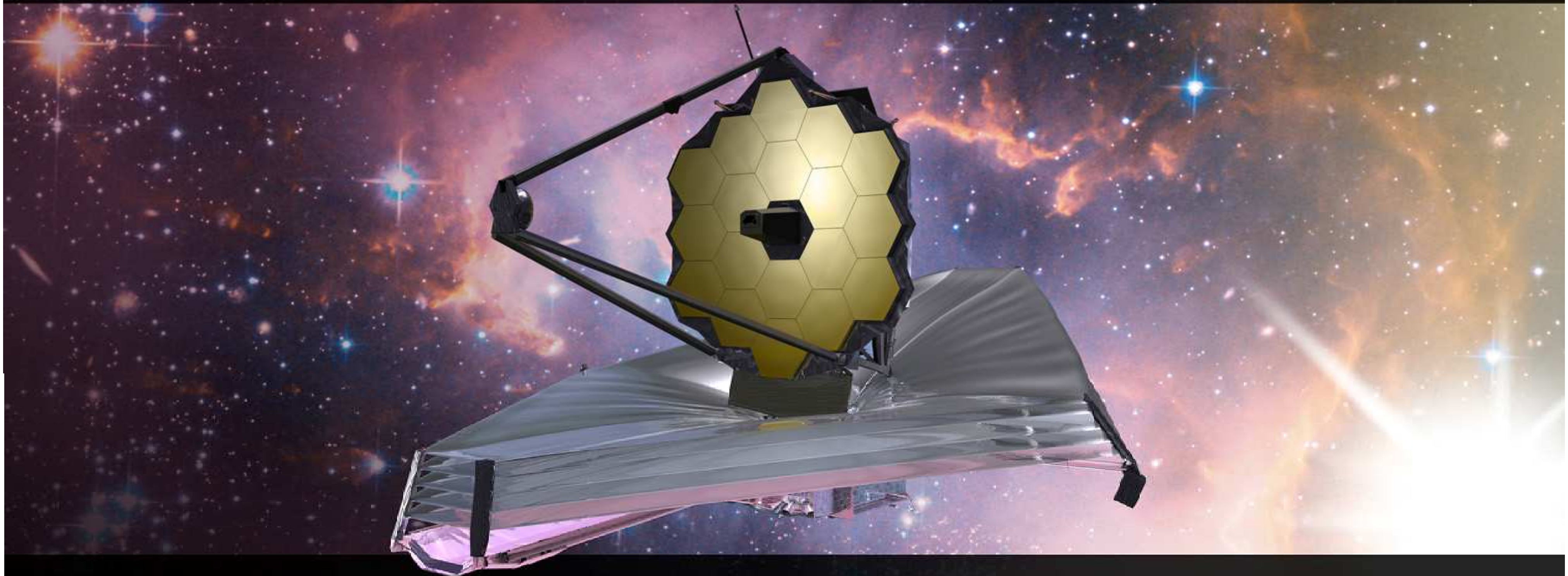
National Aeronautics and Space Administration



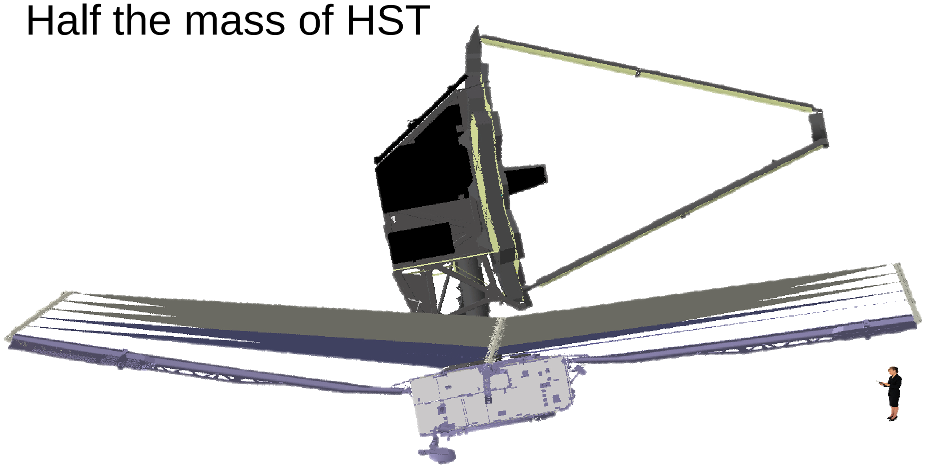
James Webb Space Telescope (JWST)

Rick Howard
JWST Program Director
NAC Technology and Innovation Committee
March 6, 2012

JWST – the next great observatory

- **JWST is the scientific and technological successor to HST**
  - HST has looked deeper into the Universe that any telescope. It took HST more than three continuous days to do so. JWST will do that in less than an hour

- **JWST is:**
  - More than 6 times the collecting area of HST
  - 100 times more sensitive than HST, over 1000 times more than Spitzer
  - Operated at 40K (~ - 400°F)
  - Operated in deep space, about 1,000,000 miles from Earth (4X further than the Moon)
  - Cooled by a deployed sunshade the size of a tennis court
  - Half the mass of HST

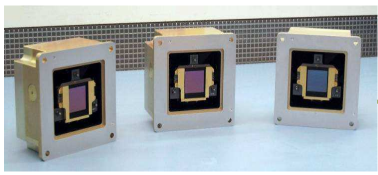


TECHNOLOGY INVENTIONS

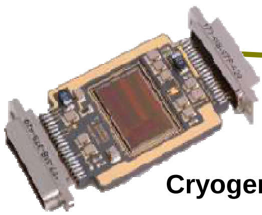
- **Segmented Beryllium Primary Mirror**
  - areal density 3 times less than HST
  - Technologies for JWST mirror manufacturing and polishing broadly applicable for future space telescopes
  - Must fold up to fit inside rocket fairing, breaking the limitation on mirror diameter
- **Composite structure to hold mirrors and instruments**
  - Behavior must be known to <40 nanometers (~1/10,000 of a human hair)
  - Must maintain this stability while being cooled over 400 degrees
- **Cryogenic Application Specific Integrated Circuit (ASIC)**
  - JWST ASIC already flying in space: Installed on Hubble Servicing Mission 4 to repair the failed Advanced Camera for Surveys (ACS) instrument
- **Micro-Shutters**
  - ~100,000 computer controlled shutters, each the width of a human hair
  - First Mirco-ElectroMechanical (MEMS) devise for science to be flown in space
  - Early research on MEMs devised for JWST helped develop analogous instrument for ground-based telescopes
- **Sunshield Membranes**
  - Lightweight deployable sunshield the size of a tennis court to passively cool JWST telescope and instruments
  - 5 thin separated membrane layers (each less than half the thickness of a piece of paper)
  - Providing a 500 F temperature difference (equivalent SPF of 1,000,000)
- **Advanced Near Infrared Detectors**
- **Advanced Mid-Infrared Detectors**
- **Cryo-cooler for Mid-Infrared Instrument**
- **Mirror Phasing and Control Software**
- **Heat Switches**

TECHNOLOGICAL ADVANCES

Advanced Near Infrared detectors



Advanced Mid-Infrared detectors



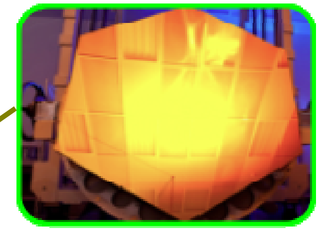
Cryogenic ASICs

Ultra-sensitive detectors on JWST could see a single candle on the Moon from 1 million km.

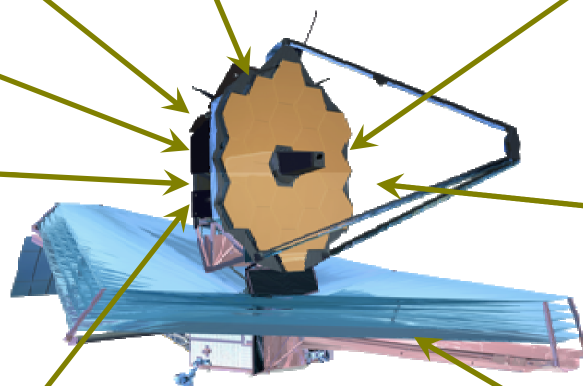
Mirror Support Structure

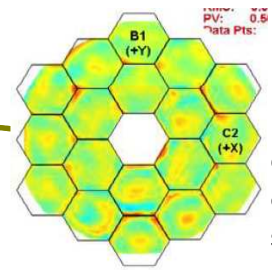
Structures hold mirrors and science instruments super stable, behavior must be known to ~38 nanometers (~1/10,000th of a human hair!)

Segmented Beryllium Mirror



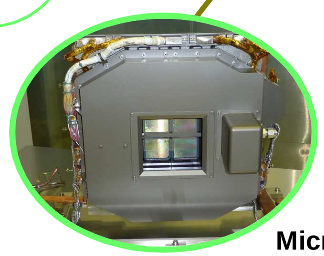
Mirrors so smooth that if "stretched" to the size of the continental US largest deviation from perfection would be ~2 inches in height.





18 mirror segments computer controlled to operate as one mirror in space

Mirror phasing and control



Microshutters

~100,000 computer controlled shutters, the width of a human hair enable optimal science return

Sunshield Membrane

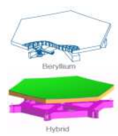
5 thin membranes (each less than half the thickness of a piece of paper) protect the side in the extreme of cold space from the warm sunlit side [Equivalent Sun Protection Factor (SPF) of 1,000,000]

Green borders denote actual spaceflight hardware, red borders are test equipment

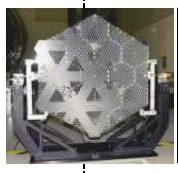
The Final Acceptance Test Completes a Decade plus Development Effort to Make JWST Mirrors

1996 | 1998 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014

Advanced Mirror System Demonstrator (AMSD)
Collaboration among 3 government agencies
15Kg/m2, 1.2M diameter segments

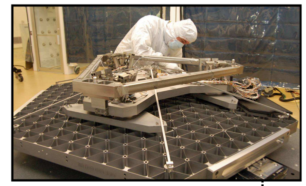


Medium Authority Glass (ULE)



Low Authority Beryllium

Technology Readiness Level-6 Demonstrated:
All key requirements and environments demonstrated

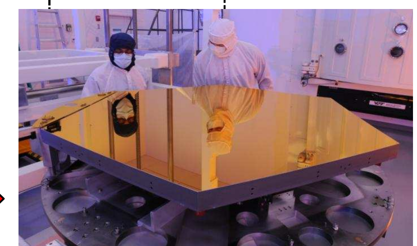


Onset of James Webb Space Telescope

AMSD Phase 1:
8 Mirror Designs

AMSD Phase 2:
3 mirrors developed

AMSD Phase 3/Six Sigma Study
Be manuf. and process improvements



OTE Optics Review (OOR): Beryllium Selected

Engineering Design Unit.

Subscale Beryllium Mirror Demonstrator (SBMD):
.5 meter diameter,

PM Manufacturing of 18 segments

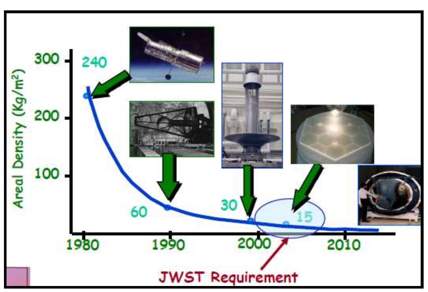
Primary Mirror Segment Assemblies Complete

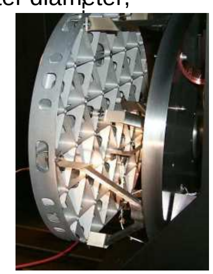
Machining Facility Complete

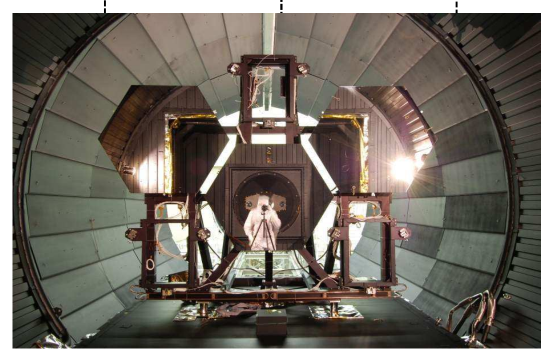
Cryo Testing

Polishing Facility Complete

Low Areal Density Mirrors Identified as Key Enabling Technology for 25 Square Meter Space Telescope

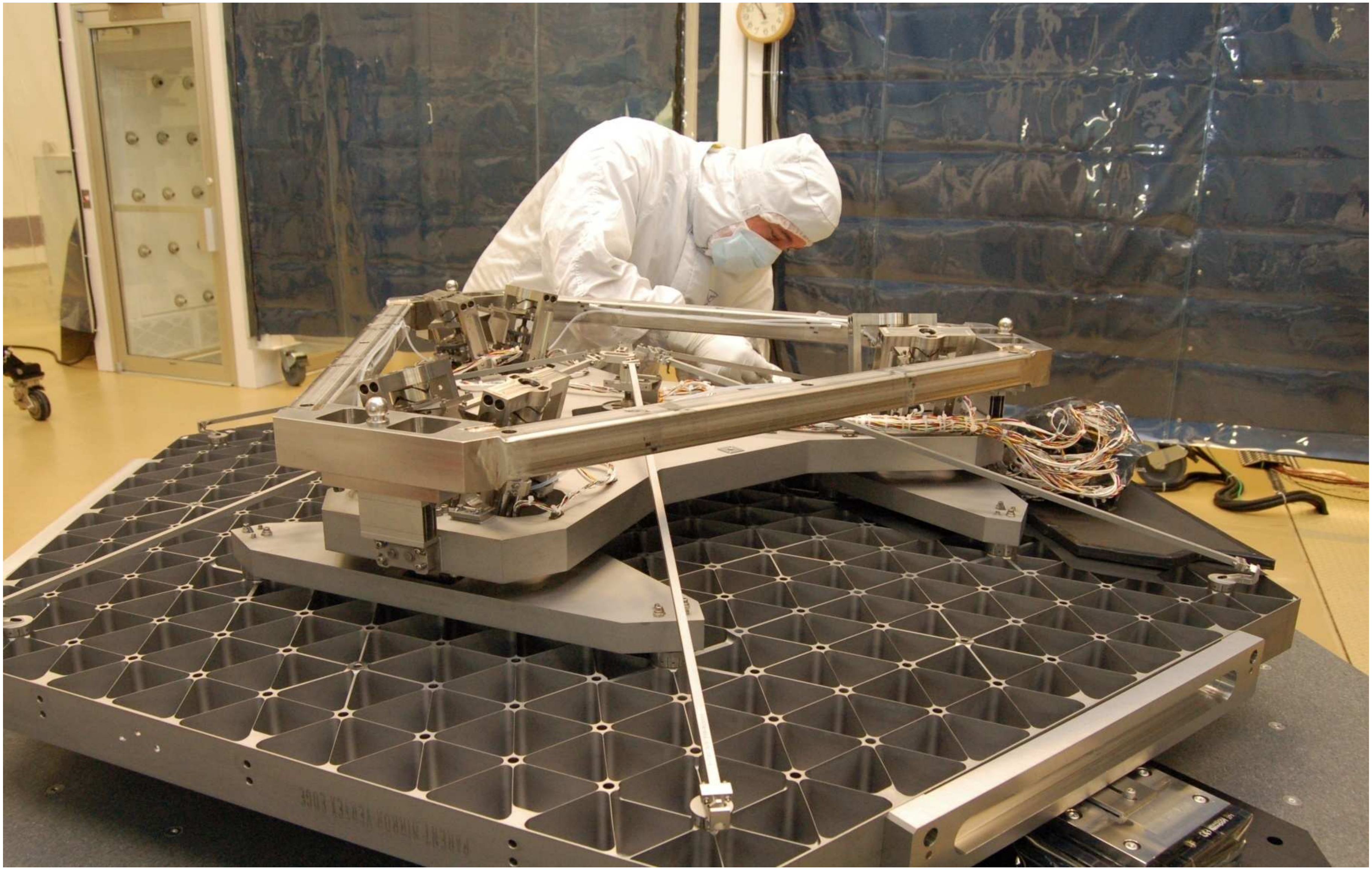






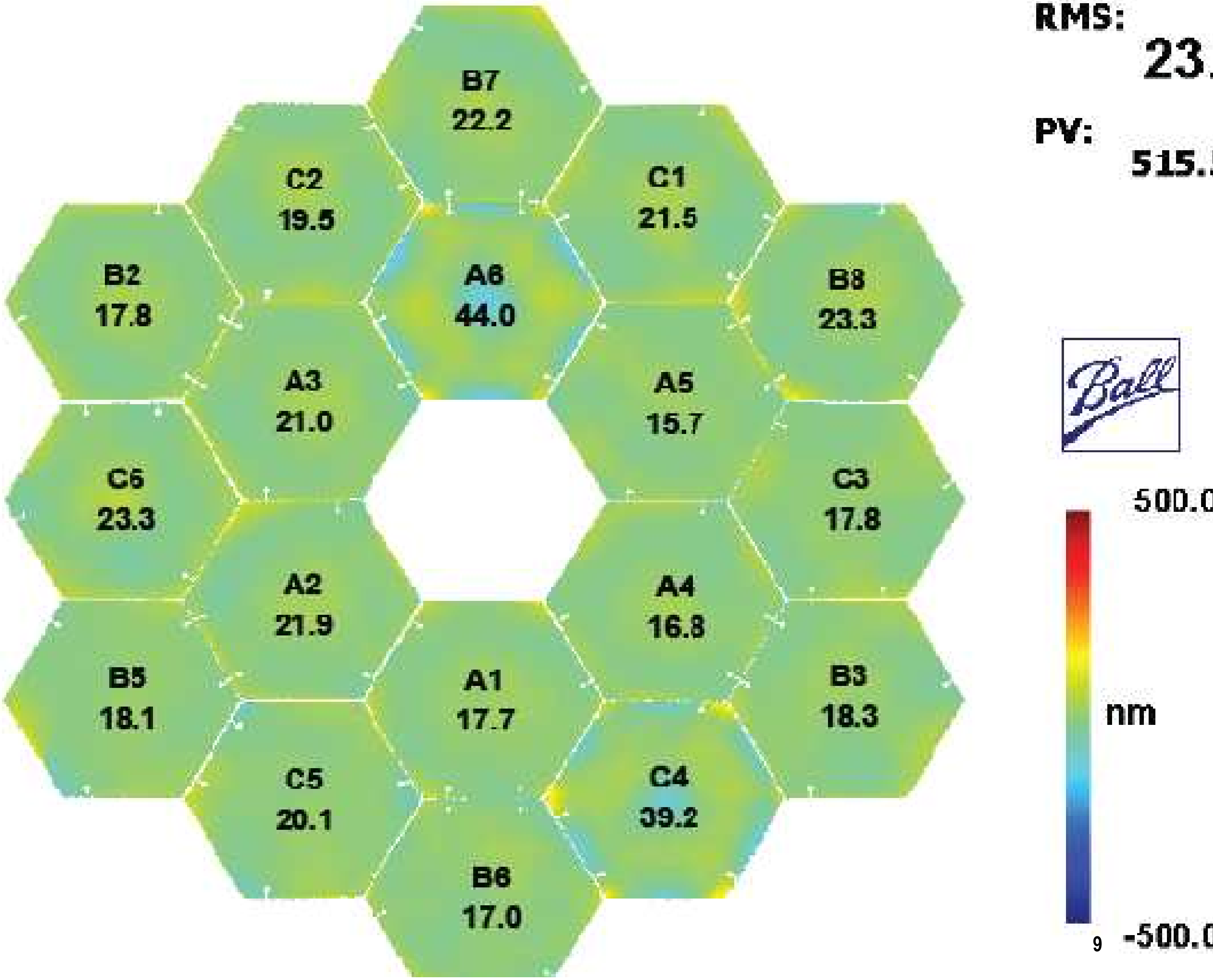
Coated Primary Mirror Segment Assembly

Primary Mirror Assembly




Mirror Acceptance Testing
A5
A4
B6
A1
A2
C3

Primary Mirror Composite

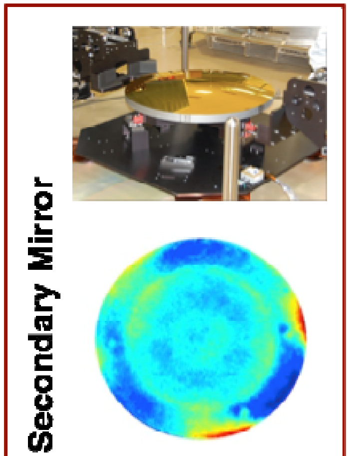


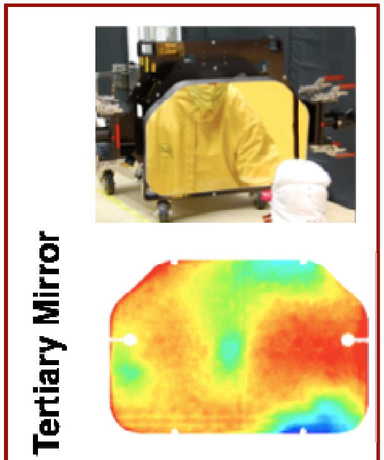
RMS: 23.2 nm

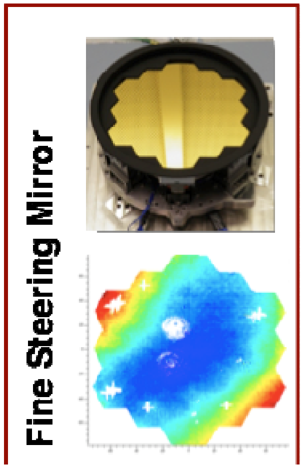
PV: 515.5 nm

Mirrors Completed

Mirror Element	RMS Surface Figure Error [nm]			
	Measured	Uncertainty	Total	Requirement
18 Primary Segments (Composite Figure)	23.7	8.1	25.0	25.8
Secondary	14.5	14.9	20.8	23.5
Tertiary	17.5	9.4	19.9	23.2
Fine Steering Mirror	14.7	8.7	17.1	17.5







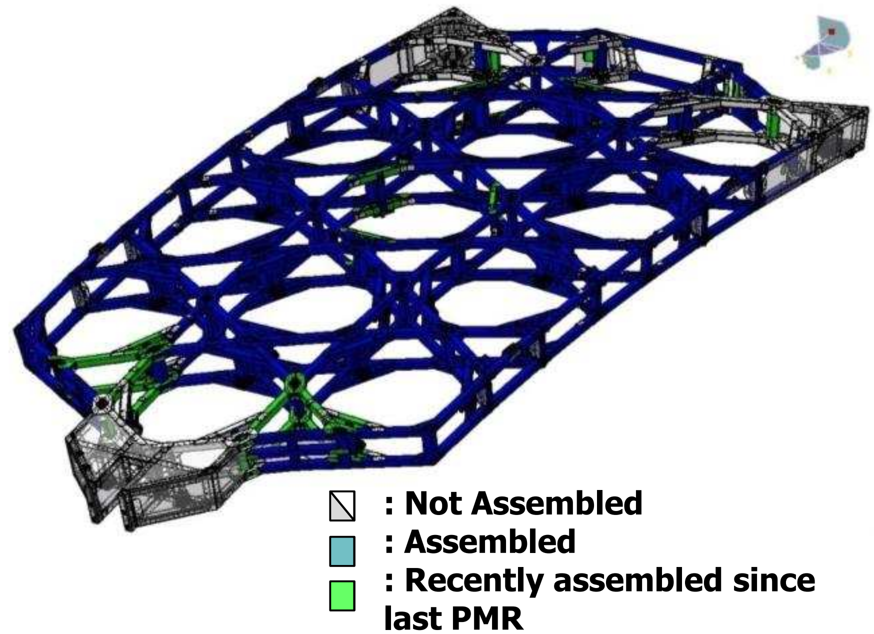
Completed Mirrors in Storage

Flight Backplane Bonding Status

Status as of: 11/30/2011

- **PMBSS Center Section fabrication and assembly**
  - Piece part fabrication - 100% complete
  - Assembly bonding continuing @ ~87% complete

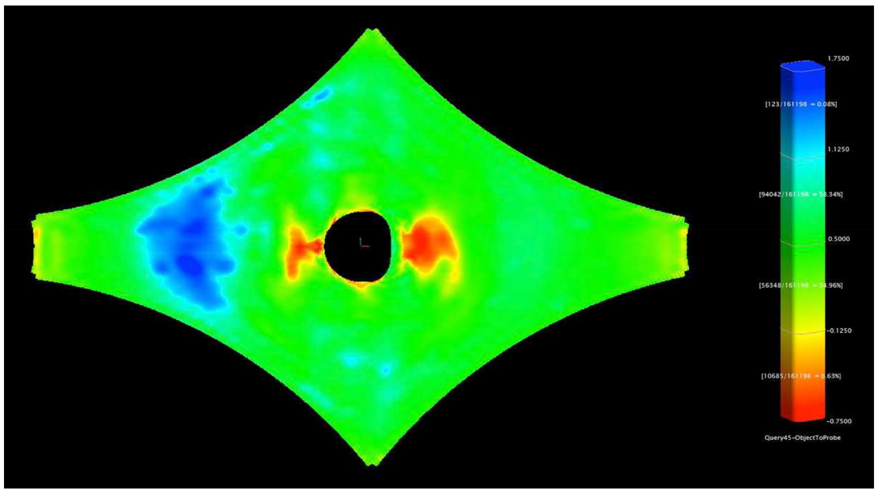
PMBSS Center Section Assembly - in process



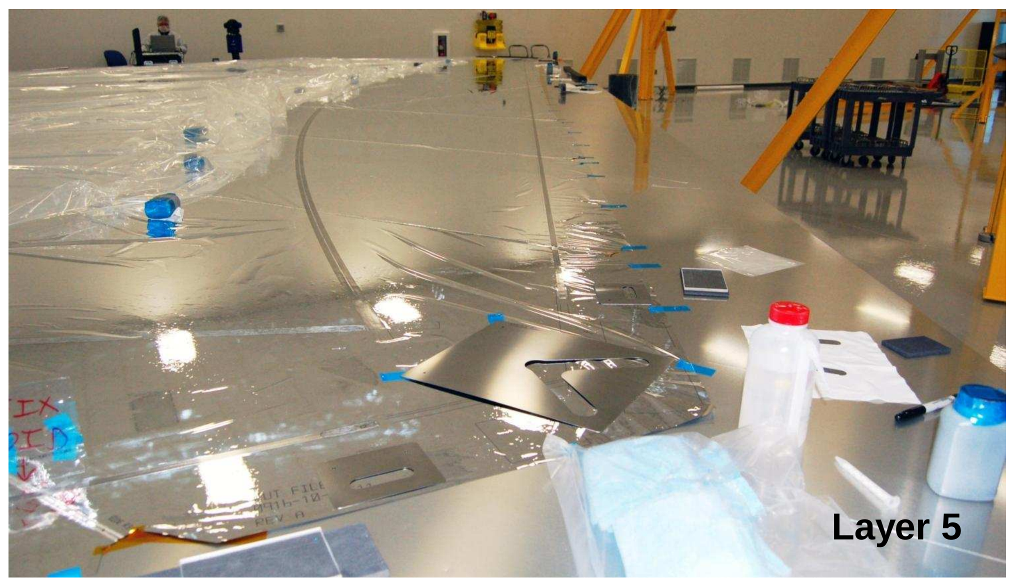
Center Section Assembly Locations

Sunshield Template Membrane Work On-Going

- **Template Layer 3 build and testing complete*. Packed for shipping to NGAS***
  - Shape measurements show RMS error of 0.71 in. versus requirement of 0.75 in.

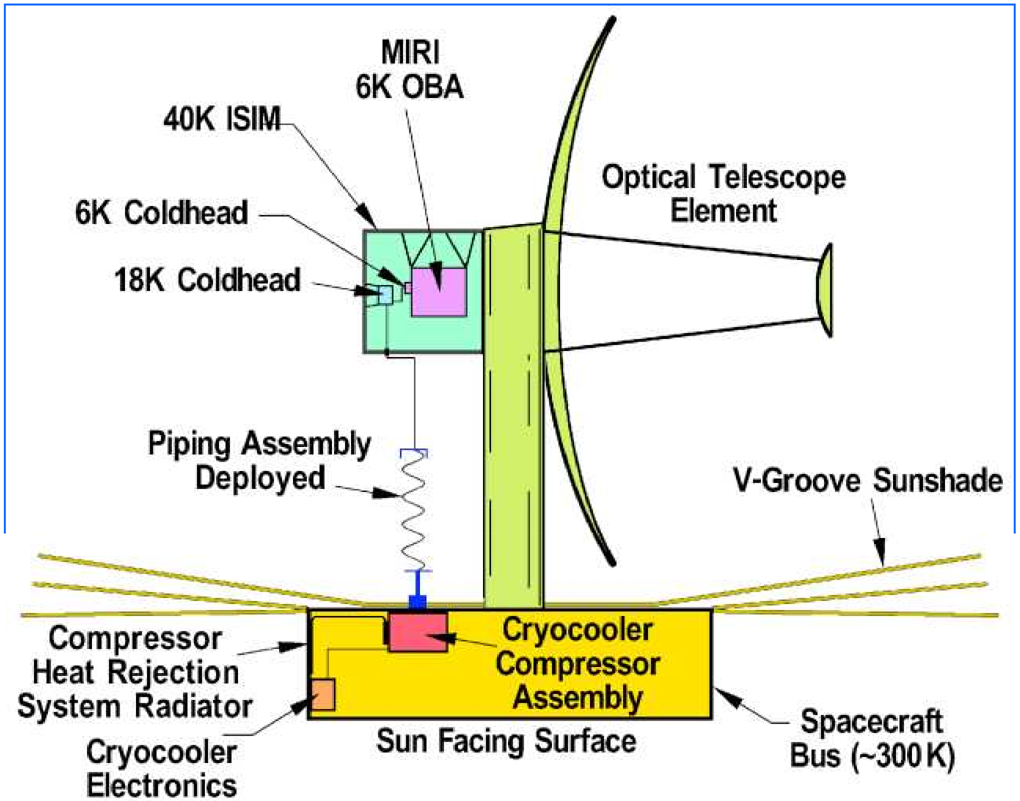


- **Template Layer 5 seamed and catenaries/fill regions installed. Currently getting edge features and grommets installed**
- **Template Layer 4 fully seamed**



MIRI Cryo Cooler Overview

- **Provides the needed active cooling to ~6K for the MIRI detectors and Optical Assembly**
  - The first long life, 6K mechanical cooler
  - Implemented as hybrid multi-stage mechanical Pulse-Tube Joule-Thomson (JT) Cooler
  - Challenging architecture with the 6K load several (~10) meters from the compressors



Technical Issue – Detector Degradation

- **Flight detector testing shows a degradation in pixel operability**
  - Impacts NIRCam, NIRSpec, and FGS

- **Detector FRB complete**
  - Found that detector degradation is caused by a design flaw which impacted its performance
    - *The Detector FRB found that the detector degradation is caused by a design flaw in the barrier layer of the pixel interconnect structure, degrading its performance*
    - *The flawed barrier layer design makes the detectors vulnerable to migration of indium from the indium bump interconnect into the detector structure*
  - Determined manufacturing and/or post-manufacture handling process changes are appropriate
  - Defined tests needed to screen-out degradation prone parts and insure the continued integrity of flight part
  - Fabrication of next generation detectors for testing (Jan-April) is underway

- **Decision for the detector swap will be in March 2012**

Technical Issue – Detector Degradation

- **ETU Detector Status**
  - Teledyne has recently completed testing Short Wave (SW) detectors fabricated for their ground-based astronomy customers.
    - Several of these SCAs were fabricated using new bake-stable process which will correct degradation issue seen on JWST detectors
      - Are similar to the JWST SW parts, thereby providing the first performance test of JWST-like parts using the new process
    - Test results show the new process does not appear to have any adverse effect on science performance
  - Still on schedule to receive the first Mid-Wave and SW detectors in early January
    - Total of 22 SCAs to be delivered (Jan-April) for testing
      - Testing starts at Teledyne in Jan, then proceeds to University of Arizona and the GSFC Detector Characterization Lab in Feb.

JWST Tech Spin Offs

New Optical Measurement Devices

- The need to accurately measure the shape of the JWST mirrors required significant improvements in wavefront sensing technology (Scanning Shack-Hartman Sensor)
- Has enabled a number of improvements in measurement technology for measurement of human eyes, diagnosis of ocular diseases and potentially improved surgery
  - Eye doctors can now get much more detailed information about the shape of your eye in seconds rather than hours
  - Four patents have been issues as a result of these innovations

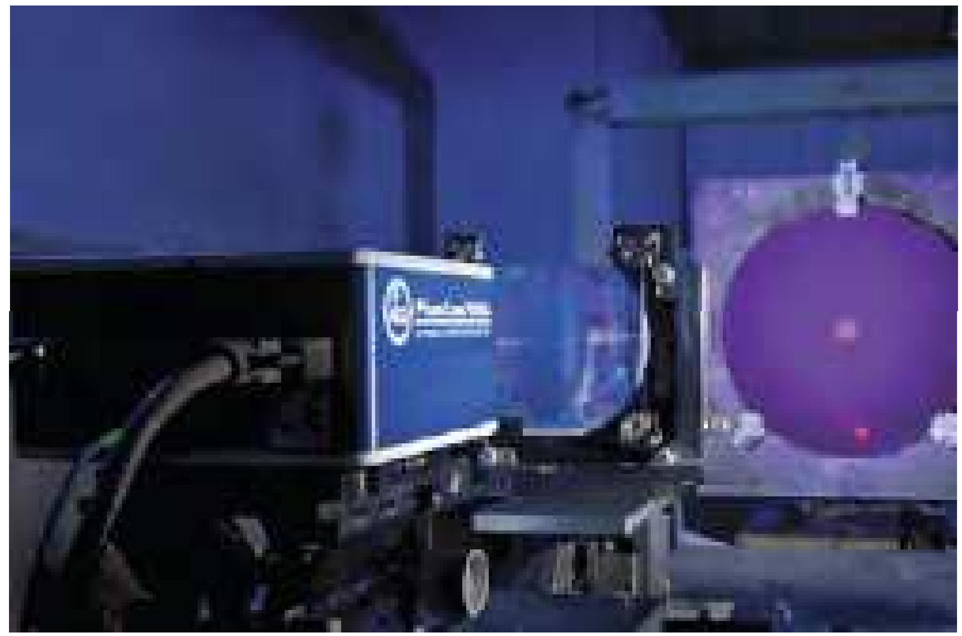
Cryogenic ASIC

- JWST developed a low-noise, cryogenic ASIC to convert the analog signals from the near-IR detectors to digital
- Same design used on ASIC now being used in the Advanced Camera for Surveys which was repaired during the HST SM-4 servicing mission
- “future heritage”

JWST Tech Spin Offs

Laser Interferometers utilizing High Speed Optical Sensors

- JWST needed to make measurements of mirrors and composite structures with nanometer precision in cryogenic vacuum chambers (with vibrations from pumping systems a constant problem)
- JWST provided 4D its first commercial contract to develop the PhaseCam interferometer system
- 4D Technology Corp has developed several new types of high-speed test devices that utilize pulsed lasers that essentially freeze out the effects of vibration
- 4D has gone on to generate over $30 M in revenue from a wide range of applications in astronomy, aerospace, semiconductor and medical industries based on the technologies developed for JWST



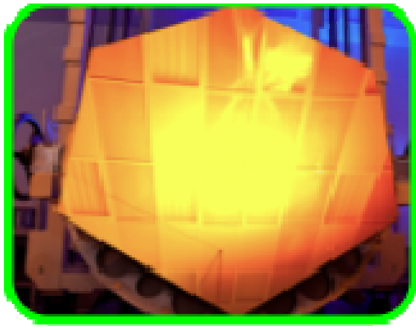
Implementing the New Baseline

- **Completed the replan (9/23/2011) with an October 2018 launch date**
  - Plan has adequate cost and schedule reserves consistent with ICRP recommendation
  - Additional $44M in FY11 was approved by Congress
  - FY12 budget approved by Congress with full funding for JWST
  - FY13 PBR fully funds the new baseline
- **Recent Accomplishments**
  - All flight optics have been cryo tested and meet requirements
  - Completed the Aft Optic System integration and alignment
  - Primary Mirror Backup Support Structure center section nearly complete (94% of bonding is complete)
  - Sunshield full scale Engineering Development Unit for layer #3 testing completed with good results
  - Instrument deliveries to GSFC begin in Spring 2012
- **Brought back in work with additional FY11 funding and FY12 budget**
  - Accelerated: Backplane Support Frame (BSF) by 4 months, completion of PMBSS by 4 months, start of Wings by 18 months, end of Flight Optics Integration by 4 months
  - Still have 13 month of funded schedule reserve on critical path
- **Instrument deliveries slipped moving ISIM delivery to OTIS by 5 months (31 months to 26 months)**
  - Even with Detector change out, still have 11 months slack for ISIM delivery to OTIS
  - ETUs for NIRSpec and NIRCam will be used in ISIM Cryo Test 1(all have flight hardware for CT 2+3)

JWST made great progress in FY11 and continues to do so in FY12, achieving milestones within cost and schedule and executing to the new baseline

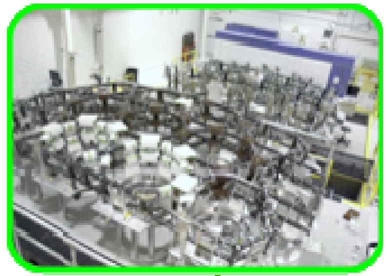
Hardware Fabrication Completion Percentages

Primary Mirror Segments



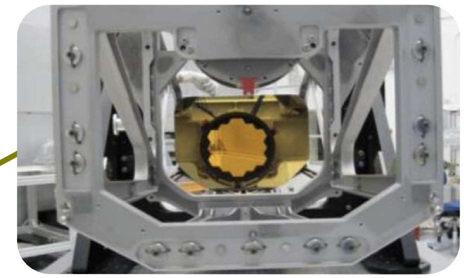
100%

Primary Mirror Support Structure



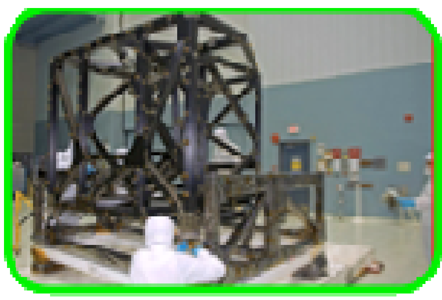
95%

Aft Optics System

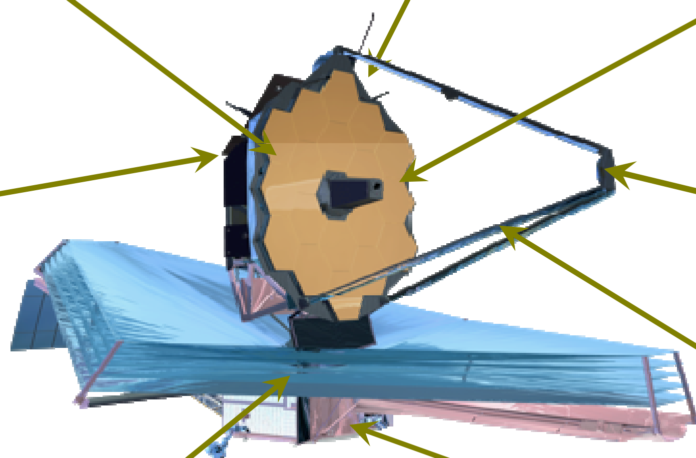


100%

Science Instrument Module & Science Instruments



90%



100%

Secondary Mirror

Green borders denote actual spaceflight hardware images, red borders are test equipment

40%

Sunshield Membranes

25%

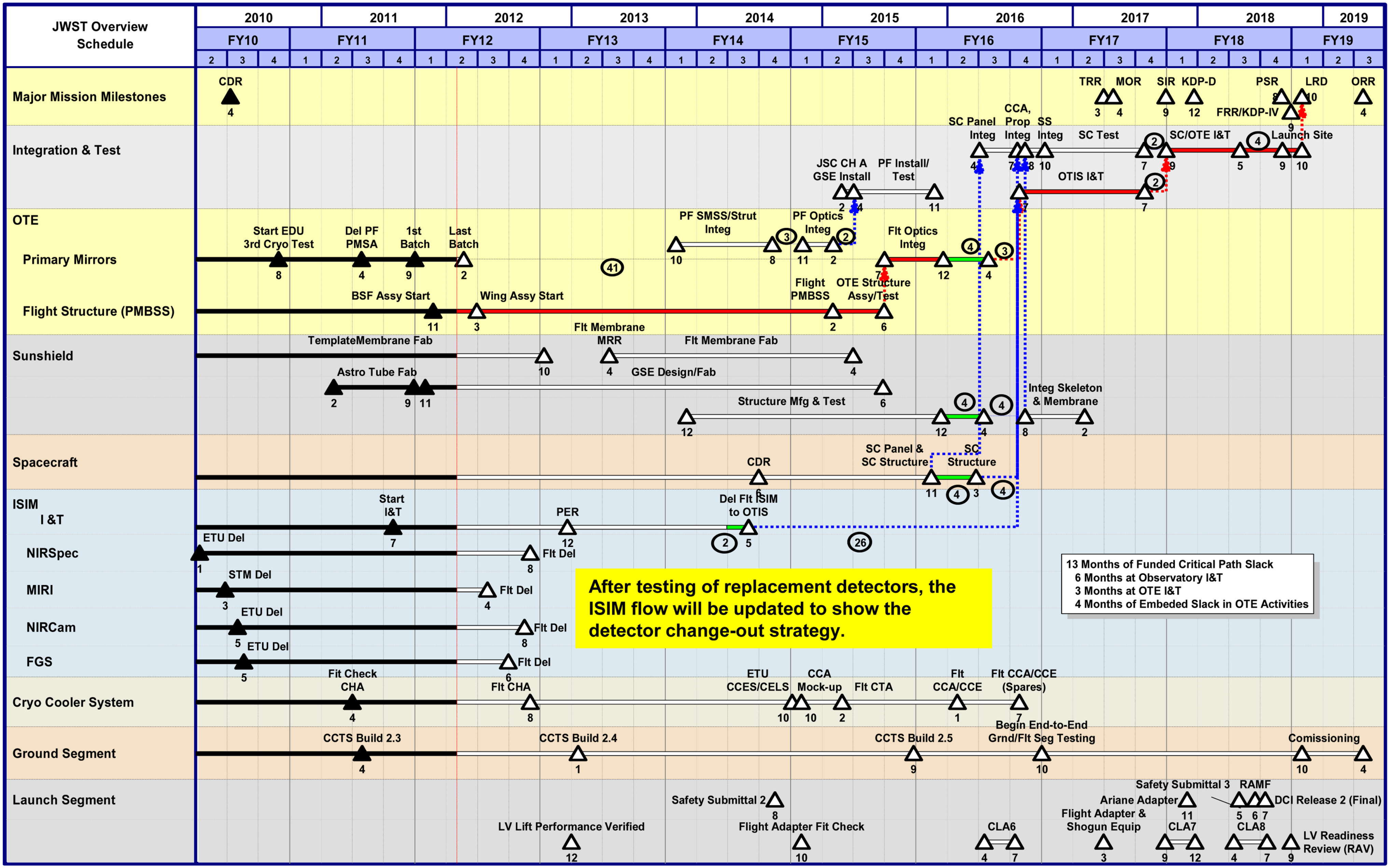
Spacecraft Bus

Secondary Supports

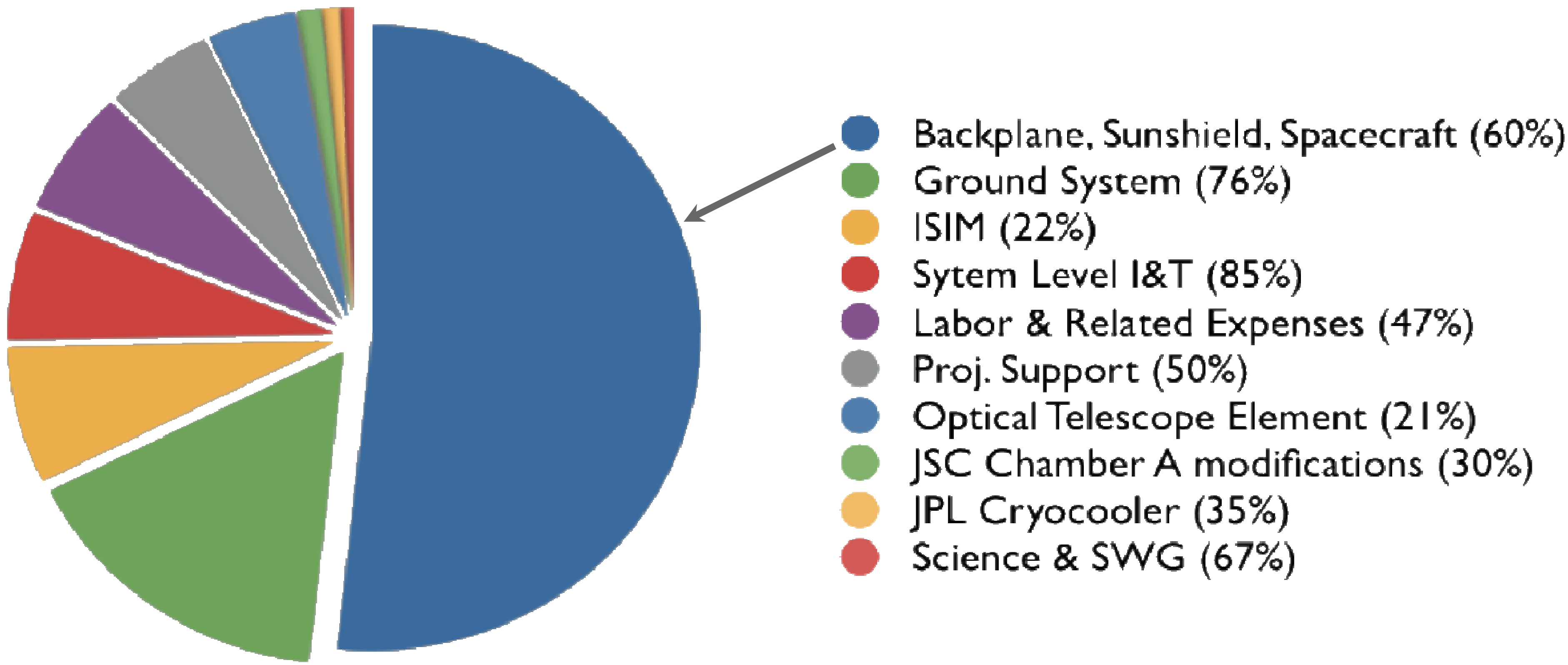
80%

As of 1/13/2012

Master Schedule



Work-To-Go (FY12 to Launch and Commissioning)



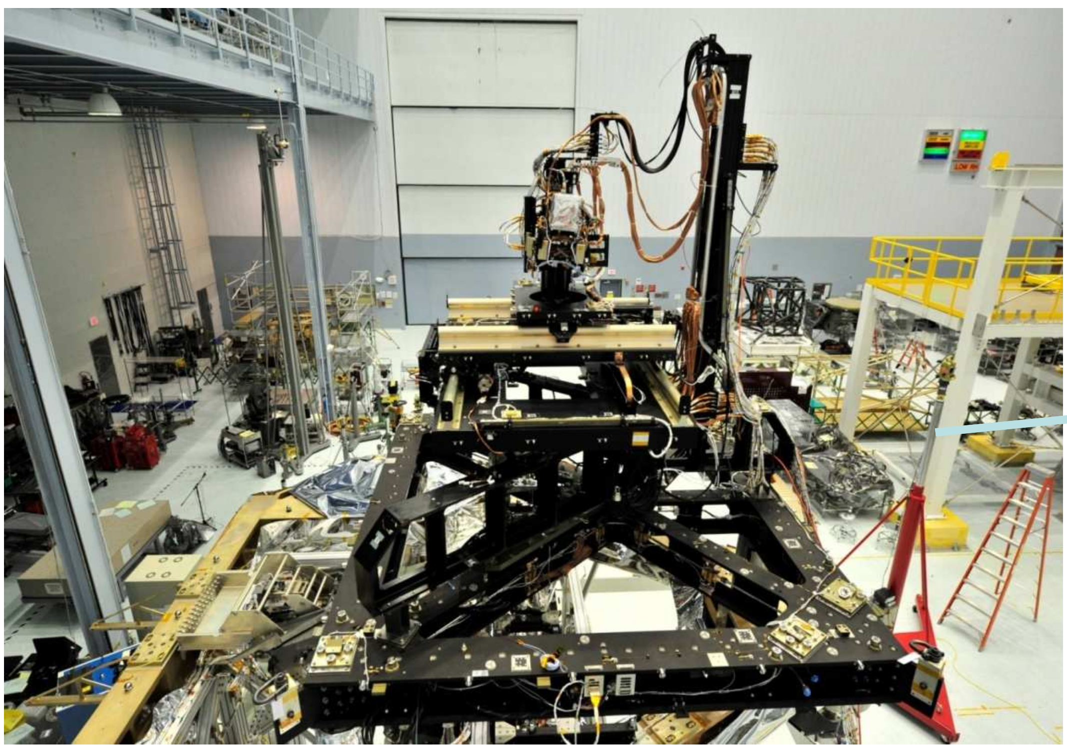
Relative proportion of project funding to-go

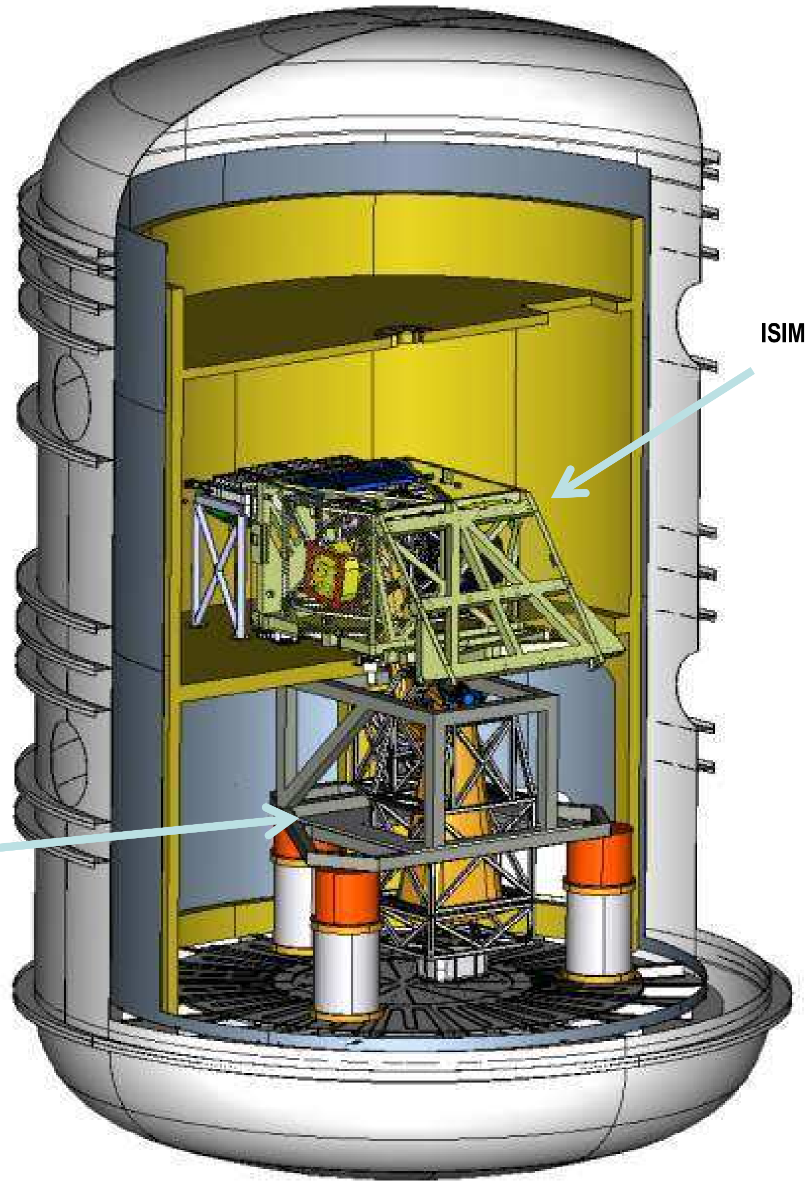
% work on this element to-go

Optical telescope element Simulator (OSIM) Integration

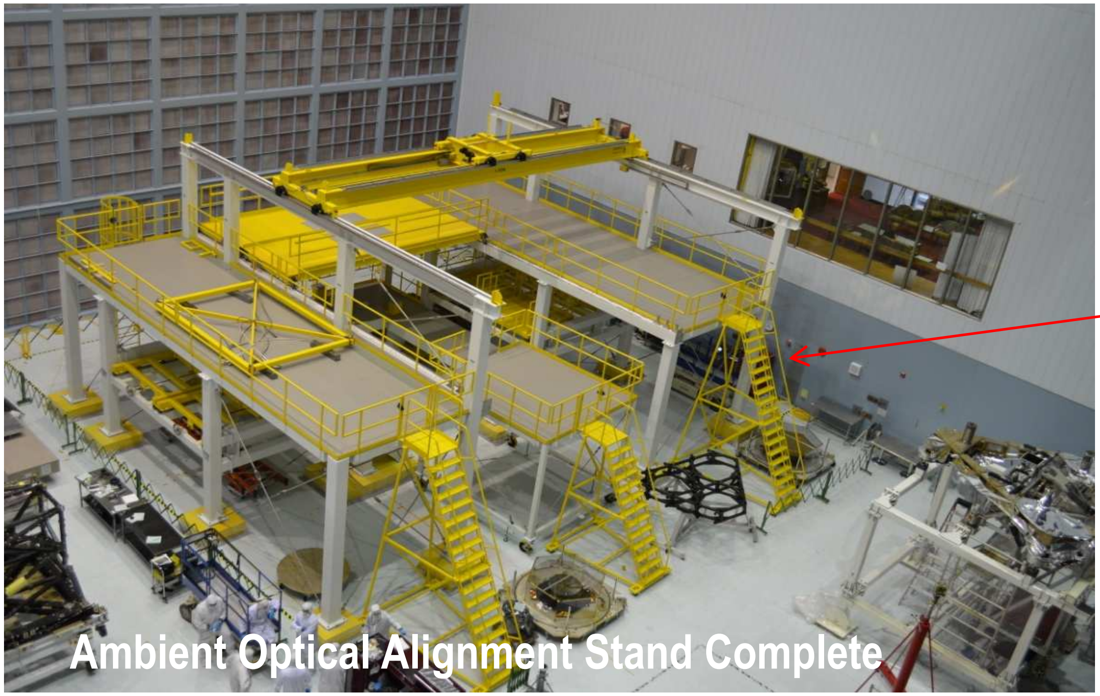
On Track for Cryo Verification mid-April 2012

Status as of: 1/31/12

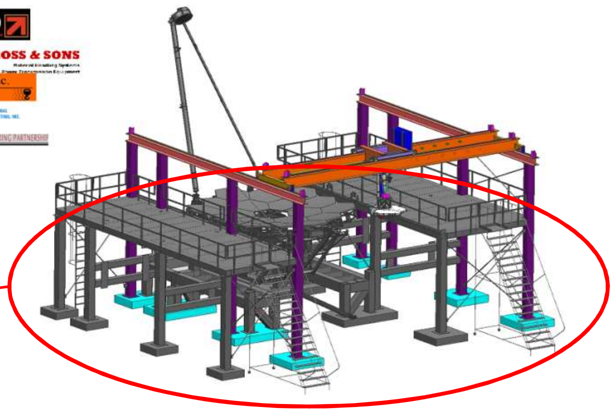




Telescope Assembly Ground Support Equipment


Ambient Optical Alignment Stand Complete

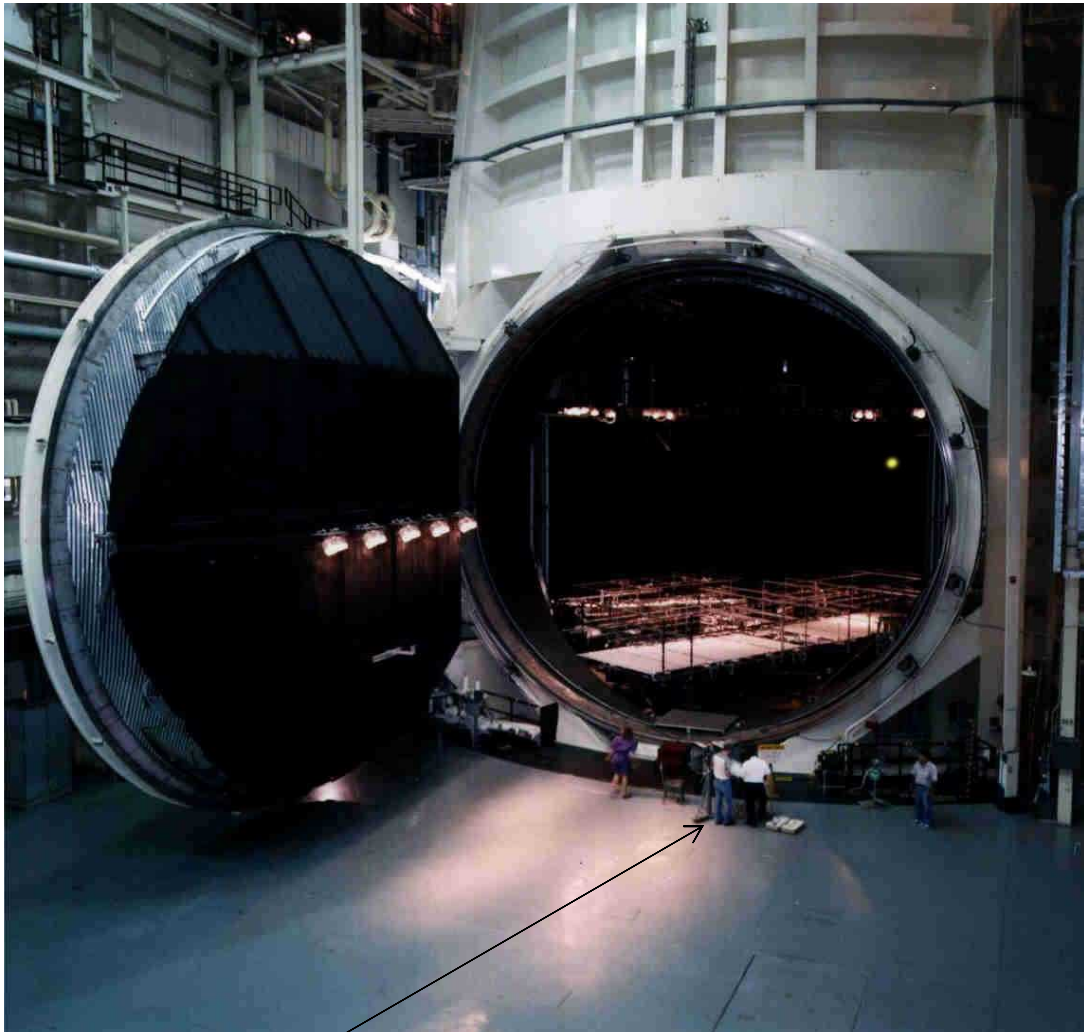
PMD
HM CROSS & SONS
Cranetech inc.
JPW



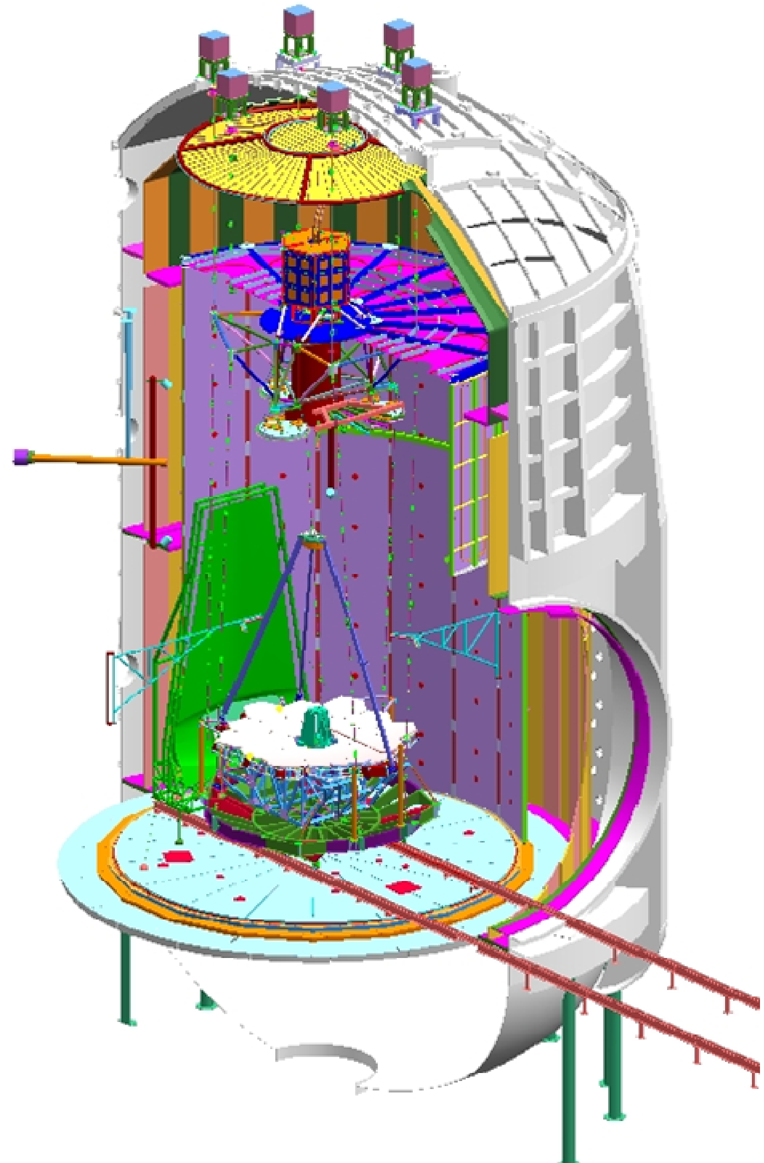
Hardware has been installed at GSFC approximately 8 weeks ahead of schedule

Landing a mirror onto backplane simulator

OTE Testing – Chamber A at JSC

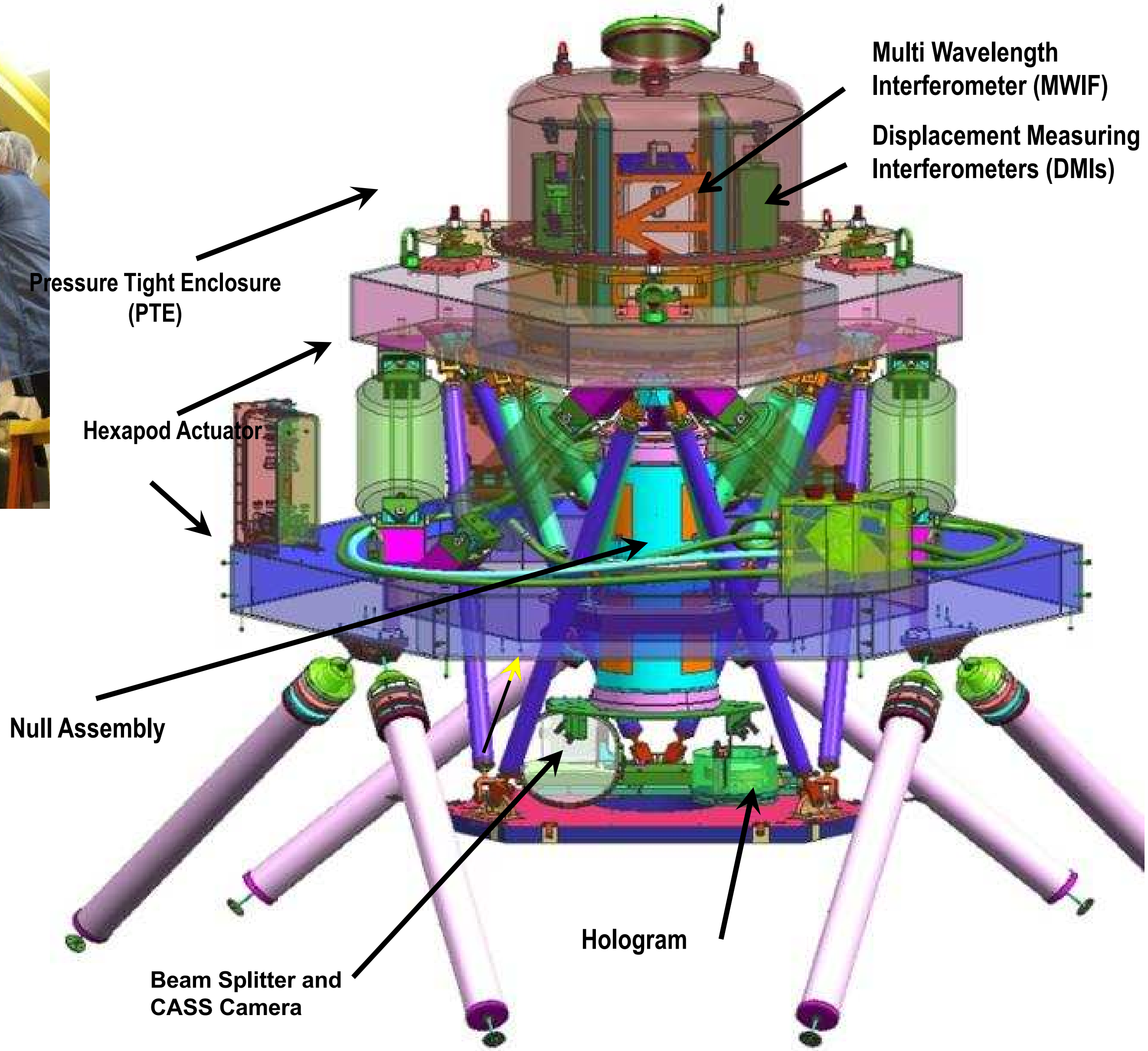


Notice people for scale



Will be the largest cryo vacuum test chamber in the world

Center of Telescope Curvature Optical Test Equipment



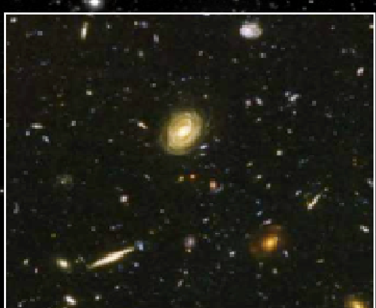
BACKUP

JAMES WEBB SPACE TELESCOPE MISSION

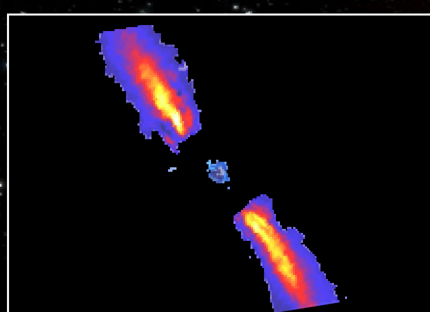
James Webb Space Telescope (JWST) goes beyond Hubble and other space telescopes by seeing things that they cannot see…

- How did the universe make galaxies?
- Are there other planets that can support life?
- How are stars made?

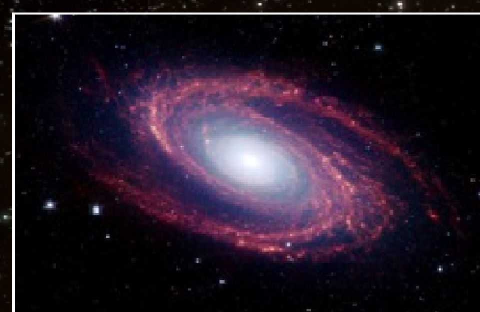
JWST is about beginnings: the beginning of galaxies, the beginning of stars, the beginning of planets and life.



First Light



Planets and the Origins of Life

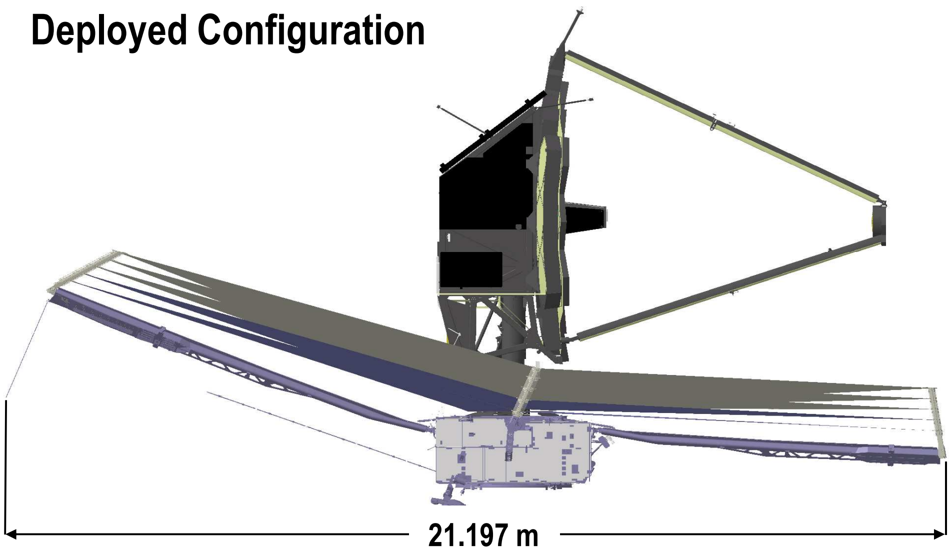


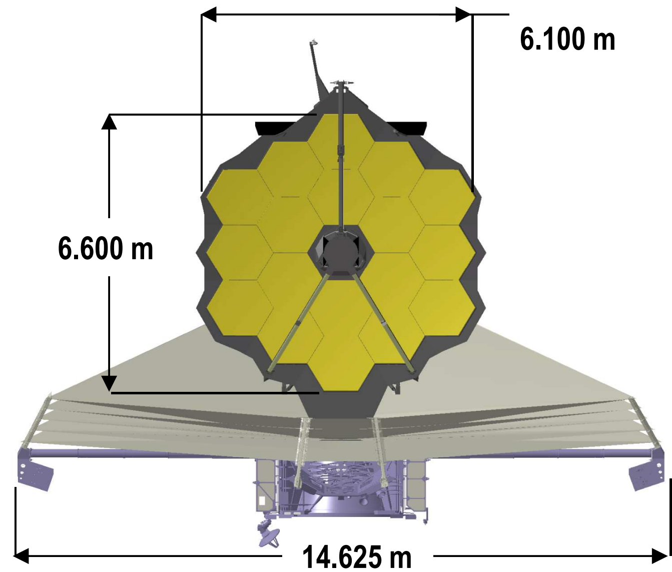
The Assembly of Galaxies

Birth of Stars and Planets

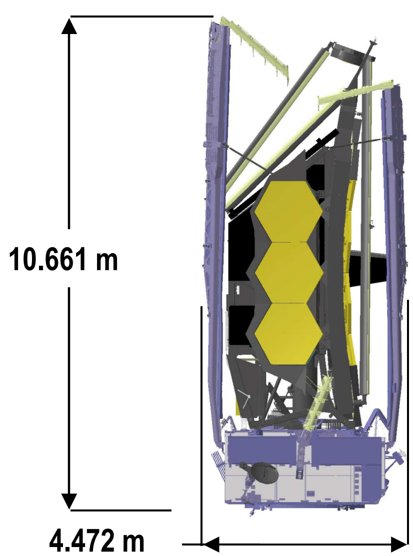
TECHNICAL DETAILS

Deployed Configuration





Stowed Configuration



- Optical Telescope Element (OTE) diffraction limited at 2 micron wavelength.
  - 25 m^2 , 6.35 m average diameter aperture.
  - Instantaneous Field of View (FOV) ~ 9' X 18'.
  - Deployable Primary Mirror (PM) and Secondary Mirror (SM).
  - 18 Segment PM with 7 Degree of Freedom (DOF) adjustability on each.
- Integrated Science Instrument Module (ISIM) containing near and mid infrared cryogenic science instruments
  - The Near-infrared camera functions as the on-board wavefront sensor for initial OTE alignment and phasing and periodic maintenance.
- Deployable sunshield for passive cooling of OTE and ISIM.
- Mass: $\leq$ 6530 kg .
- Power Generation: 2000 Watts Solar Array.
- Data Capabilities: 471 Gbits on-board storage, 229 Gbits/day science data.
- Science Data Downlink: 32 Mbps.
- Life: 5 years [Designed for 11 years (goal) of operation].