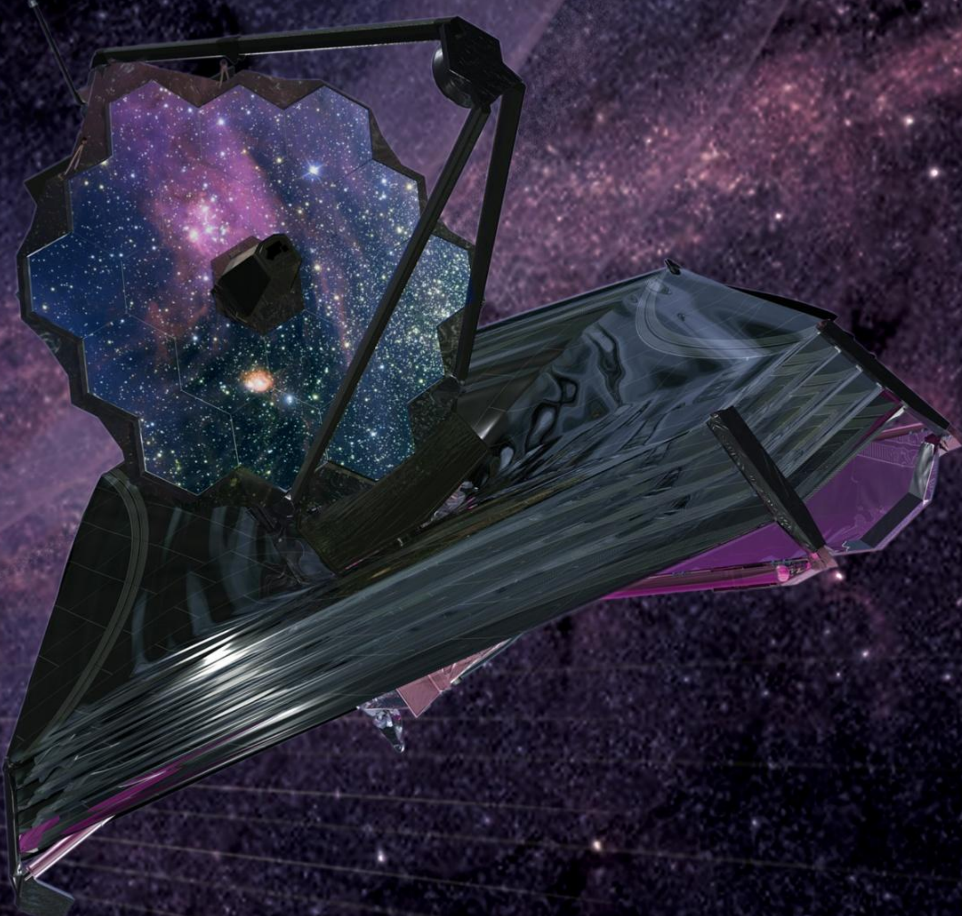
The James Webb Space Telescope Mission



Matt Greenhouse

JWST Project Office

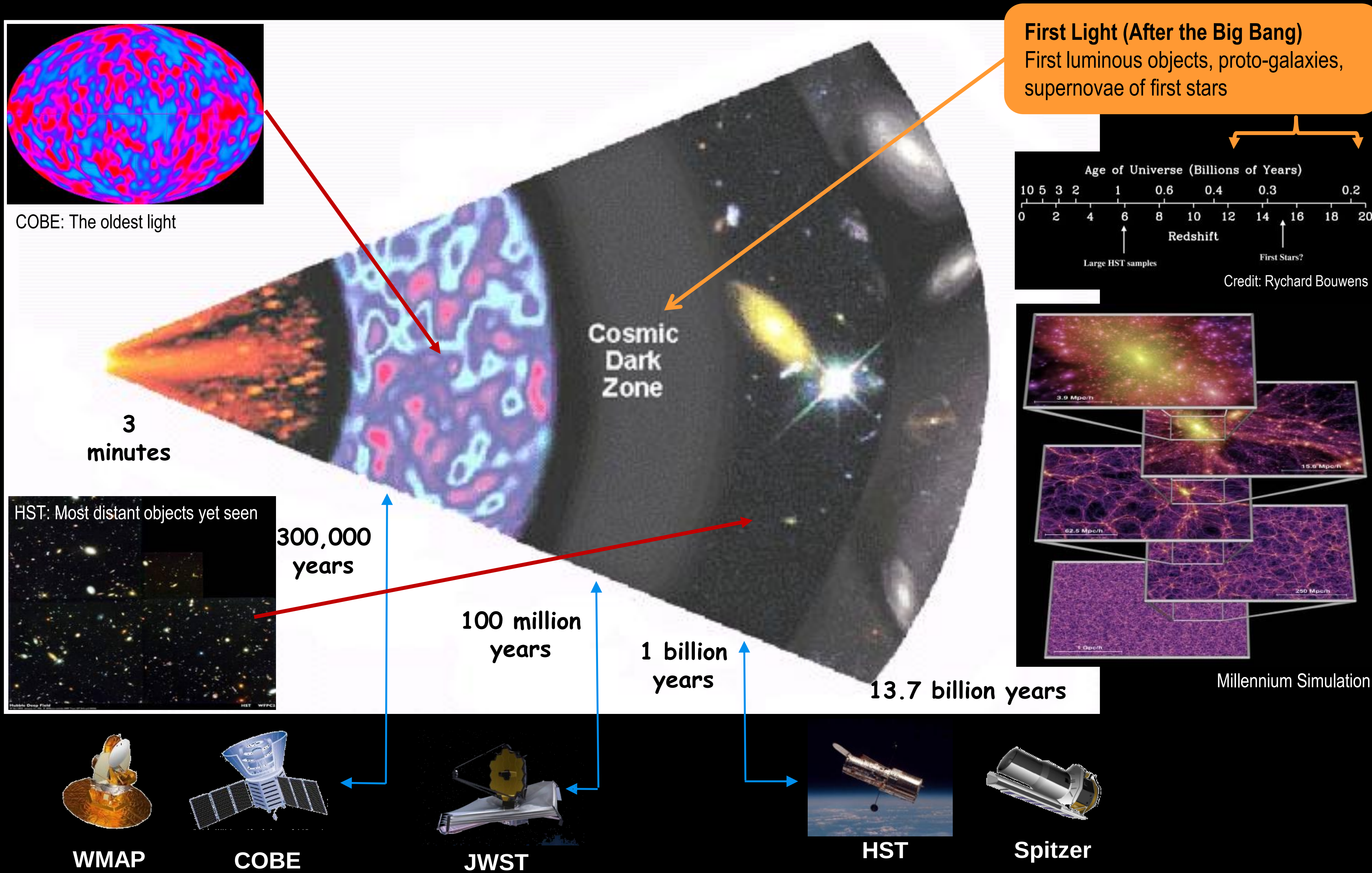
NASA Goddard Space Flight Center

22 July 2016

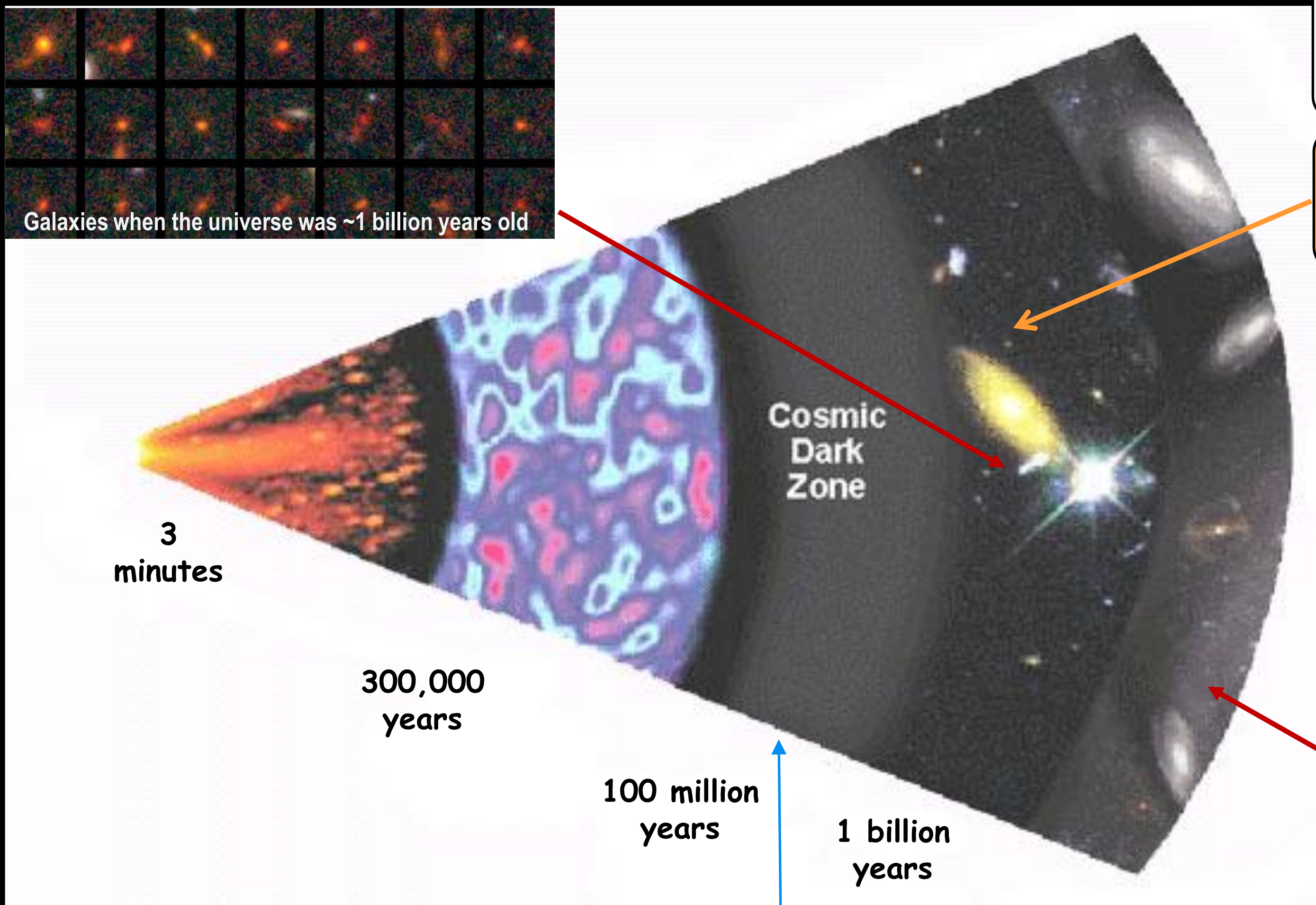
@NASAWebbTelescp

#JWST

JWST is designed to look back in time to see the first galaxies

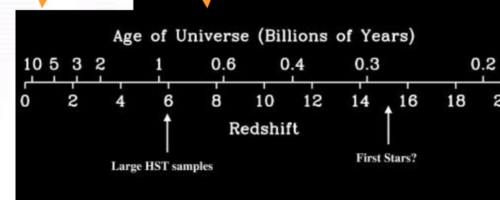


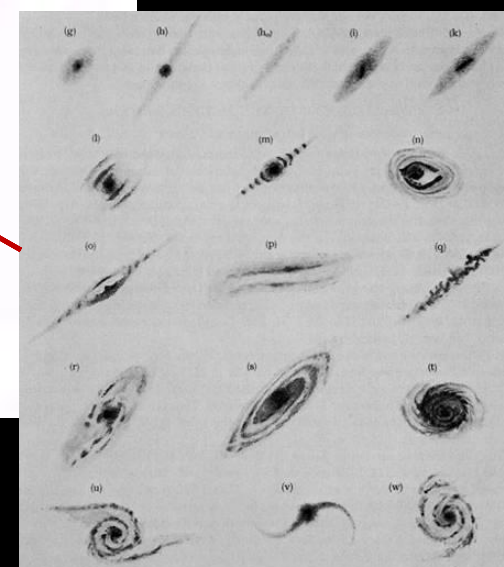
JWST will image the infrared universe with unprecedented clarity



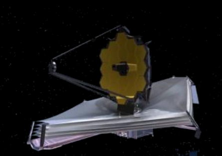
First Light (After the Big Bang)
First luminous objects, proto-galaxies, supernovae, black holes

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



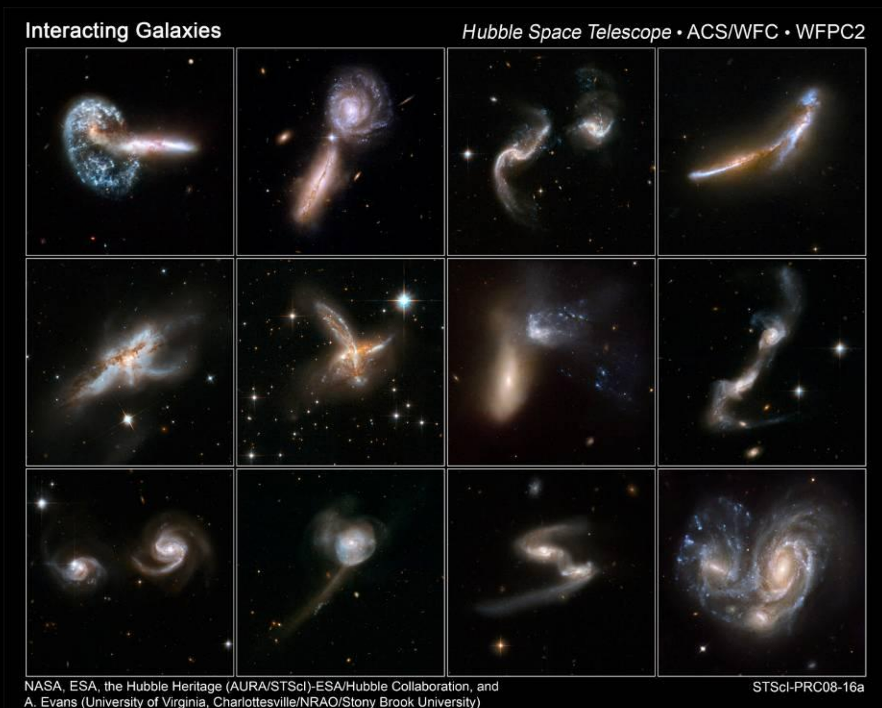


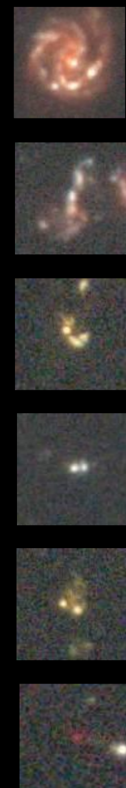
Galaxies today



JWST

JWST will see how the structure and composition of galaxies evolve across cosmic time





5.8 Gyr

3.3 Gyr

2.2 Gyr

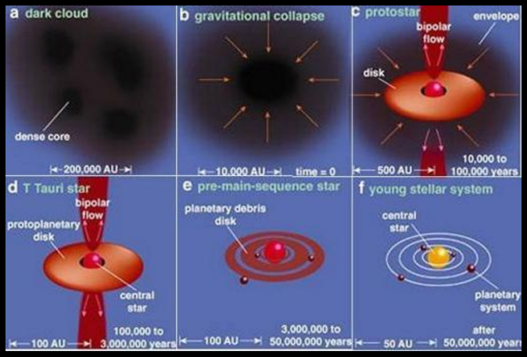
2.2 Gyr

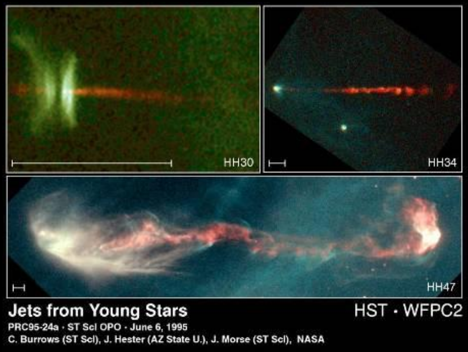
1.8 Gyr

1.0 Gyr
(z~6)

JWST will see into the birthplaces of stars to reveal how they form

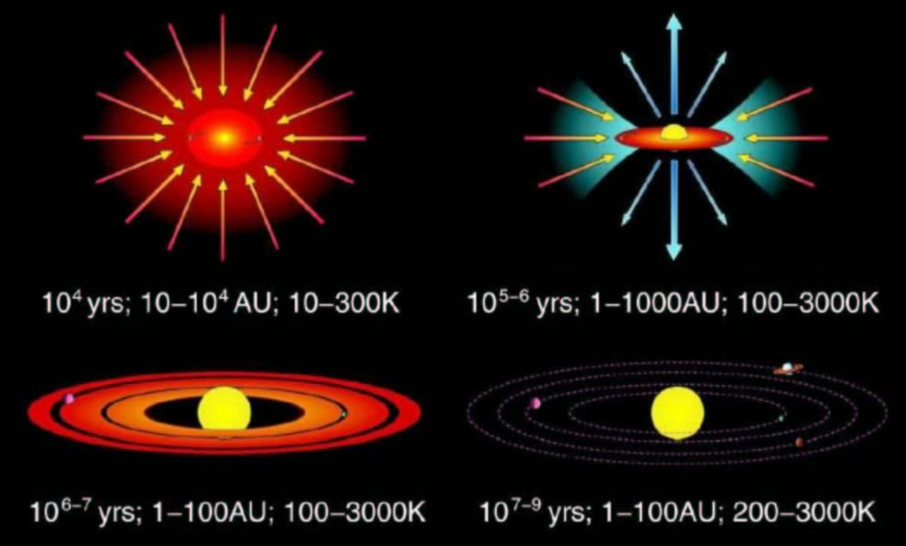
Birth of Stars and Planetary Systems
How stars form and chemical elements are produced





Protostar

Circumstellar disk

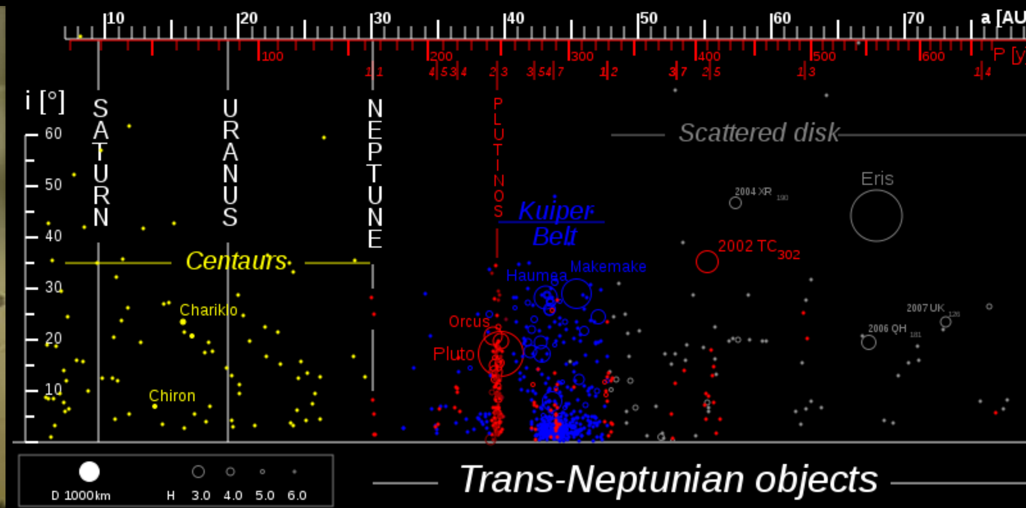


Planetesimals

Mature planetary system

The Eagle Nebula as seen in the near-infrared

JWST will observe how planetary systems form and evolve

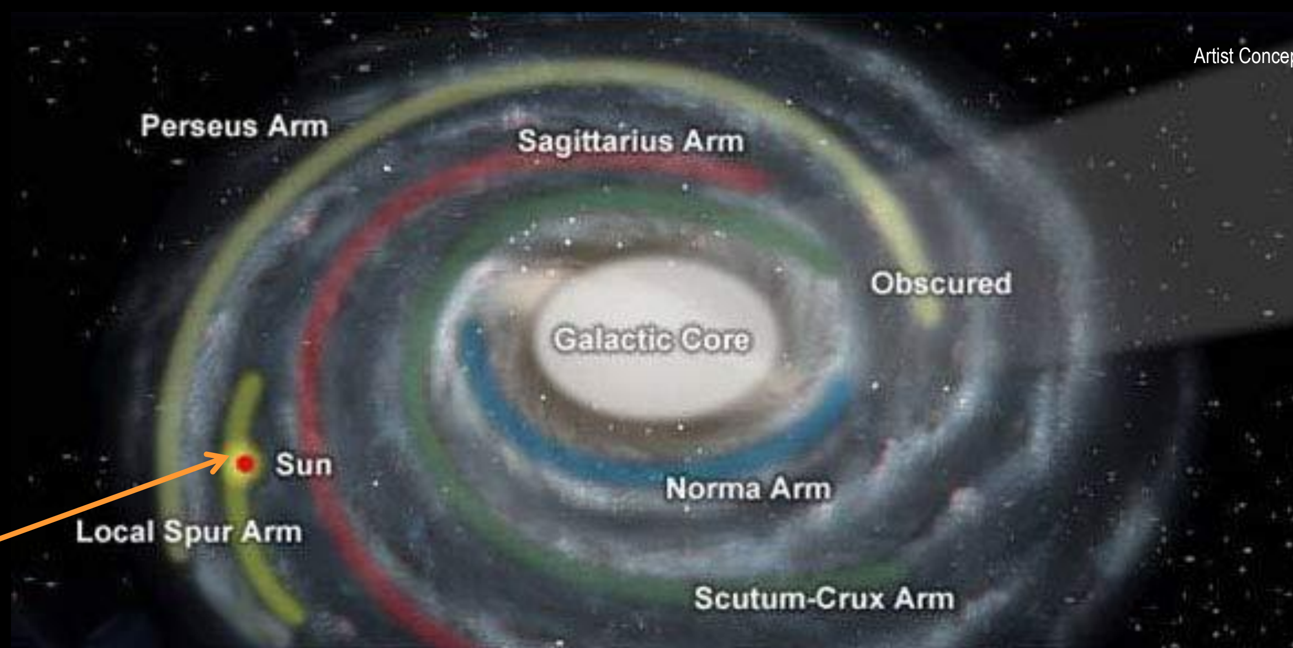


First Light (After the Big Bang)
First luminous objects, proto-galaxies, supernovae, black holes

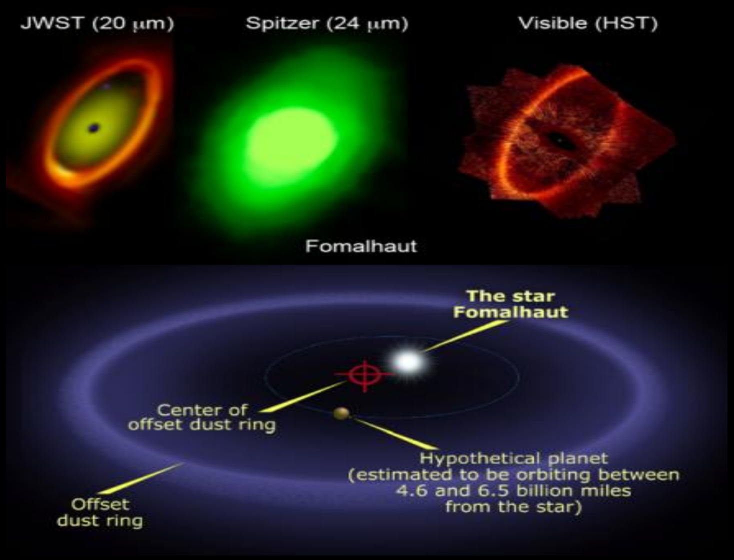
Assembly of Galaxies
Merging of proto-galaxies, effects of black holes, history of star formation

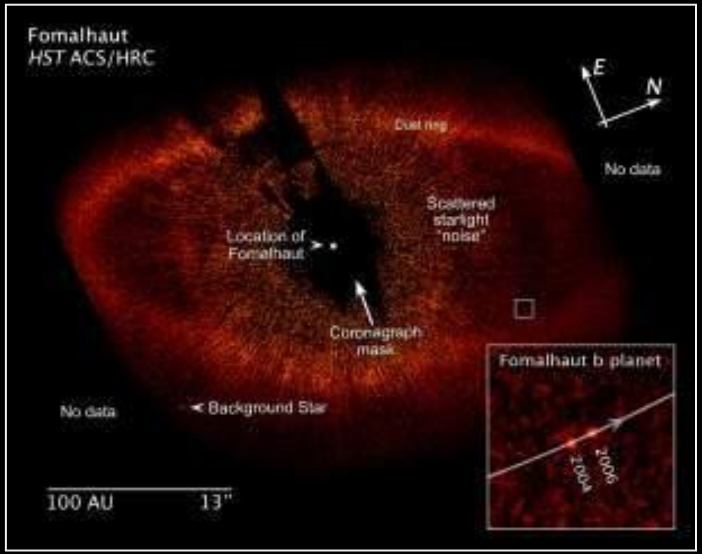
Birth of Stars and Planetary Systems
How stars form and chemical elements are produced

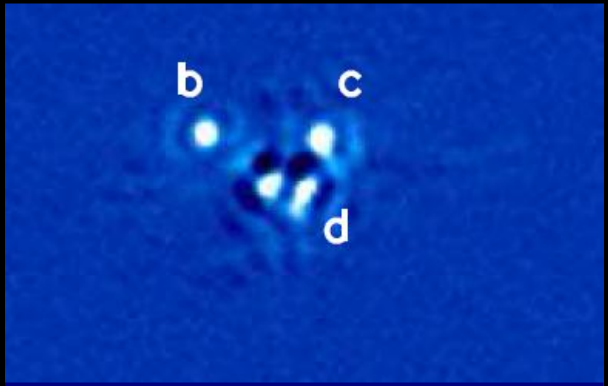
Planetary Systems & Origins of Life
Formation of planets



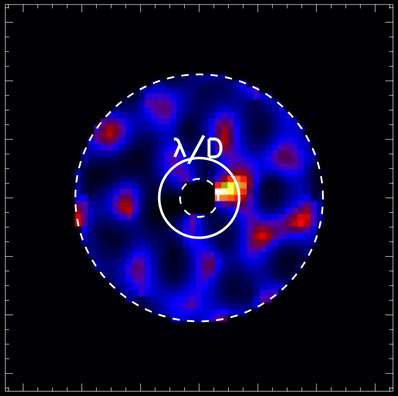
JWST will image exoplanets (planets orbiting stars other than the Sun)







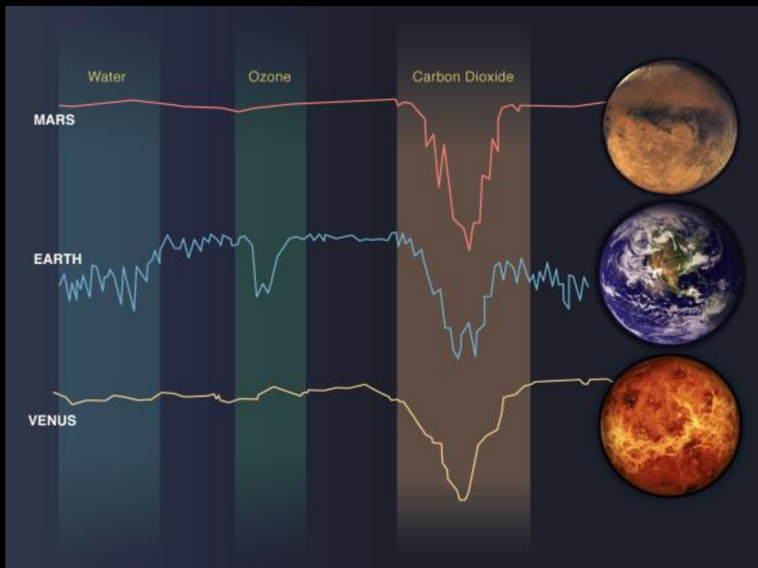
JWST simulated mid-infrared image of planets orbiting star HR 8799.

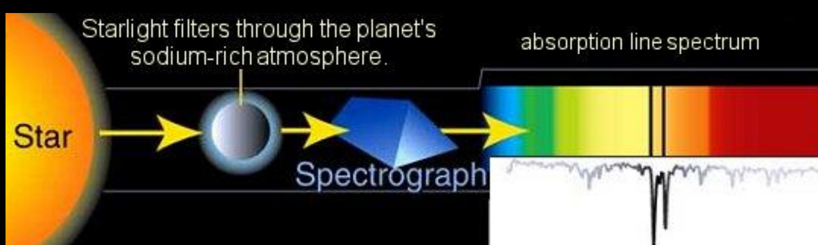


JWST simulated near-infrared image of a 1-2 M_{Jup} planet at ~1 AU of a M0V star 10 pc from the Sun.

JWST will revolutionize understanding of exoplanet atmospheres

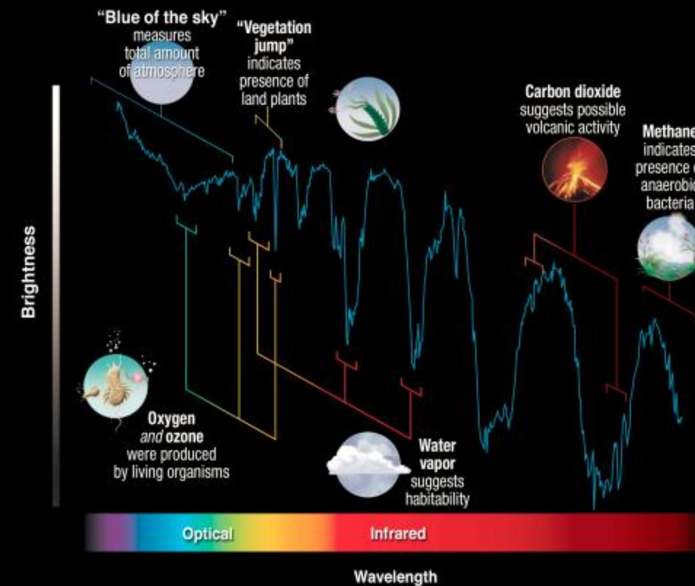
Composition is revealed by spectroscopy

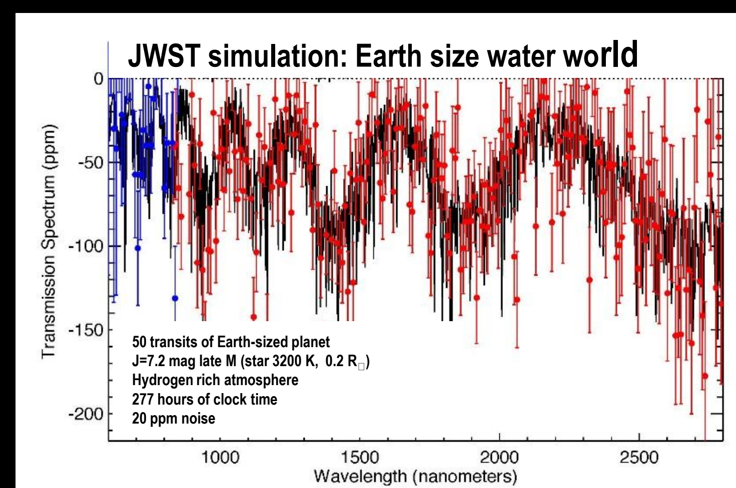




There are tens of billions of habitable worlds in our galaxy. JWST can detect liquid water on an exoplanet that is a few times the size of the Earth.

So is the presence of life!

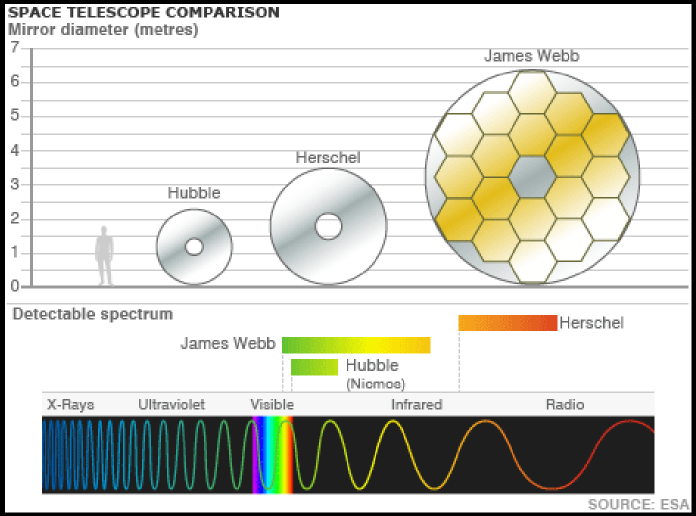


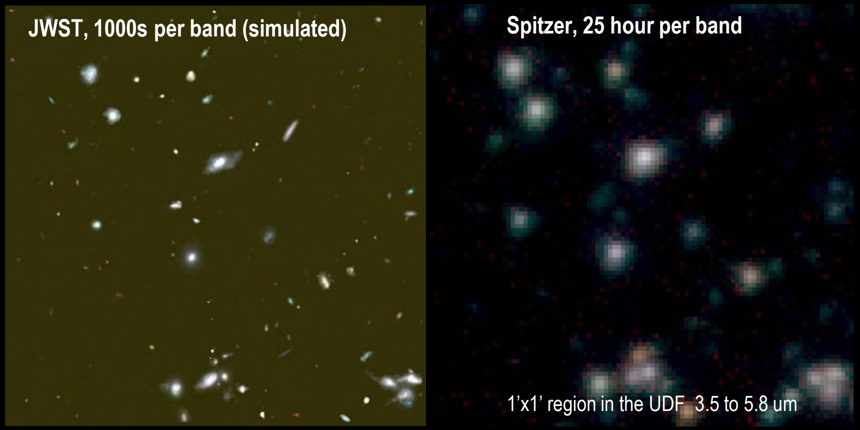


JWST requires the largest cryogenic telescope ever constructed

To achieve its science objectives, the JWST mission requires:

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





JWST will provide the first high definition view of the infrared universe

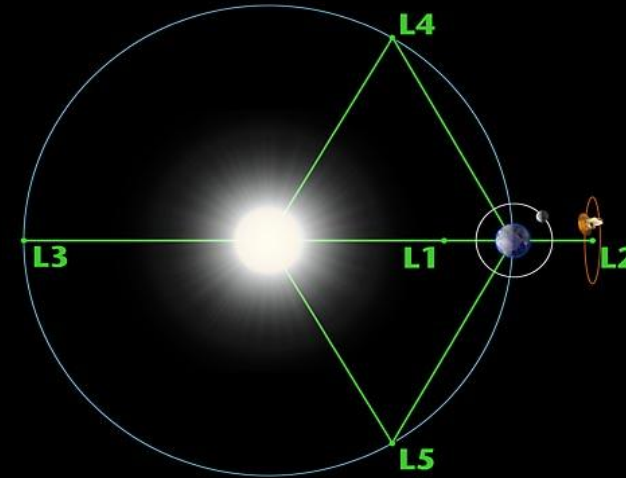
To meet these requirements, the JWST team had to solve two key problems:

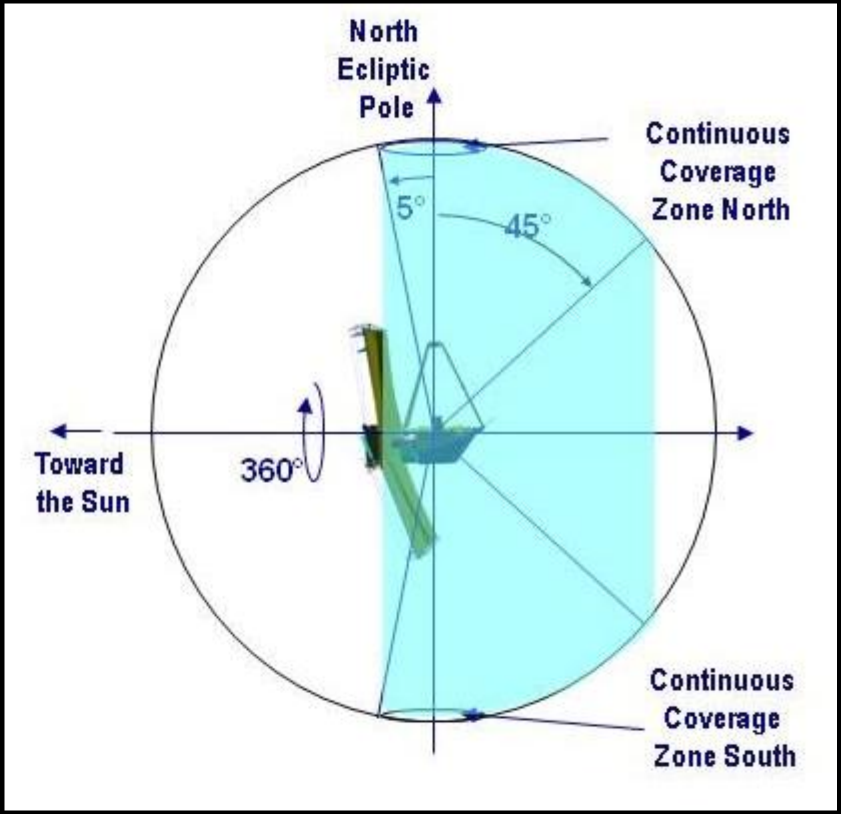
- Provide a primary mirror that is larger in diameter than available rocket fairings
- Achieve a high stability cryogenic 40K (-233 C, -388 F) operating temperature

The JWST will be placed in orbit about the Sun-Earth L2 point approximately 1.5 million km (1 million miles) from Earth

An L2 point orbit was selected for JWST to enable passive cryogenic cooling

- Unstable orbit: station-keeping thrusters required
- Propellant sized for 10 years (delta-v ~ 93 m/s)
- ~100 day direct transfer trajectory



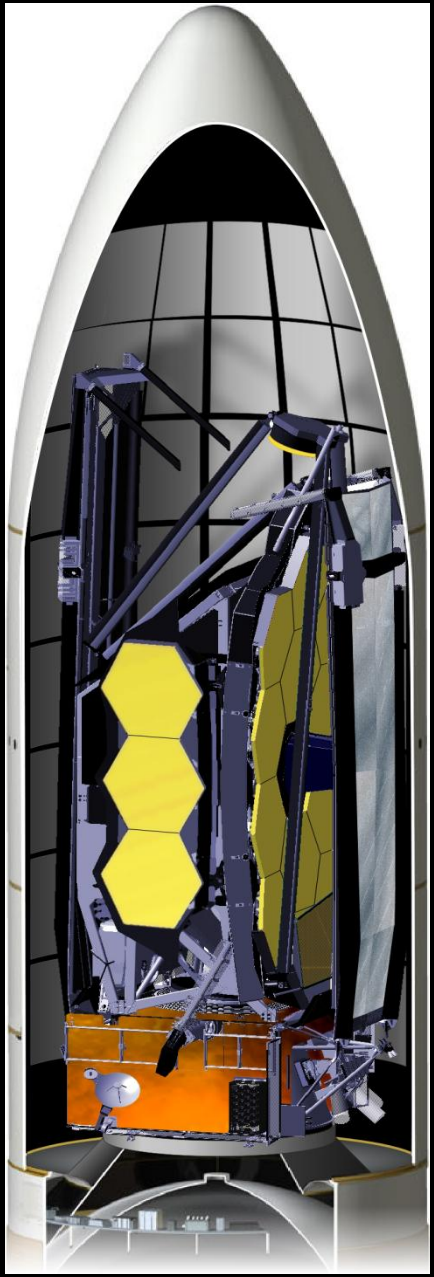


The JWST can observe the whole sky while remaining continuously in the shadow of its sunshield

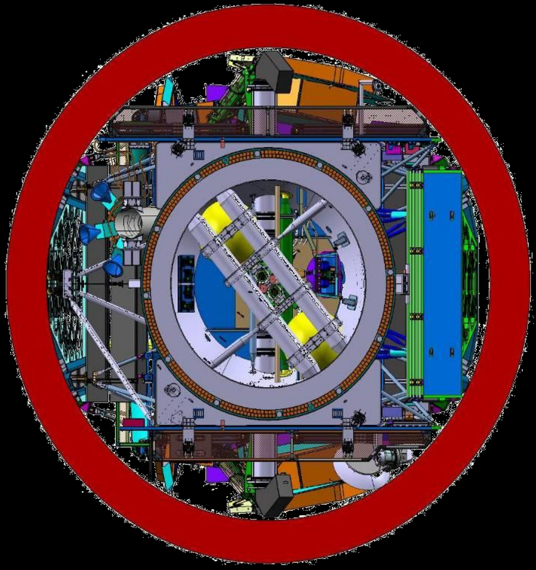
- Field of Regard is an annulus covering 35% of the sky
- The whole sky is covered twice each year with small continuous viewing zones at the Ecliptic poles

The telescope requires a segmented deployable mirror

Ariane 5 ECA

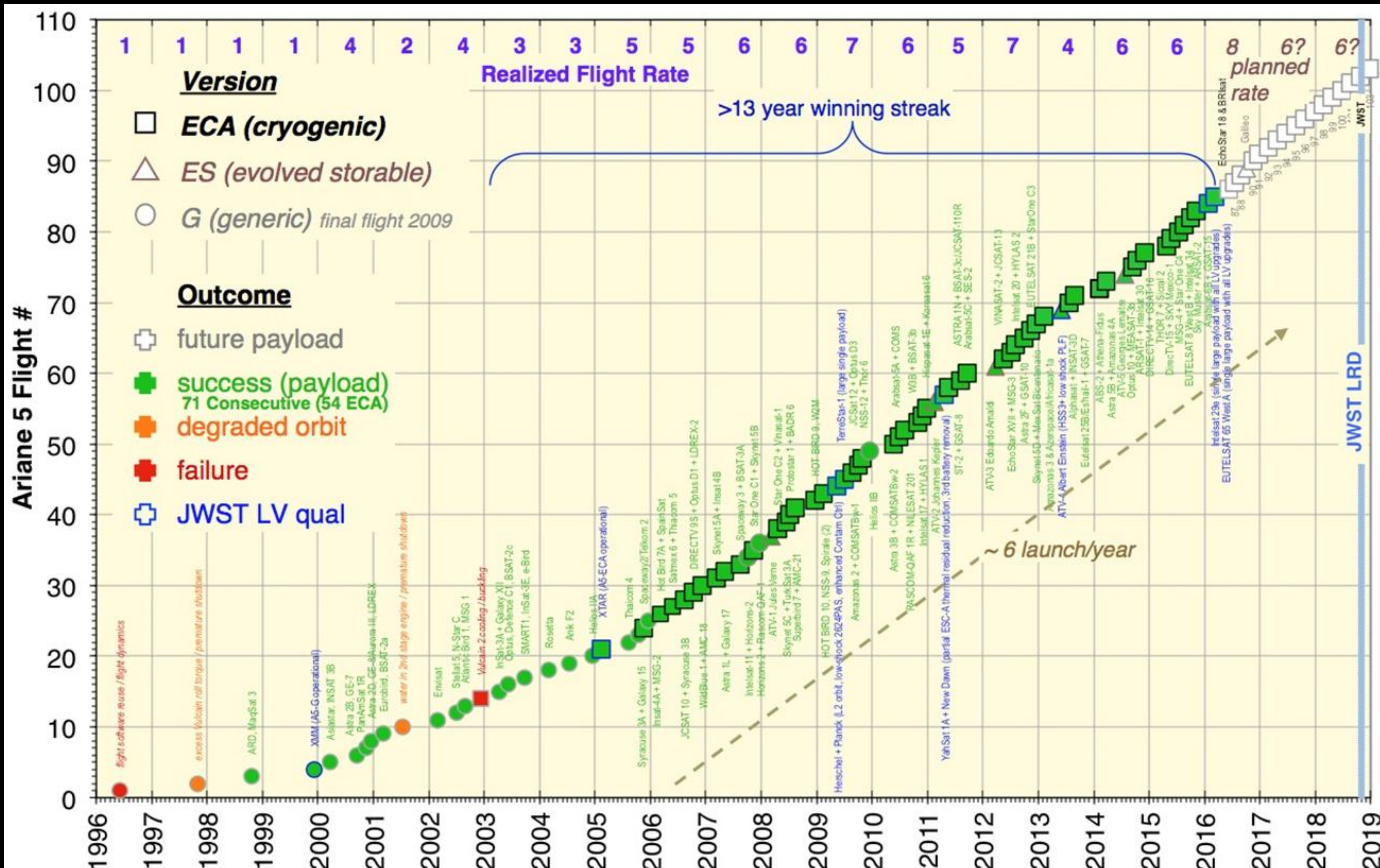


- Ariane V ECA launch vehicle (5 m diameter fairing)
- Launch from Kourou Launch Center (French Guiana) with direct transfer to L2 point.
- 6530 kg payload launched at ambient temperature with on orbit cooling to 50 K via passive thermal radiators
- 40 deployable structures and 178 release devices



The Ariane 5 ECA has over 55 consecutive successes to date

Status as of July 2016



The JWST program is a multi-agency partnership

Launch Segment

Ariane Launcher

- Launch Vehicle
- Payload Adapter
- Launch Site Services

Observatory Segment

JWST Observatory

- Optical Telescope Element (OTE)
- Integrated Science Instrument Module (ISIM)
  - NIRCam
  - MIRI
  - NIRSpec
  - FGS
- Spacecraft Element (SE)
  - Spacecraft Bus
  - Sunshield

Ground Segment

Deep Space Network

Space Telescope Science Institute

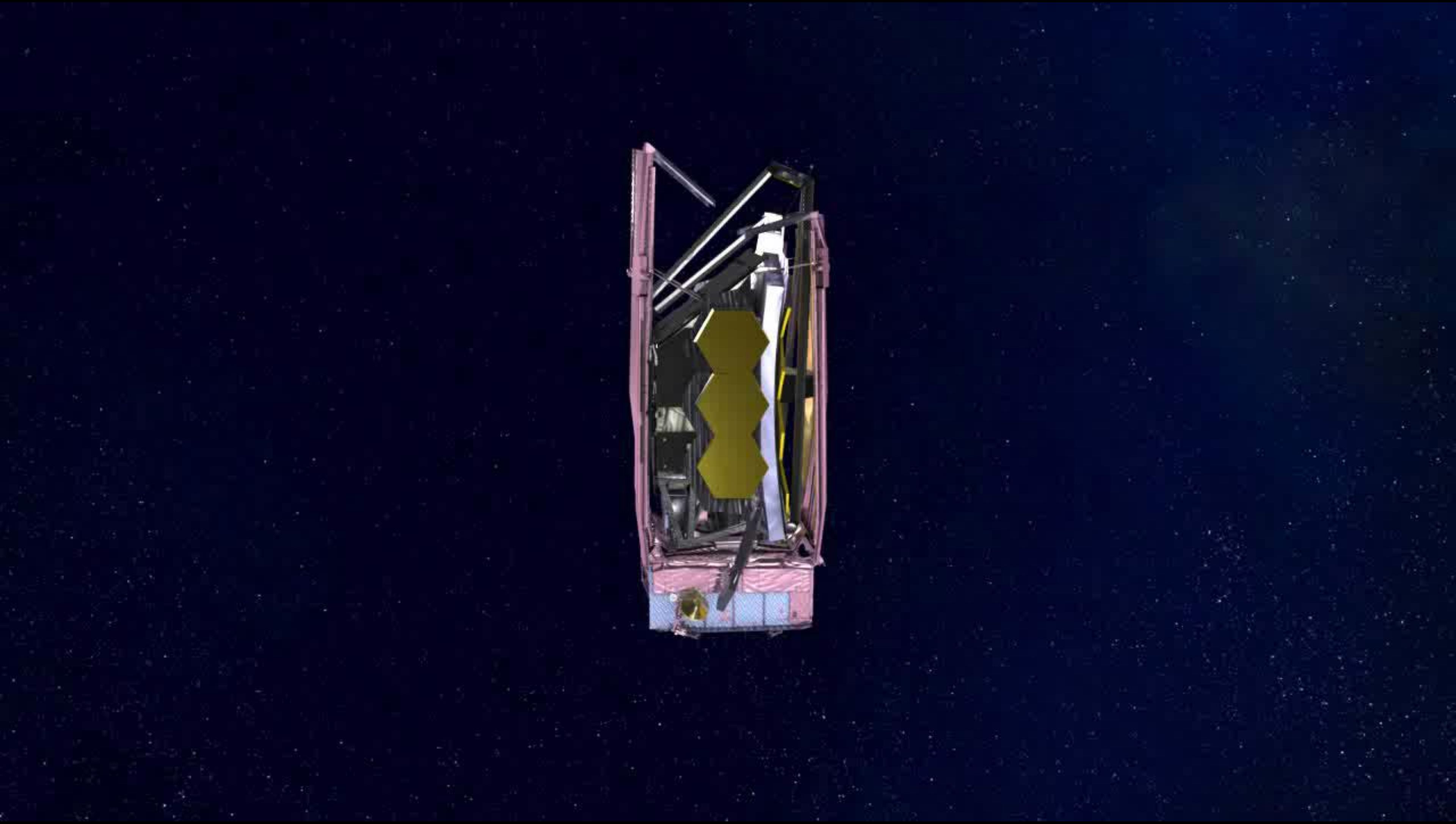
- Science and Operations Center (SOC)
- Common Systems

Provided by NASA

Provided by ESA

Provided by CSA

Deployment Sequence Overview

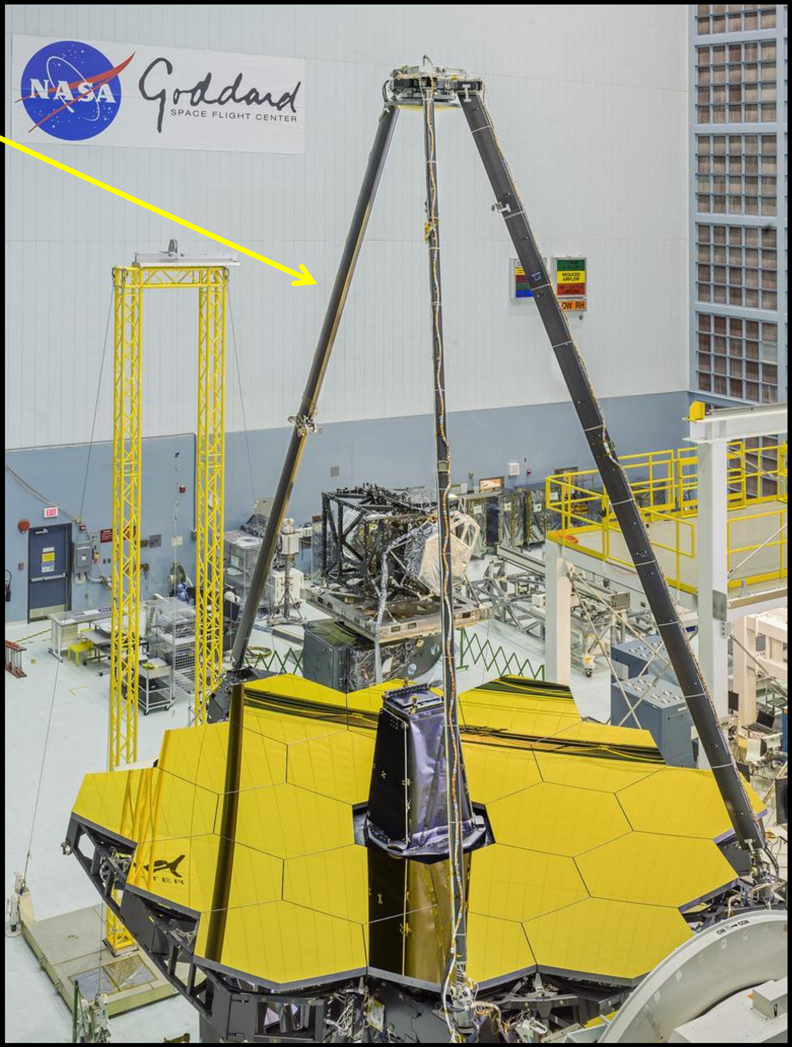


The JWST space vehicle consists of three elements

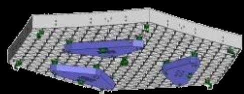
Optical Telescope Element (OTE)
Collects star light from distant objects

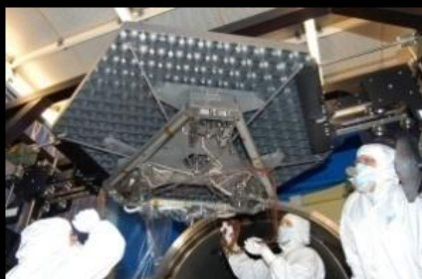
Integrated Science Instrument Module (ISIM)
Extracts physics information from star light

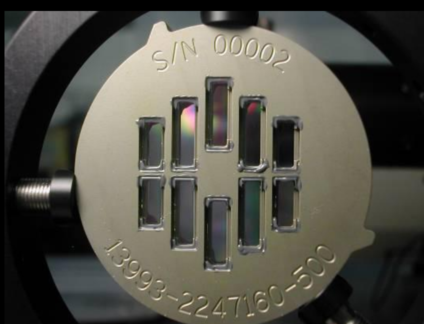
Spacecraft
Attitude control, telecom, power & other systems

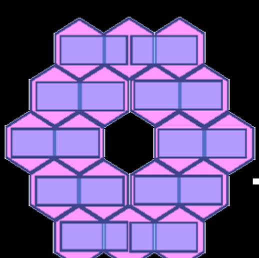


The mirror segments are adjusted in tip/tilt and radius of curvature during flight, enabling them to perform together as a single large mirror.

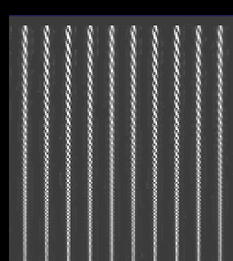








Coarse phasing w/DHS



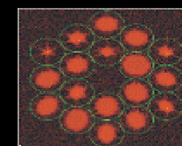
DHS at pupil

wavefront error

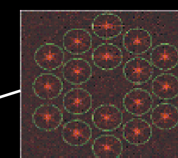
Begin: ~L+1 month, Complete: ~L+2 months

- OTE Deployment
- SM Focus Sweep
- Segment ID
- Segment Search (if needed)
- Segment-Image Array
- Global Alignment
- Image Stacking
- Coarse Phasing
- Fine Phasing
- Multi-Field Alignment
- Wavefront Maintenance

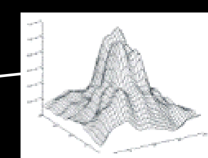
if necessary



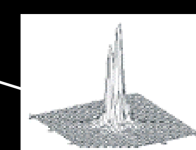
Segment images following segment-image array



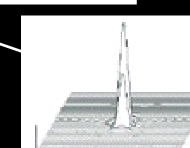
Segment images following global alignment



PSF following initial image stacking



PSF following coarse phasing



PSF following fine phasing is >0.8 Strehl at 2 microns

The telescope mirrors are fabricated from Beryllium

Key physical properties of Beryllium:

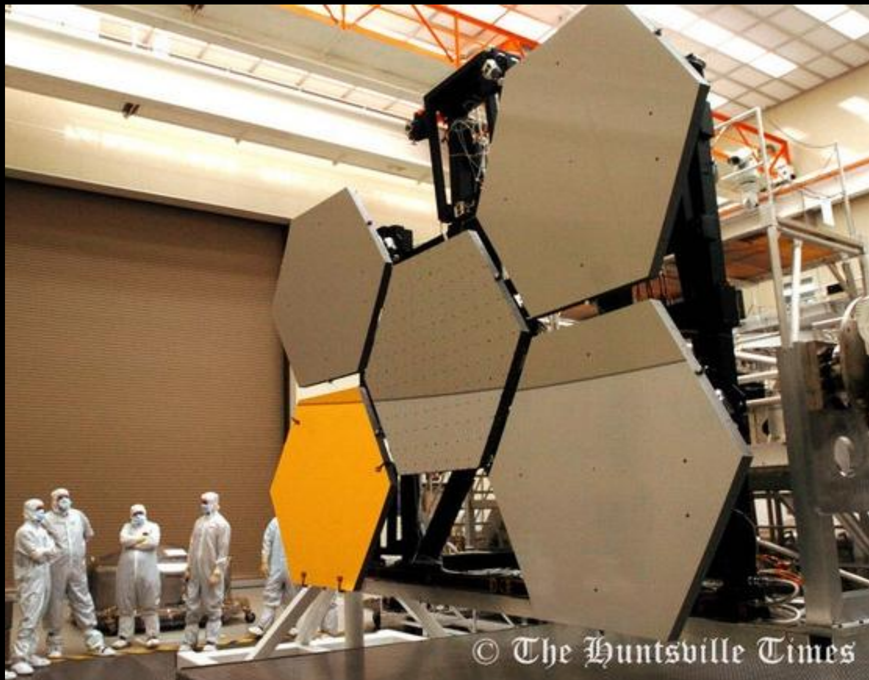
- low coefficient of thermal expansion at 50 K
- high thermal conductivity
- high stiffness to mass ratio

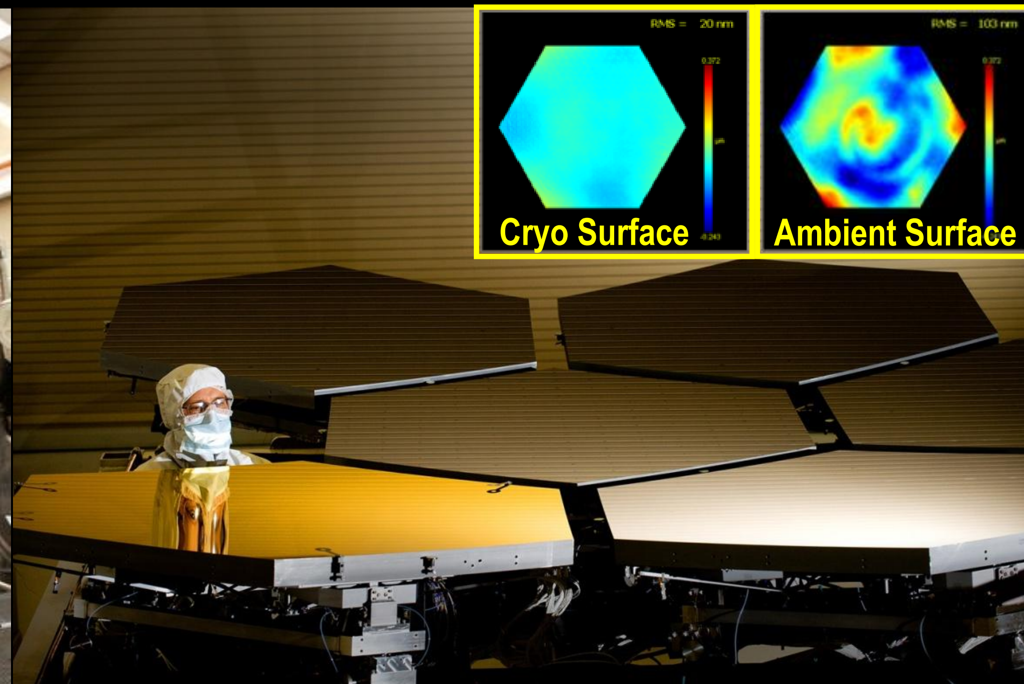
- Type O-30 spherical powder
  - uniform CTE, high packing density, low oxide content

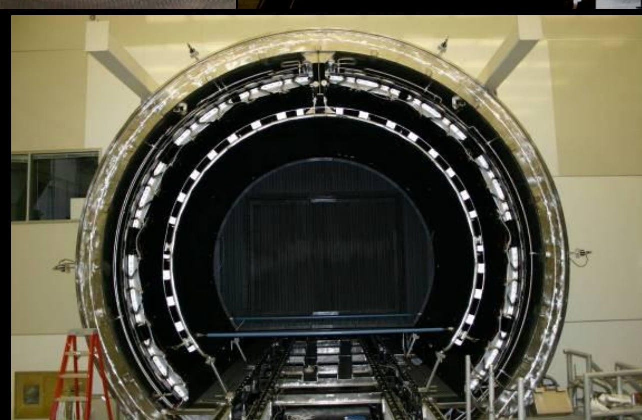
Primary mirror mass properties

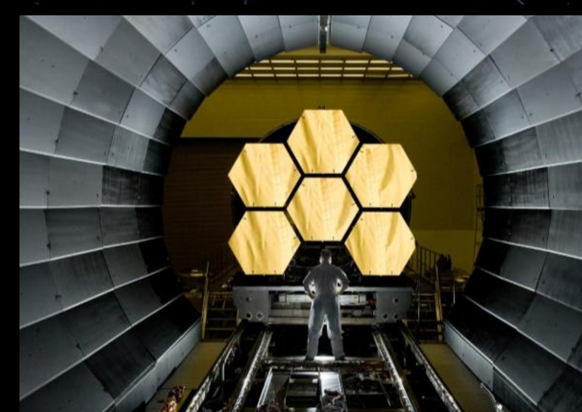
- substrate: 21.8 kg
- segment assembly: 39.4 kg
- OTE area density: ~28 kg m^{-2}
  - HST (ULE) ~ 180 kg m^{-2} (~ 6X heavier)
  - Keck (Zerodur) ~ 2000 kg m^{-2} (~71X heavier)

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

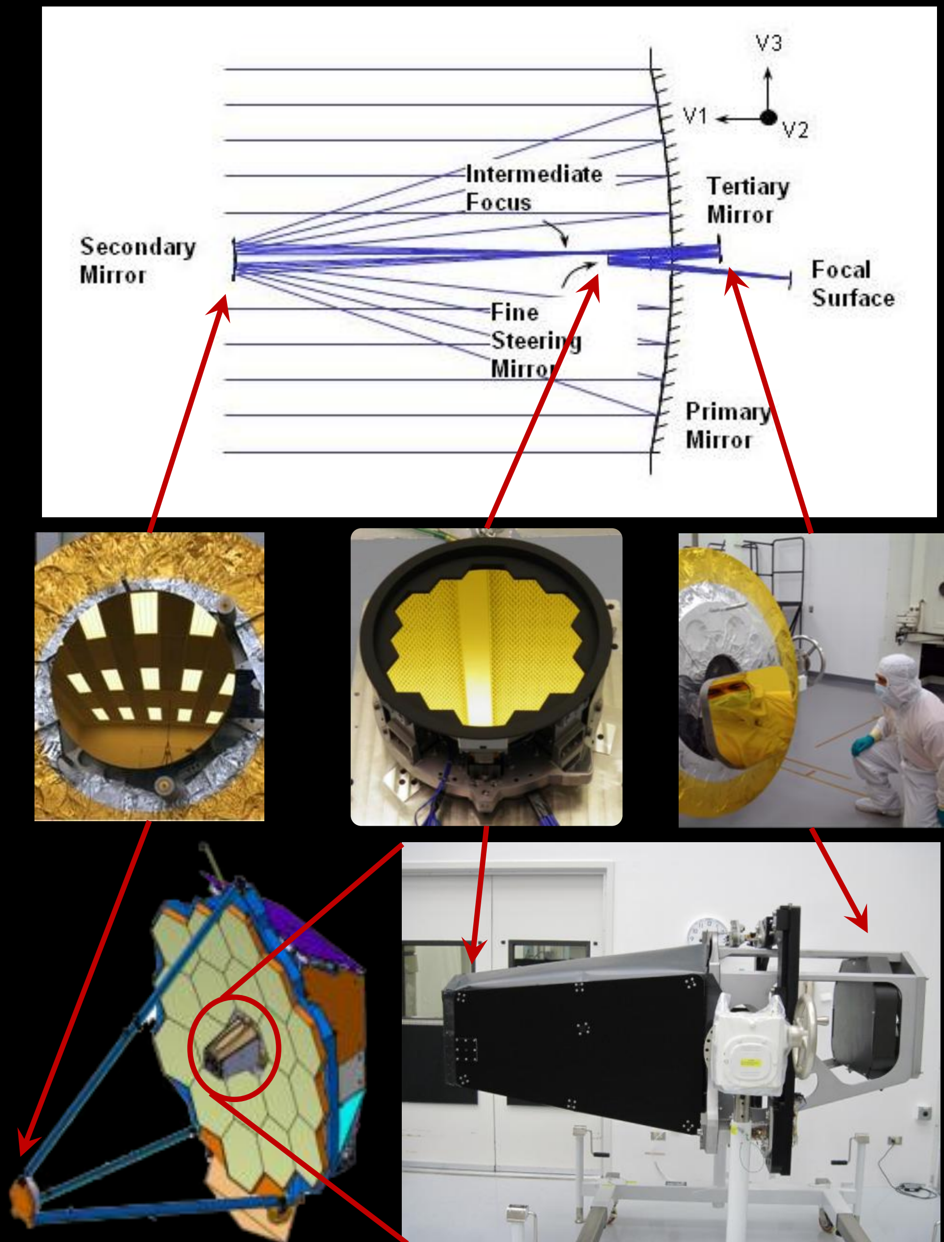






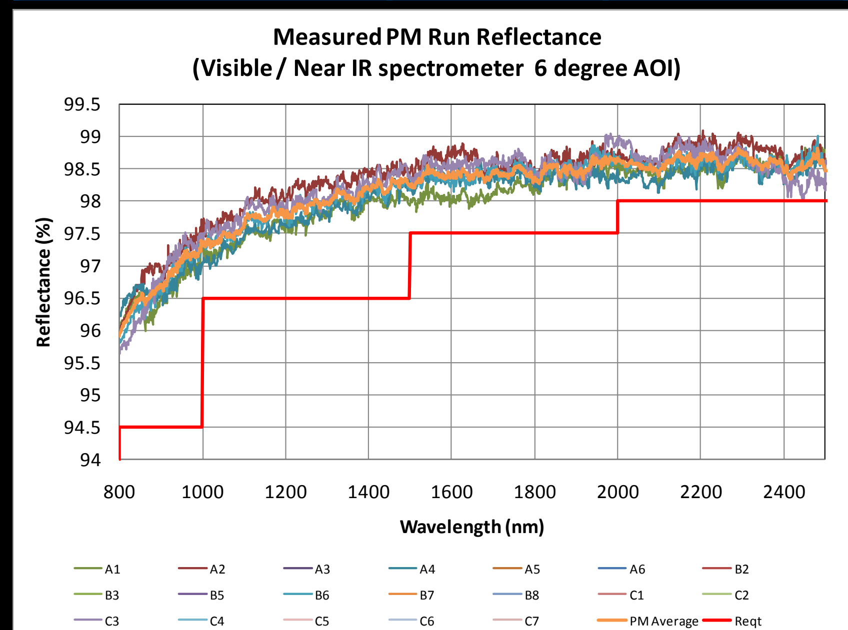


All telescope optics are in-spec in every respect



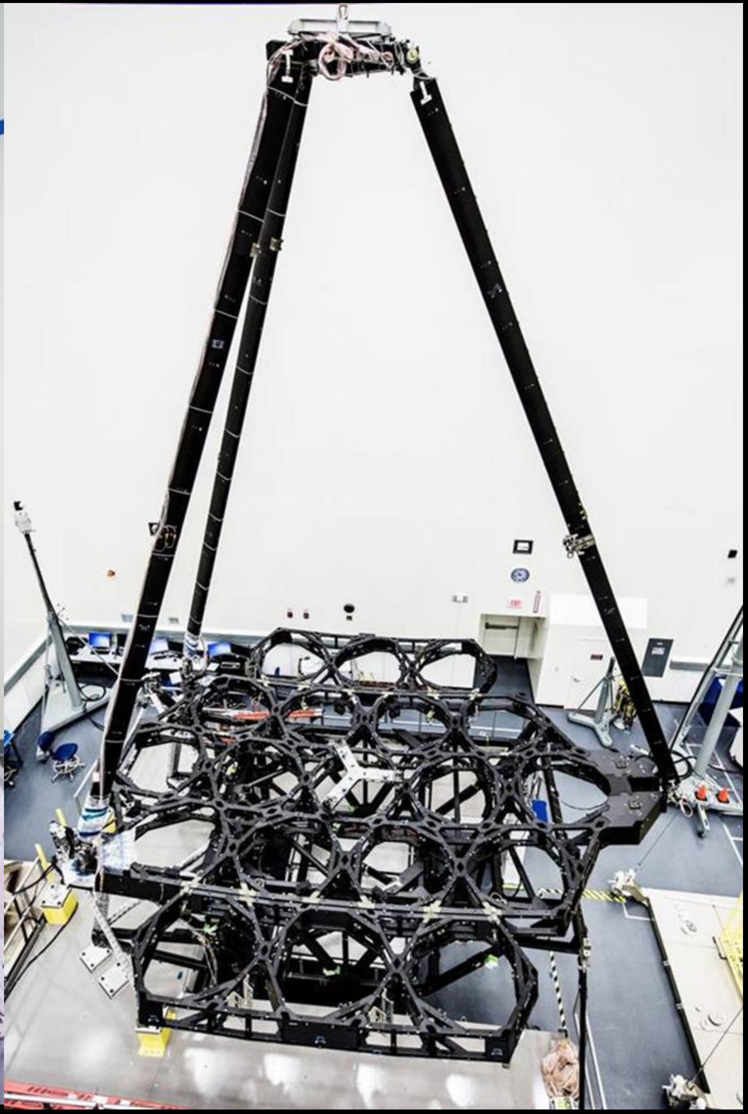
All of the mirrors are seen through testing to be smooth and reflective enough to enable the mission science objectives

Mirror	Total RMS SFE (nm)	Requirement RMS SFE (nm)
18 primary Segments (Composite Figure)	25.0	25.8
Secondary	19.8	23.5
Tertiary	20.5	23.2
FSM	14.7	18.7



Buildup of telescope flight structure is complete

The structure consists of ~3,200 bonded composite piece parts



OTE pathfinder structure manual deployment test: June 2014

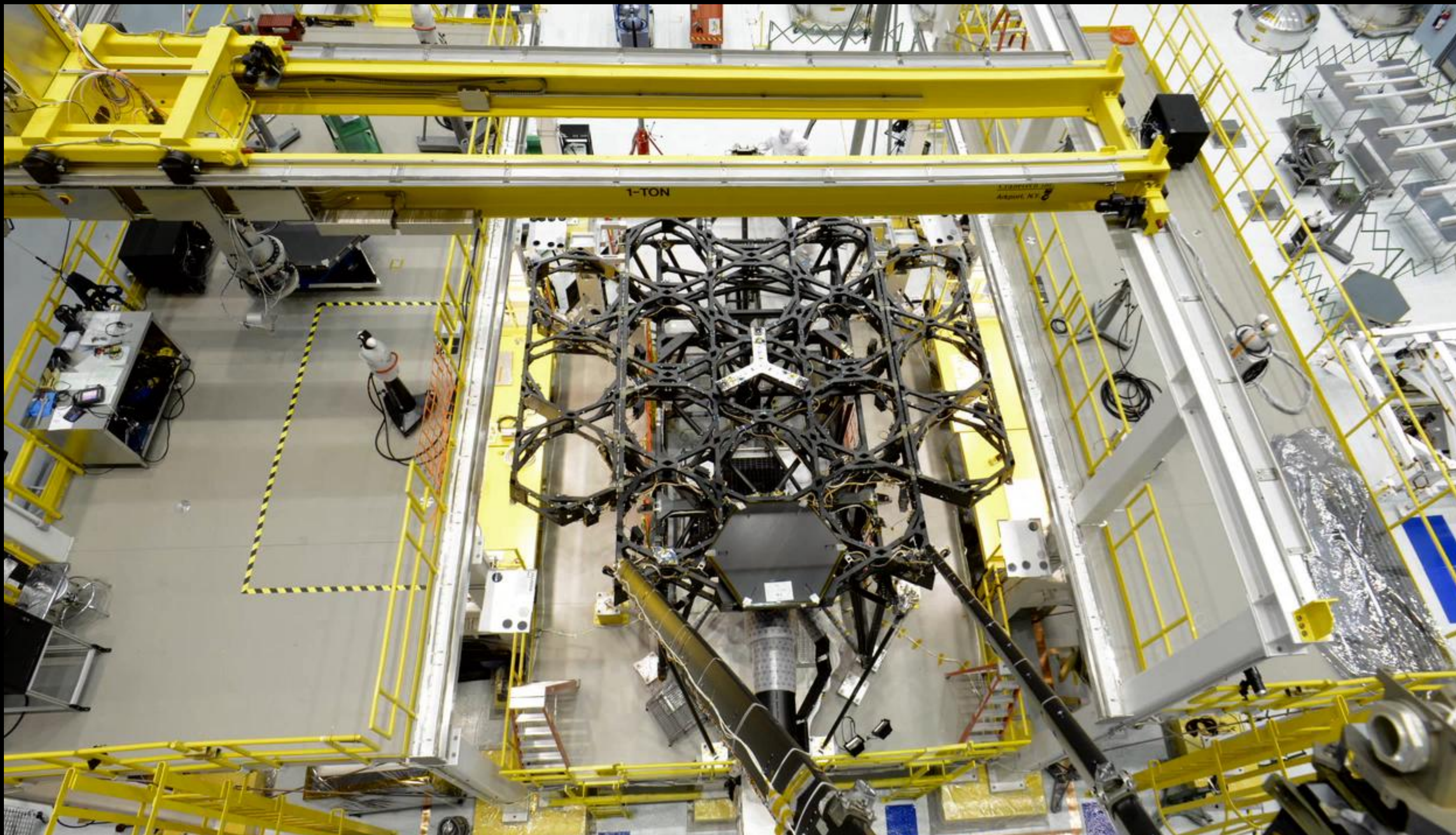
The spacecraft bus structure is nearing completion

Spacecraft and OTE structure fit check has been completed

OTE Structure

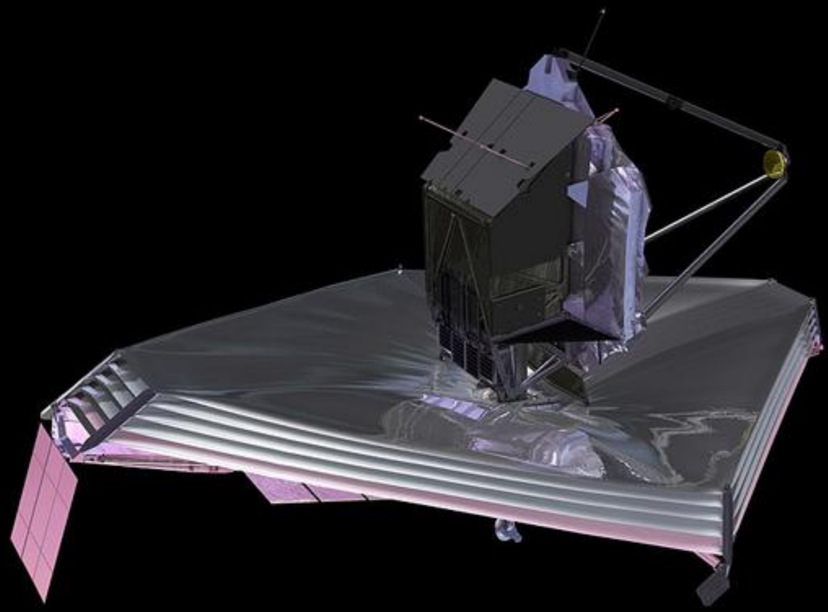
Spacecraft Structure

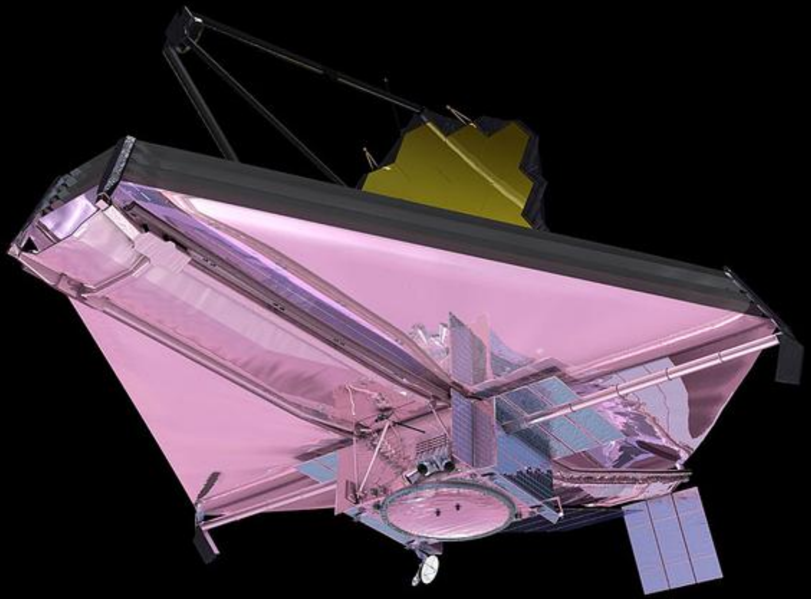
Integration of the flight telescope mirrors with the structure has been completed



Integration of other telescope elements is ongoing

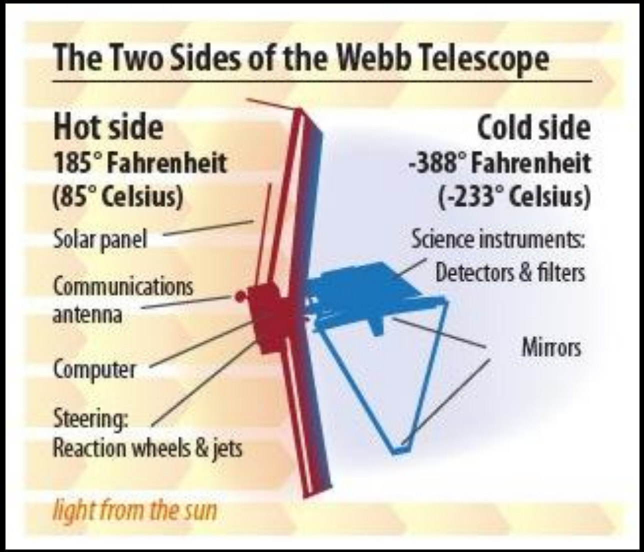
The JWST's 5 layer sunshield has an SPF of ~10^6





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 (85° C), dark side stays at 40 K (-233° 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 Manual Deployment Test: June 2014

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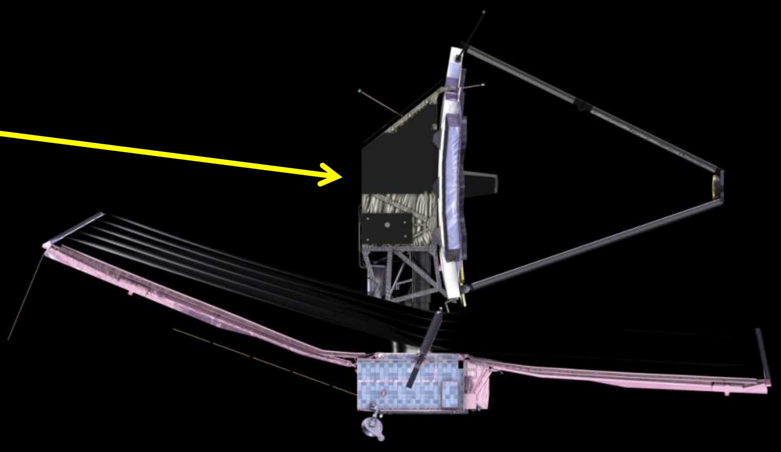
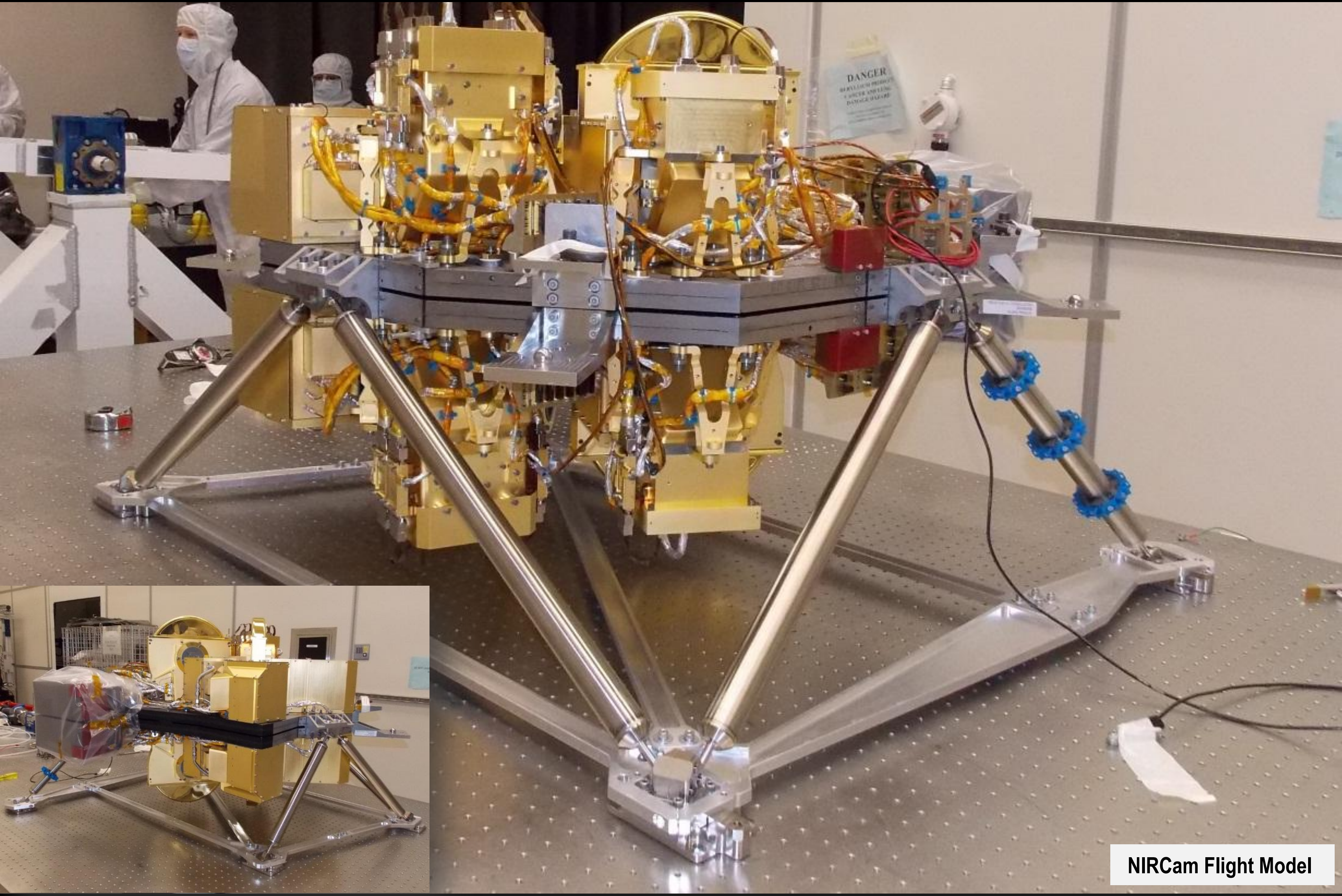
Attitude control, telecom, power & other systems



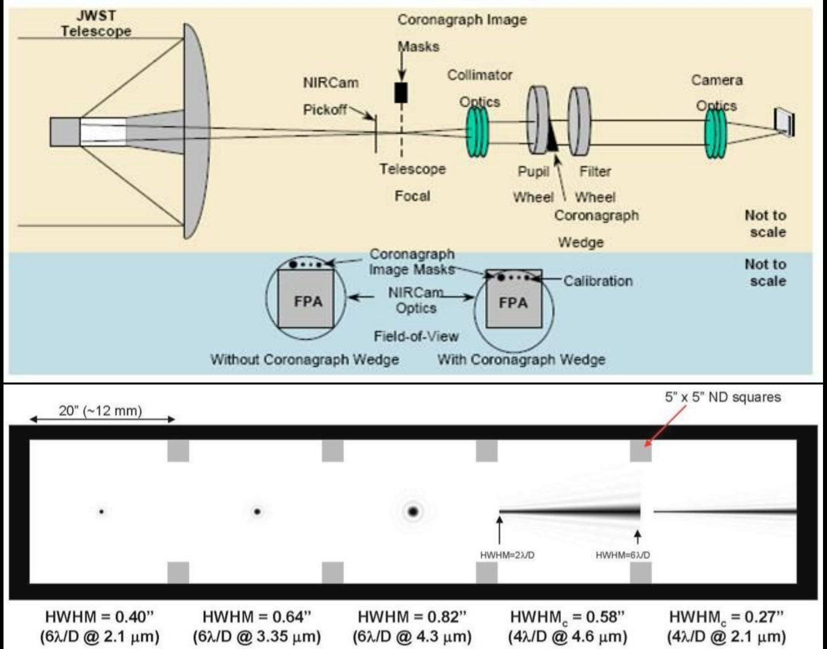
The NIRCam will image the earliest epoch of galaxy formation

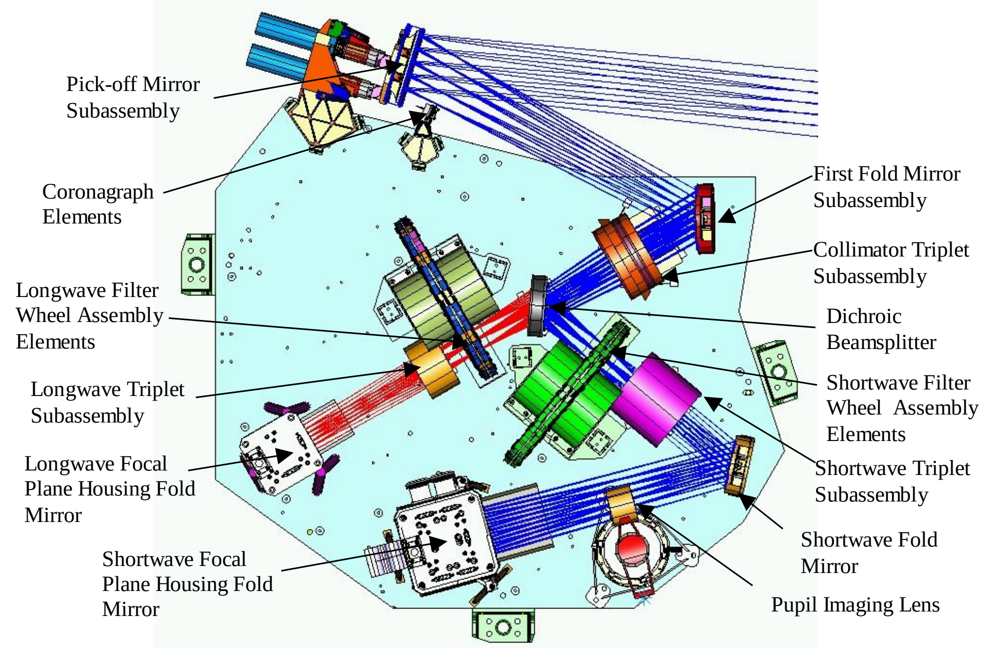


NIRCam Flight Model

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

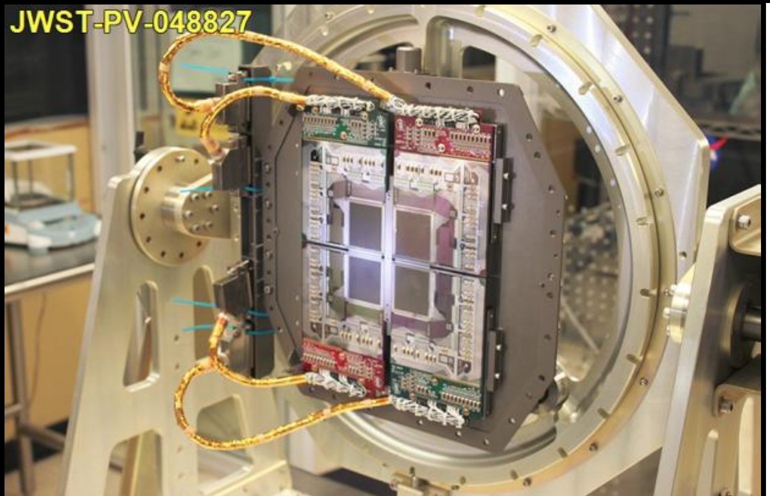
- Developed by the University of Arizona with Lockheed Martin
  - Operating wavelength: 0.6 – 5.0 microns
  - Field of view: 2.2 x 4.4 arc minutes
  - Angular resolution (1 pixel): 32 mas < 2.3 microns, 65 mas > 2.4 microns
  - Imagery: R= 4, 10, 100 filters
  - Spectroscopy: grisim (slit-less) R~2000 2.4 – 5 microns
  - Coronagraph

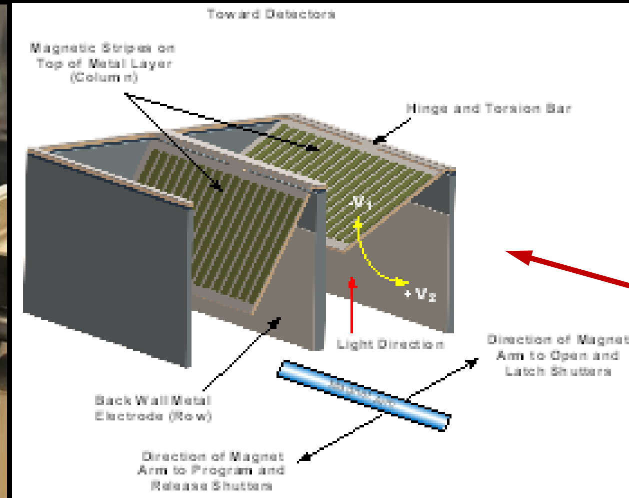


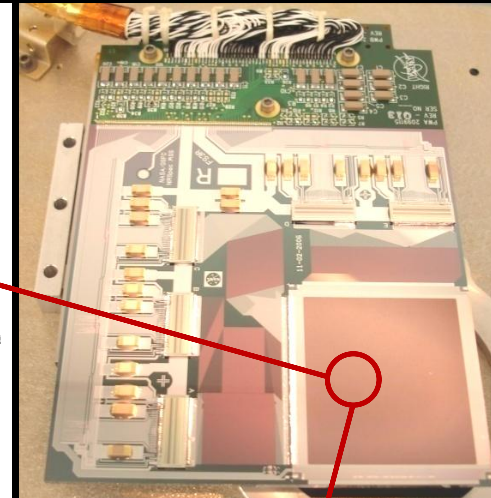


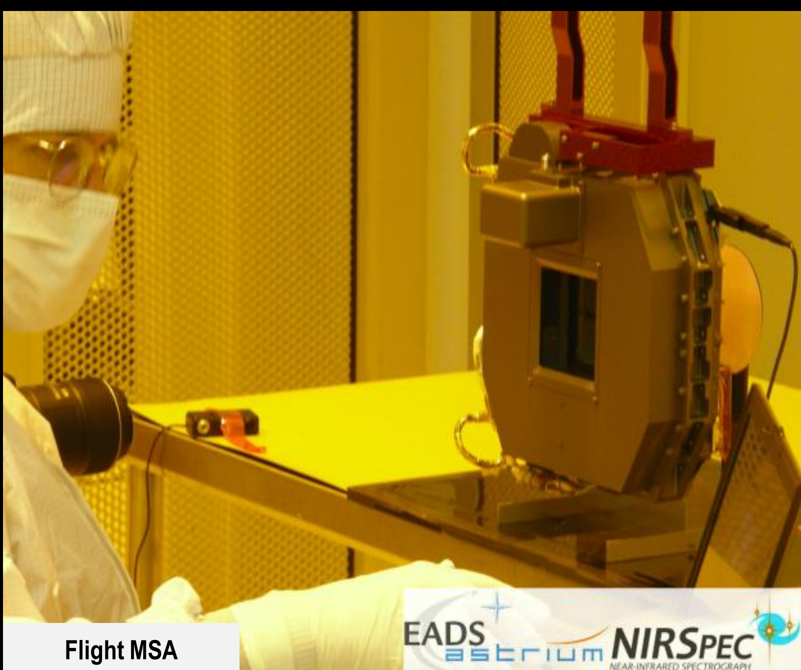
NIRSpec can obtain spectra of 100 compact galaxies simultaneously

Aperture control: 250,000 programmable micro-shutters

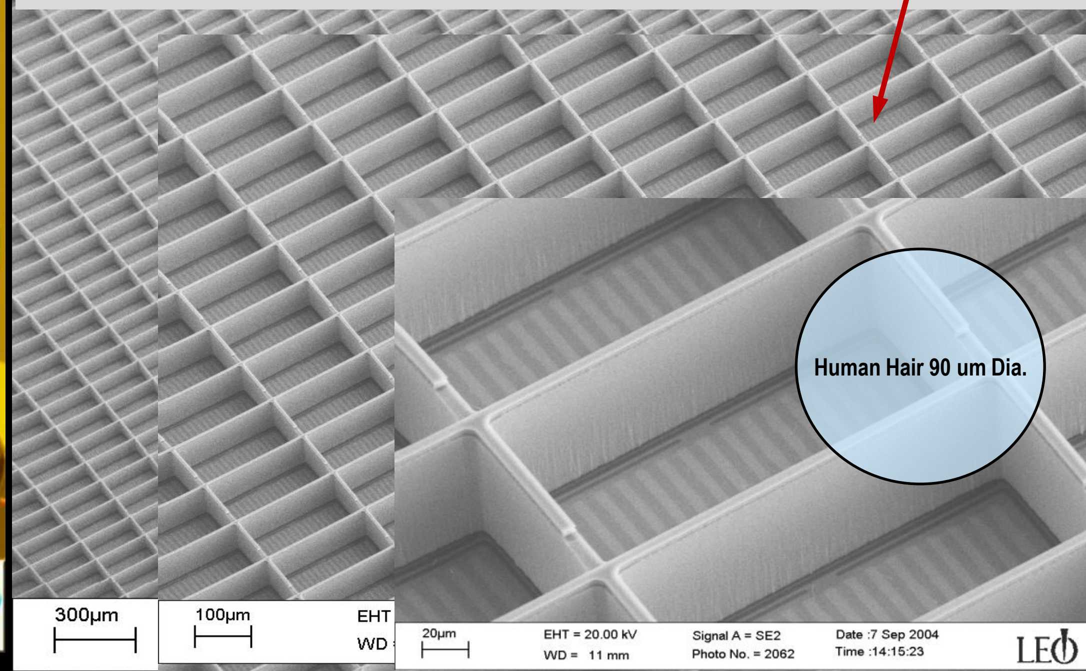




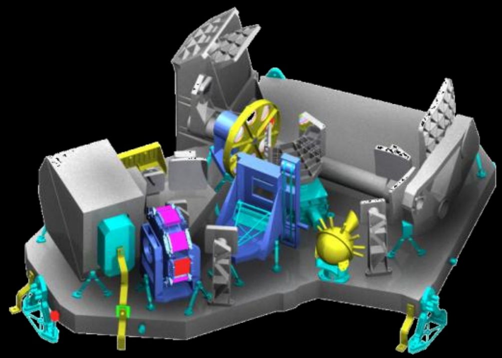


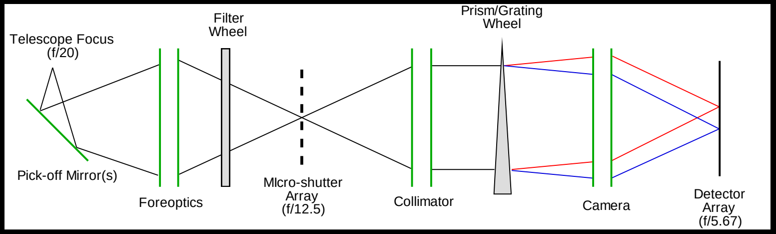


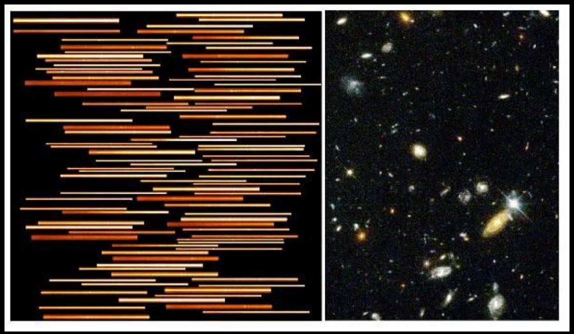
203 x 463 mas shutter pixel clear aperture, 267 x 528 mas pitch, 4 x 171 x 365 array



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





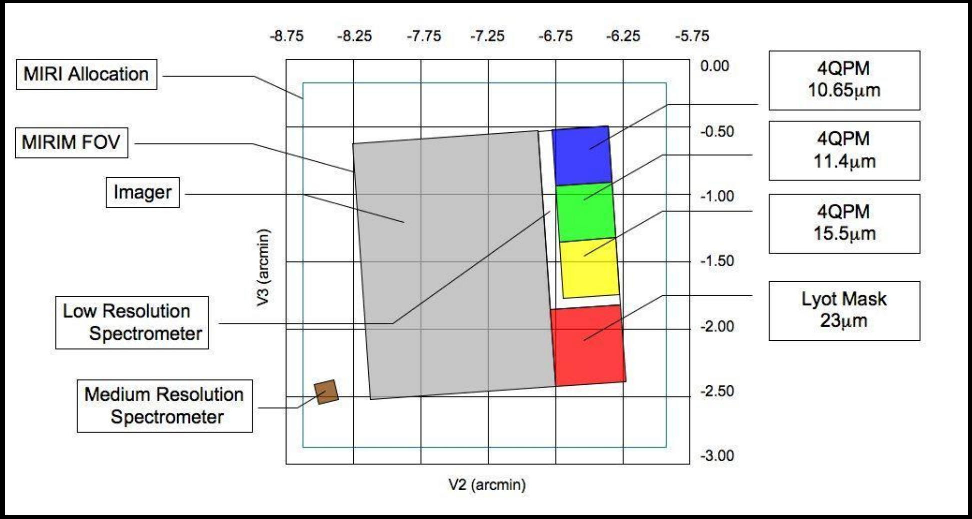


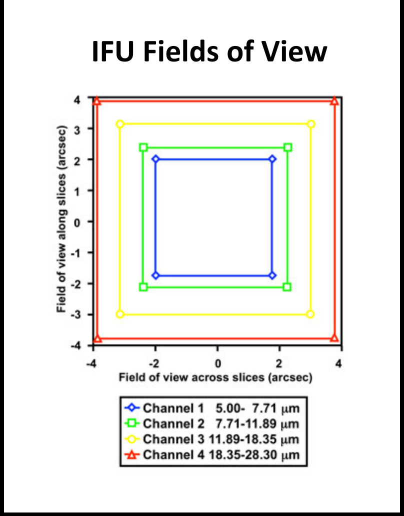
- Developed by the European Space Technology Center (ESTEC) with Astrium and Goddard Space Flight Center
  - Operating wavelength: 0.6 – 5.0 microns
  - Spectral resolution: 100, 1000, 3000
  - Field of view: 3.4 x 3.4 arc minutes
    - Aperture control:
      - Programmable micro-shutters, 250,000 pixels
        - 203 x 463 mas clear aperture (267 x 528 mas pitch)
      - Fixed long slits & transit spectroscopy aperture
        - 200, 400, 1600 mas slit width
      - Image slicer (IFU) 3x3 arc sec FOV (100 mas slice width)
  - All aperture control modes available with any spectral resolution mode

MIRI will provide humanity's first high definition view of the mid-infrared universe

MIRI flight model

The MIRI 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 – 28.5 microns
  - Broad-band imagery: 1.9 x 1.4 arc minutes FOV, 110 mas/pixel, 9 filters (R~5)
  - Spectroscopy:
    - R~100 long slit spectroscopy 5 x 0.2 arc sec
    - R~3000 IFU spectroscopy (4 image slicers fed by dichroic beam splitters)
      - Slice width: 19, 19, 24, and 27 mas
  - Coronagraphic imagery: Three 4QPMs and 1 Lyot occulting mask, 110 mas/pixel

FGS can sense pointing to 1 millionth degree precision
NIRISS can image exoplanets that are too close to their star for coronagraphs

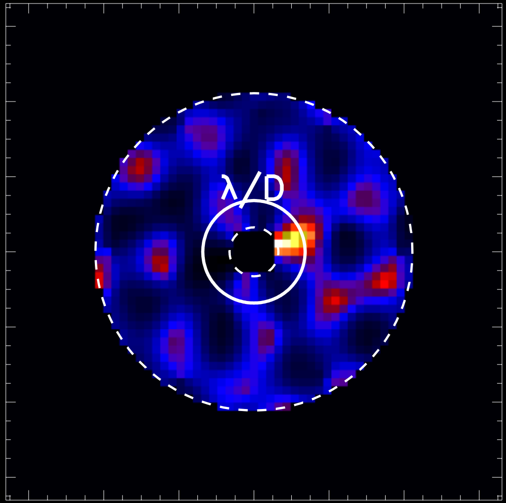
Flight FGS

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

- Developed by the Canadian Space Agency with ComDev

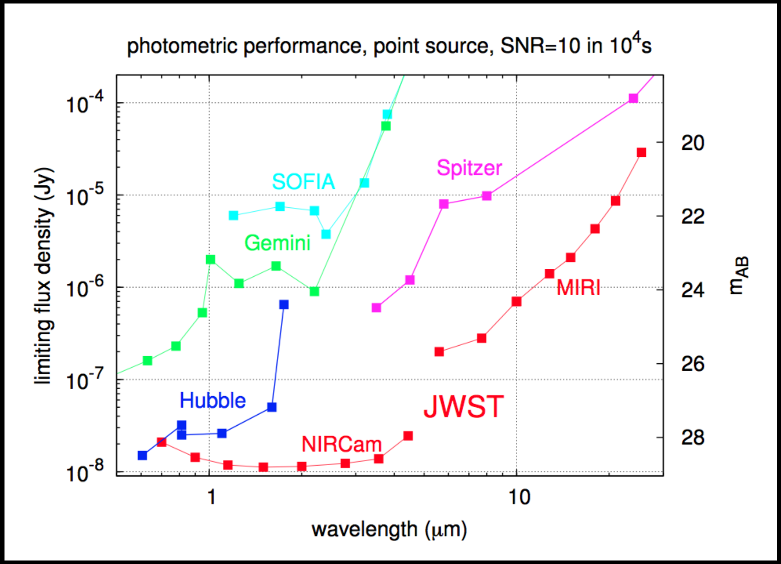
- **FGS:** 4 mas noise equivalent angle (0.6 – 5 microns)
  - ~95% probability of guide star acquisition over whole sky
  - 7 mas LOS pointing stability

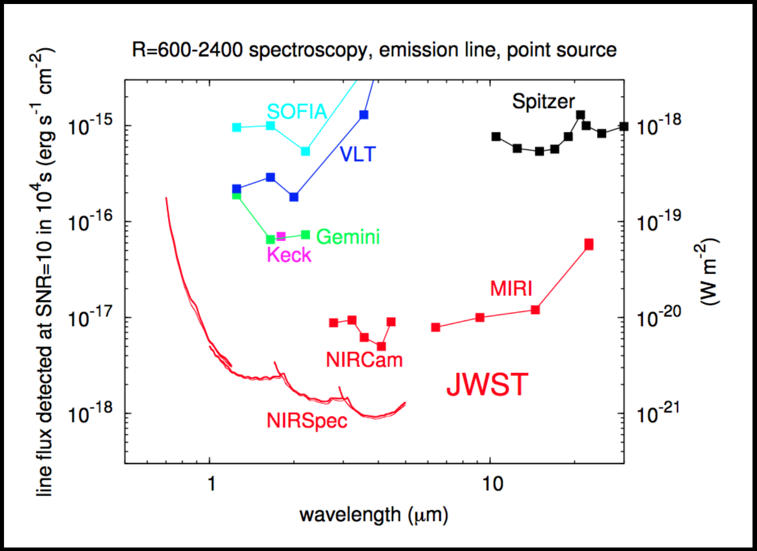
- **NIRISS:**
  - Wide-field slit-less spectroscopic imagery (grism)
    - R ~ 150, 0.8 – 2.25 microns optimized for Ly alpha galaxy surveys
  - Single object spectroscopic imagery (grism): 3 orders cross-dispersed
    - R ~ 700, 0.7 – 2.5 microns optimized for exoplanet transit spectroscopy
  - Aperture mask interferometric imaging (7 aperture NRM, 21 unique baselines) 3.8, 4.3, and 4.8 microns (IWA ~ 0.5λ/D)
  - 68 mas/pixel all modes



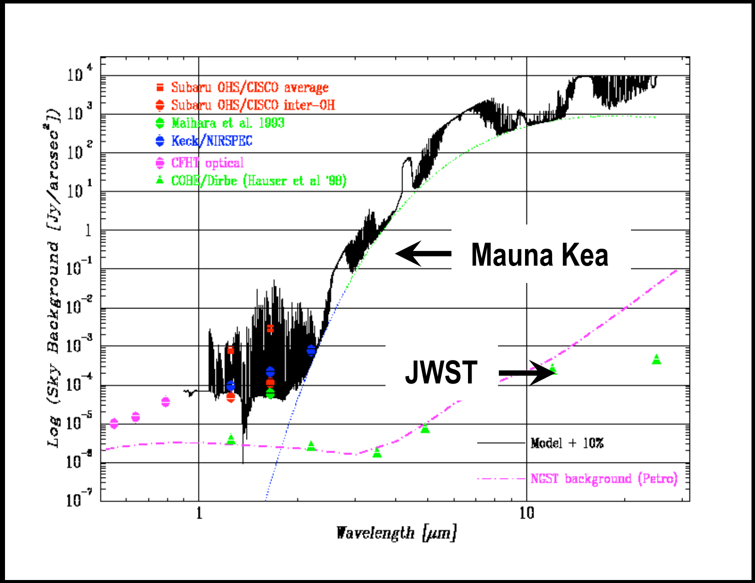
Simulated NIRISS aperture mask near-infrared image of a 1-2 M_{Jup} planet at ~1 AU of a M0V star 10 pc from the Sun.

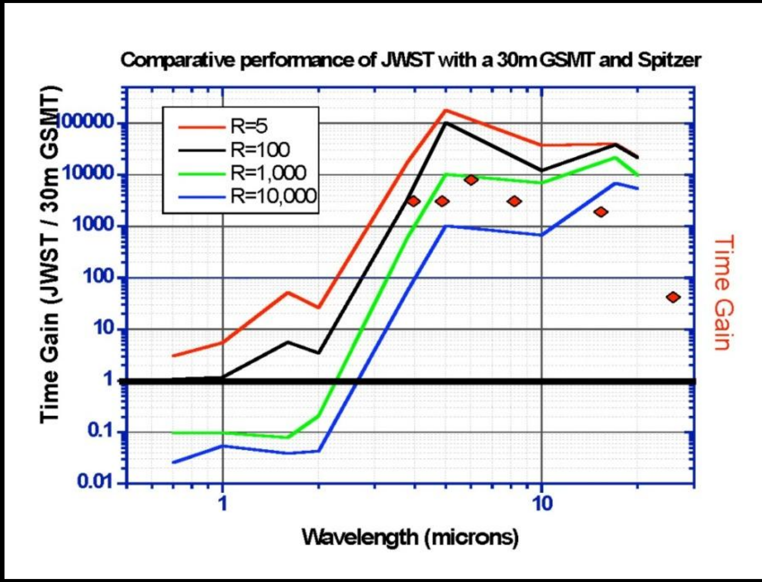
JWST will achieve unprecedented infrared sensitivity





However, 30 m ground-based facilities can challenge JWST performance for R > 1000 spectroscopy at wavelengths < 1.7 microns



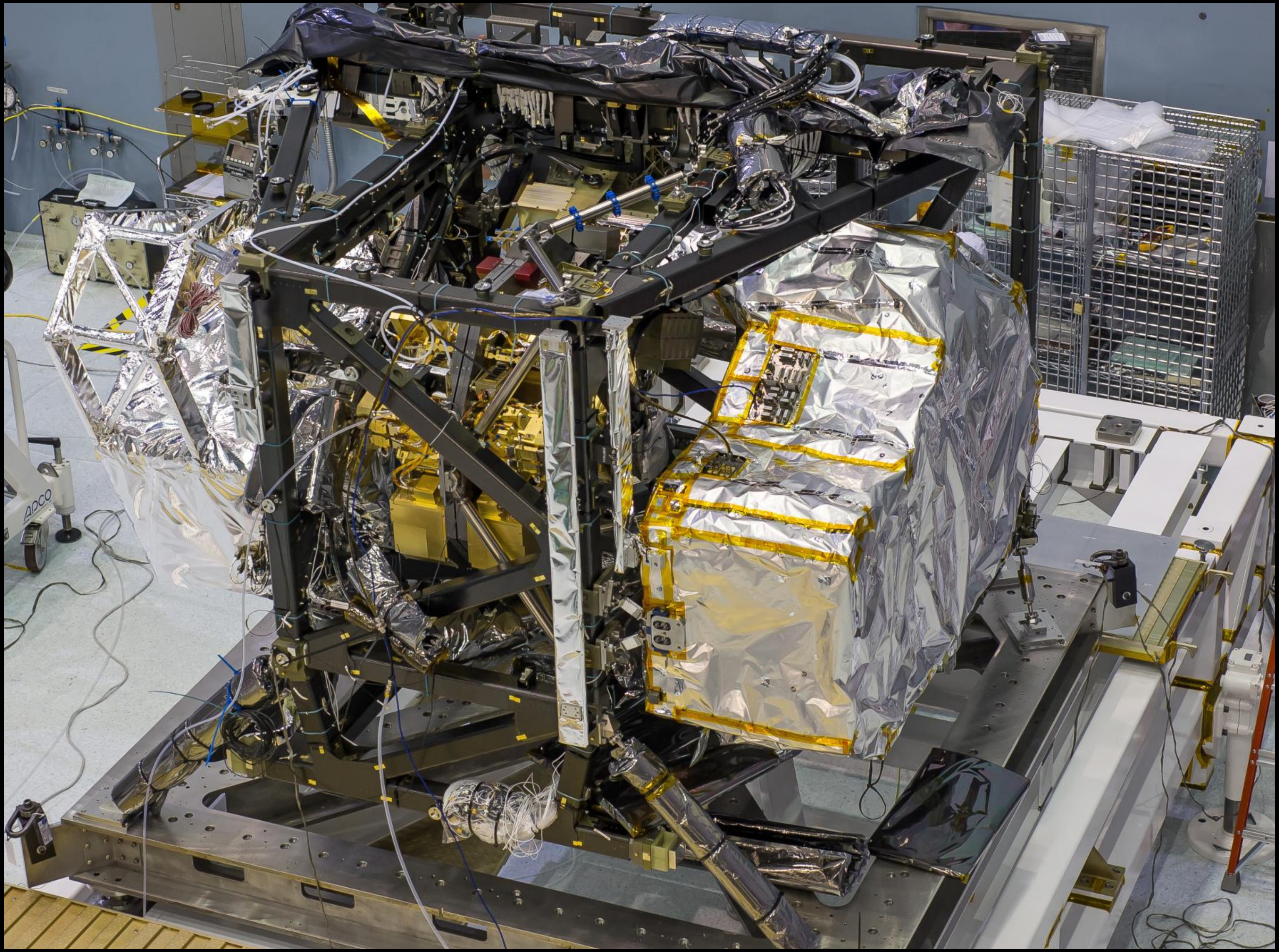


Observer take-aways

- The ISIM contains a Fine Guidance Sensor that enables the observatory to achieve 7 mas pointing stability
- The ISIM includes 4 science sensors that enable:
  - Nyquist sampled imagery in broad-band filters
  - Coronagraphic imagery with contrast ~10^4 - 10^5 over the whole JWST wavelength range
  - Slit-less, long slit, and multi-object spectroscopy with R ~ 10^2 - 10^3
  - IFU spectroscopy over the whole JWST wavelength range
  - Interferometric imagery over 4-5 microns with resolution $0.5\lambda/D$

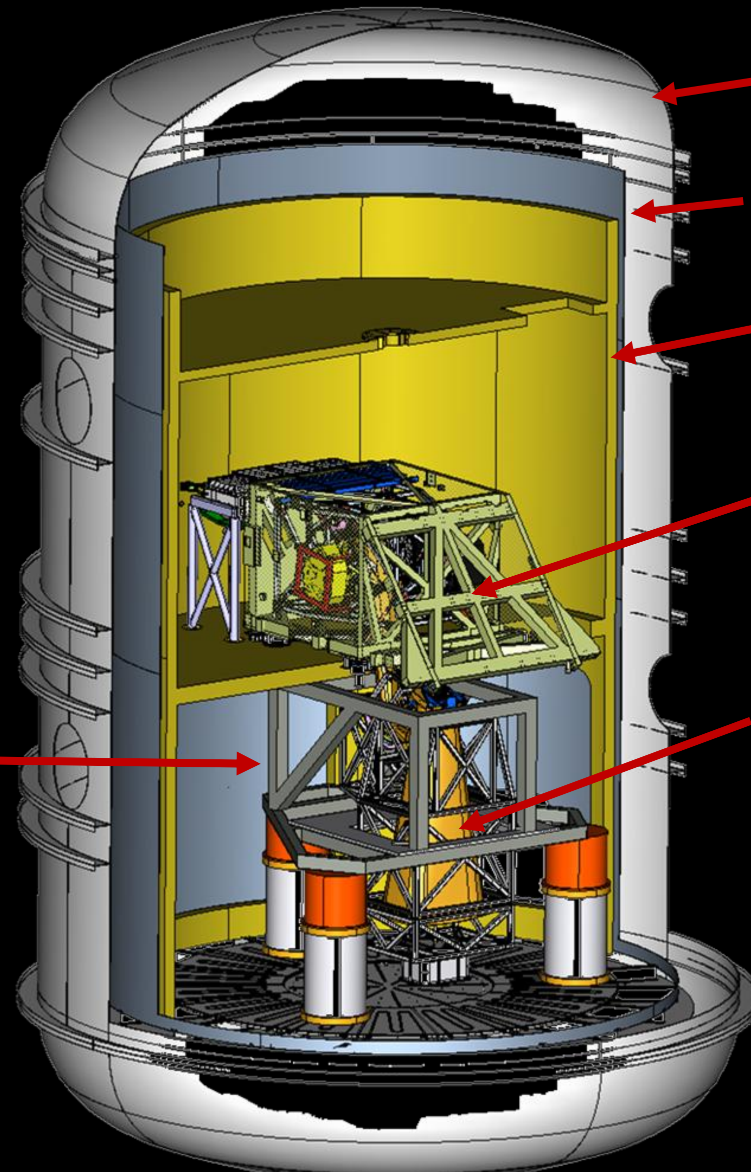
- All ISIM sensors have sub-array detector readout capability to enable observation of bright targets
- All ISIM sensors are designed for simultaneous and continuous operation

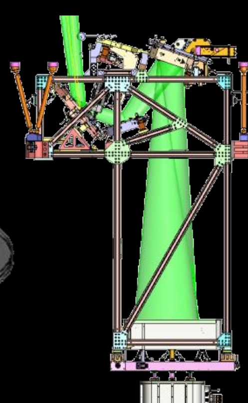
The science instrument payload (ISIM) began construction during 2006 and completed acceptance testing during March 2016



ISIM was tested in the Goddard Space Environment Simulator (SES) chamber using a cryogenic telescope simulator (OSIM)

The 3rd of 3 100 day SES test cycles of the ISIM was completed during Feb 2016





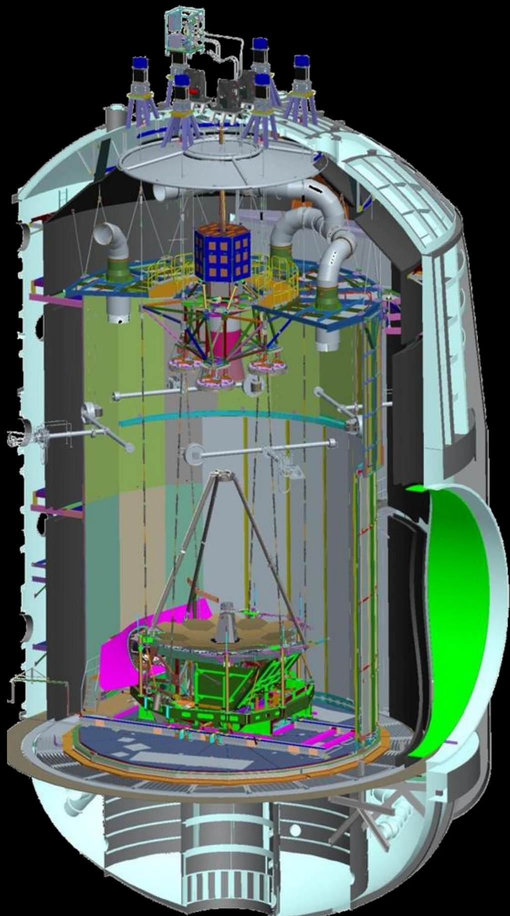
The telescope and instrument module will be integrated to each other at GSFC and will then be sent to Johnson Space Flight Center during 2016

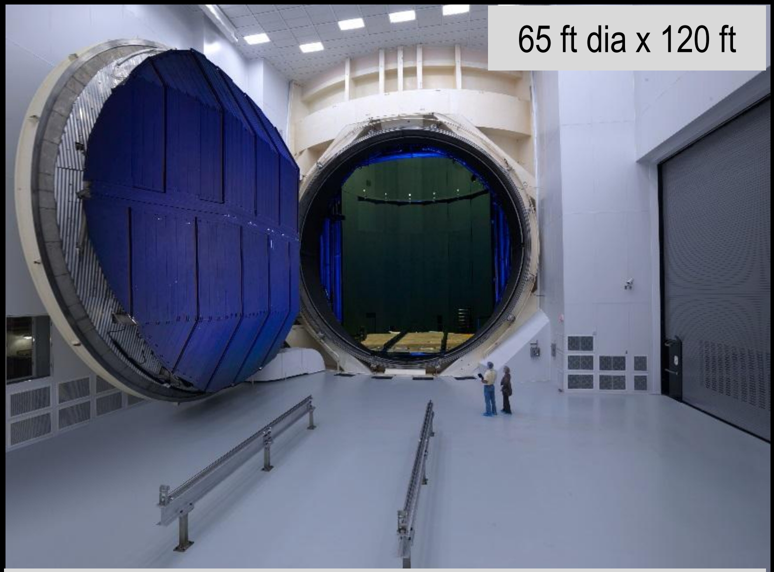
STTARS being loaded into a C5 aircraft

Space Telescope Transporter for Air Road and Sea (STTARS)

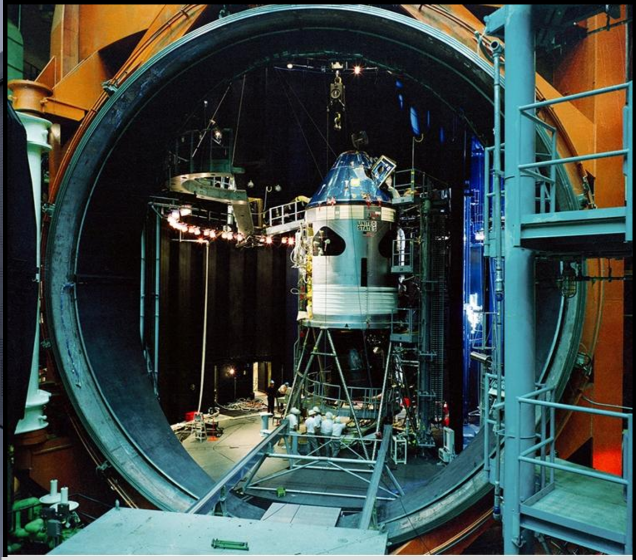
Then, during February 2017, the OTE + ISIM will be tested in the largest space simulation chamber in the world

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





JSC Chamber A today

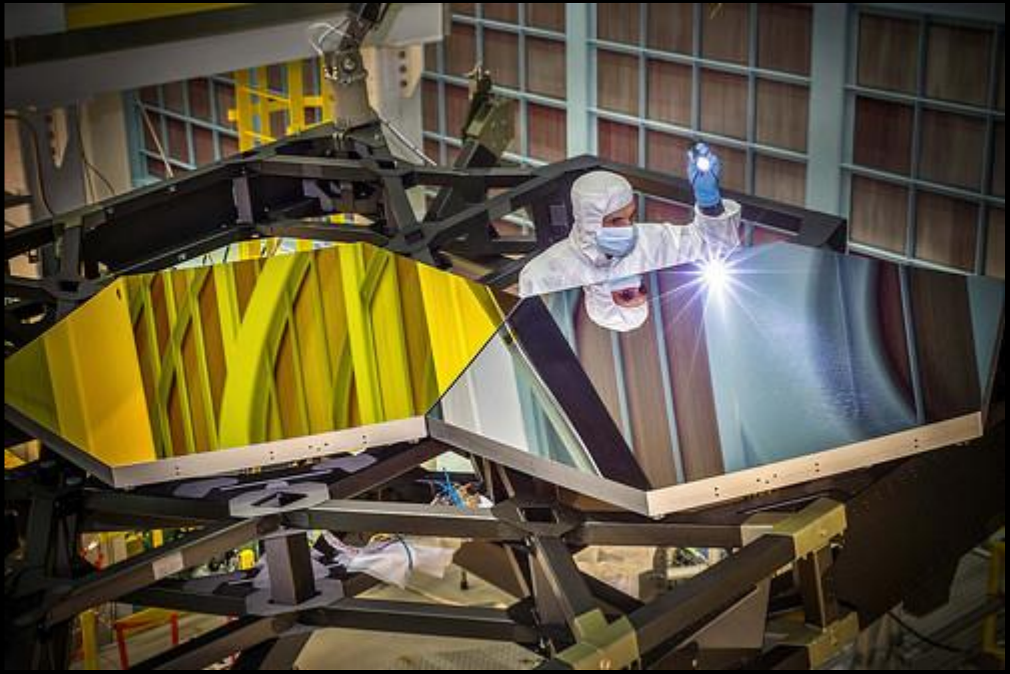


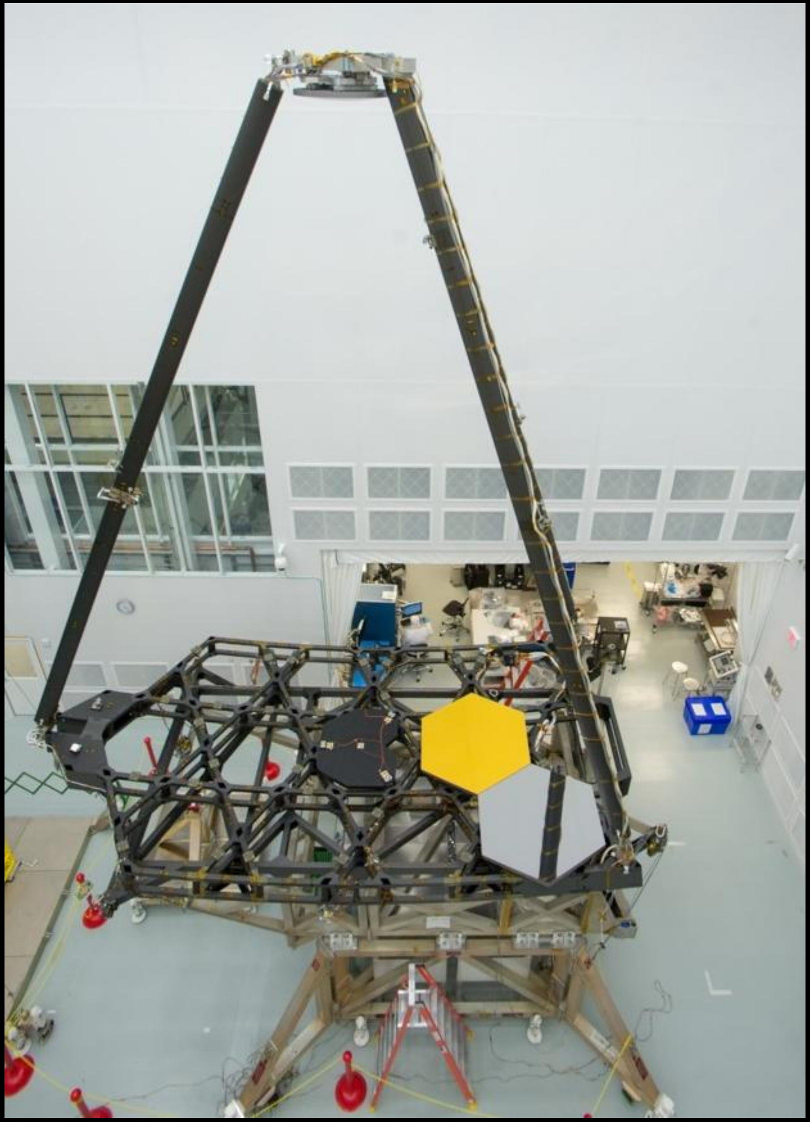
JSC Chamber A during Apollo

The Pathfinder telescope structure began cryogenic testing at Johnson Space Flight Center during May 2015

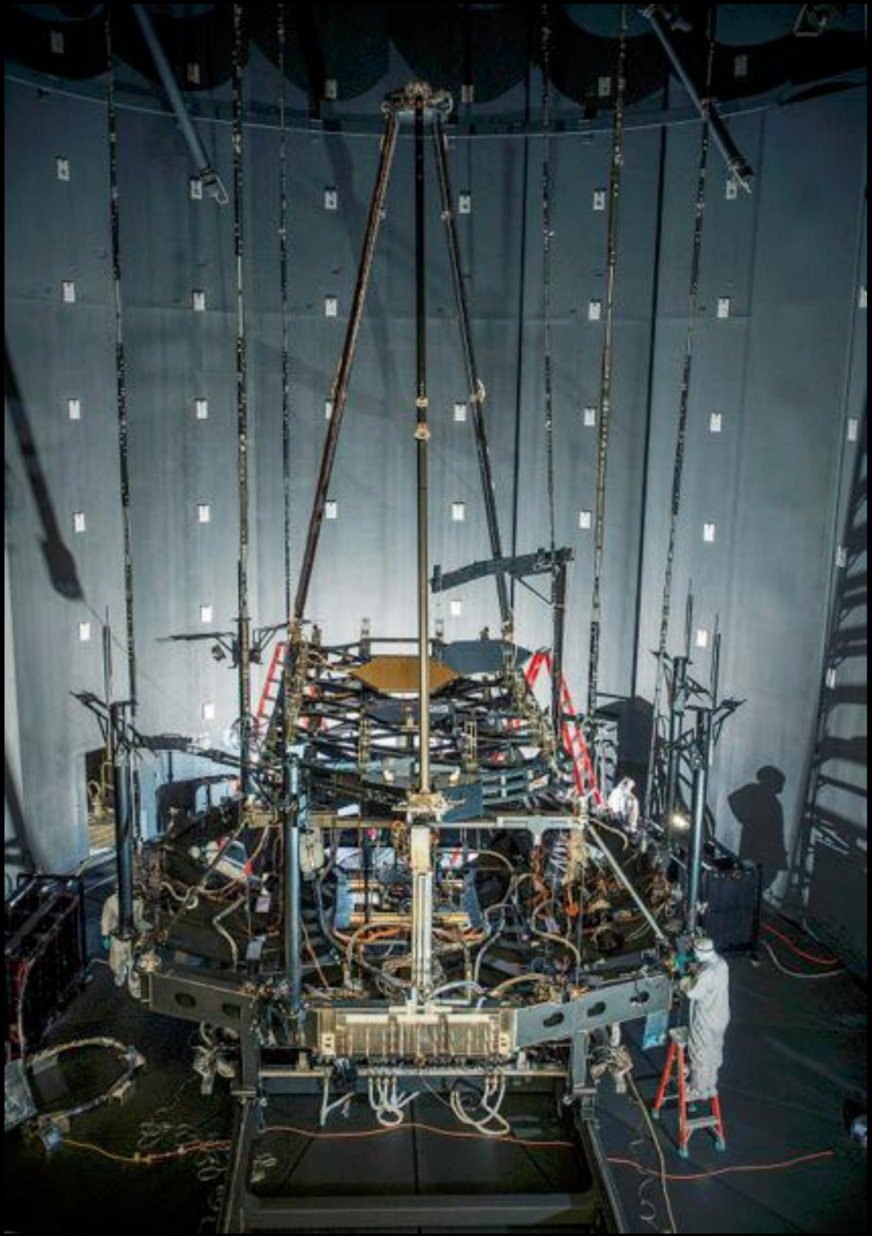
The Pathfinder is flight-like in every respect expect:

- Does not include the deployable "wings" of the backplane
- Is populated with two flight spare mirror segments

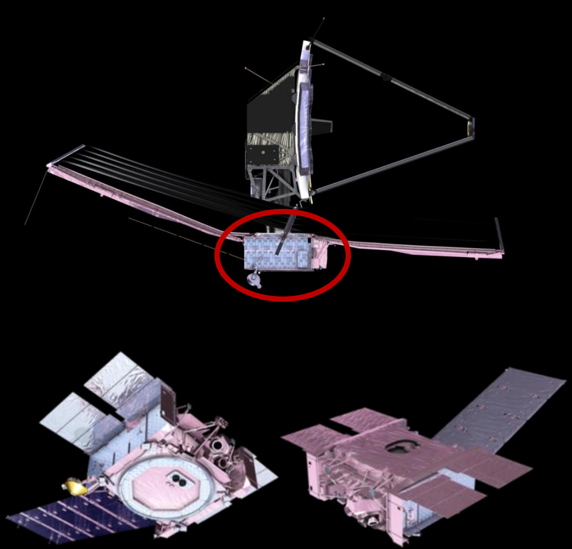




Space simulation testing of the pathfinder telescope was completed during December 2015



The telescope and instrument module will then be sent to Northrop Grumman Aerospace Systems for integration with the spacecraft bus and sunshield during June 2017



Space Telescope Transporter for Air Road and Sea (STTARS)

Then … The JWST will be transported by ship through the Panama Canal to French Guiana for launch during 2018

6900 Nautical Miles
Approximately 20 days

Roll on roll off transport ship built in the Netherlands by Merwede Shipyards
Length 116m
Displacement about 4200 metric tons
Garage deck length 95m (plenty of room for STTARS)
Speed: 15 knots

Space Telescope Transporter for Air Road and Sea (STTARS)

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 …

You can follow the action: @NASAWebbTelescp #JWST