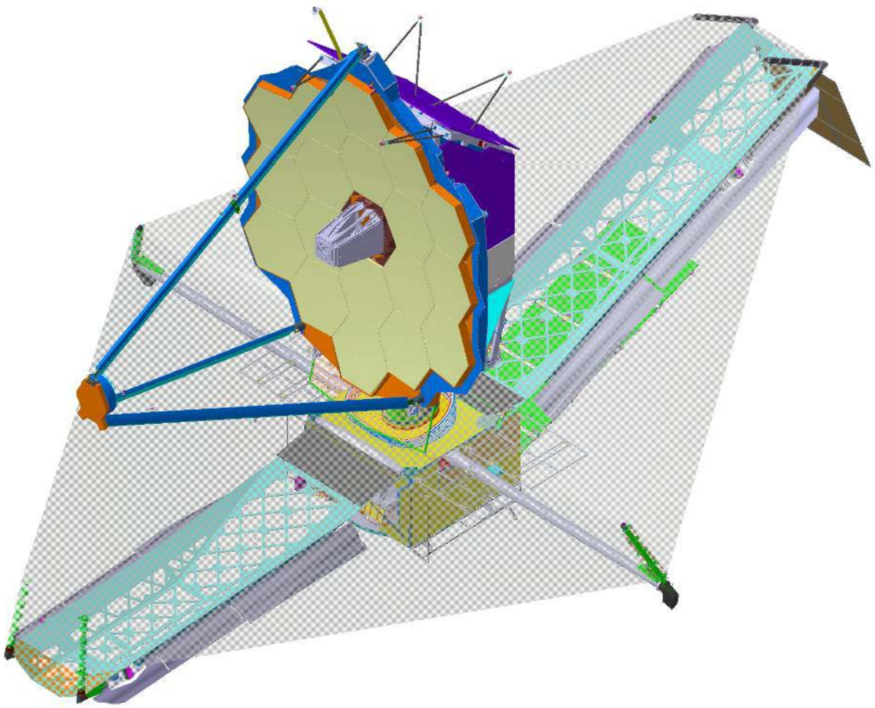
# JWST requires a segmented deployable primary mirror

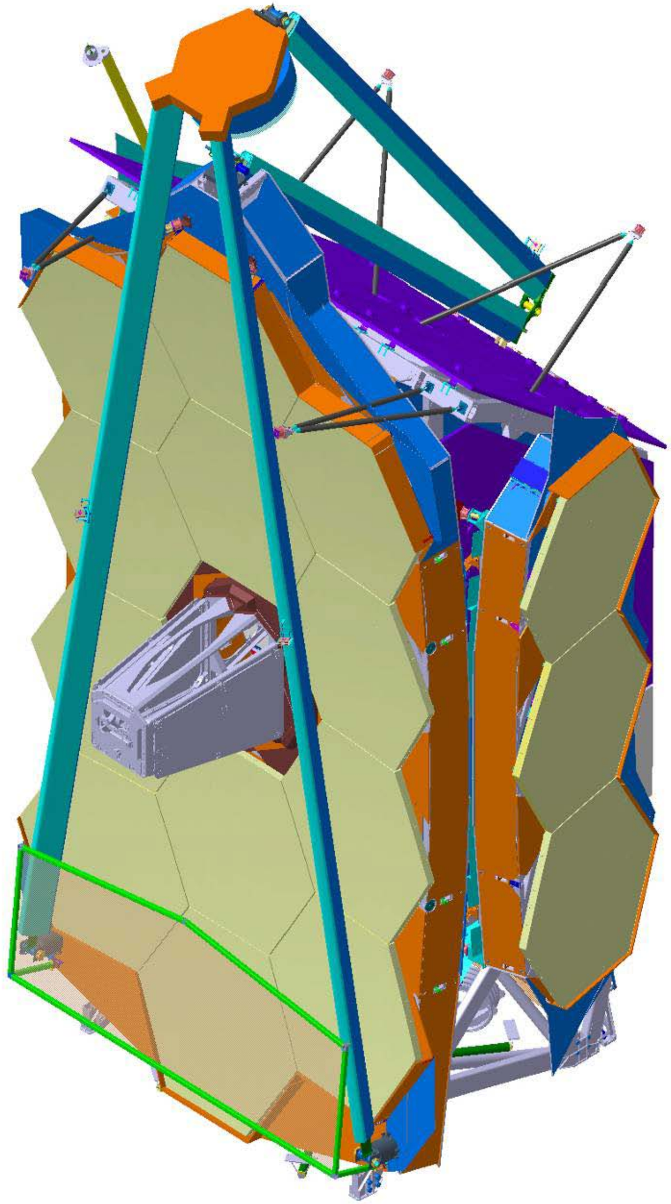

Ariane 5 ECA

- JWST is designed to integrate with an Ariane V launch vehicle and 5 m diameter fairing
- Launch from Kourou Launch Center (French Guiana) with direct transfer to L2 point.
- Payload launched at ambient temperature with on orbit cooling to 50 K via passive thermal radiators
- JWST payload: 6330 kg

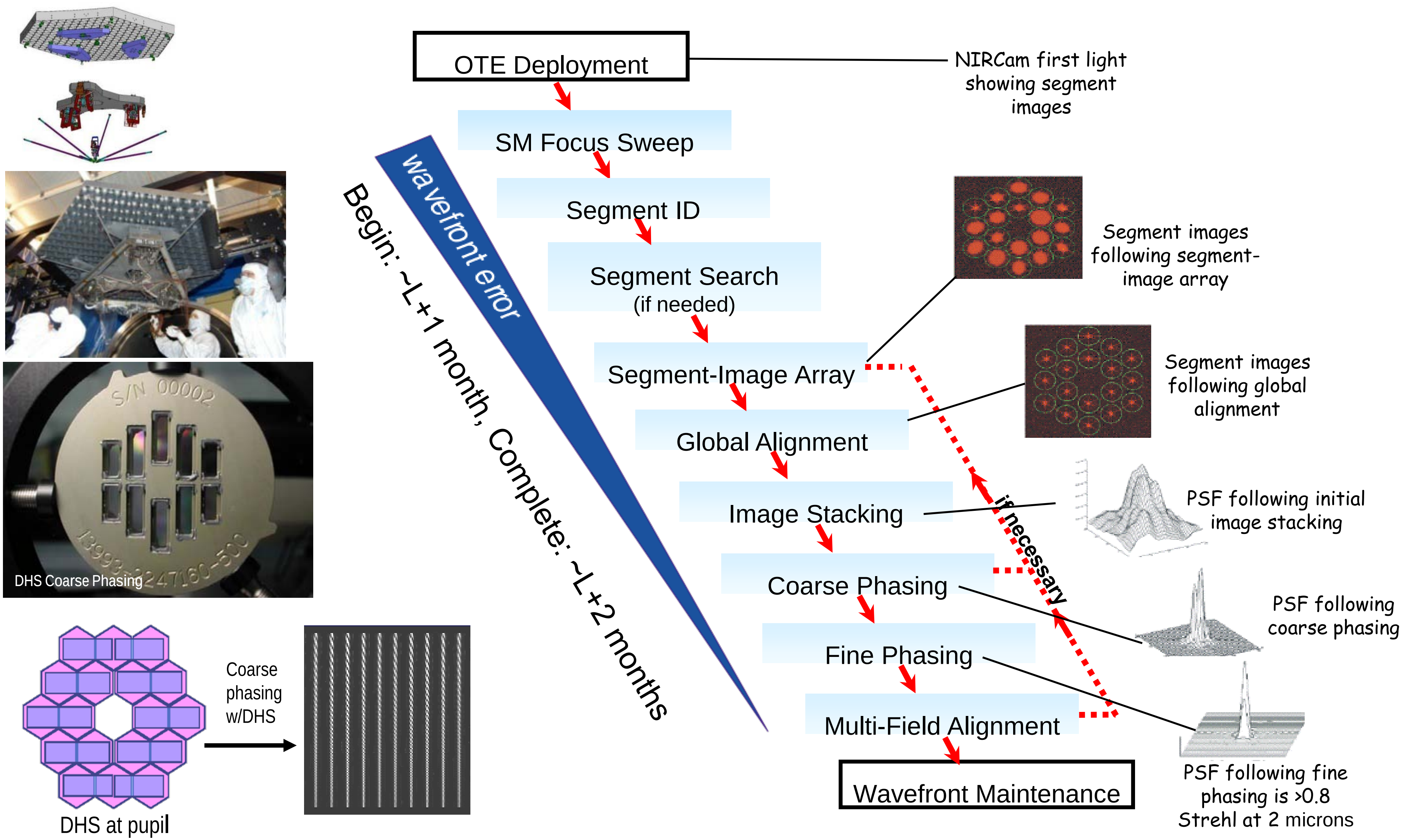
# Deployment Sequence Overview

Click video

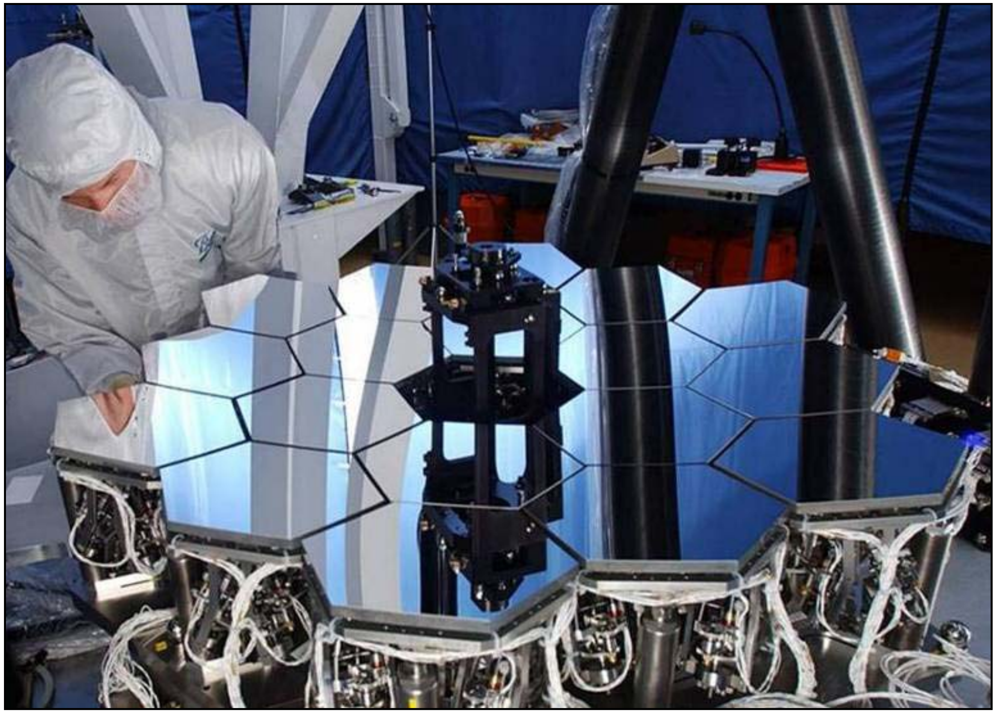




# The mirror segment mounts are mechanized, and a wavefront control system will be used to adjust each segment during flight, thus enabling them to perform together as a single large mirror.



# The telescope wave front sensing and control procedure has been validated on a 1/6$^{th}$ scale fully functional engineering model



- Primary use is in validation of Flight Algorithms and software
- Also used to test JSC I&T process
- WFSC Testbed Telescope is a 1/6th scale, fully functional model of the JWST telescope with performance traceable to JWST (TMA, 18 7-dof segments, etc.).
- Used to perform TRL-6 end to end testing.
- Supports Multi-Field Measurements

# The telescope mirrors are fabricated from Beryllium

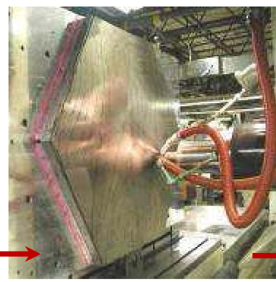
Key physical properties of Beryllium:

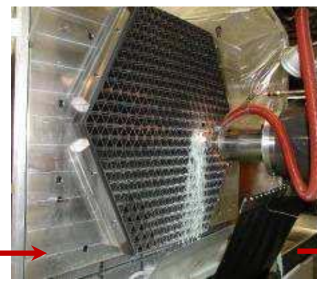
- low coefficient of thermal expansion at 50 K
- high thermal conductivity
- high stiffness to mass ratio

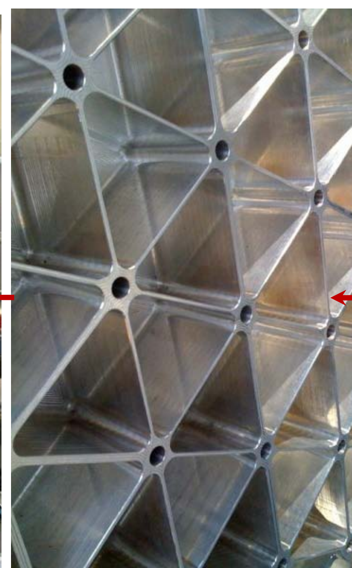
- Type O-30 spherical powder
  - uniform CTE, high packing density, low oxide content

Primary mirror mass properties

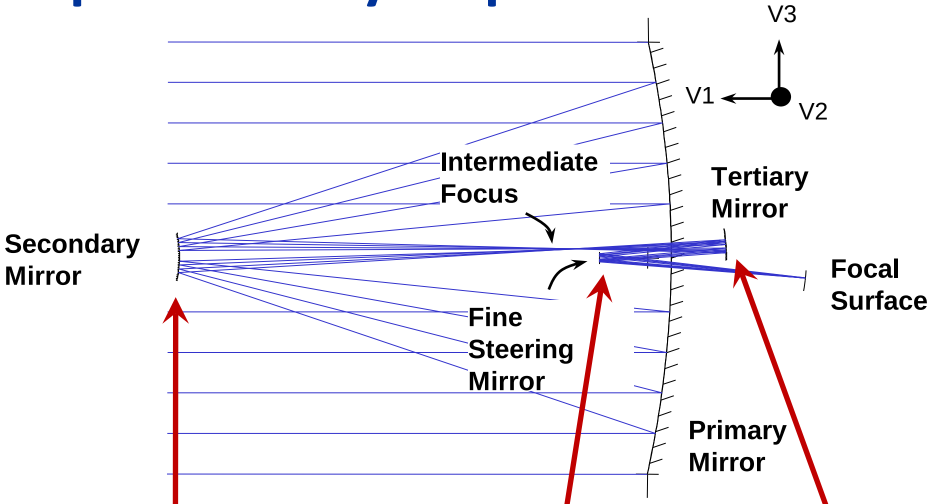
- substrate: 21.8 kg
- segment assembly: 39.4 kg
- OTE area density: ~28 kg m$^{-2}$
  - HST (ULE) ~ 180 kg m$^{-2}$
  - Keck (Zerodur) ~ 2000 kg m$^{-2}$

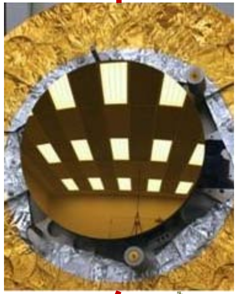


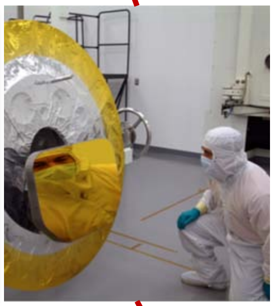


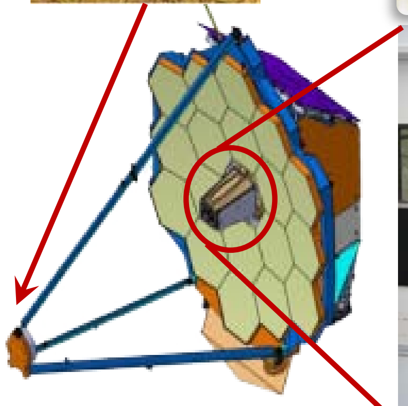
# All telescope optics are complete through cryo testing and are in spec in every respect

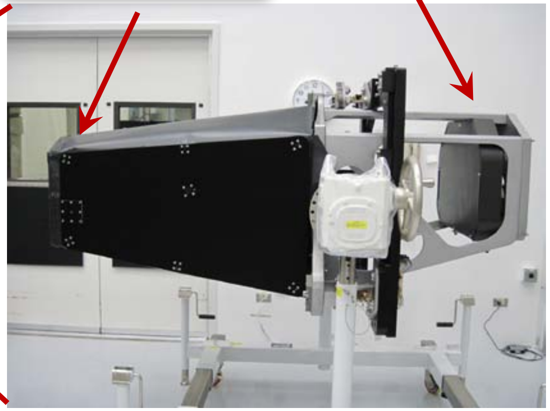


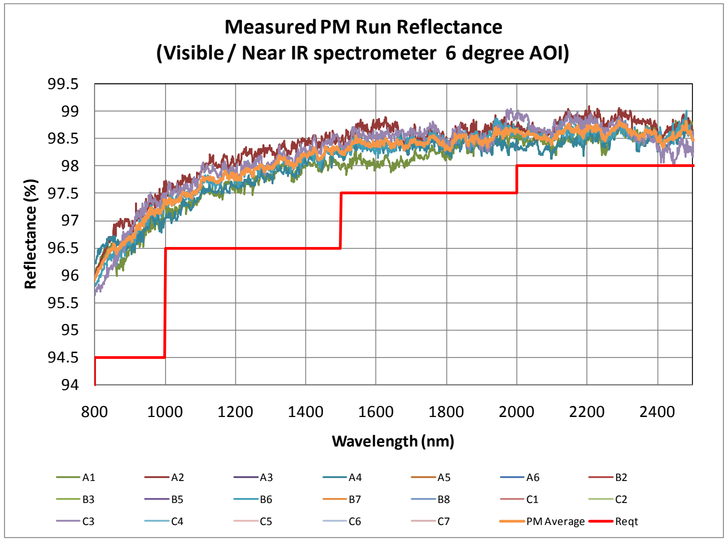




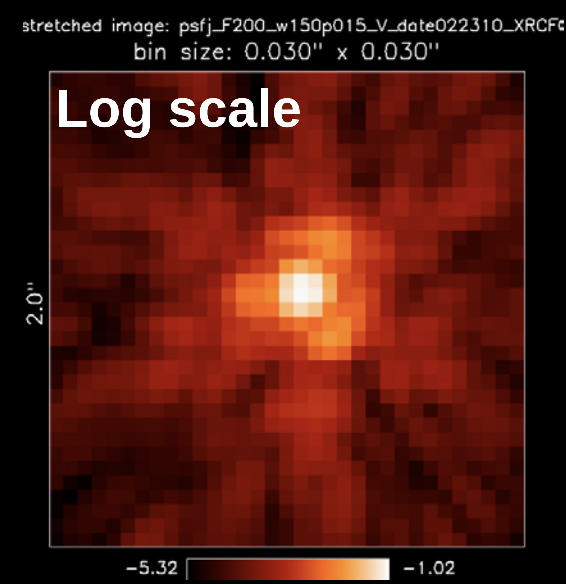


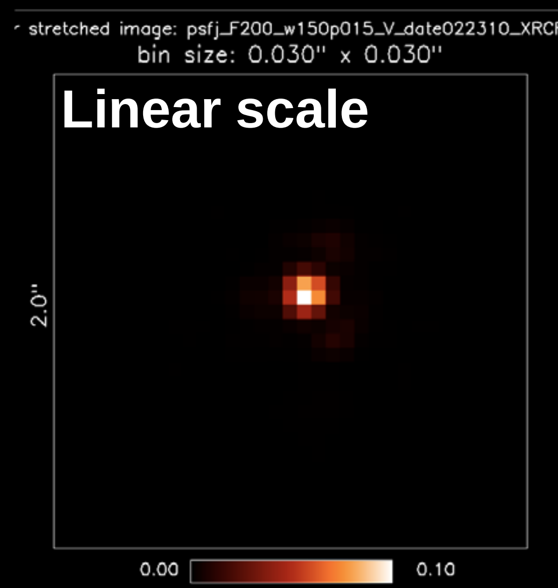






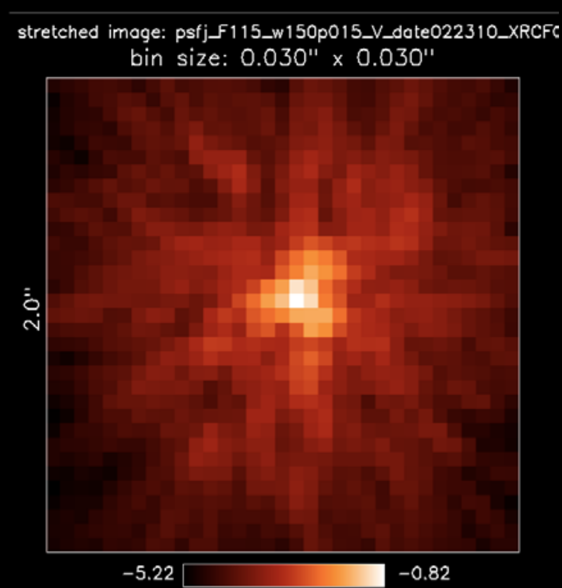
# Predicted image quality meets requirements

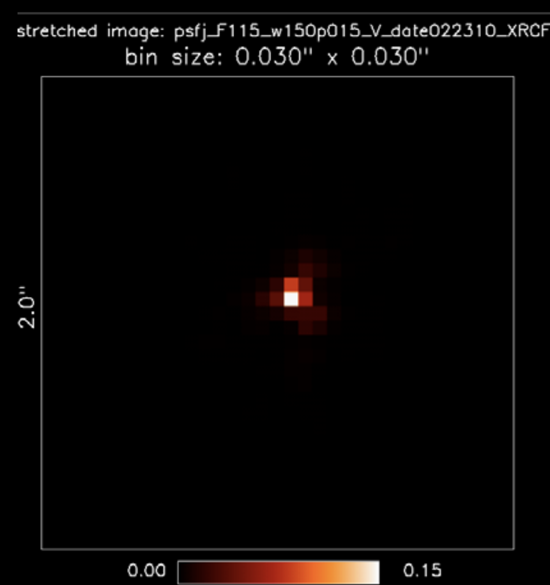



**2 µm (diffraction limited, Nyquist sampled by NIRCam)**

**2.0” x 2.0” box**

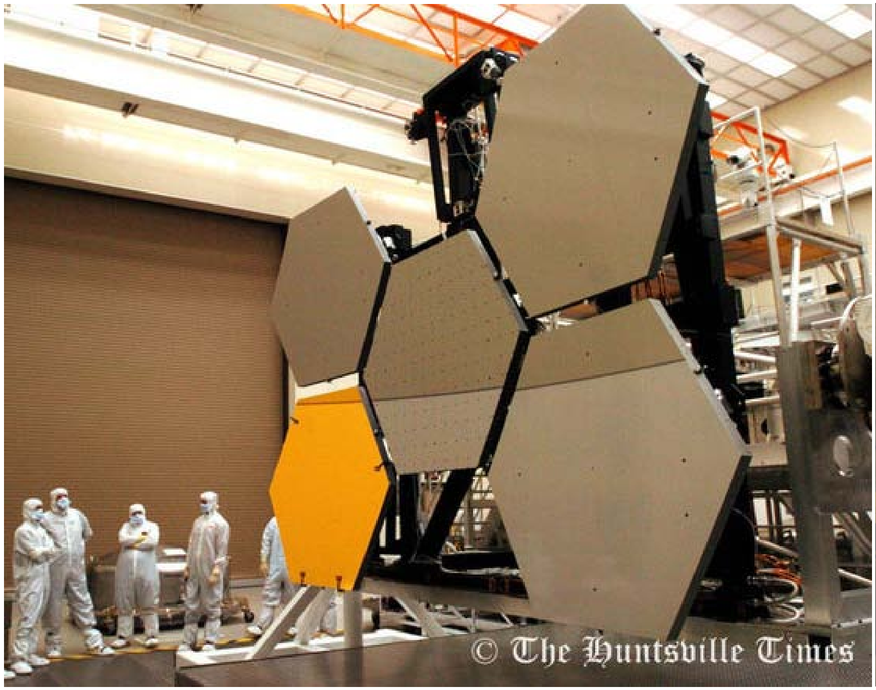


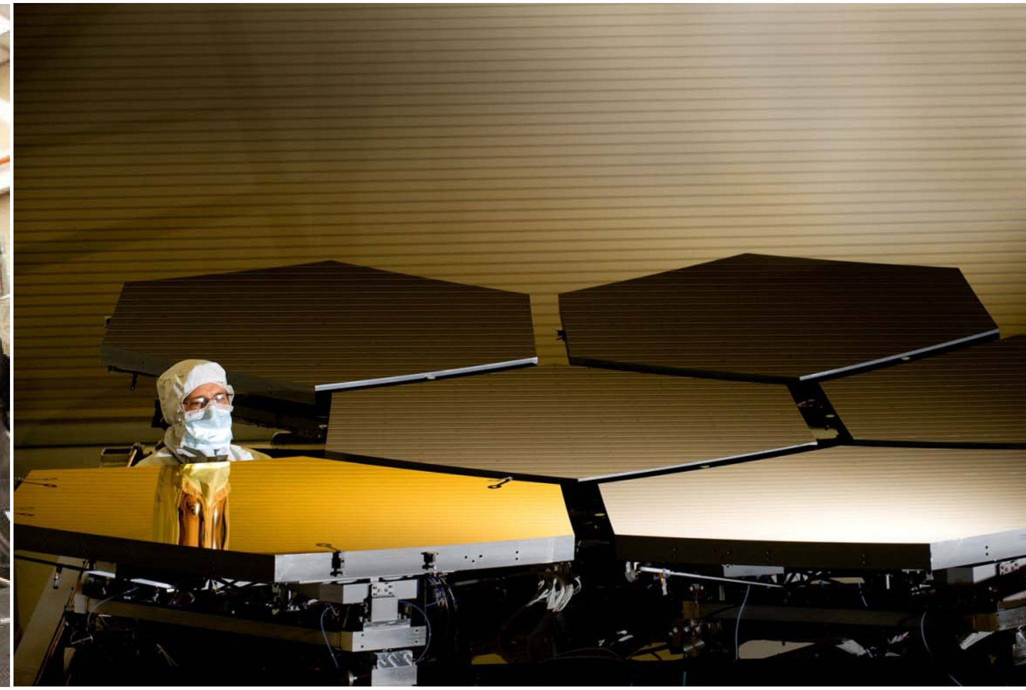



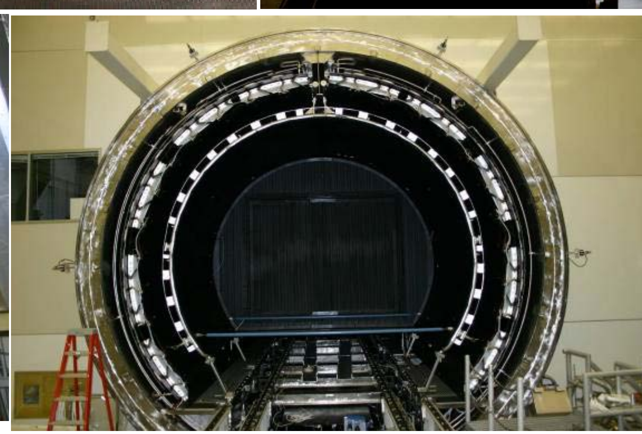

**1 µm (Sub-Nyquist sharp core 0.03 arcsec, requires dithering)**

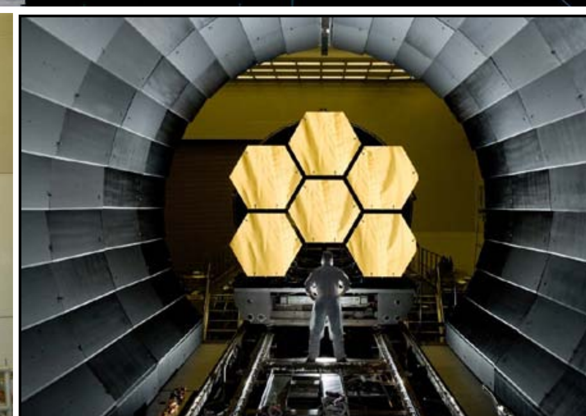
**2.0” x 2.0” box**

# A specially instrumented space simulation chamber at MSFC was used to optically test the primary mirror segments at 50 K (-225 C, -370 F)





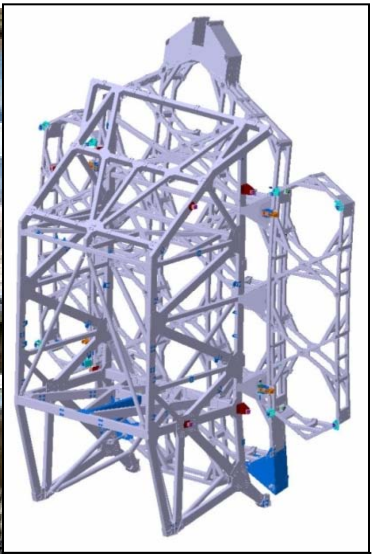


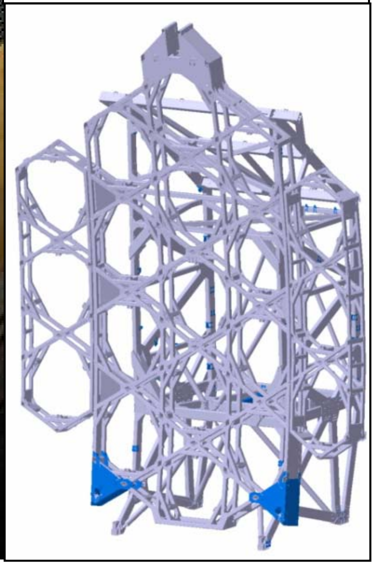
# Buildup of telescope flight structure is nearing completion

Assembly consists of ~3,200 bonded composite piece parts

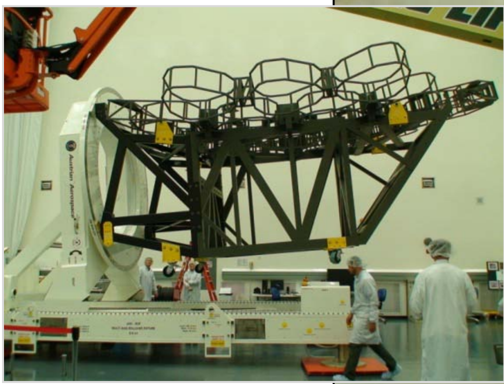
Center section of the flight backplane was completed during April 2012

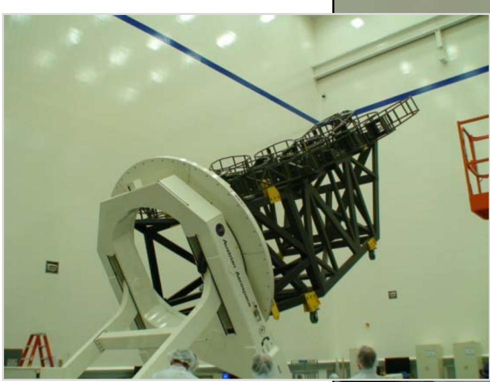
JWST OTE flight backplane center section at ATK facility

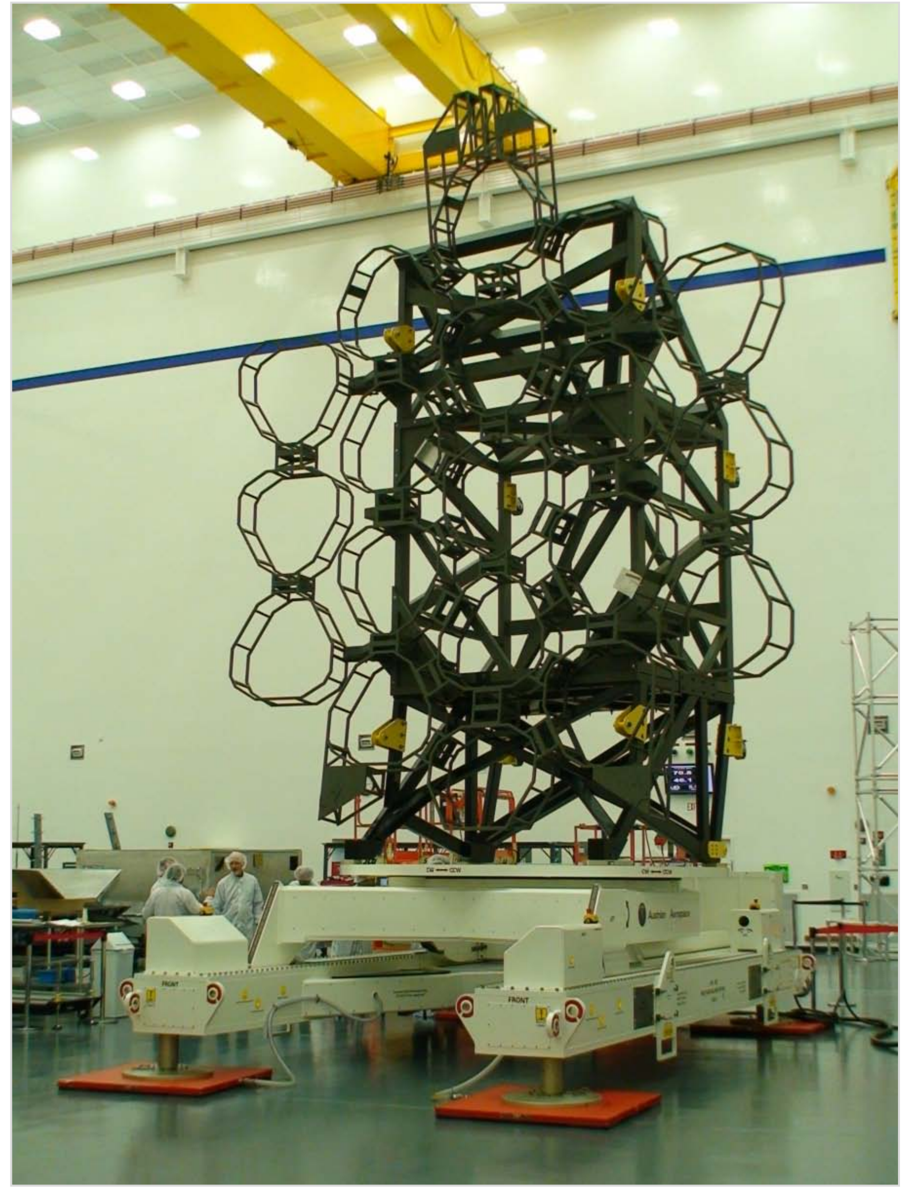




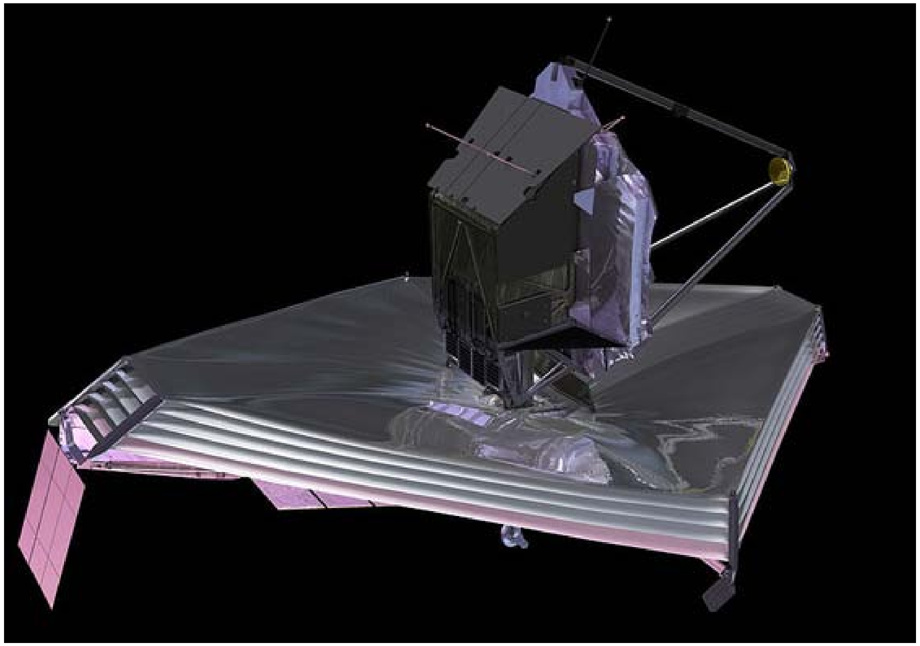
# Full scale OTE mockup in handling test at NGAS

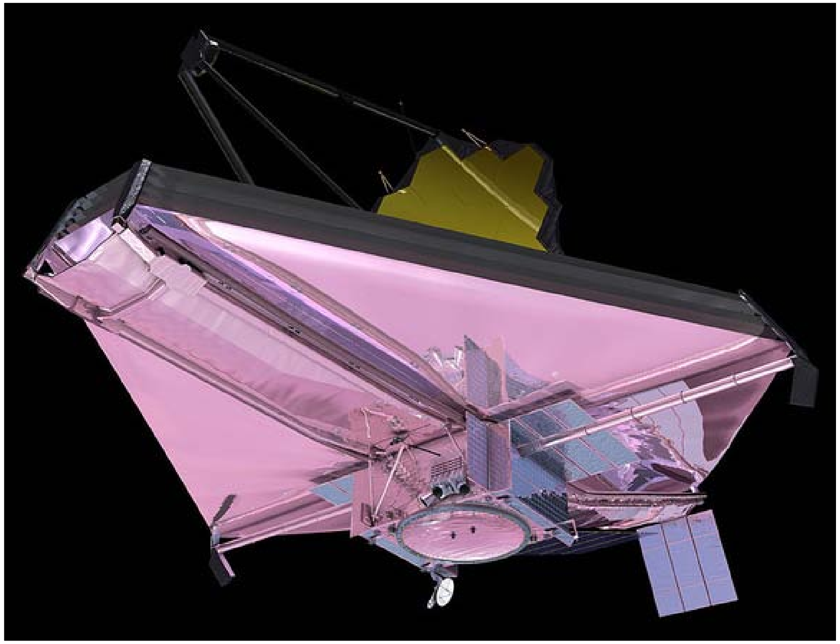






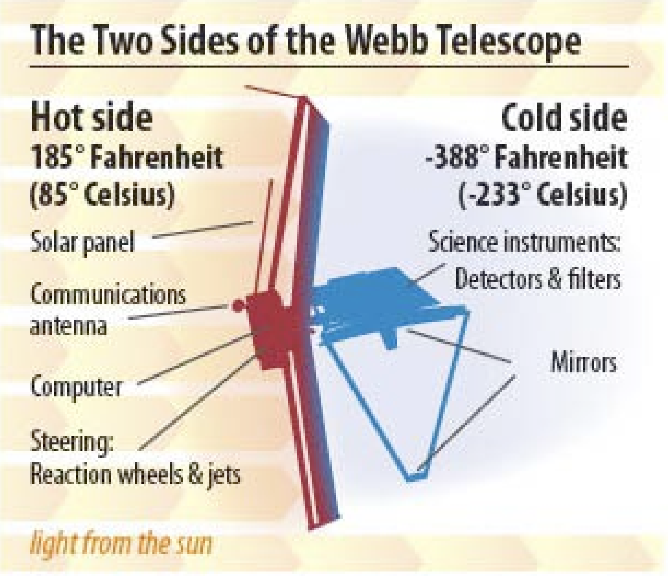
# The JWST's 5 layer sunshield has an SPF of ~$10^6$





## Sunshield Facts

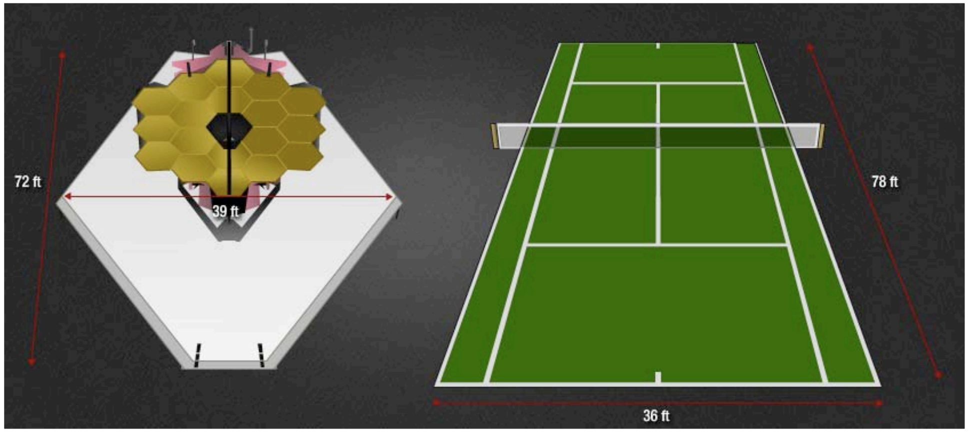
- Measures 73 x 40 feet and has 5 layers
- Made of heat-resistant Kapton coated with silicon on sun side and aluminum on other surfaces
- Sun side reaches 358 K (85º C), dark side stays at 40 K (-233º C)
- Each of 5 layers consist of 50 pieces to form shape
- Seaming involves 7,000 inches of thermal welds
- Seam-to-seam accuracy ~ 0.05 inch with shape of (tennis court size) layers accurate to a few tenths of an inch



# Sunshield thermal performance has been validated by a 1/3 scale test in a space simulation chamber

1/3 scale cryo-vac test article

Full scale engineering unit layer 3 undergoing LIDAR shape measurement

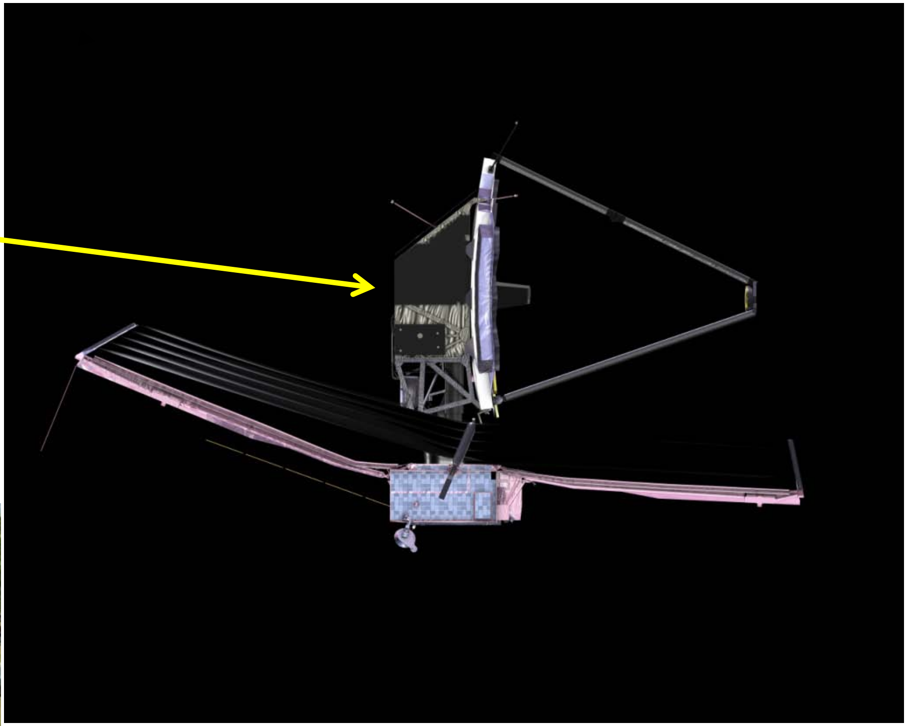


# The JWST space vehicle consists of three elements

**Optical Telescope Element (OTE)**
Collects star light from distant objects

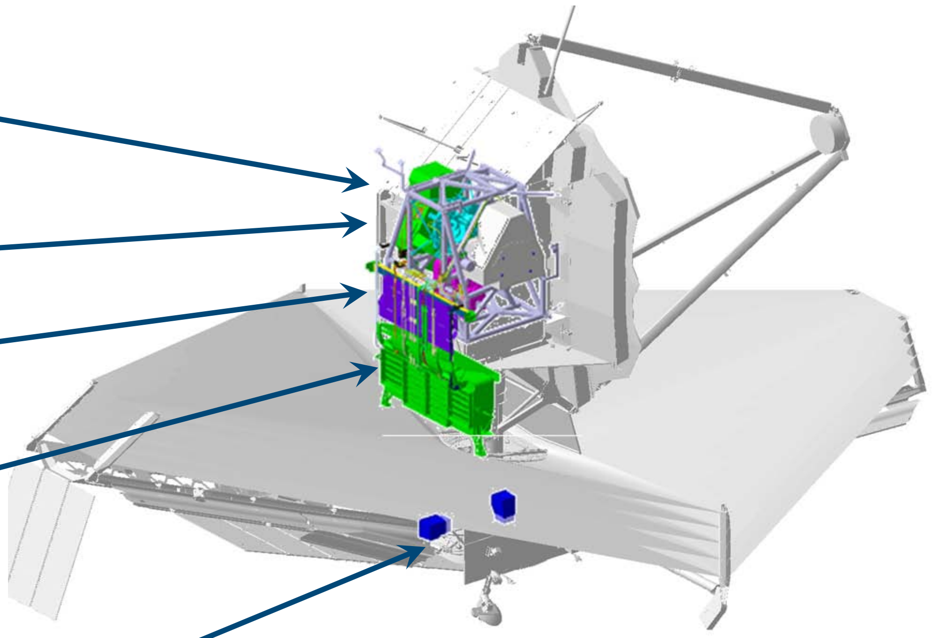
**Integrated Science Instrument Module (ISIM)**
Extracts physics information from star light

**Spacecraft**
Attitude control, telecom, power & other systems

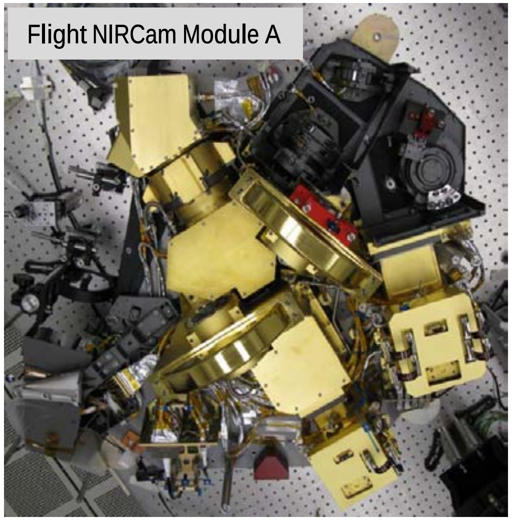


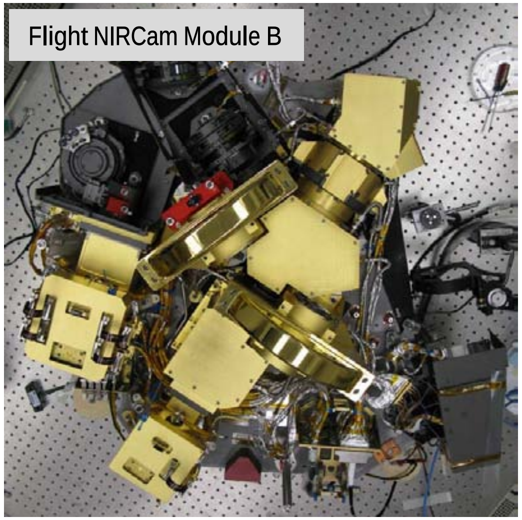
# The Integrated Science Instrument Module (ISIM) is the science instrument payload of the JWST

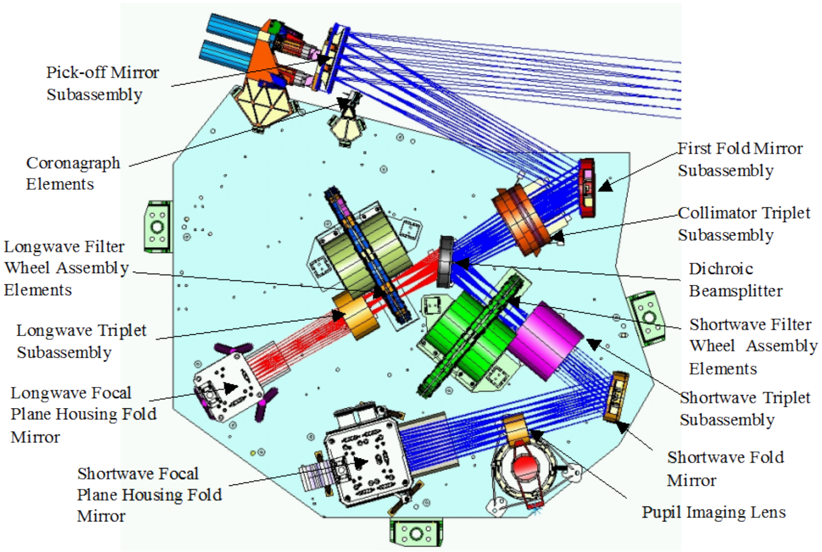
- ISIM is one of three elements that together make up the JWST space vehicle
  - Approximately 1.4 metric tons, ~20% of JWST by mass
  - Completed its Critical Design Review during 2009 and is currently in integration and test
- The ISIM system consists of:
  - Four science instruments
    - Complete - MIRI, FGS, NIRCam, NIRSpec
  - Nine instrument support systems:
    - Complete - Optical metering structure system
    - Dec 2012 - Electrical Harness System
    - Nov 2012 - Harness Radiator System
    - Complete - ISIM electronics compartment
    - Complete - ISIM Remote Services Unit
    - Dec 2012 - Cryogenic Thermal Control System
    - Complete - Command and Data Handling System
    - Flight Software System
    - Operations Scripts System



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



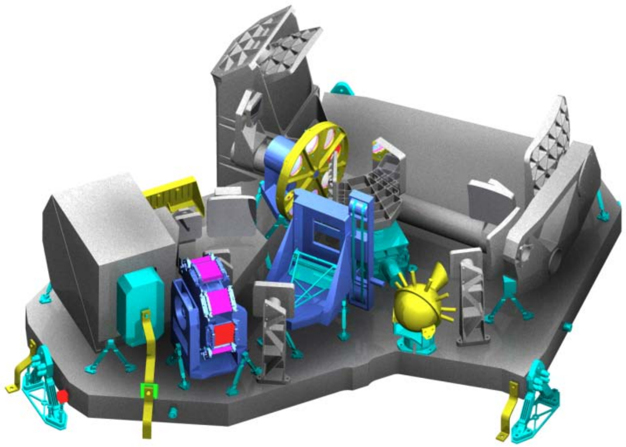



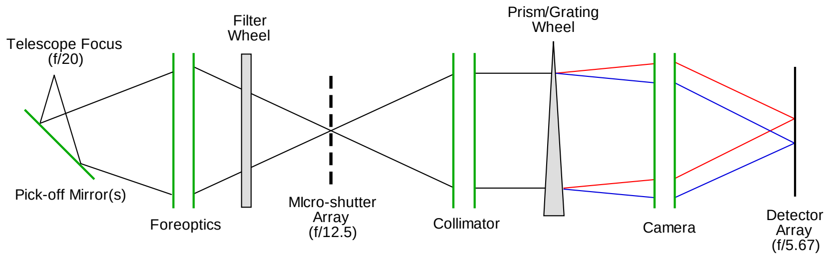



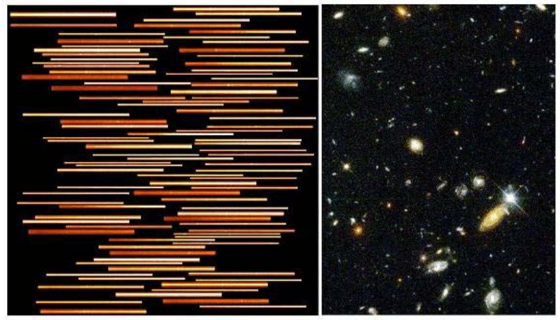

- Developed by the University of Arizona with Lockheed Martin ATC
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 4, 10, 100 (filters + grism), coronagraph
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns
  - Detector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

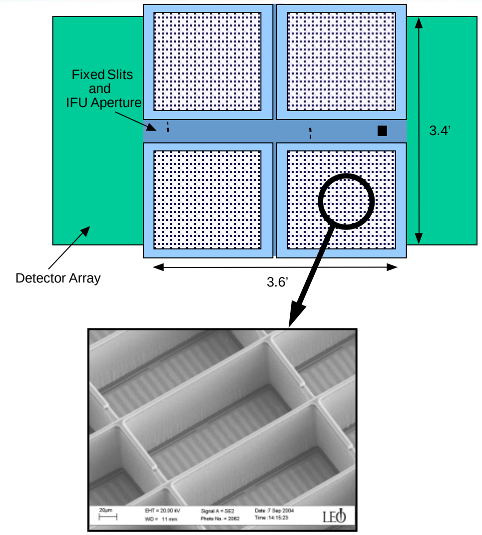
# NIRCam will arrive at GSFC during December 2012


# The NIRSpec will acquire near-infrared spectra of up to 100 objects in a single exposure



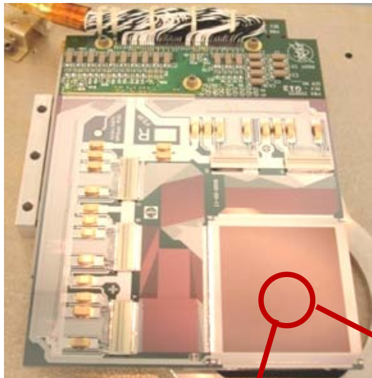


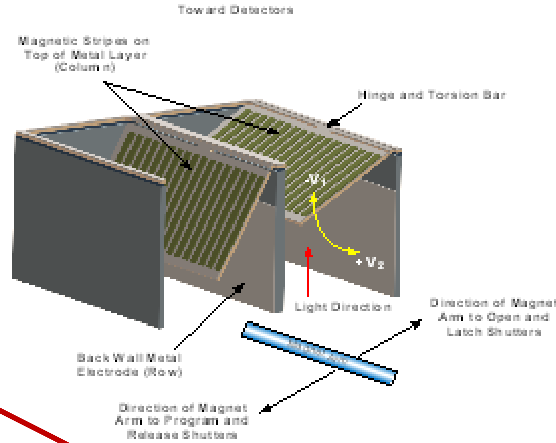



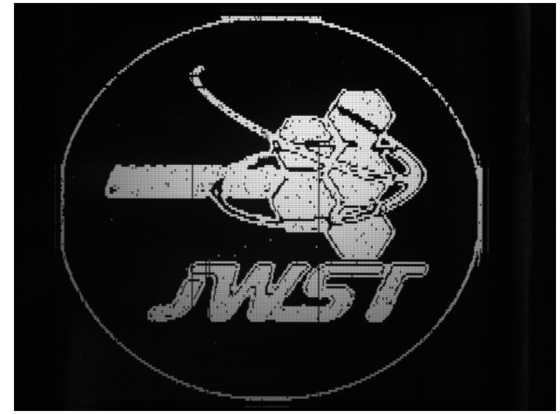


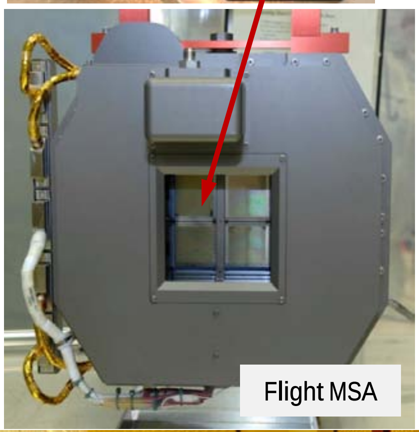

- Developed by the European Space Technology Center (ESTEC) with Astrium and Goddard Space Flight Center
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
    - Aperture control:
      - Programmable micro-shutters, 250,000 pixels
      - 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, Silicon Carbide  structure and optics

# Aperture control: 250,000 programmable micro-shutters
# System flight qualified and delivered to ESA June 2010

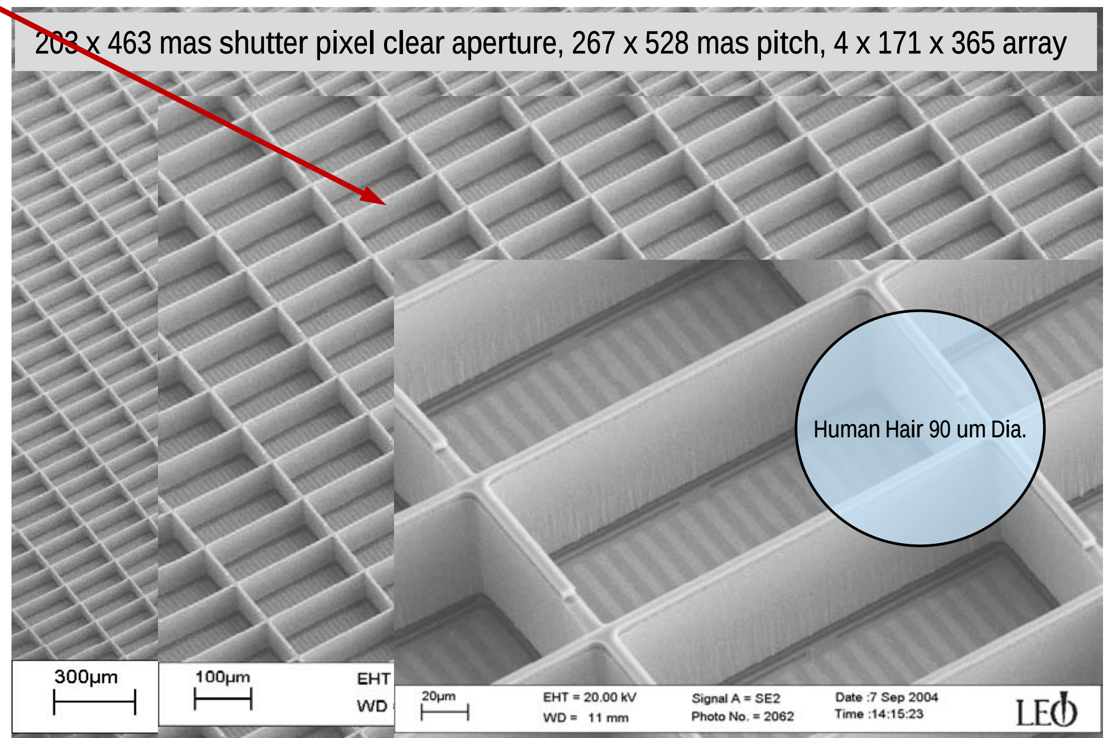




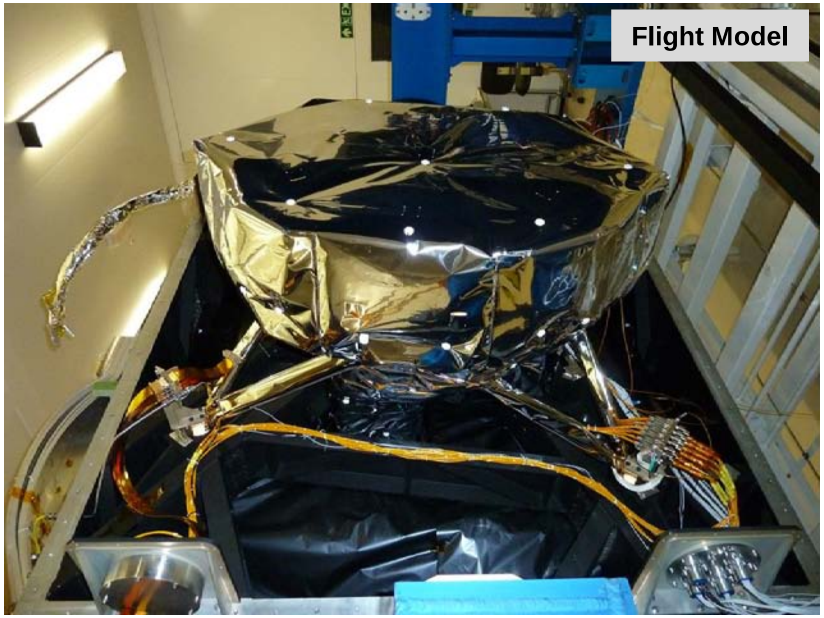







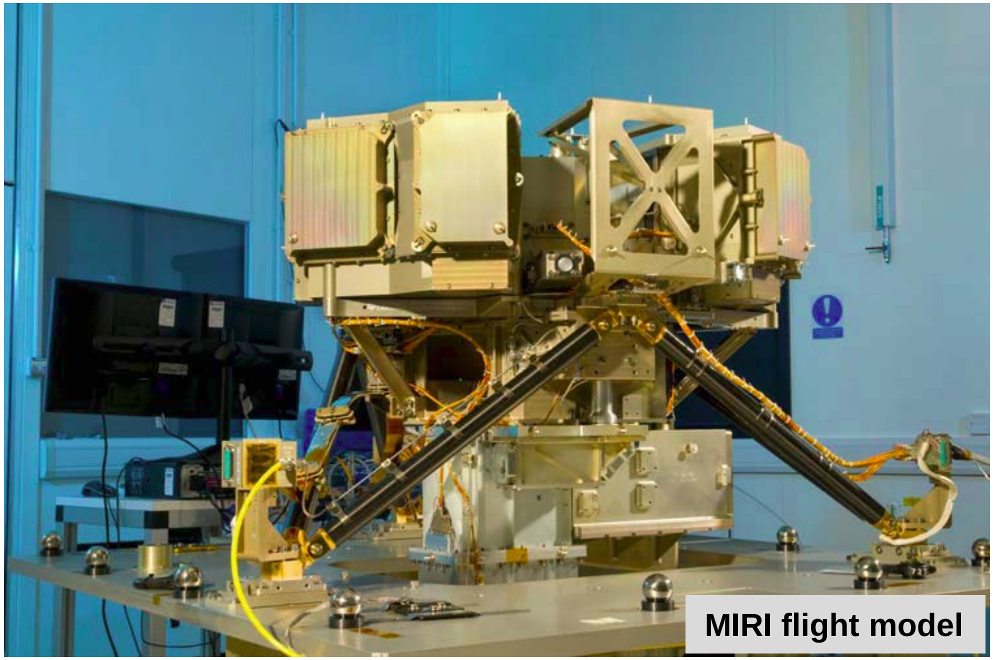
# NIRSpec delivery is expected during June 2013

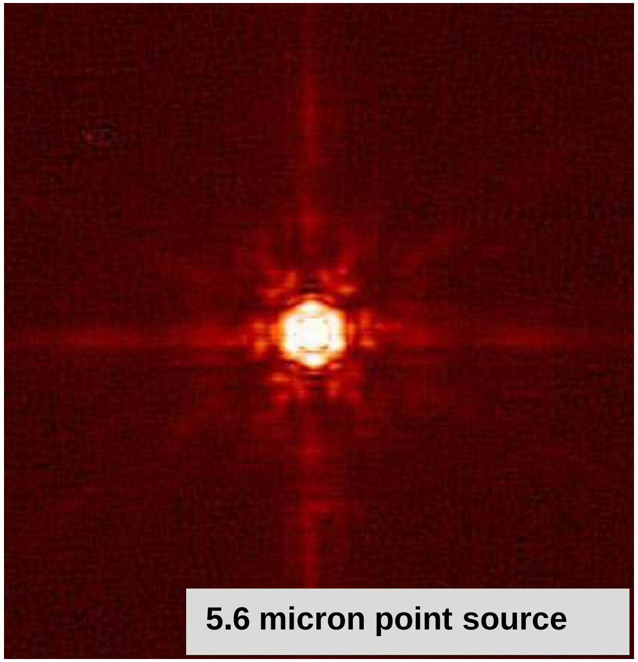
## The MIRI instrument will characterize circumstellar debris disks, extra-solar planets, and the evolutionary state of high redshift galaxies

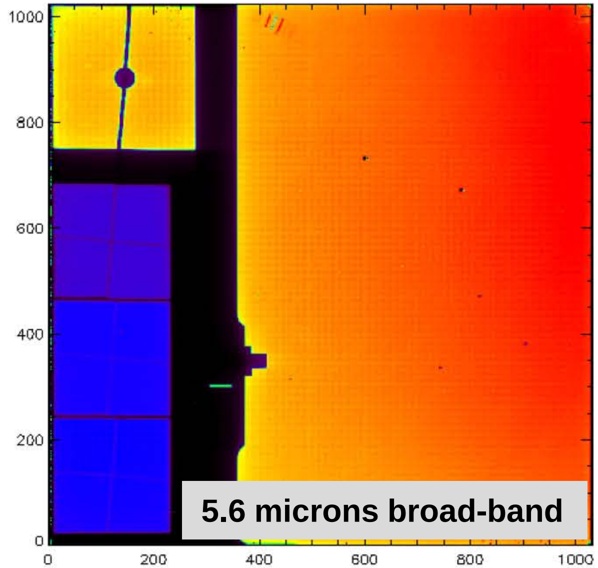



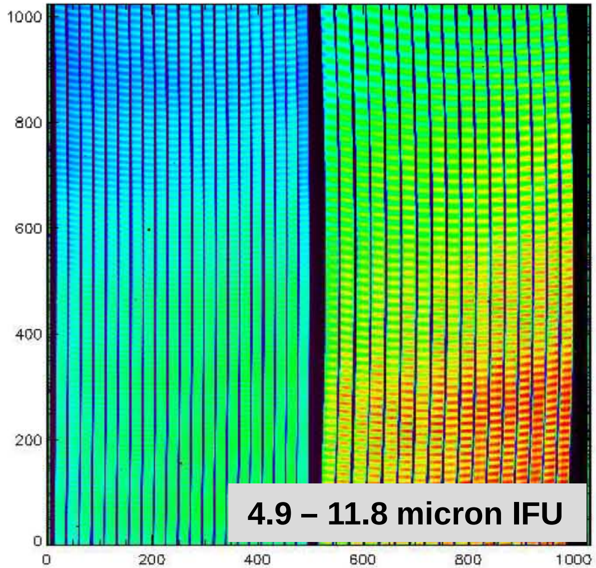

- Developed by a consortium of 10 European countries and NASA/JPL
  - Operating wavelength: 5 - 29 microns
  - Spectral resolution: 5, 100, 2000
  - Broad-band imagery: 1.9 x 1.4 arc minutes FOV
  - Coronagraphic imagery
  - Spectroscopy:
    - R100 long slit spectroscopy 5 x 0.2 arc sec
    - R2000 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

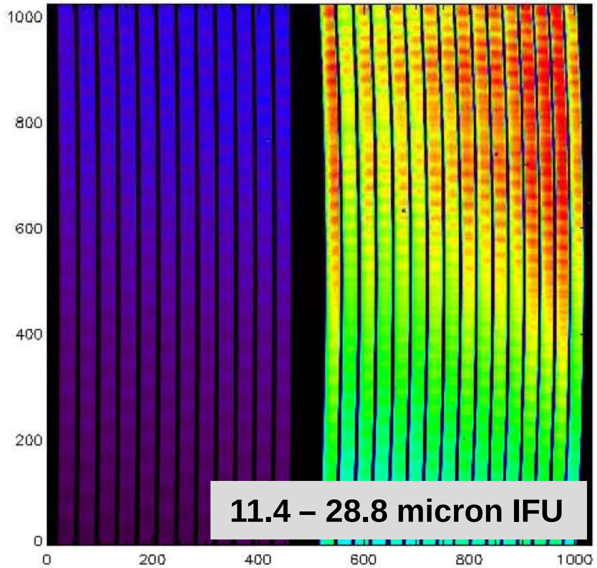
# MIRI was delivered to ISIM I&T during May 2012



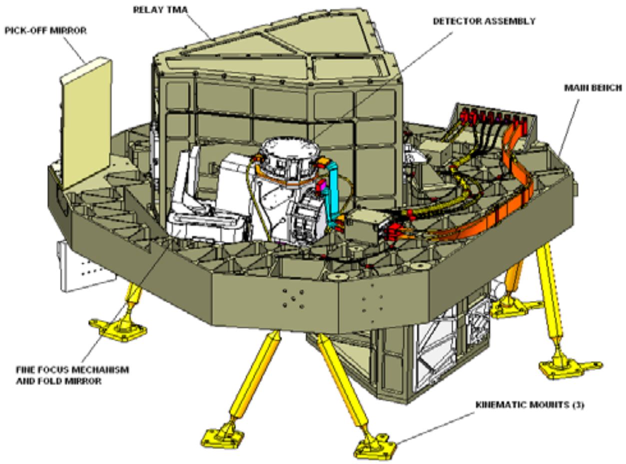



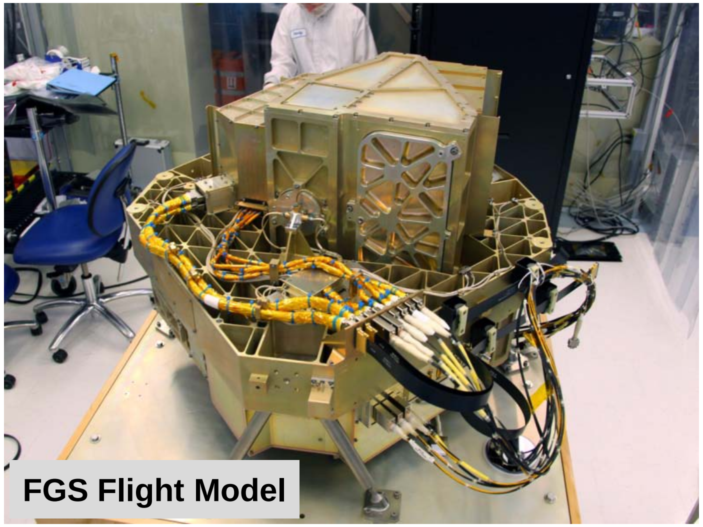



# The FGS-Guider and -NIRISS provide telescope pointing control imagery & slitless spectroscopy for Ly-$\alpha$ galaxy surveys and extra-solar planet transits



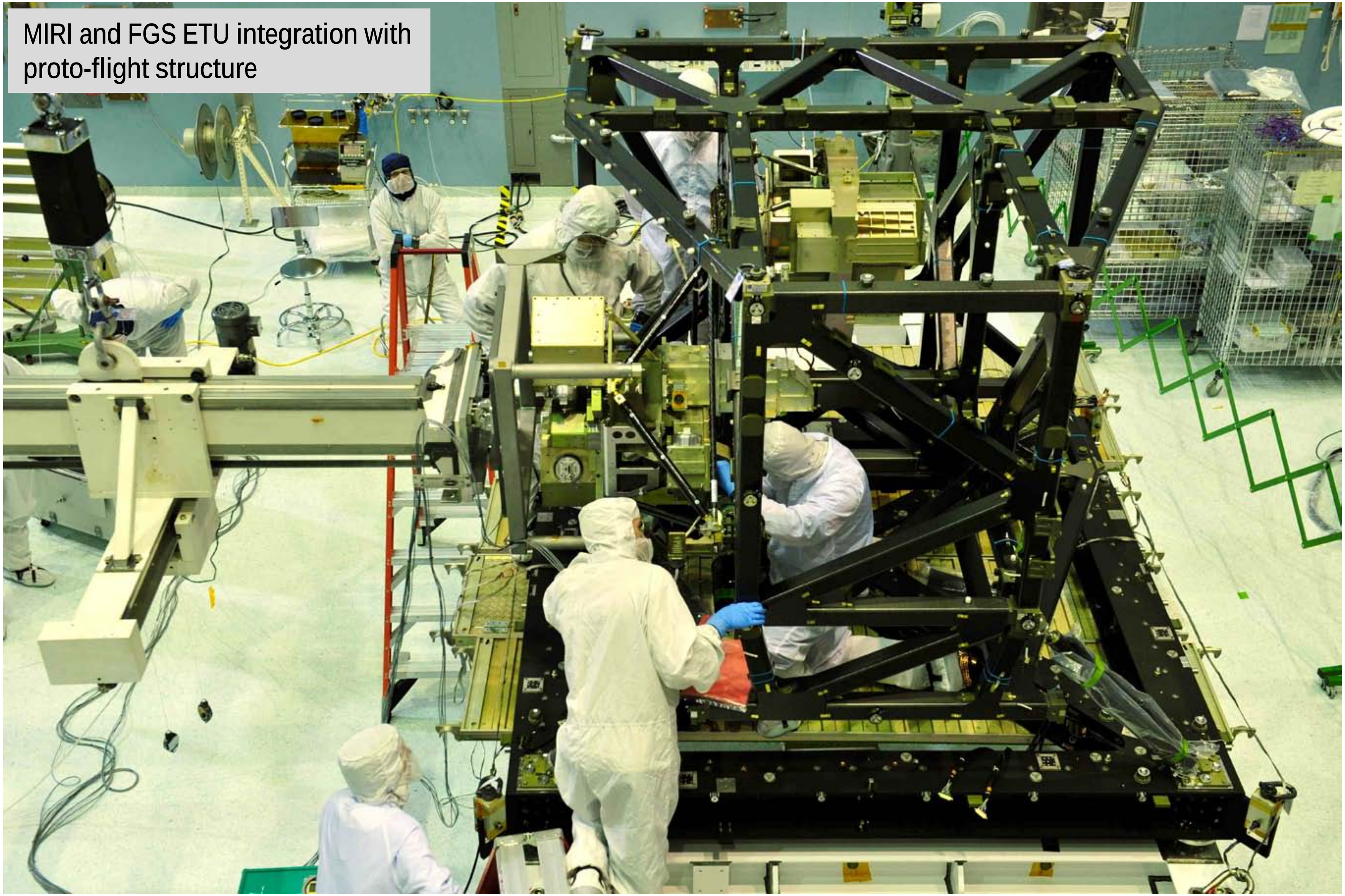




- Developed by the Canadian Space Agency with ComDev
  - Broad-band guider (0.6 – 5 microns)
  - Field of view: 2.3 x 2.3 arc minutes
  - Science imagery:
    - Slitless spectroscopic imagery (grism)
      - R ~ 150, 0.8 – 2.25 microns optimized for Ly alpha galaxy surveys
      - R ~ 700, 0.7 – 2.5 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

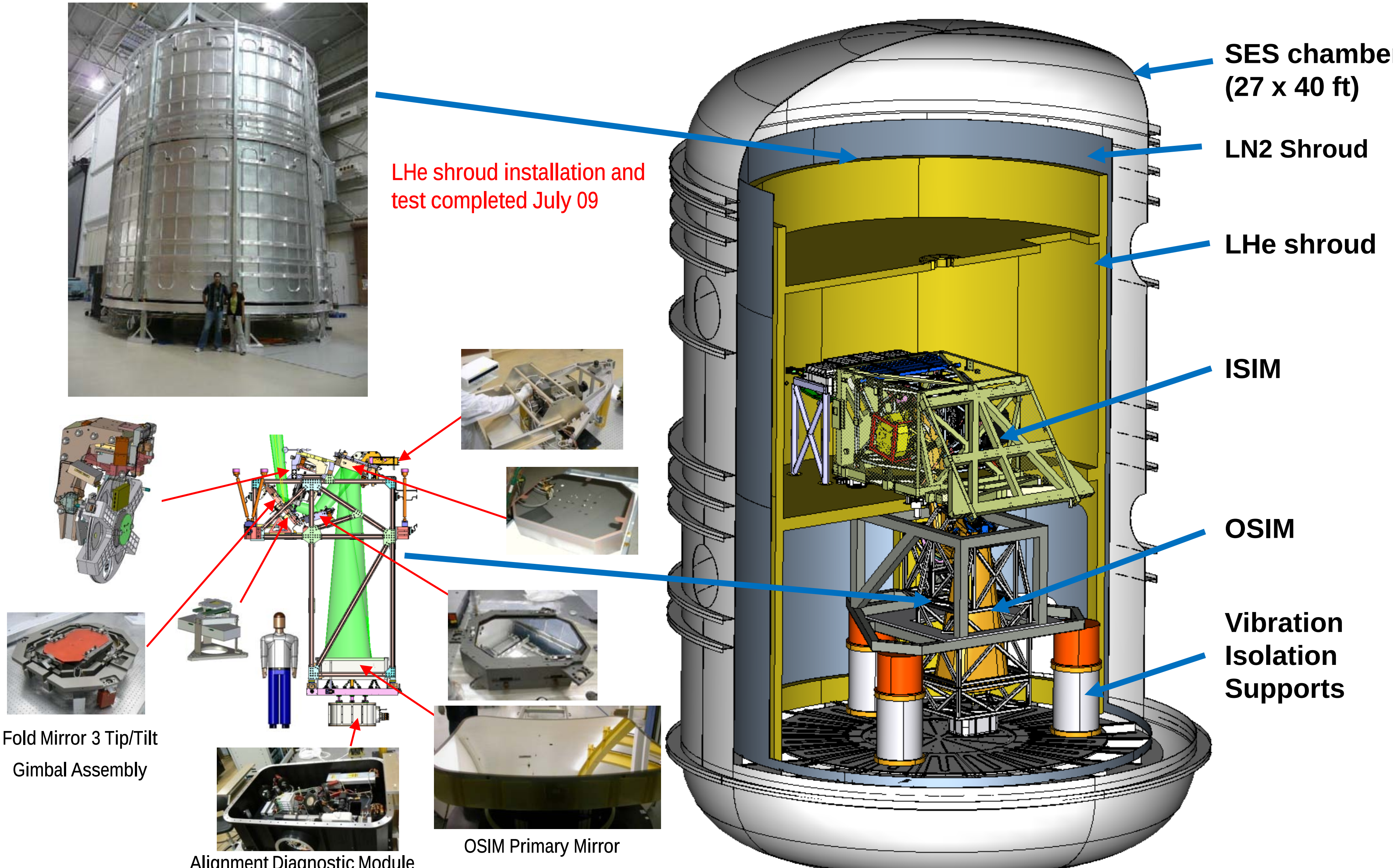
# FGS was delivered to ISIM I&T during July 2012

# Integration of engineering model science instruments with the flight ISIM structure is proceeding well

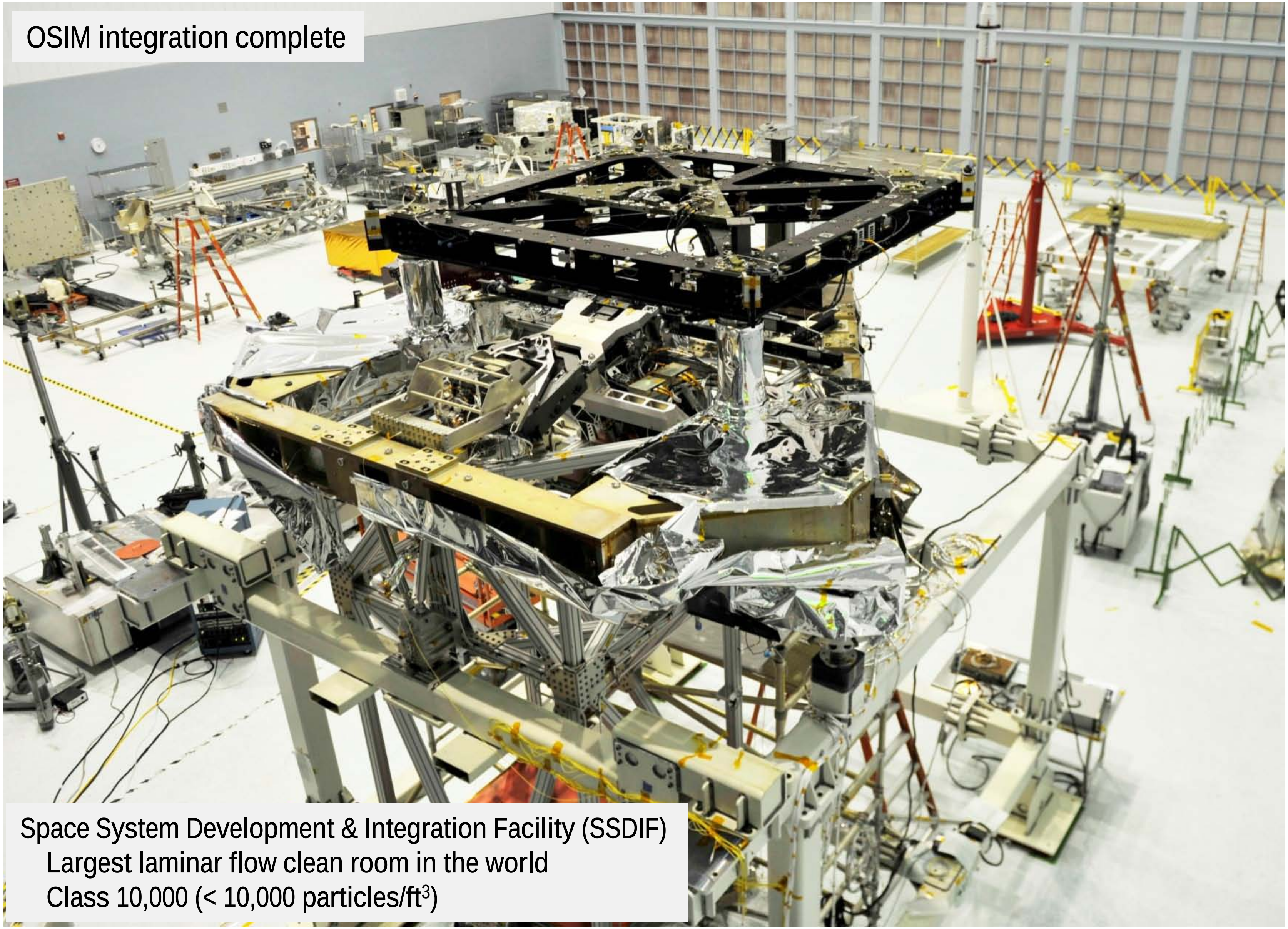
MIRI and FGS ETU integration with proto-flight structure



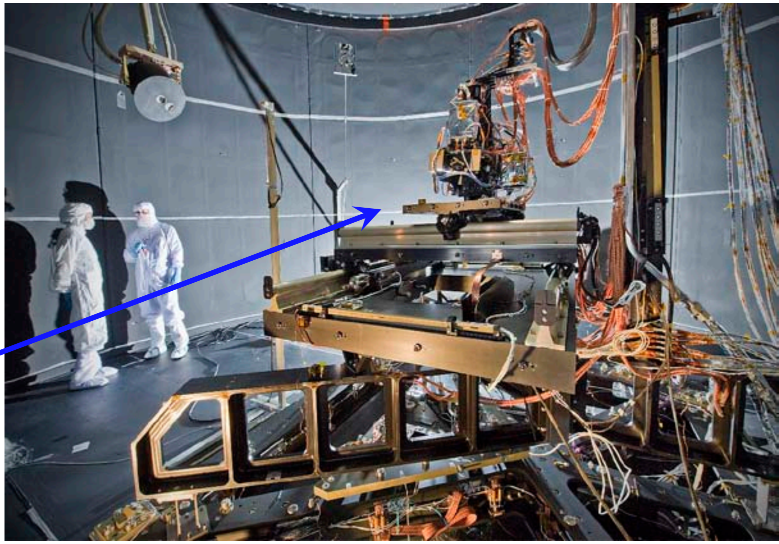
# ISIM will be tested at ~35 K in the GSFC SES chamber using a cryogenic telescope simulator (OSIM)



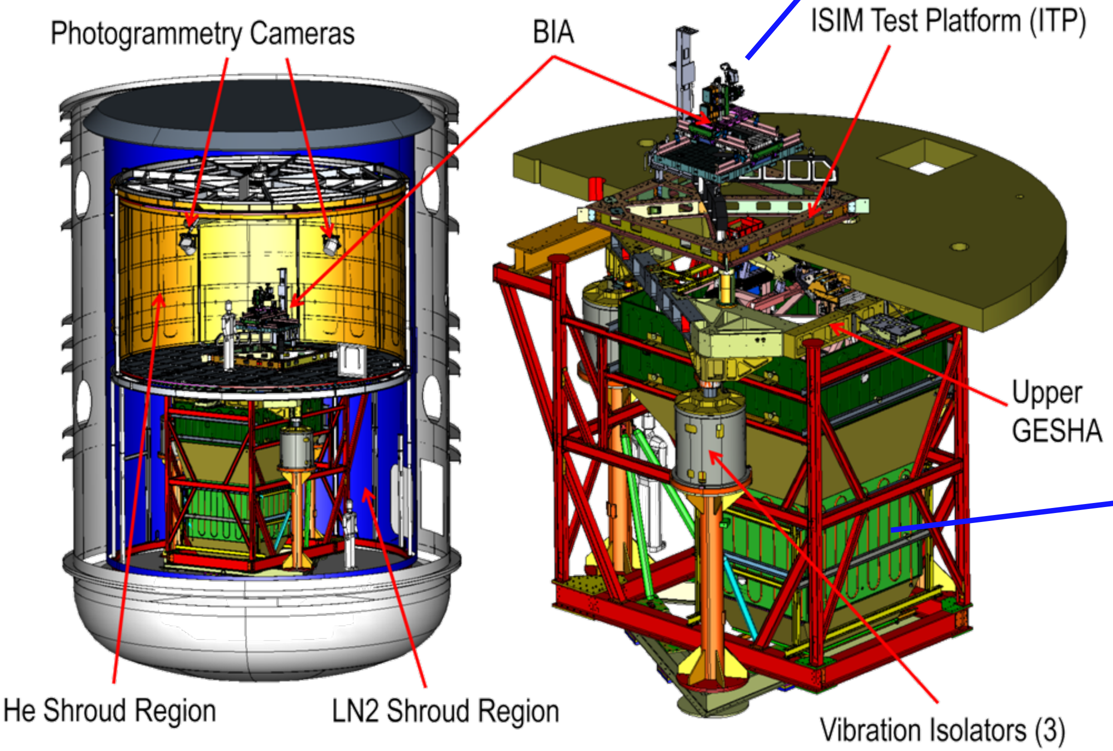
# The telescope simulator completed the first of two cryo-vac certification test cycles during June 2012

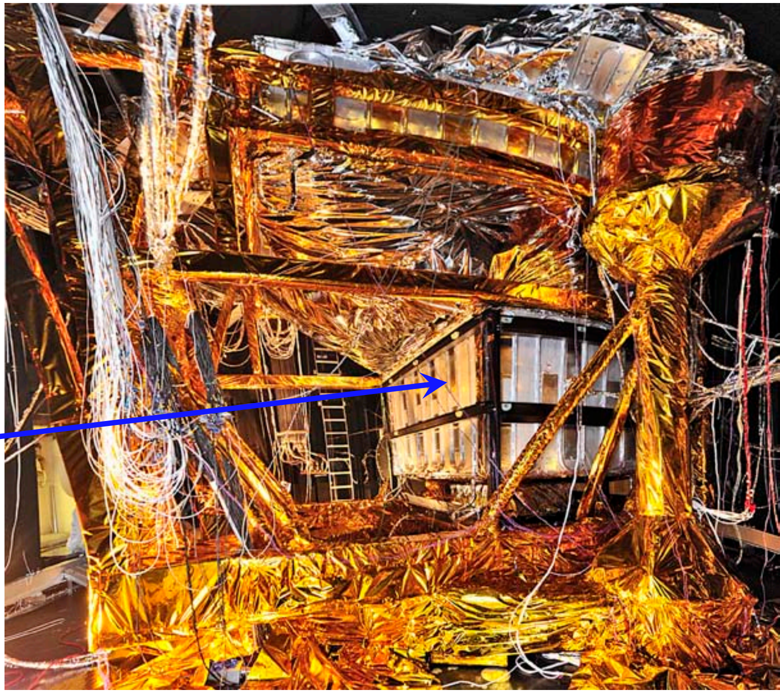


# OSIM-1 test configuration in SES chamber: June 2012

## OSIM cryo-vac test configuration



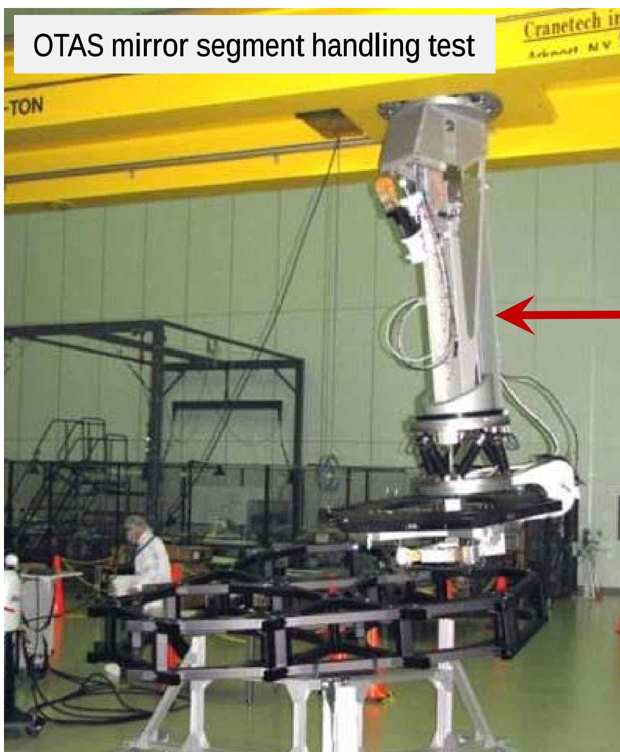
# Optical Telescope Assembly Stand (OTAS) installation at GSFC is on schedule to support OTE integration

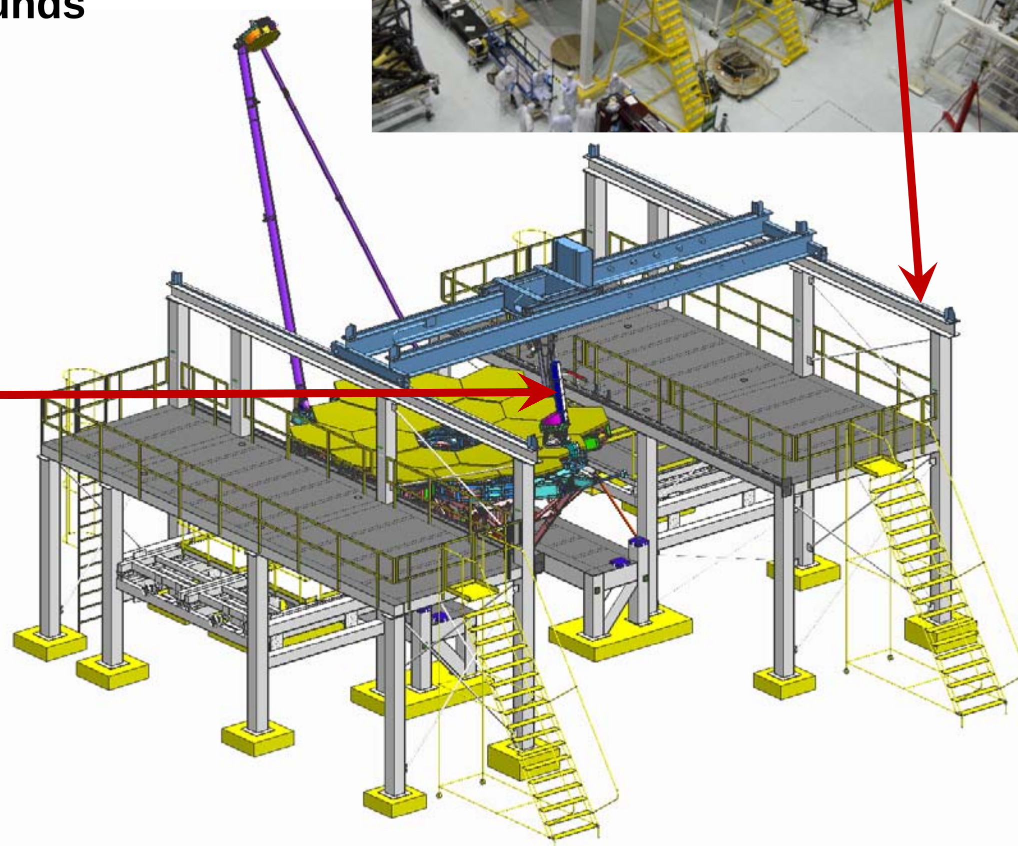
**Used to manipulate primary mirror segments during integration with telescope backplane**

**Supports weight of entire optical telescope – a load of more than 3.7 metric tons.**

**OTAS itself weighs 139,000 pounds**

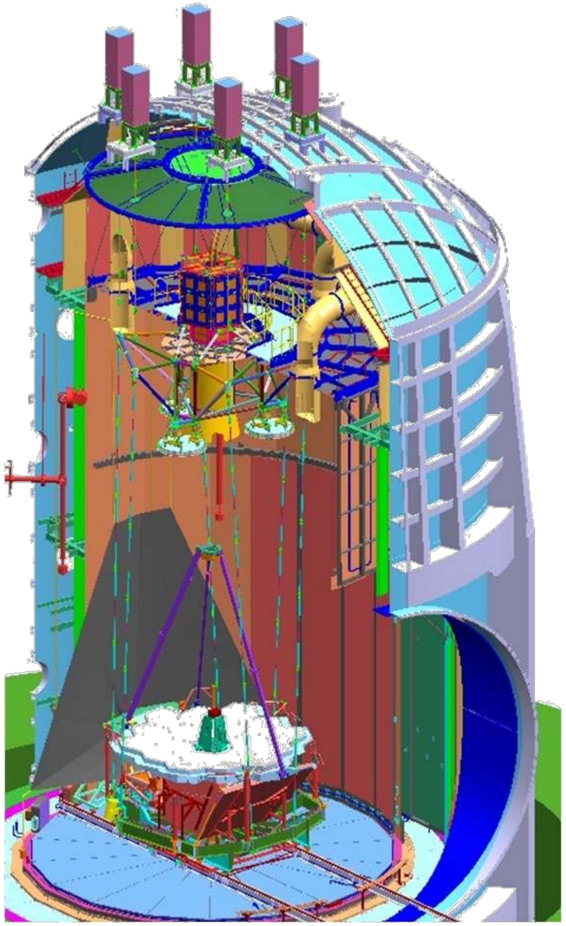

OTAS installation in GSFC SSDIF as of April 2012


OTAS mirror segment handling test



# Then …. the OTE + ISIM will be tested in a larger space simulation chamber at Johnson Space Flight Center

**Apollo era facility extensively refurbished for JWST**
**Largest deep cryogenic space simulation chamber in the world**
**Performance certification completed during Aug 2012**
**13 K and $10^{-8}$ Torr reached during test**



**Learn** more at:

www.jwst.nasa.gov

http://webbtelescope.org/webb_telescope/progress_report/

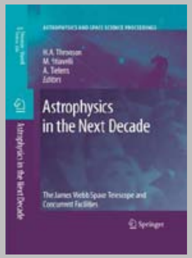
**Watch** the JWST being built at:

www.jwst.nasa.gov/webcam.html

**Read** about JWST science mission objectives at:

http://www.jwst.nasa.gov/science.html

http://www.stsci.edu/jwst/science/whitepapers/


**Explore** your science objectives with the JWST observing time estimator:

http://jwstetc.stsci.edu/etc/

**Interact** with the JWST Science Working Group:

http://www.jwst.nasa.gov/workinggroup.html

**The End (of this presentation)**

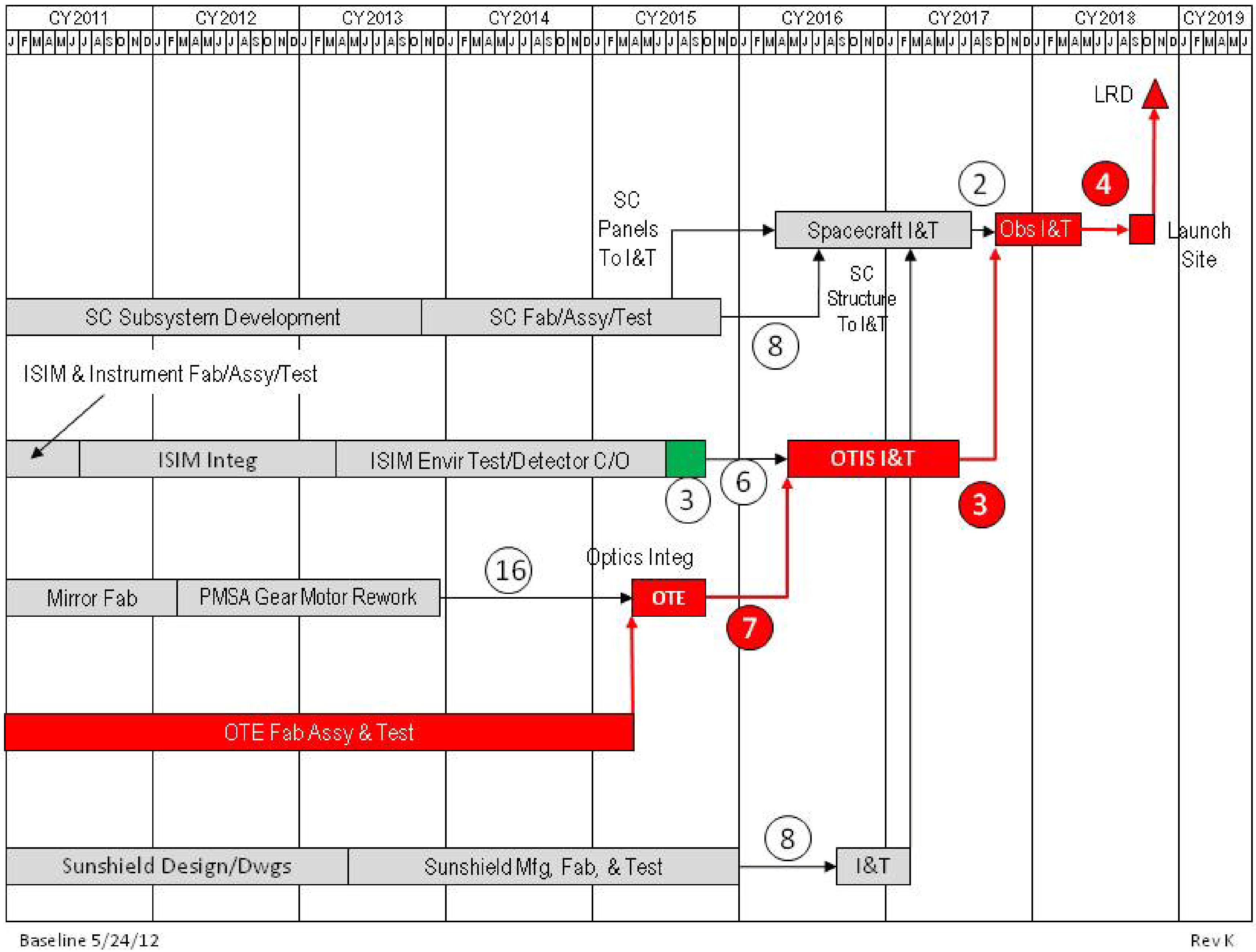
**But**

**with JWST, we will see the beginning of *everything***

The first galaxies
The origins of galactic structure
The birth of stars
The creation of planets
and more
.
.
.

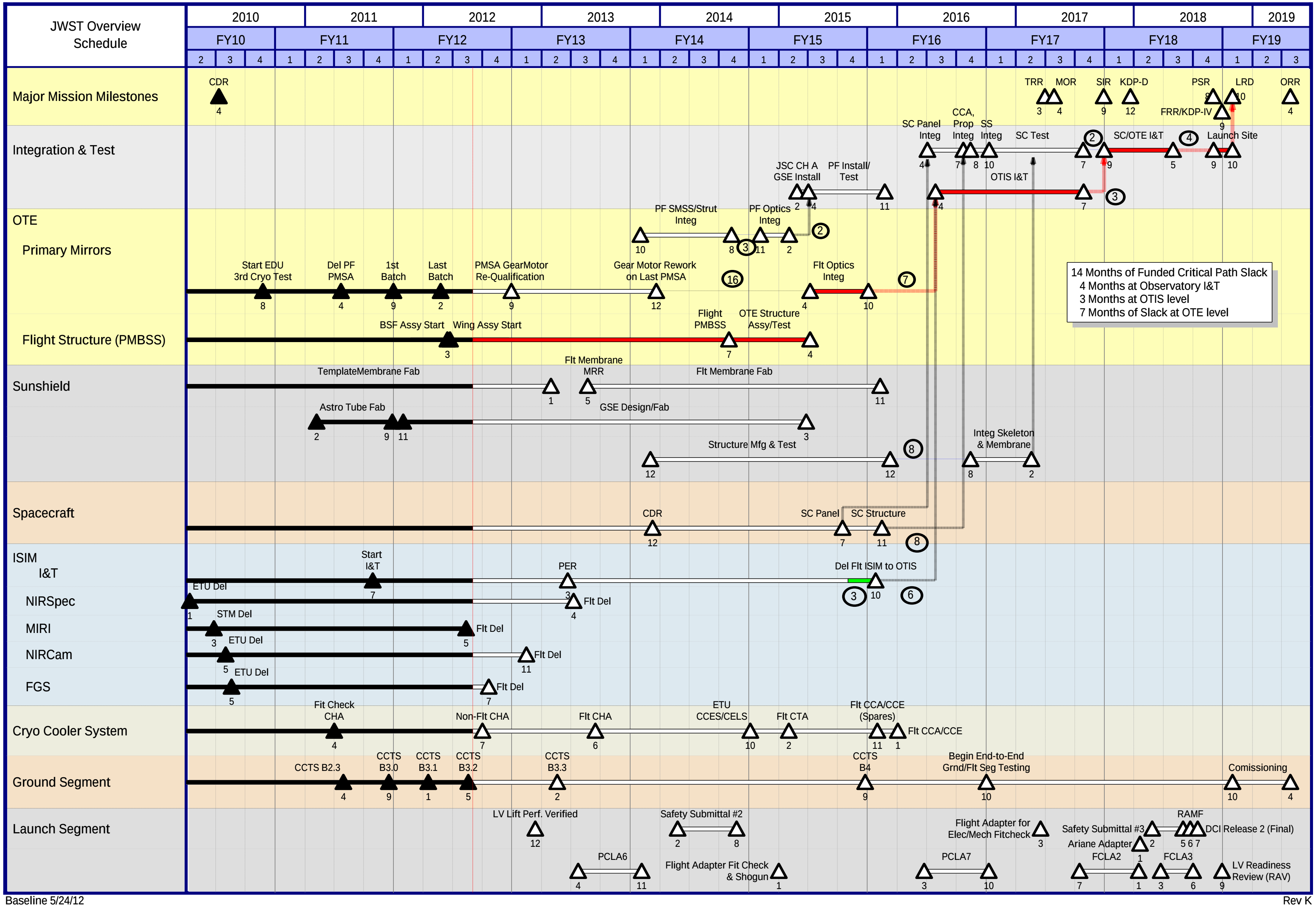
# Supplemental Slides

# Master Schedule - Baseline

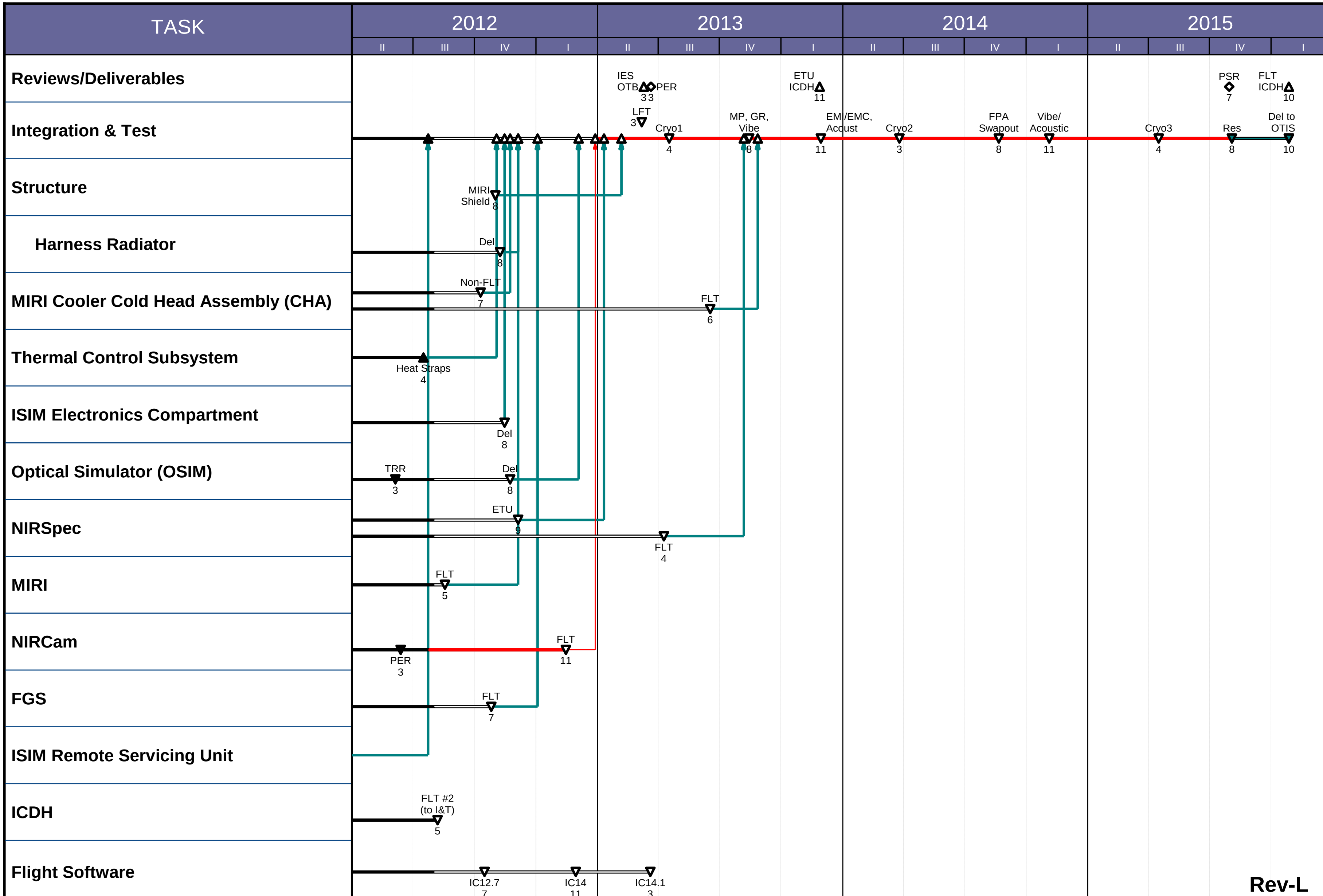


# JWST Replan Master Schedule

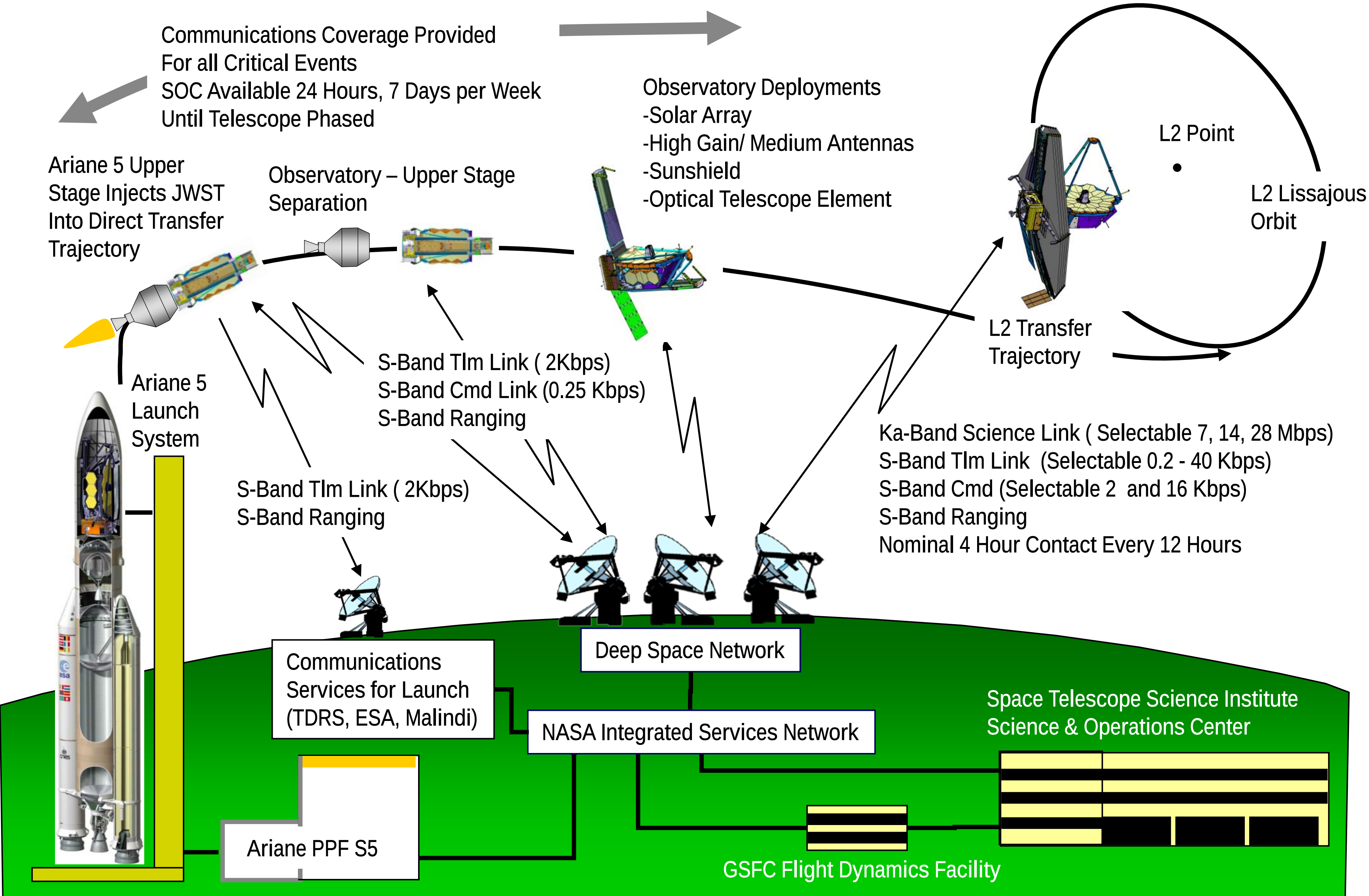
Status as of: 05/31/12



# ISIM MASTER SCHEDULE



# JWST System Architecture

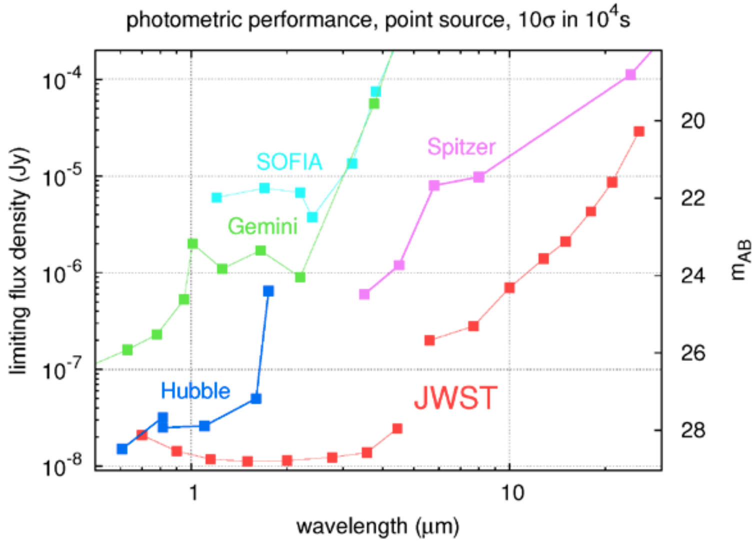


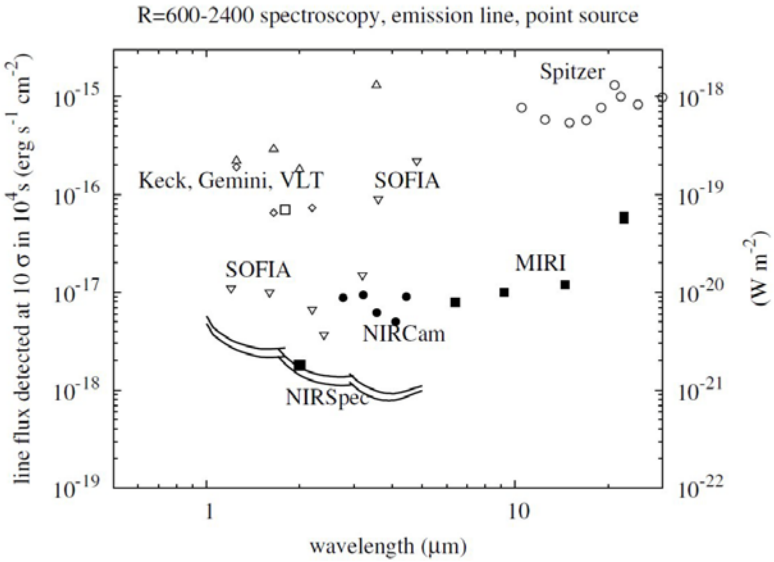
# The James Webb Space Telescope

**James Webb (1906 – 1992)**

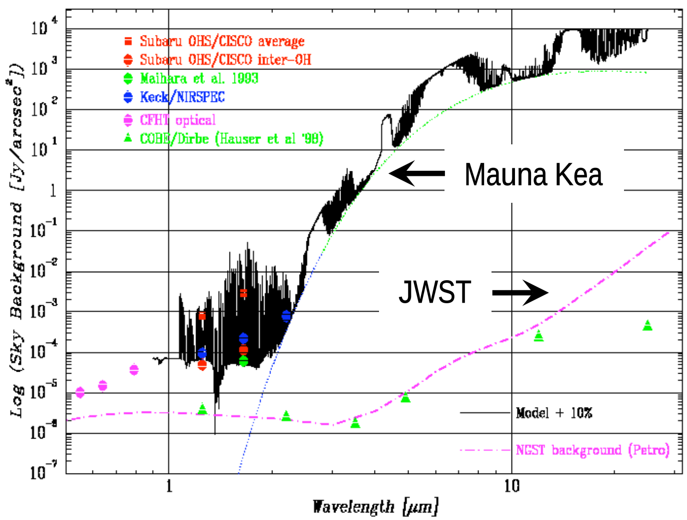
- **Second Administrator of NASA (1961 – 1968)**
- **Oversaw first manned spaceflight program (Mercury)**
- **Oversaw second manned spaceflight program (Gemini)**
- **Oversaw Mariner and Pioneer planetary exploration programs**
- **Oversaw Apollo program**

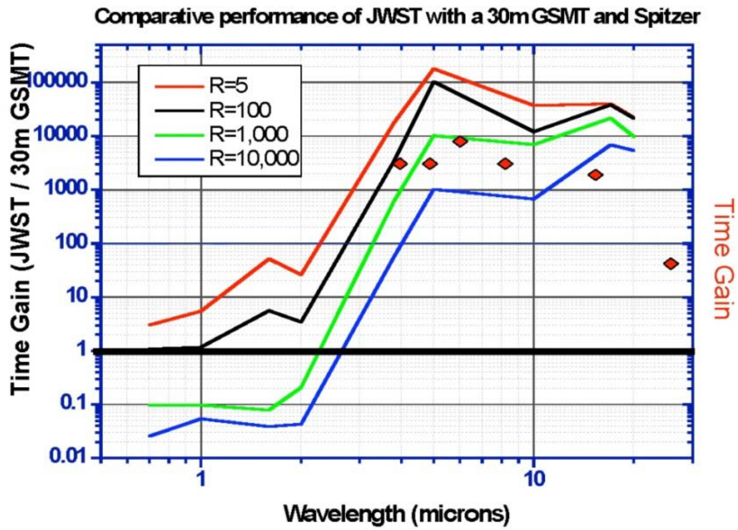
# JWST will achieve unprecedented sensitivity over the 0.6 – 29 micron spectrum




## Providing discovery potential that is unique wrt 30 m ground-based facilities for wavelengths > 2 microns



# The Ariane 5 ECA has had over 30 consecutive success to date