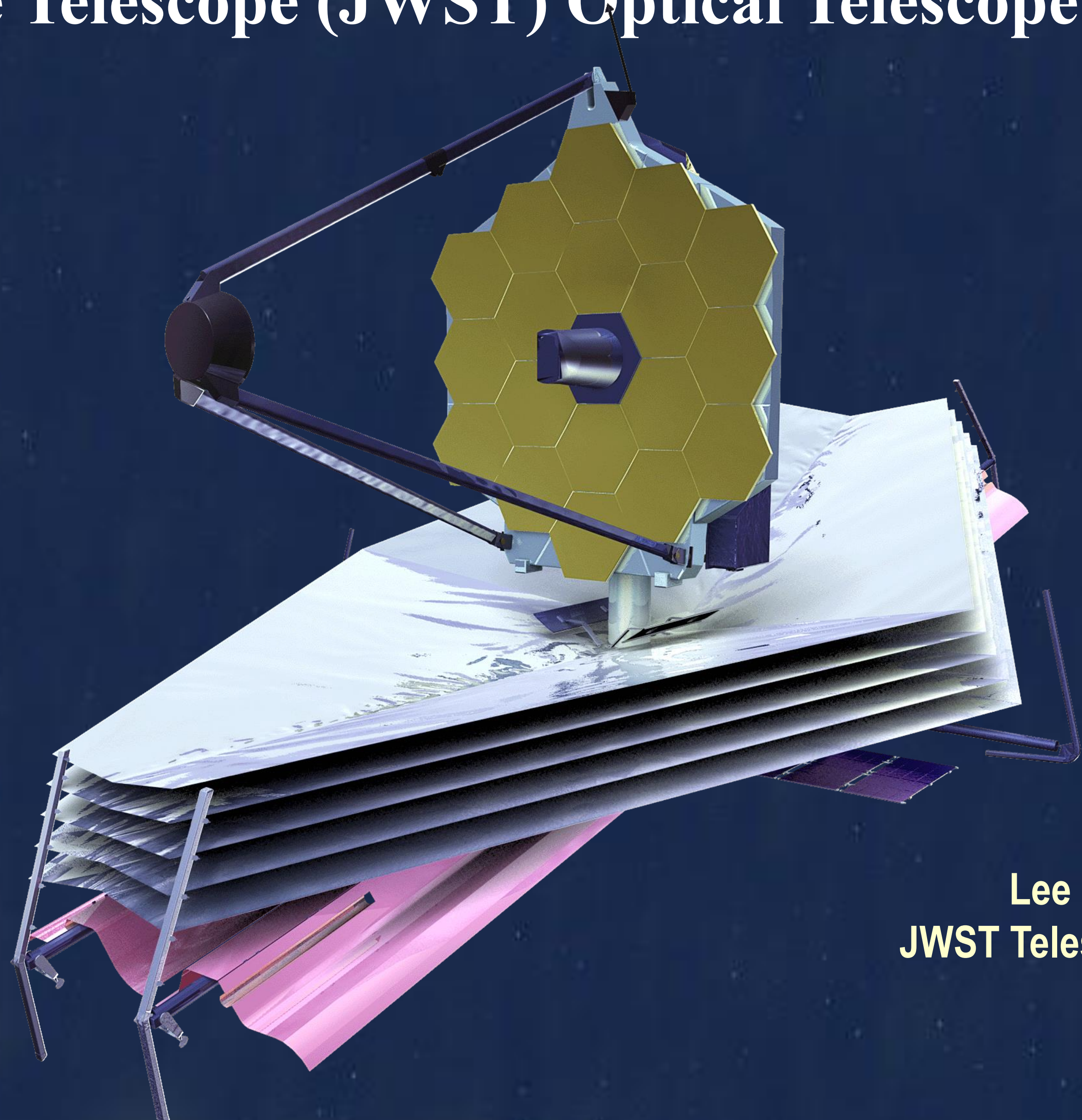
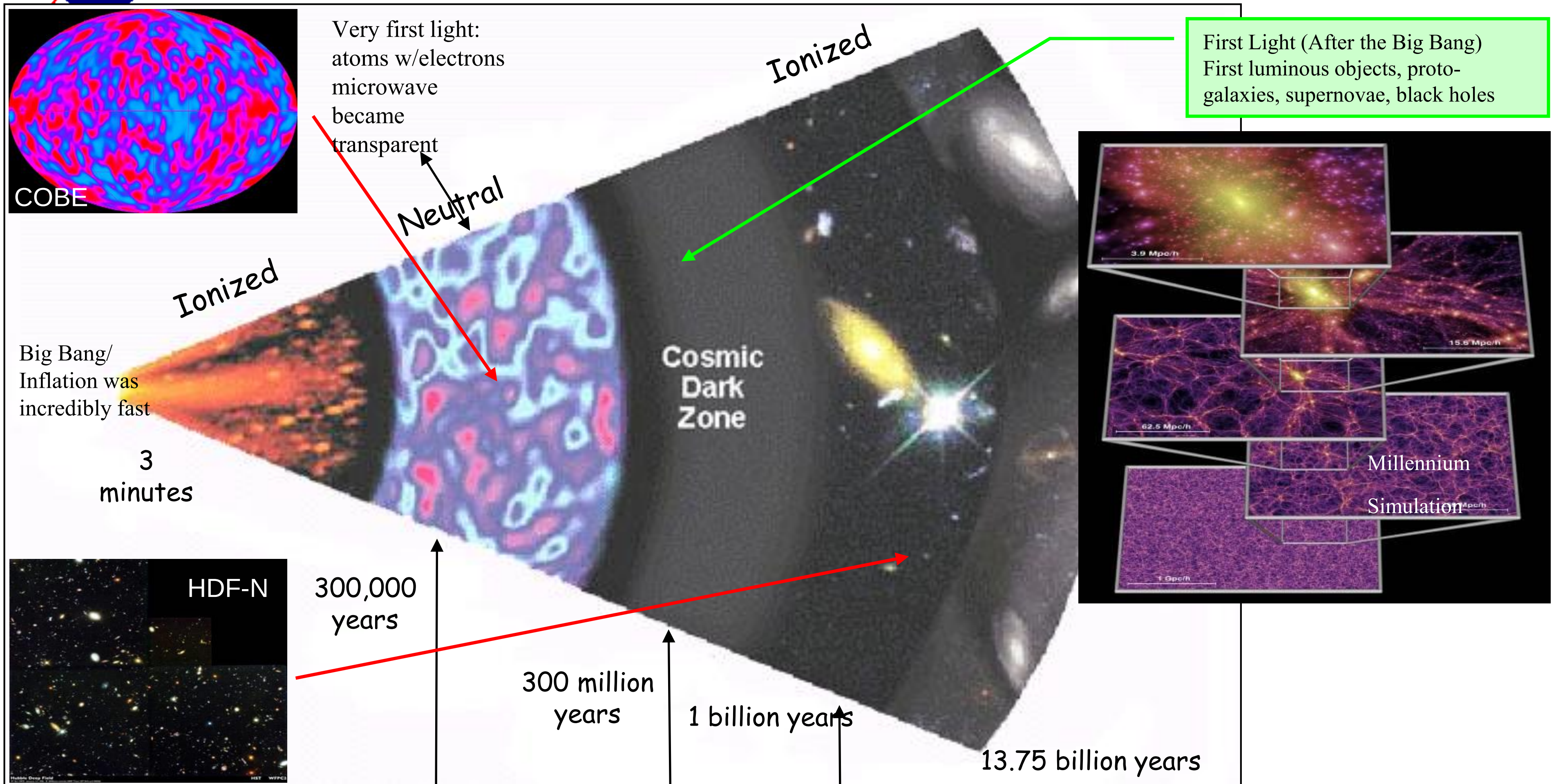
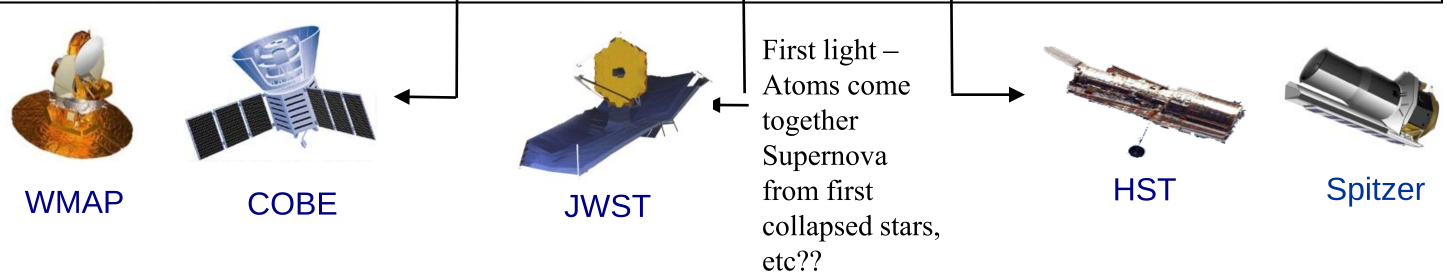
Looking Back in Time: Building the James Webb Space Telescope (JWST) Optical Telescope Element



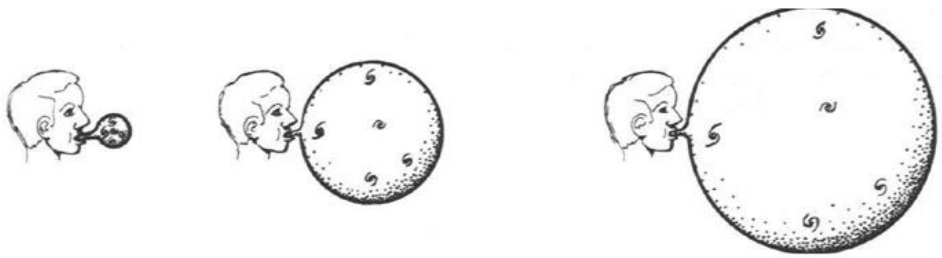
Lee Feinberg
JWST Telescope Manager

JWST is designed to observe formation of the first galaxies

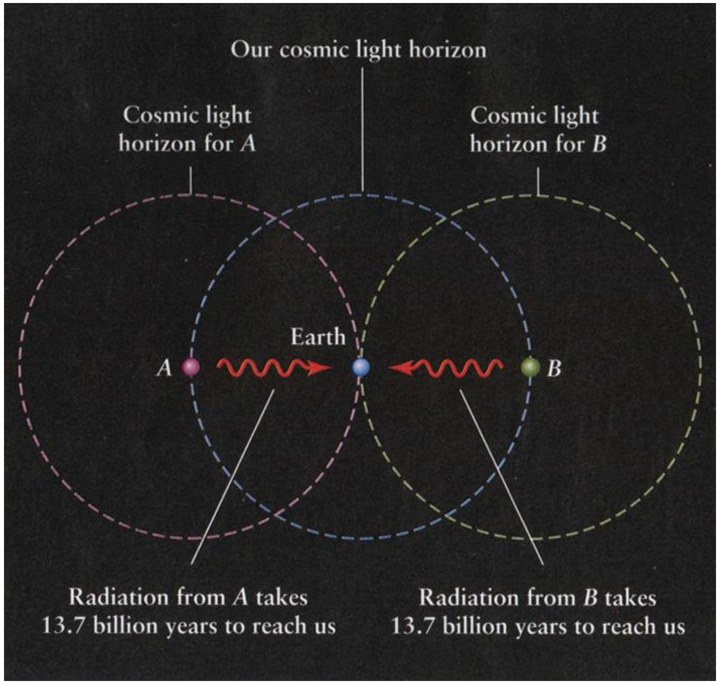




Looking back, seeing the Edge of Time (cosmic light horizon)



The Expanding Universe

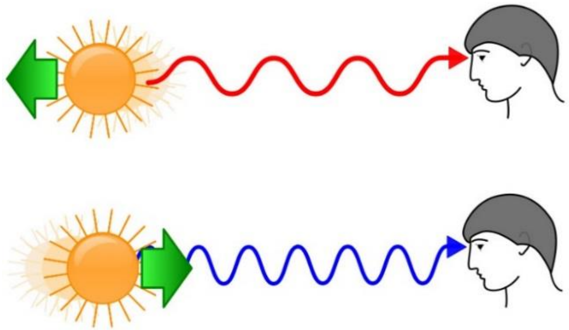


Need to look at farthest region of sky to see 13.4 billion years back (first light) – other first light has already passed us…

Fabric of space stretches thus making light red shifted to infrared (1.5um-2um ?)

Really far so dim (need > 25 sq meters)

These photons could not have communicated with each other unless inflation took place during the very early Universe



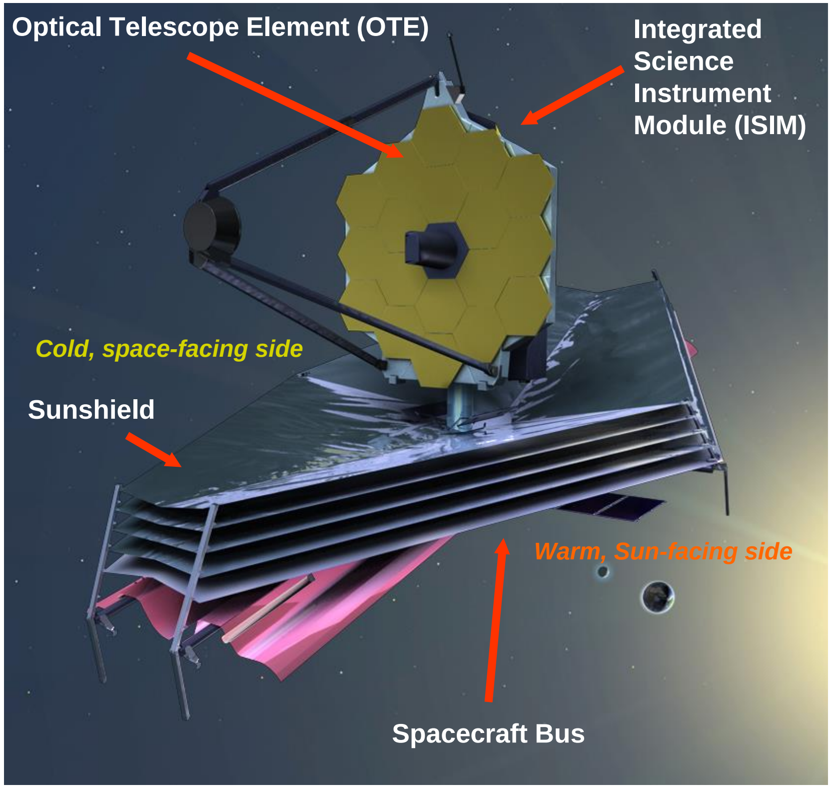
From: http://www.ctc.cam.ac.uk/outreach/origins/inflation_zero.php

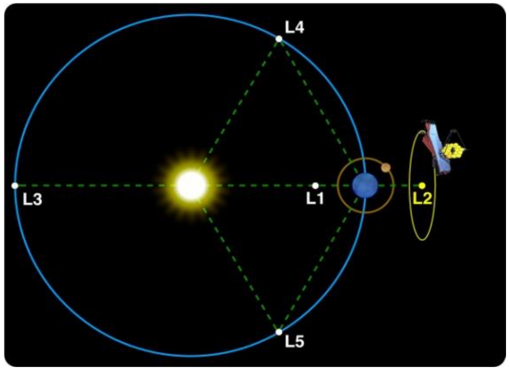
James Webb Space Telescope (JWST)

Mission Objective

- Study the origin and evolution of galaxies, stars and planetary systems
  - *Optimized for infrared observations (0.6 – 28 μm)*

- **Organization**
  - Mission Lead: Goddard Space Flight Center
  - International collaboration with ESA & CSA
  - Prime Contractor: Northrop Grumman Space Technology
  - Instruments:
    - Near Infrared Camera (NIRCam) – Univ. of Arizona
    - Near Infrared Spectrograph (NIRSpec) – ESA
    - Mid-Infrared Instrument (MIRI) – JPL/ESA
    - Fine Guidance Sensor (FGS) – CSA
  - Operations: Space Telescope Science Institute (STScI)



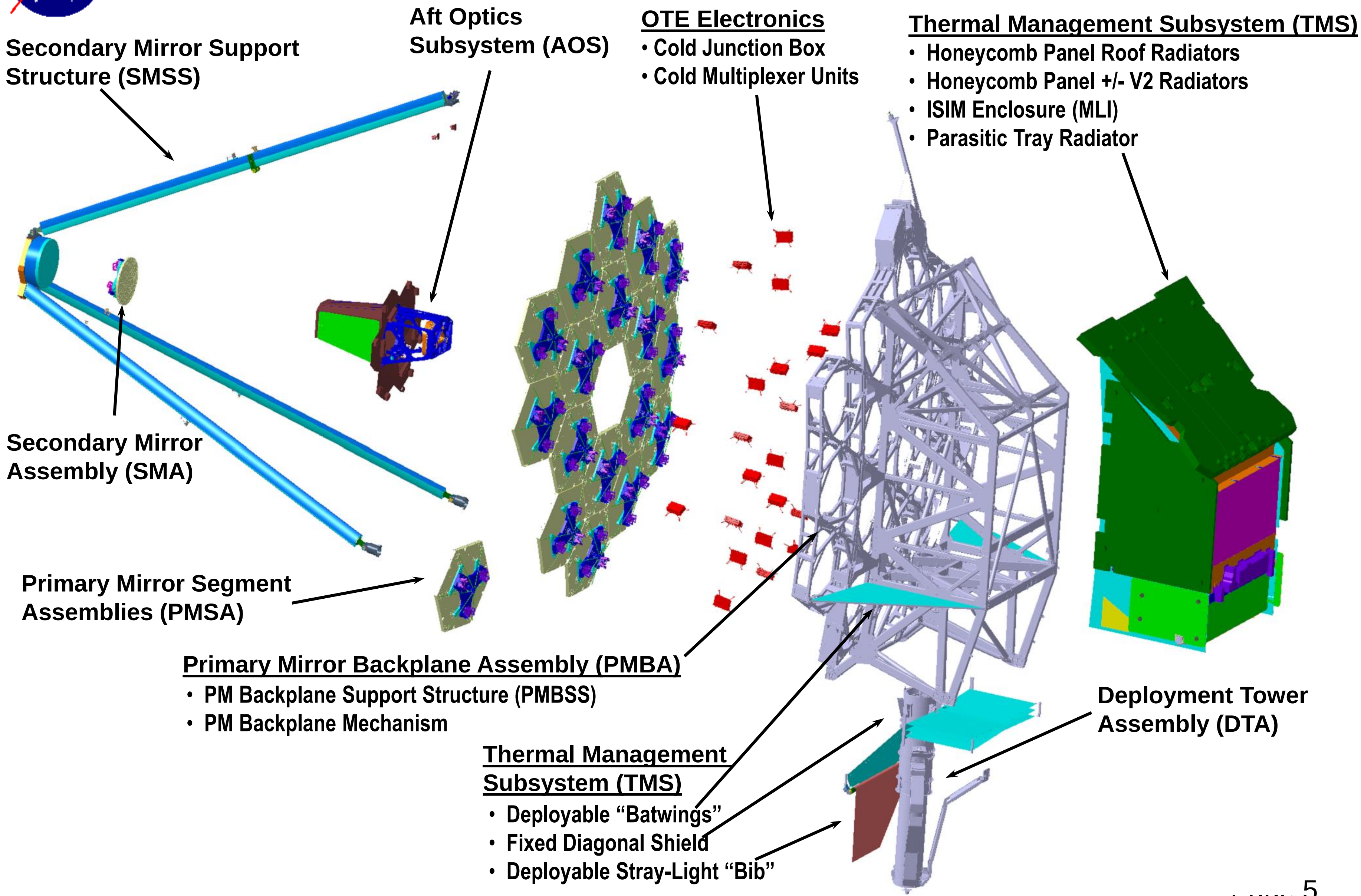


Description

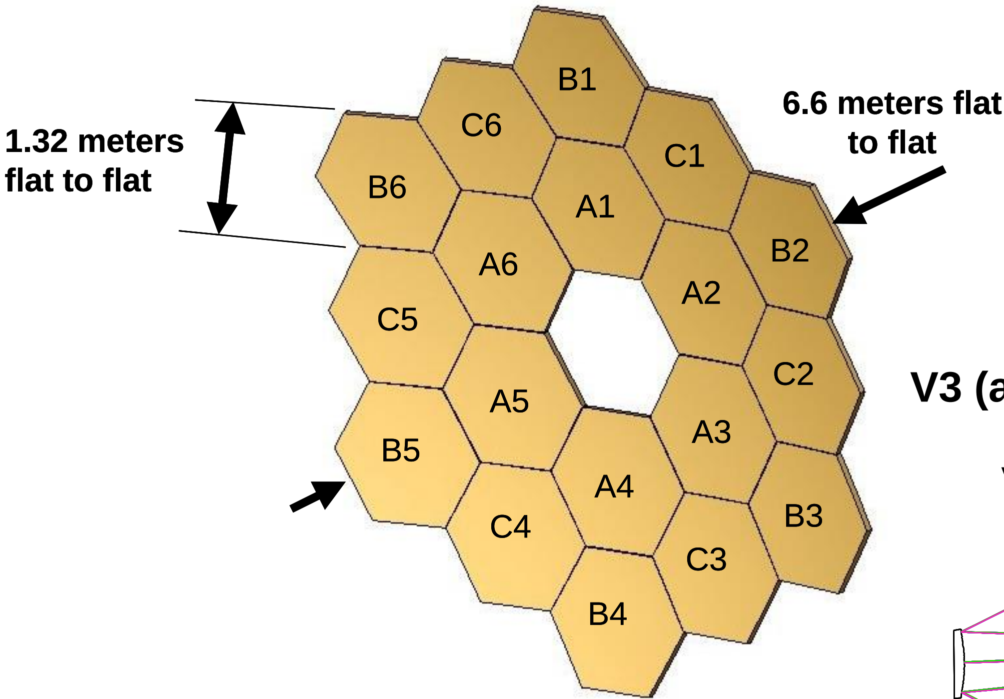
- Deployable telescope w/ 6.5m diameter segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
  - 50K, -370F
- Launch NET Oct 2018 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

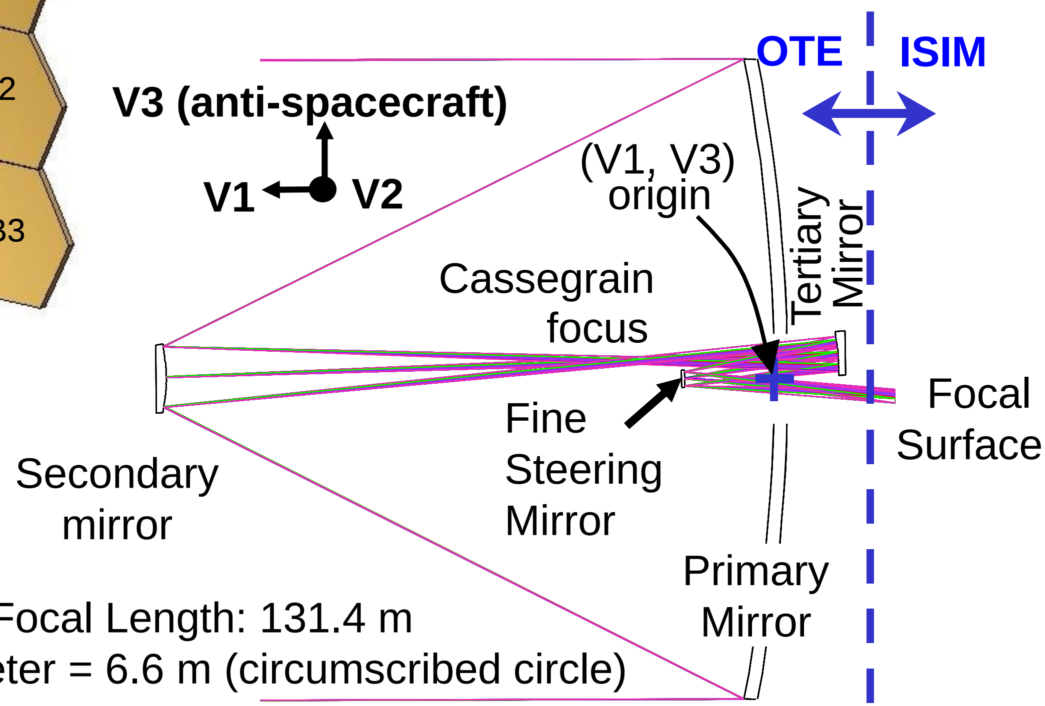
www.JWST.nasa.gov

OTE Architecture Overview



Three Mirror Anastigmat Optical Design Provides a Wide Field-of-View





f/#: 20.0

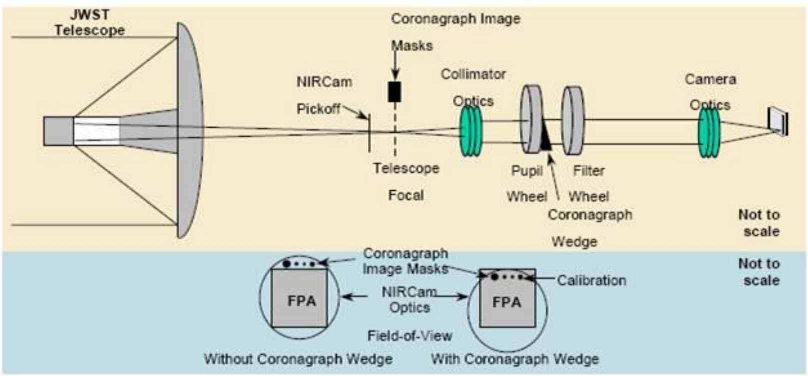
Effective Focal Length: 131.4 m

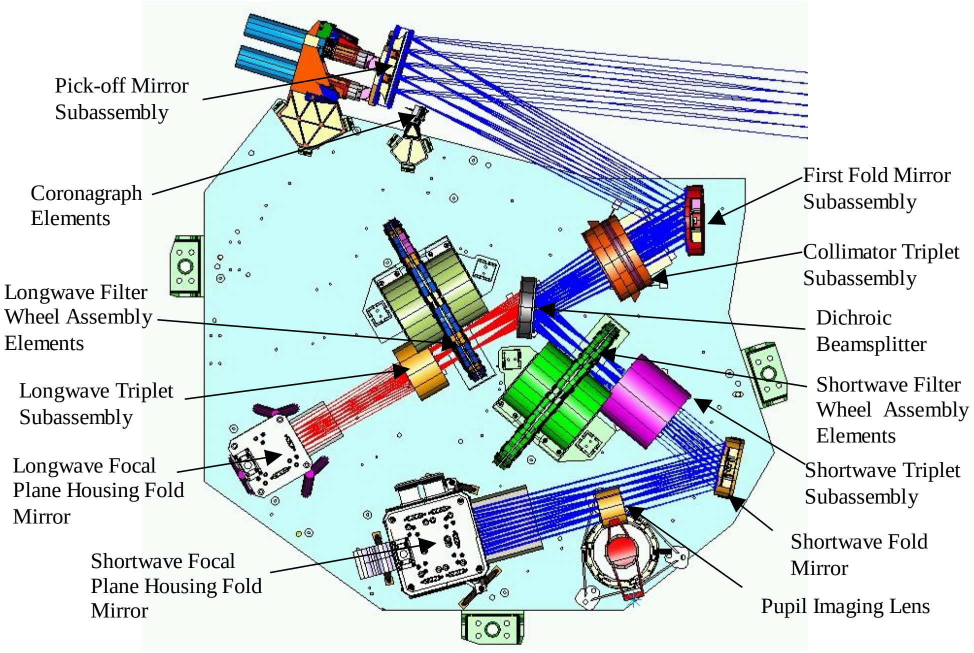
PM diameter = 6.6 m (circumscribed circle)

NIRCam serves as the main Wavefront Sensor for the OTE

Developed by the University of Arizona with Lockheed Martin ATC

- Operating wavelength: 0.6 – 5.0 microns
- Field of view: 2.2 x 4.4 arc minutes
- 2 redundant channels each with Short (.6-2.5um) and Long Wave (up to 5um)
- Short wave channels host OTE wavefront sensing elements:
  - Weak lenses and filters for fine phasing
  - Grisms for coarse phasing
  - Pupil imaging lens used by I+T and for pupil illumination and alignment



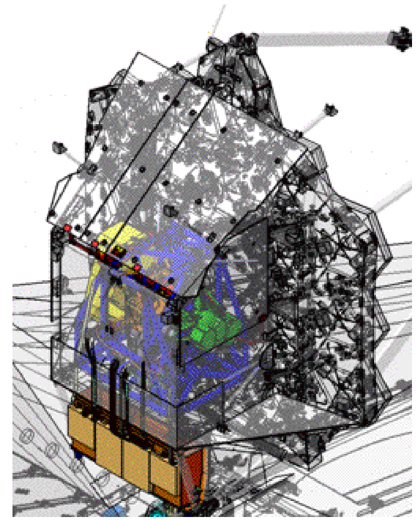


Why 18 segments?

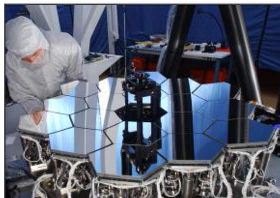
- **Original Northrop Grumman proposal was for a 7 meter, 36 segment telescope with 3-degrees of freedom per mirror**
- **Trades were done to:**
  - Save money by reducing size slightly, enabling 18 segment option
  - Adding 6-degree of freedom of hexapods on mirrors gives us adjustability in decenter and rotation – this wound up being critical!
  - Segmentation trade of 18 vs 36
    - Larger segments had more risk of misalignment but hexapods mitigated that risk
    - Based on mirror technology developments, we learned the effort to make a mirror was not strongly influenced by size and thus making half as many would be less effort.
    - Having hexapods drove us more to a few actuator thus fewer segment option
    - In the end, the decision to go with mirrors that had hexapods was incredibly important or our I+T program would be much more difficult and thus 18 made sense

JWST Technology validated by NAR/PDR
1-year in advance at Technology NAR
OTE PDR in November 2007, Mission PDR in 2008

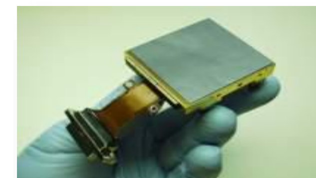
Backplane



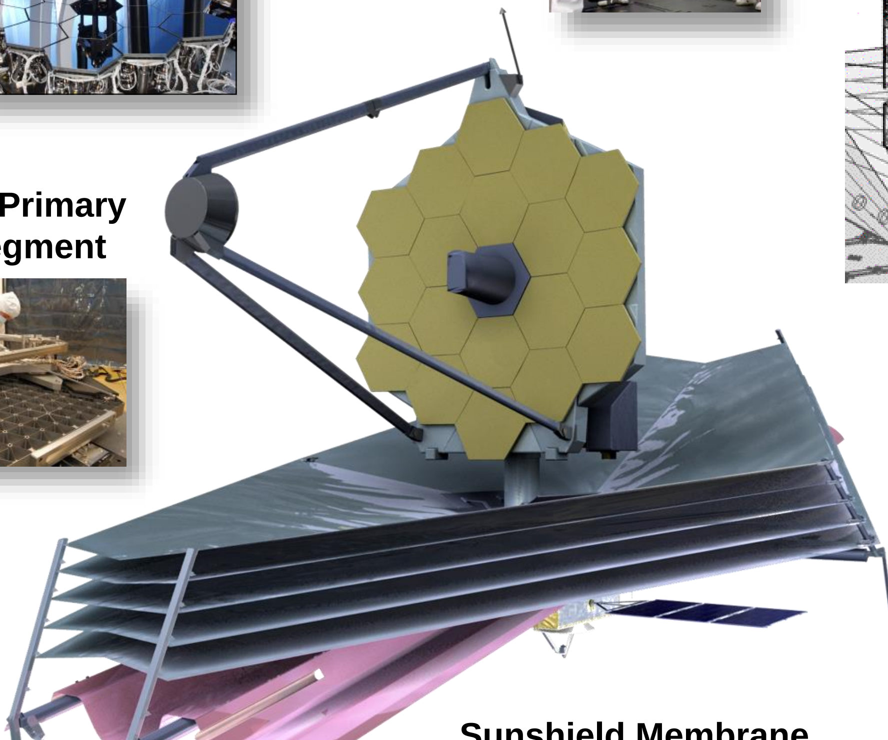
Mirror Phasing Algorithms



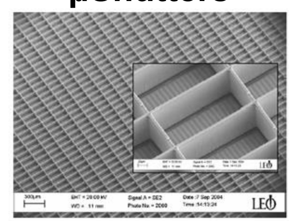
Near-Infrared Detector



Beryllium Primary Mirror Segment

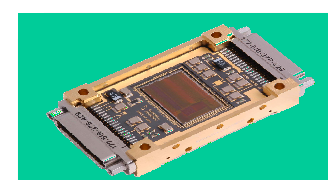


µShutters



Mid-Infrared Detector

Cryogenic ASICs

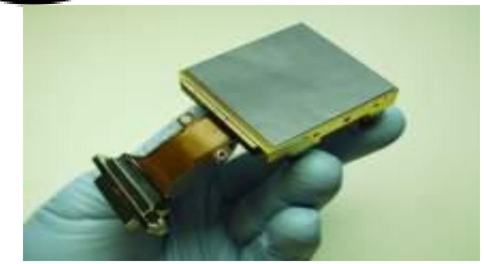


Cryocooler

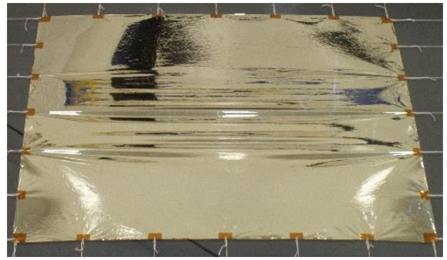
Sunshield Membrane

Technologies Demonstrated in 2006

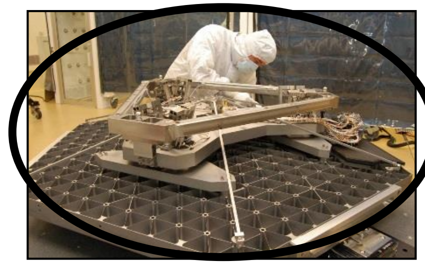
(All our mission critical technologies, OTE are circled)



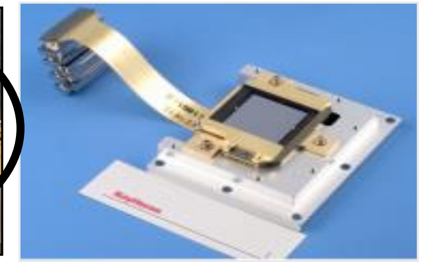
Near Infrared Detectors
April 2006



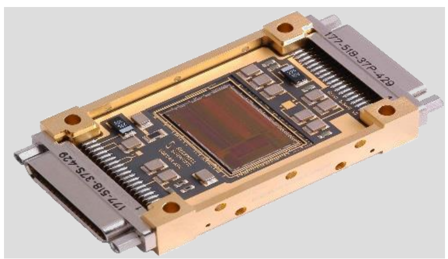
Sunshield Material
April 2006



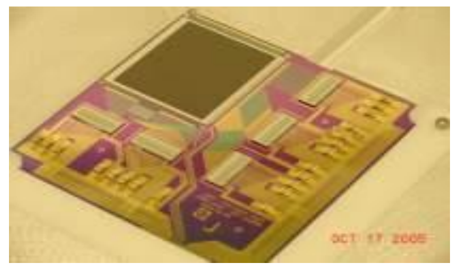
Primary Mirror Segment Assembly
June 2006



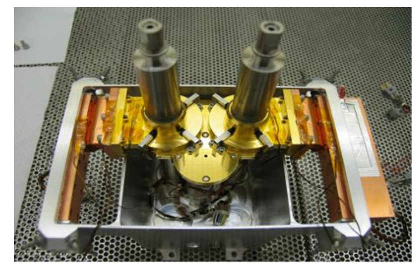
Mid Infrared Detectors
July 2006



Cryo ASICs
August 2006

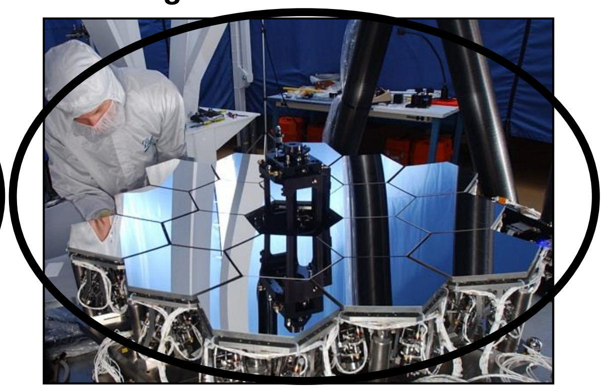


Microshutter Arrays
August 2006

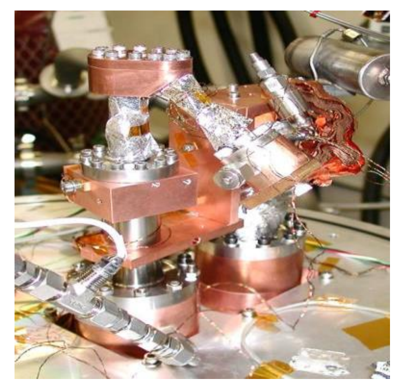


Heat Switches
September 2006

Large Precision Cryogenic Structure
November 2006



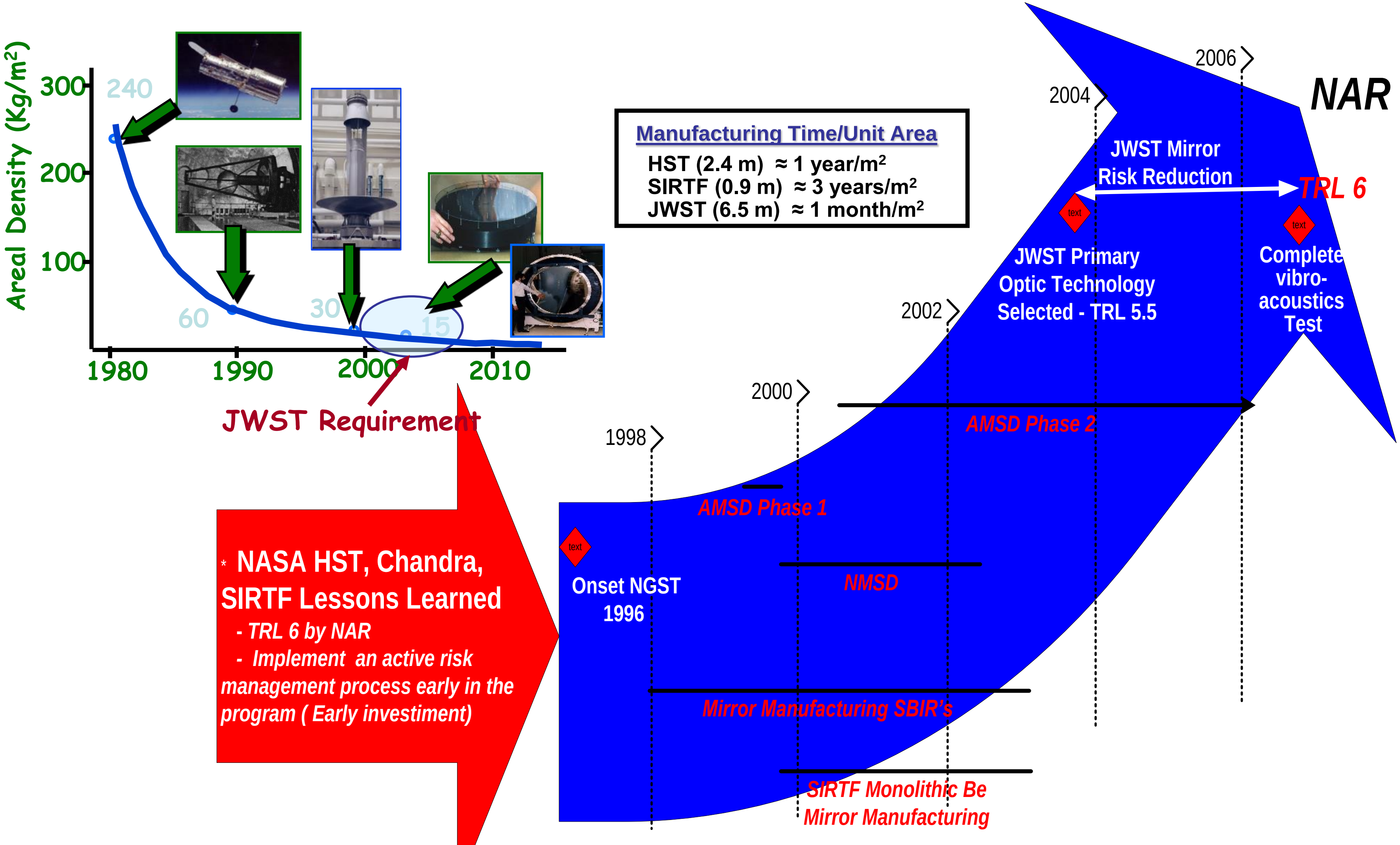
Wavefront Sensing & Control
November 2006



Cryocooler
December 2006

MIRRORS

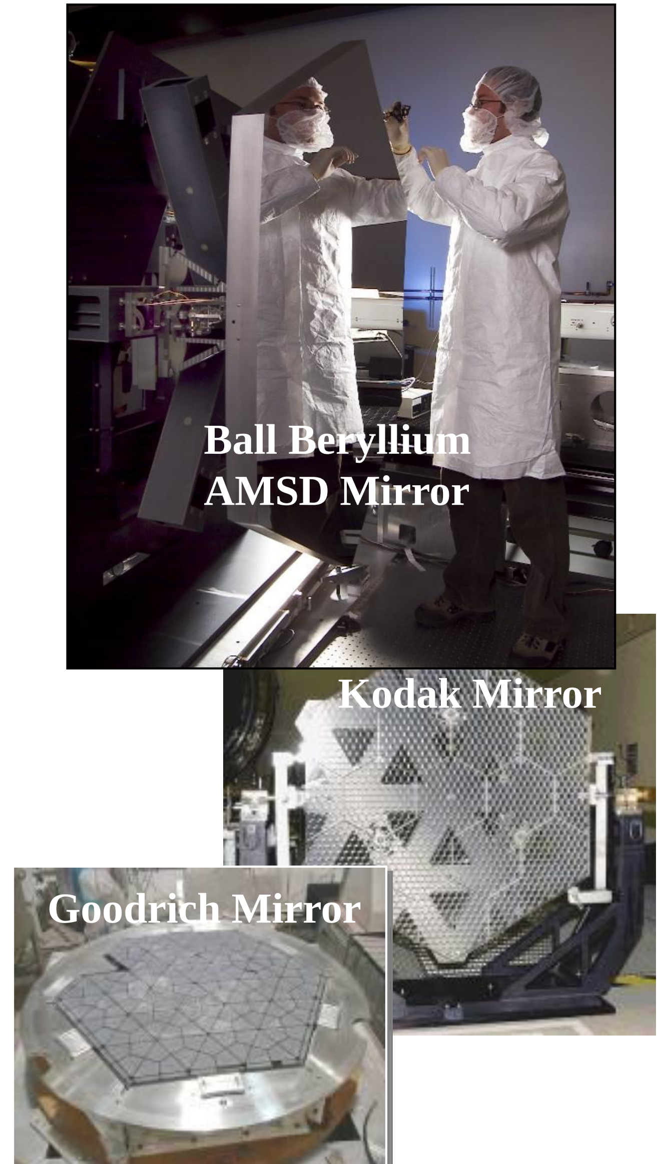
JWST Mirror Technology History



Based on lessons learned, JWST invested early in mirror technology and mirror production to address lower areal densities and manufacturing time

Advanced Mirror System Demonstrator (AMSD)

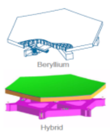
- NASA, DOD, NRO $50M partnership funded 3 lightweight mirror technologies shown on the right
- Ball beryllium mirror technology completed and baselined for JWST in 2003
  - Ball beryllium mirror demonstrated all key aspects of JWST technology except for demonstration of vibro-acoustics survival which was demonstrated on the Engineering Design Unit mirror
- Mirror manufacturing of flight mirrors started in September 2003



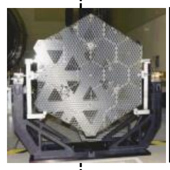
Mirror History

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**

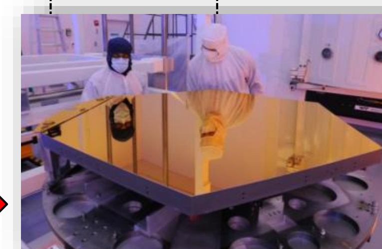
Technology Readiness Level-6 Demonstrated:
All key requirements and environments demonstrated

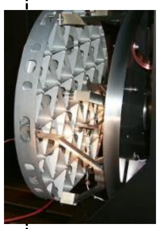
Onset of **James Webb Space Telescope**

AMSD Phase 1: 8 Mirror Designs

AMSD Phase 2: 3 mirrors developed

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





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

OTE Optics Review (OOR): Beryllium Selected

Engineering Design Unit.

PM Manufacturing of 18 segments

Primary Mirror Segment Assemblies Complete

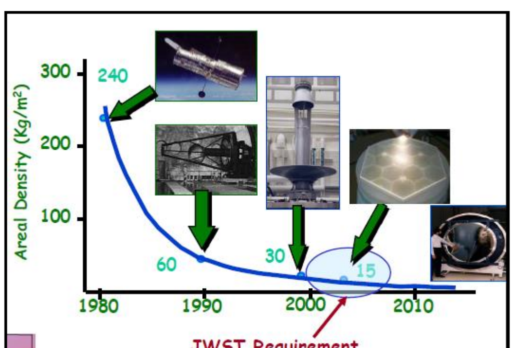
Machining Facility Complete

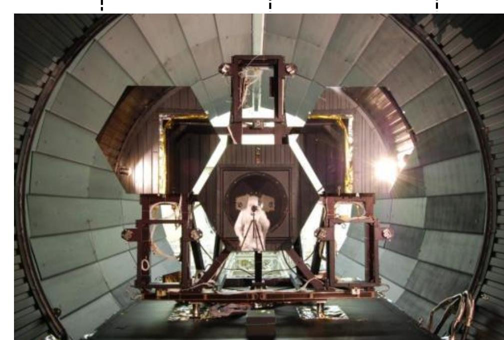
Cryo Testing

Polishing Facility Complete

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

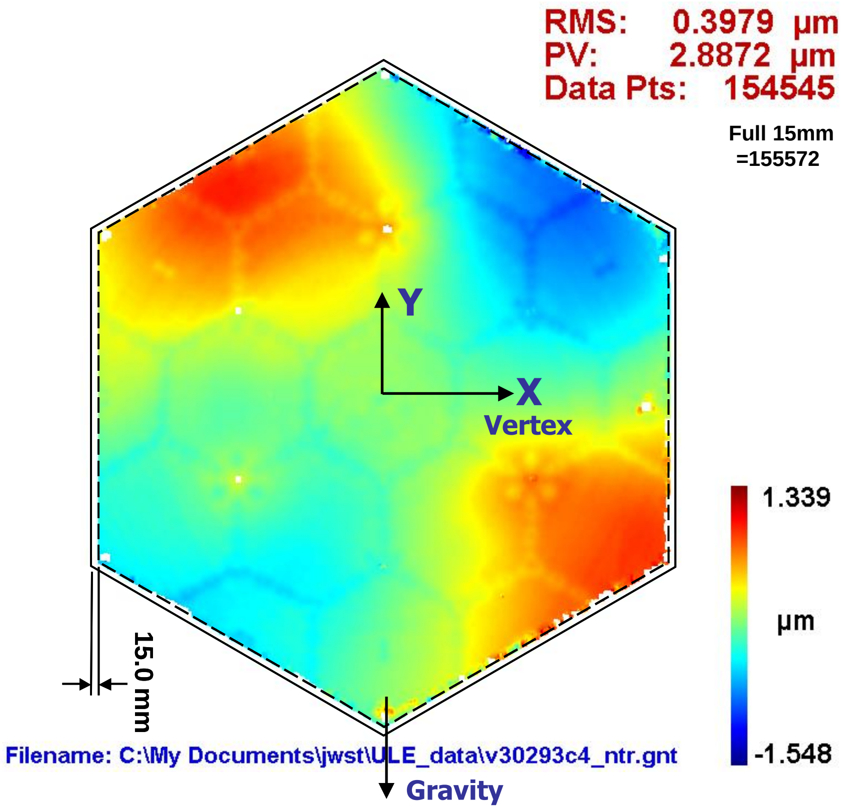
NGST Mirror System Demonstrator (NMSD): Other architectures that were not successful



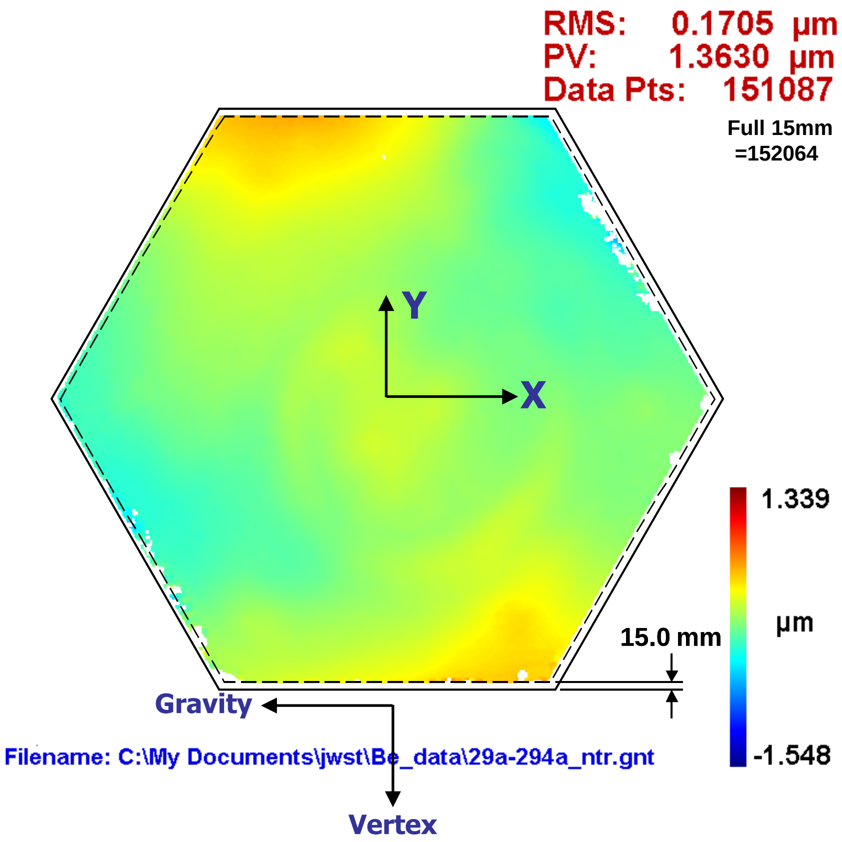


Mirror Technology Choices

~30 K minus Ambient



ULE



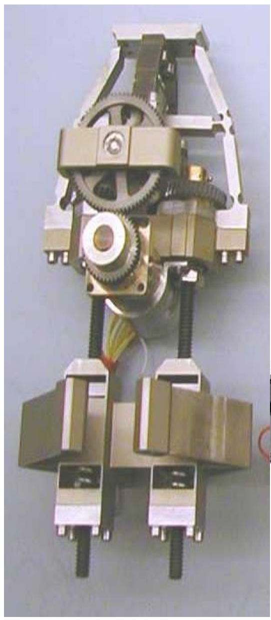
Be

Beryllium Mirror Selected Because of Superior Cryogenic Properties

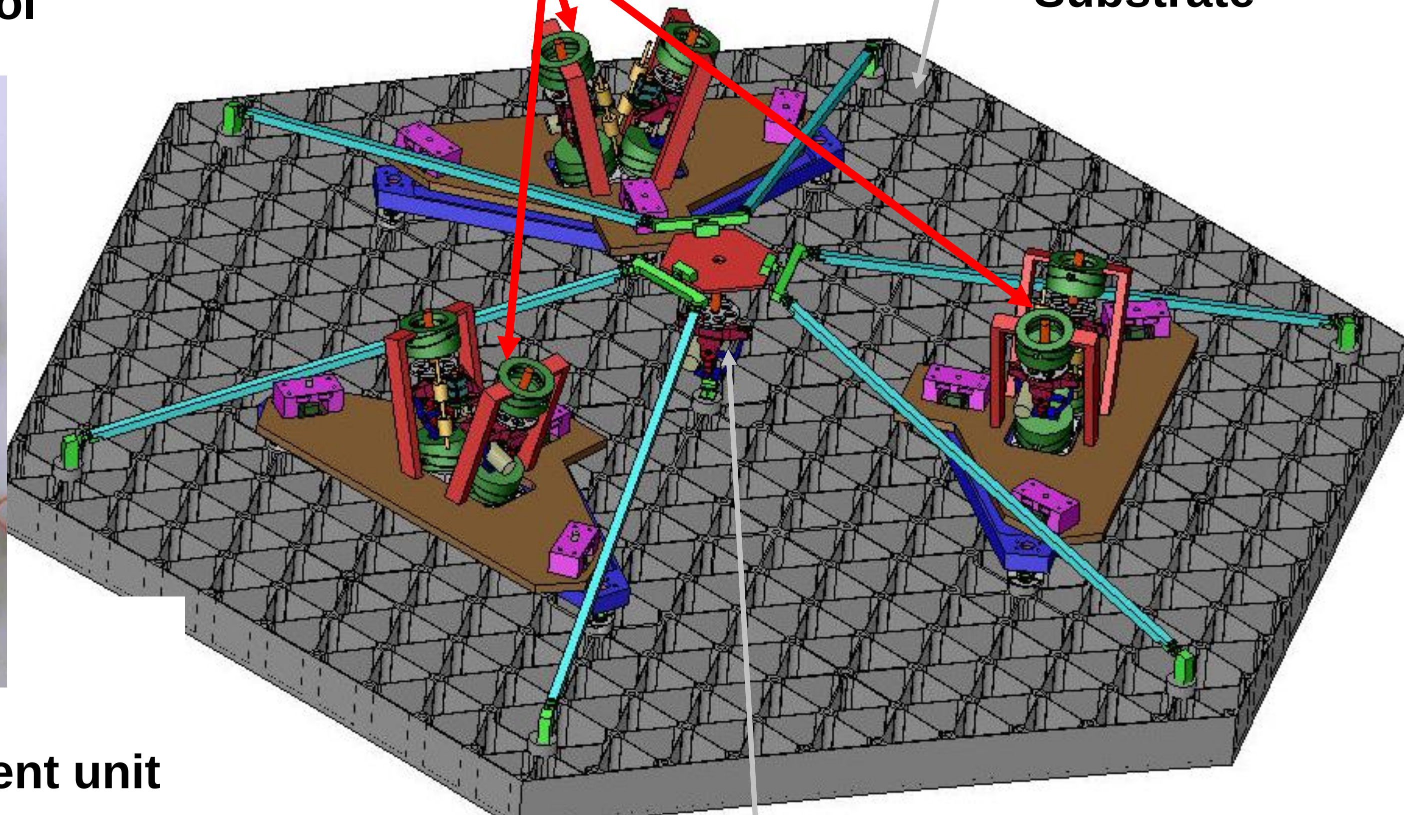
Primary Mirror Segment Actuations

Actuators for 6 degrees of freedom rigid body motion, independent of ROC control

Lightweighted Beryllium Mirror Substrate



Actuator development unit

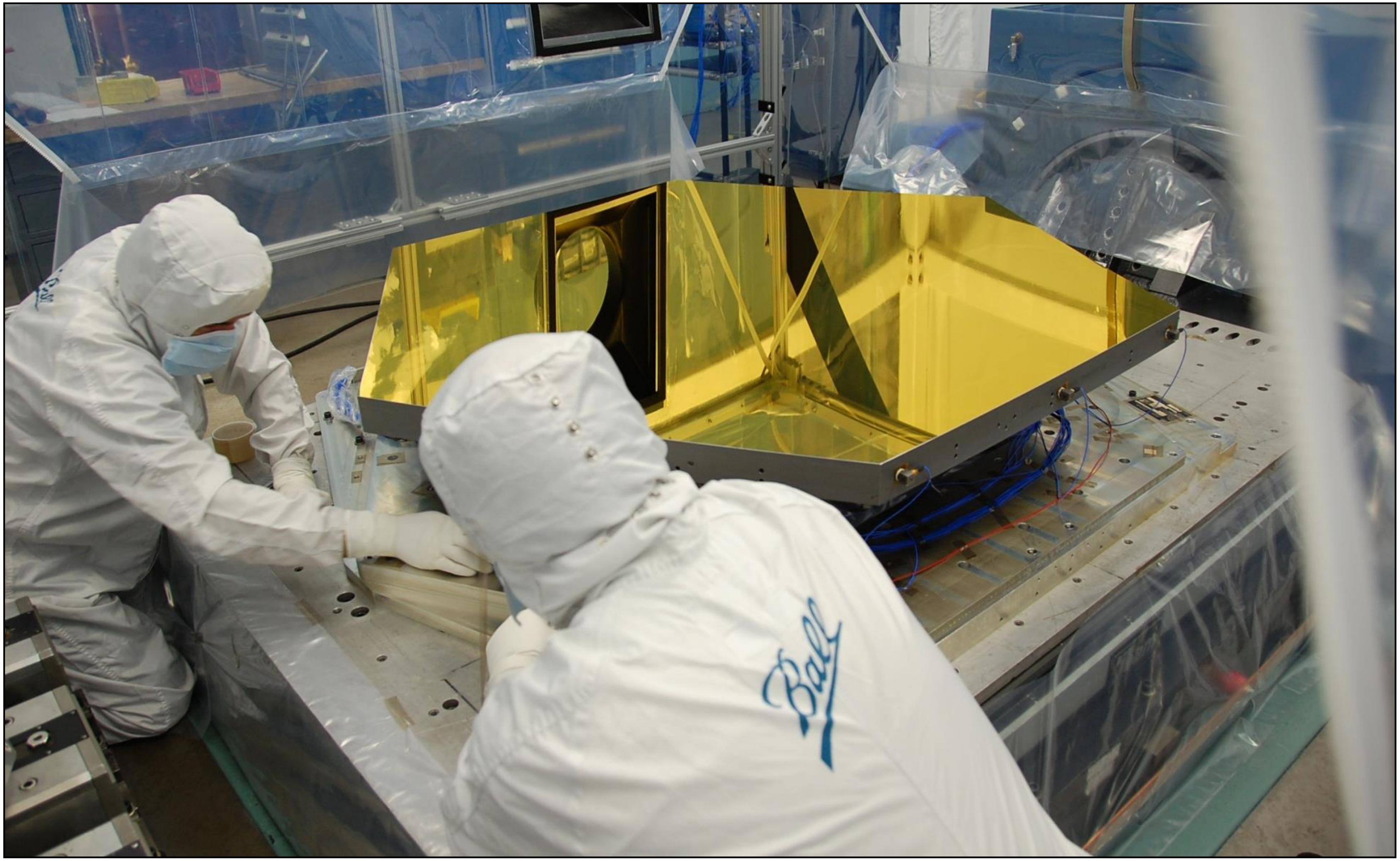


Actuator for radius of curvature adjustment

Observatory optical quality (mid and high spatial frequency) is manufactured into segments

National Aeronautics and Space Administration
Goddard Space Flight Center

Primary Mirror Vibration Testing



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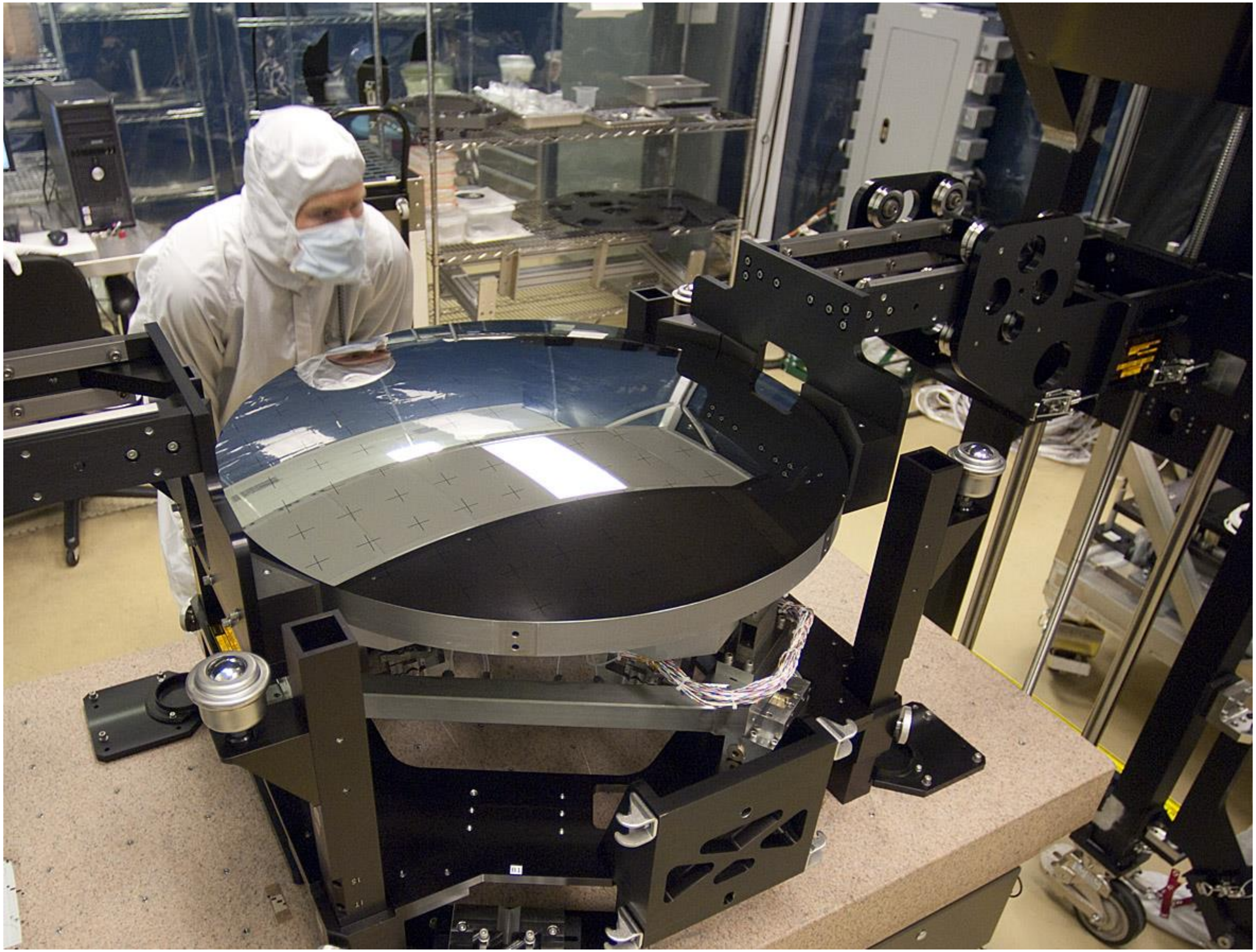
Goddard Space Flight Center

Secondary Mirror



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Goddard Space Flight Center

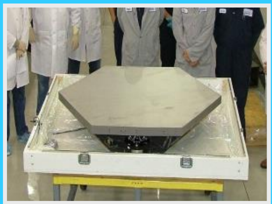
Secondary Mirror Cryo-Optical Testing

All Primary Mirror Blanks Completed

Axsys Machining Facility

Dedicated facility and machining centers for JWST mirror production

Beryllium Flight Mirror Machining Complete at Axsys Technologies

Pathfinder  ***Done at Axsys!!*** PMSA #1 (EDU-A / A1)	Pathfinder  ***Done at Axsys!!*** PMSA #2 (11 / B3)	Pathfinder  ***Done at Axsys!!*** PMSA #3 (12 / C3)	 ***Done at Axsys!!*** PMSA #4 (5 / A2)	 ***Done at Axsys!!*** PMSA #5 (6 / B2)	 ***Done at Axsys!!*** PMSA #6 (7 / C2)
 ***Done at Axsys!!*** PMSA #7 (13 / A4)	 ***Done at Axsys!!*** PMSA #8 (17 / B5)	 ***Done at Axsys!!*** PMSA #9 (4 / C1)	 ***Done at Axsys!!*** PMSA #10 (16 / A5)	 ***Done at Axsys!!*** PMSA #11 (20 / B6)	 ***Done at Axsys!!*** PMSA #12 (15 / C4)
 ***Done at Axsys!!*** PMSA #13 (8 / A3)	 ***Done at Axsys!!*** PMSA #14 (22 / B7)	 ***Done at Axsys!!*** PMSA #15 (18 / C5)	 ***Done at Axsys!!*** PMSA #16 (19 / A6)	 ***Done at Axsys!!*** PMSA #17 (3 / B1) (TRL6 PMSA)	 ***Done at Axsys!!*** PMSA #18 (21 / C6)

Tinsley Built A New Large Optics Facility To Support the JWST Program

Mirror Grinding/Polishing Status at L-3 SSG-Tinsley

Batch #1 (Pathfinder)


PMSA #1 (EDU-A / A1)

Batch #1 (Pathfinder)


PMSA #2 (11 / B3)

Batch #1 (Pathfinder)


PMSA #3 (12 / C3)

Batch #2


PMSA #4 (5 / A2)

Batch #2

PMSA #5 (6 / B2)

Batch #2


PMSA #6 (7 / C2)

Batch #3


PMSA #7 (13 / A4)

Batch #3

PMSA #8 (17 / B5)

Batch #3

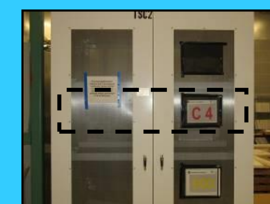
PMSA #9 (4 / C1)

Batch #4

PMSA #10 (16 / A5)

Batch #4


PMSA #11 (20 / B6)

Batch #4


PMSA #12 (15 / C4)

Batch #5

PMSA #13 (8 / A3)

Batch #5

PMSA #14 (22 / B7)

Batch #5


PMSA #15 (18 / C5)

Batch #6

PMSA #16 (19 / A6)

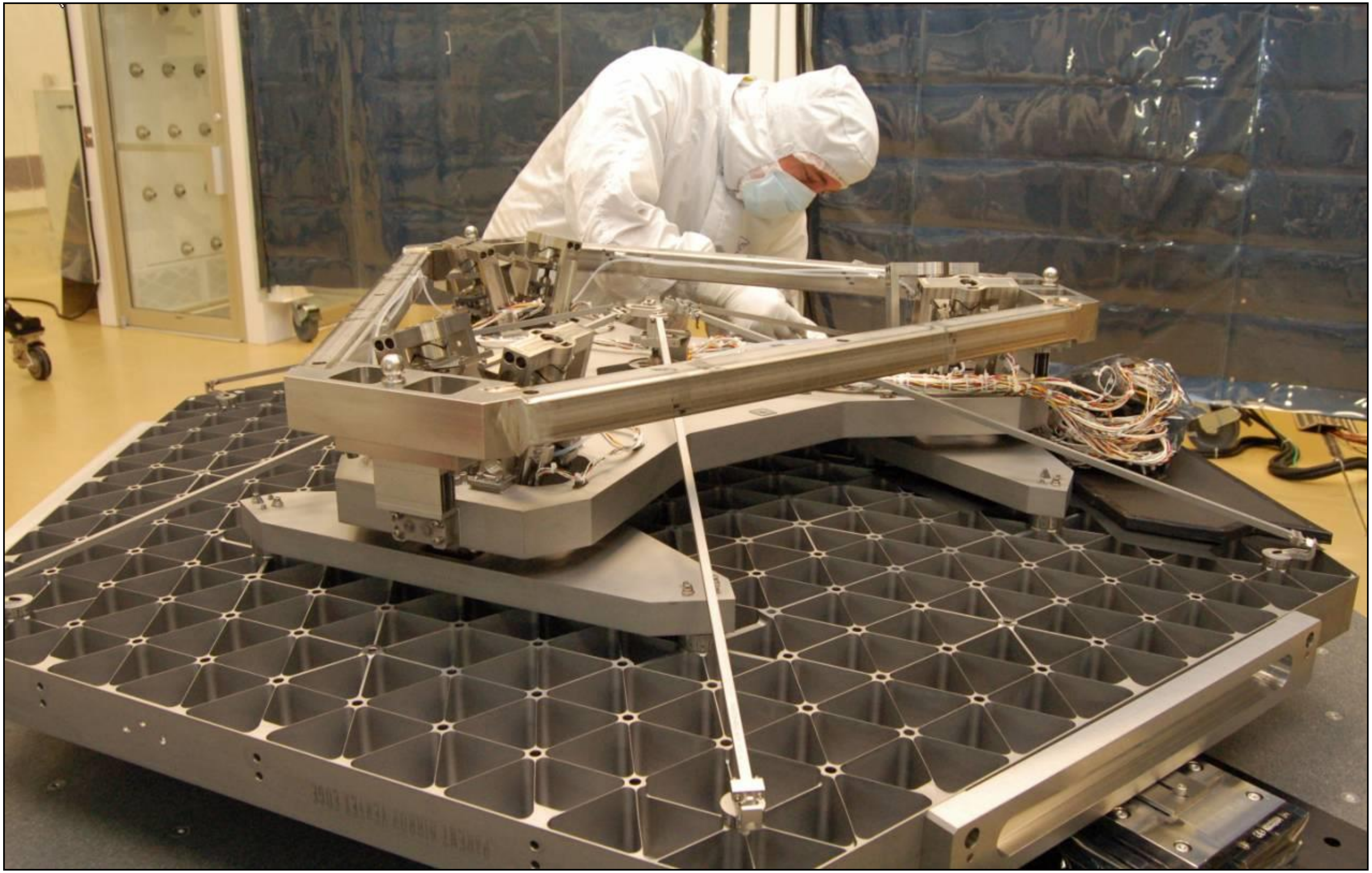
Batch #6

PMSA #17 (3 / B1)
(TRL6 PMSA)

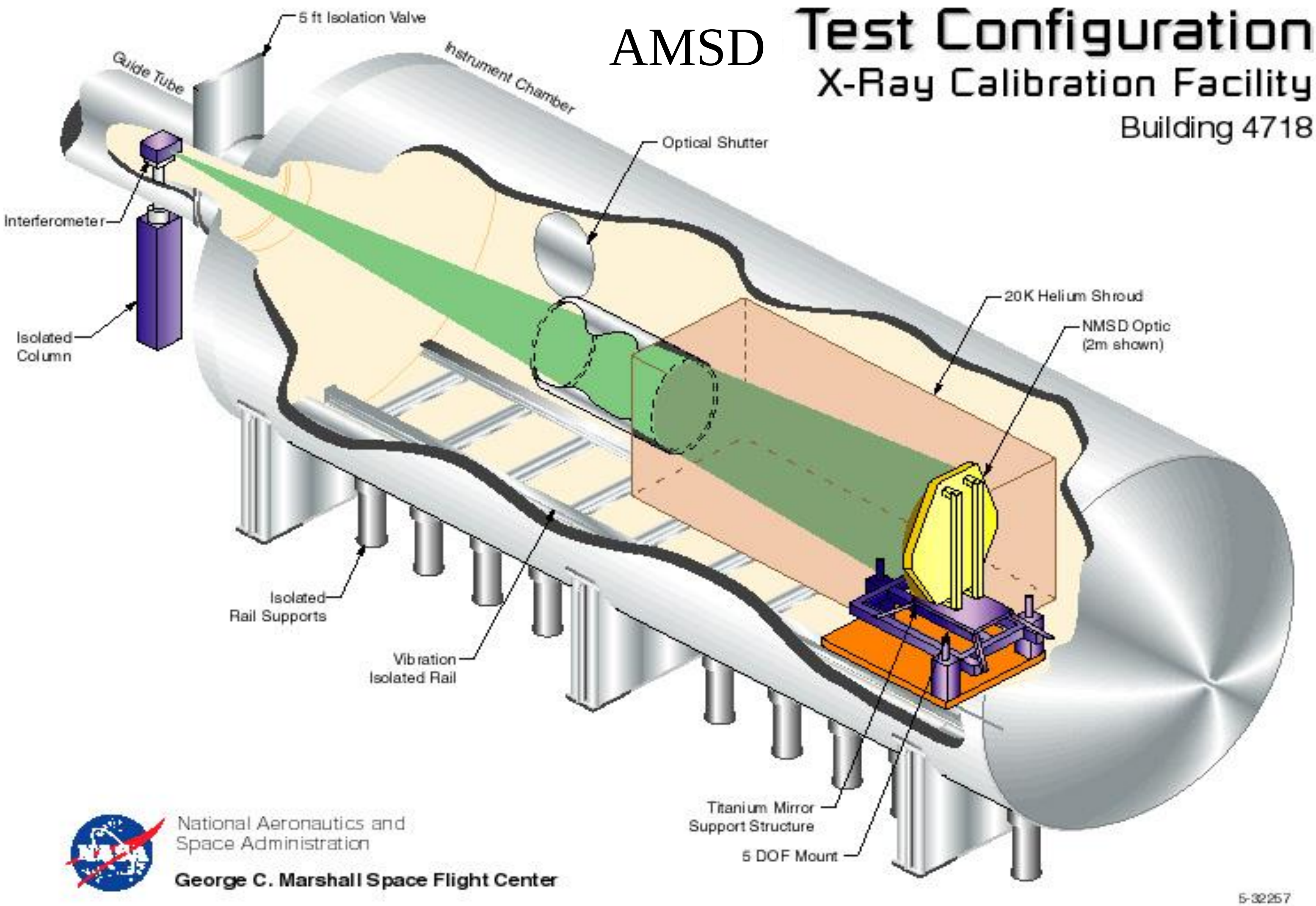
Batch #6

PMSA #18 (21 / C6)

PMSA Assembly Technology Demonstrator



External metrology has been demonstrated as part of JWST Mirror Test Configuration

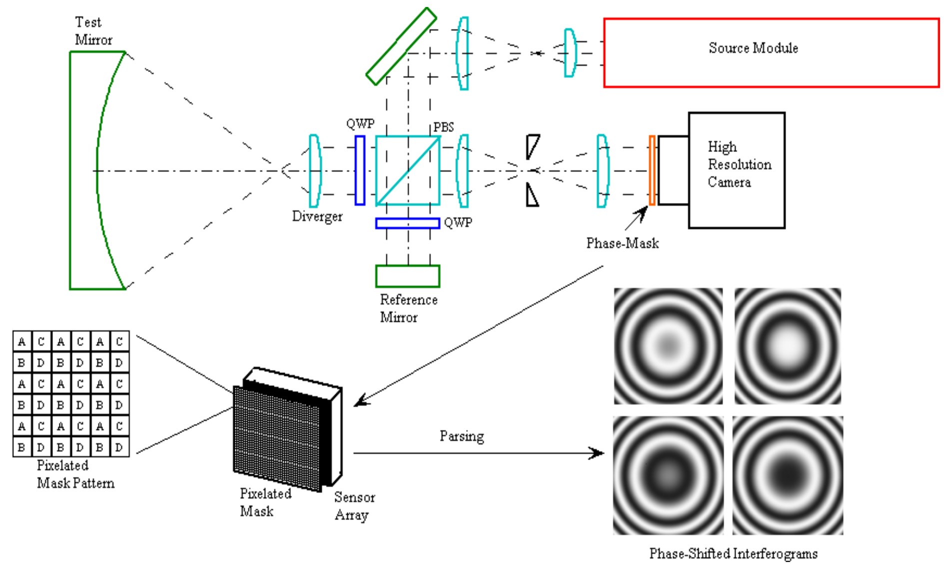


First test with Coated EDU

Instantaneous Acquisition Phase Shifting Interferometry for JWST

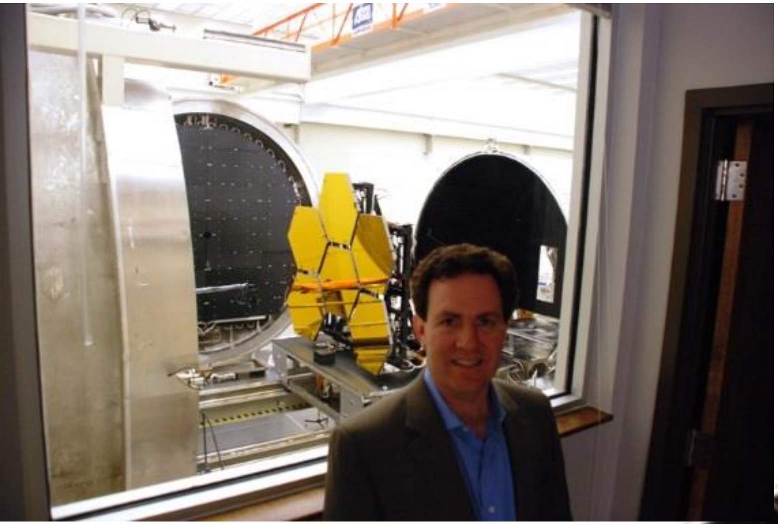
- Instantaneous phase shifting interferometry is key to successfully test the large, deployable, JWST telescope at cryo
- Interferometer requirements:
  - High sensitivity
  - Fast exposure time <100μs
  - Insensitivity to vibration
- 4D Technology is developing two new interferometers:
  - Multiple wavelength interferometer provides independent test of phasing of the Primary Mirror and the Telescope
  - Electronic Speckle Pattern Interferometer allows testing of deformations in large, diffuse structures to nanometer level at cryo
- Pixelated phase mask that allows simultaneous capture of four phase shifted interferograms is the key feature in both interferometers.

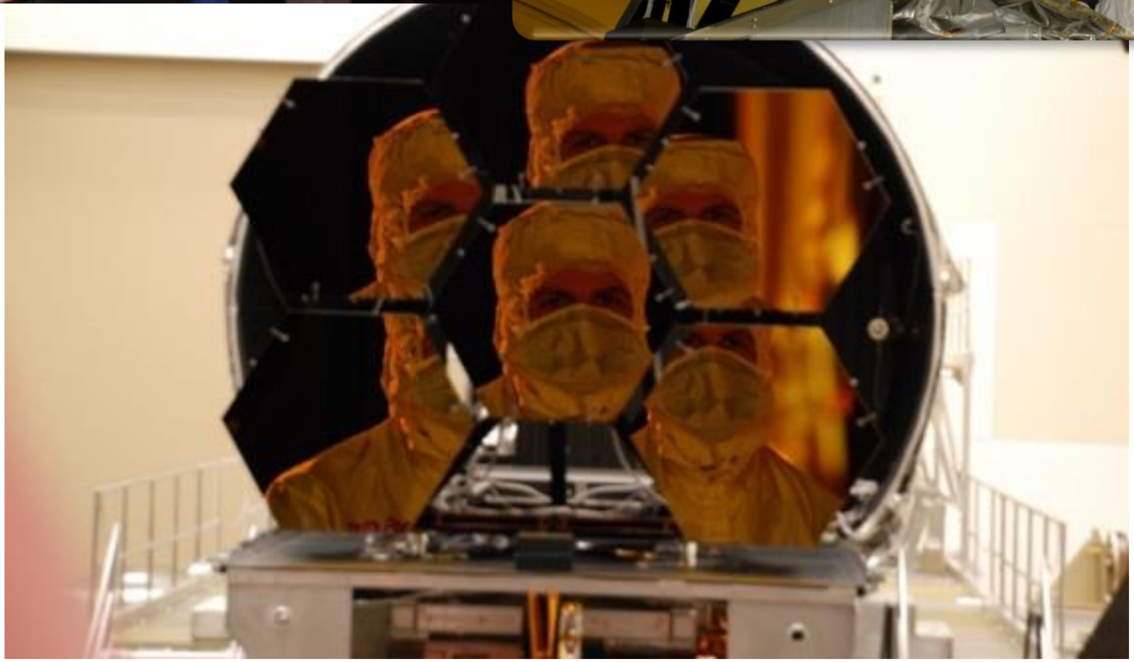
System Layout



Four Phase-shifted Interferograms Captured Simultaneously

Testing at XRCF





JWST Dedicated Mirror Coating Chamber at QCI/Denton

Coated Primary Mirror Segment Assembly

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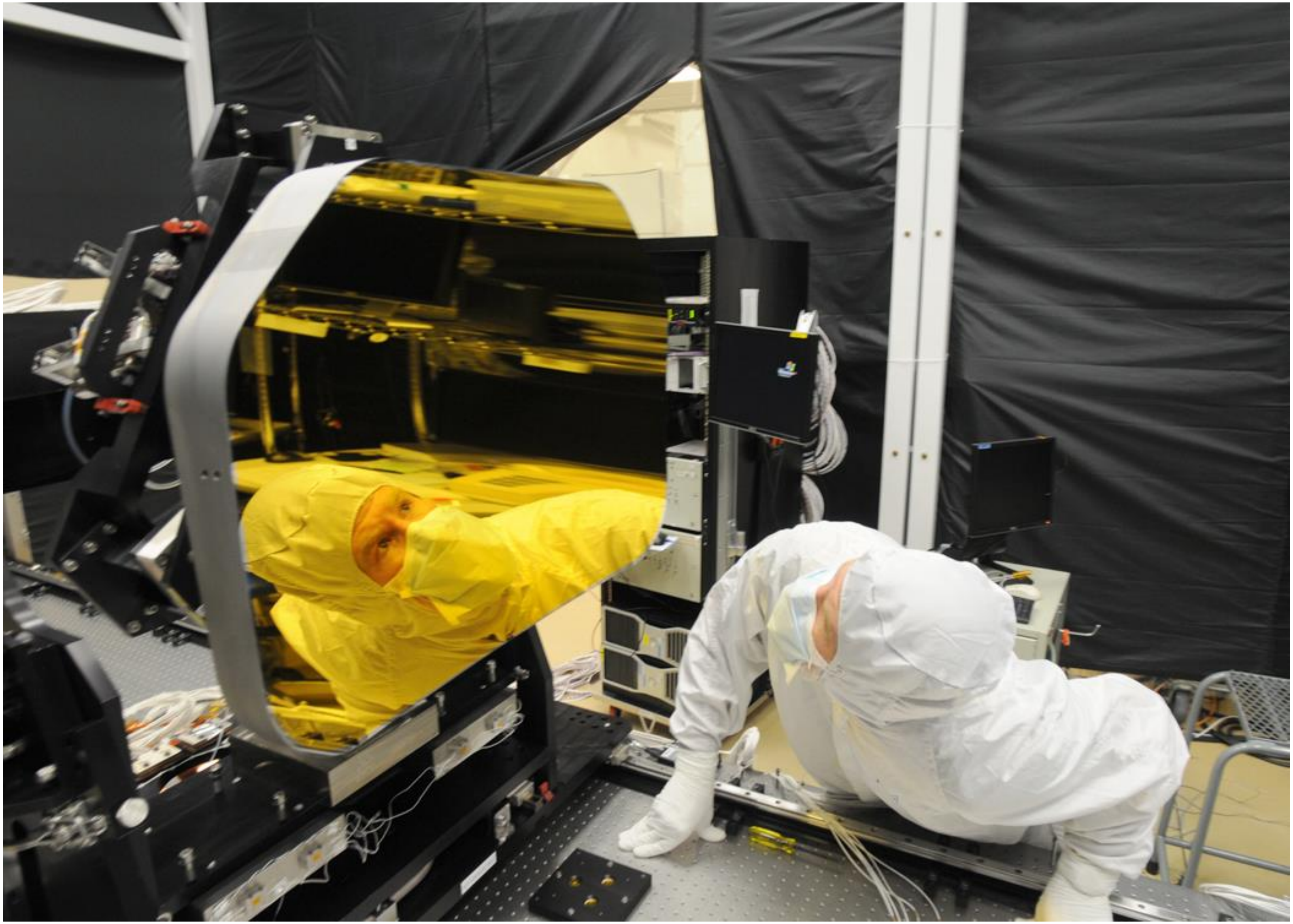
Goddard Space Flight Center

Aft Optics Subsystem Bench

Tertiary Mirror



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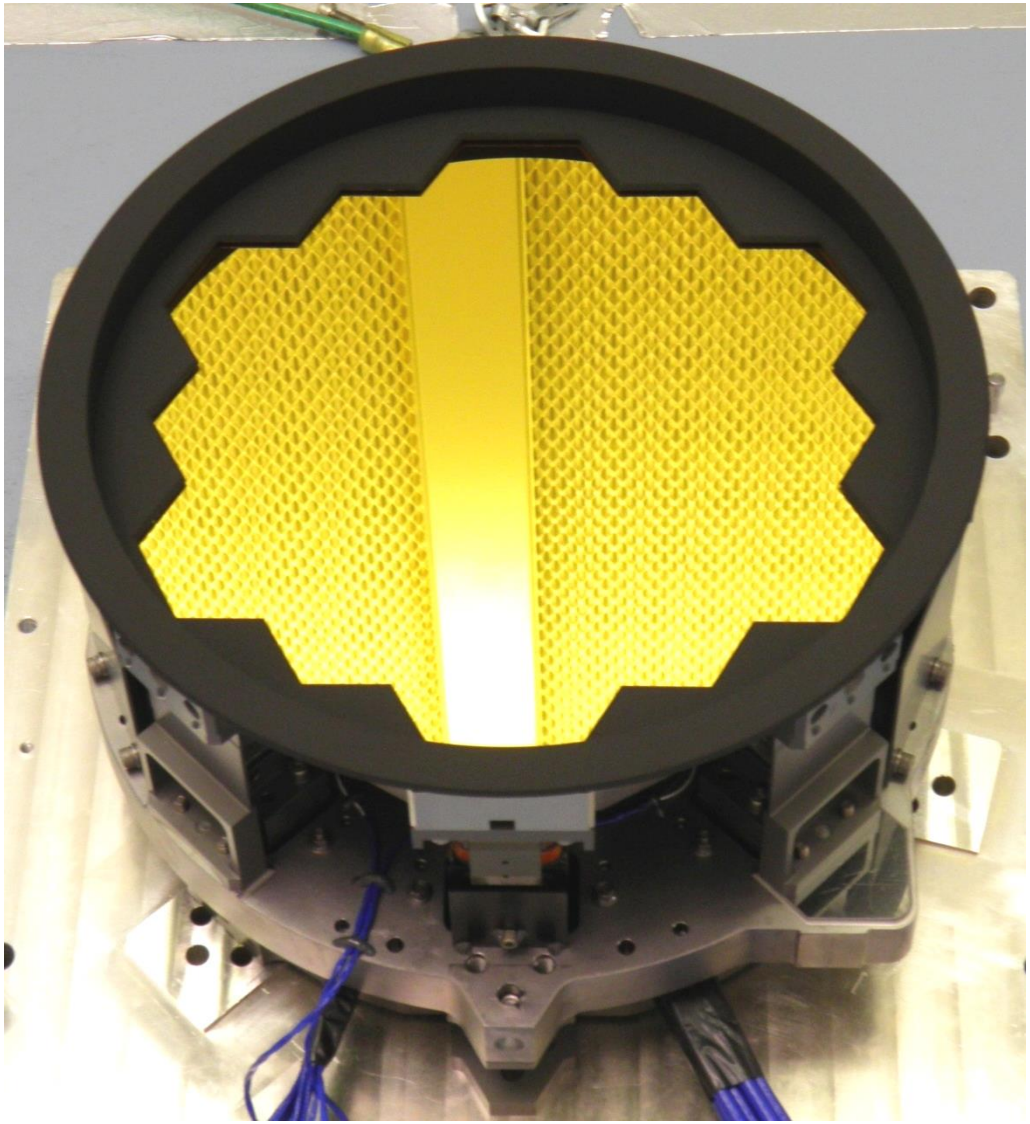
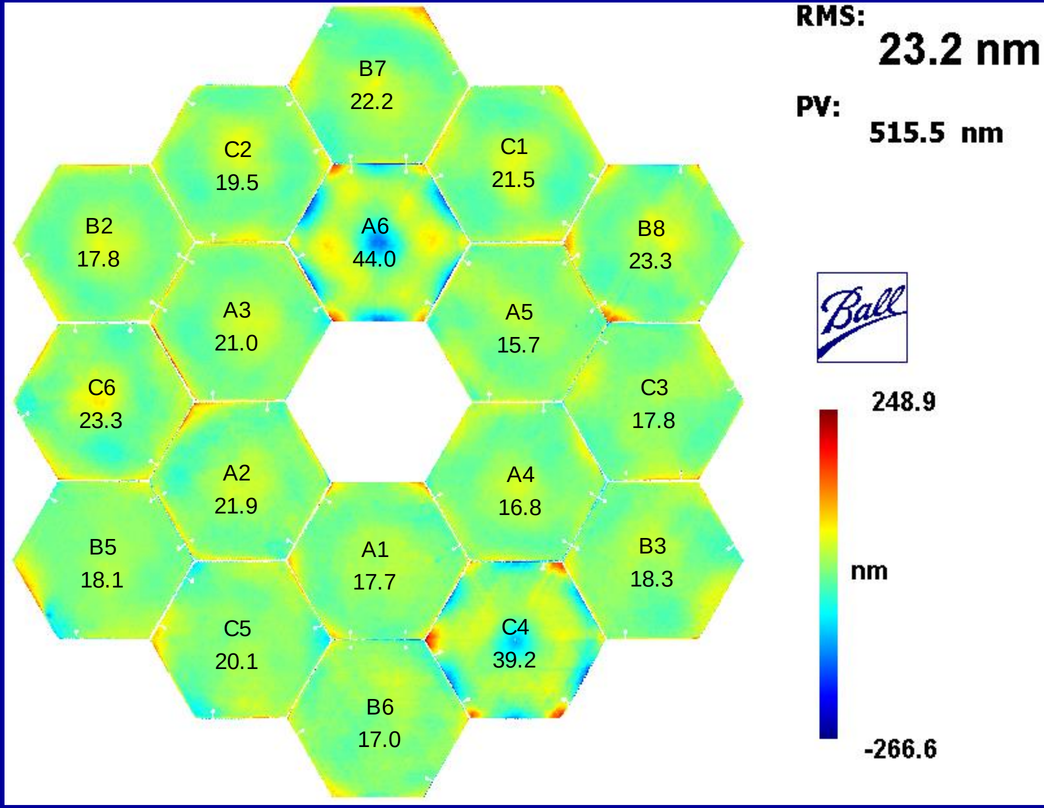
Fine Steering Mirror



Measured Primary Mirror Cryogenic Surface Figure Error meets requirements

6 PMSAs ready for cryo testing

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



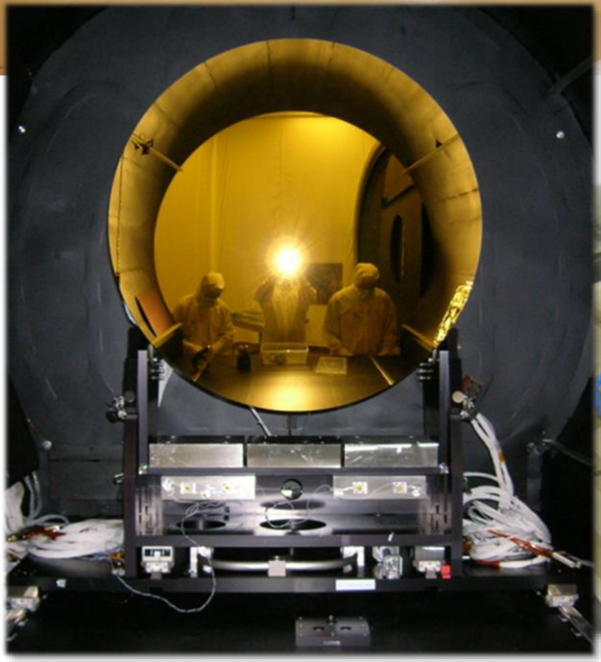
Composite Primary Mirror meets requirements

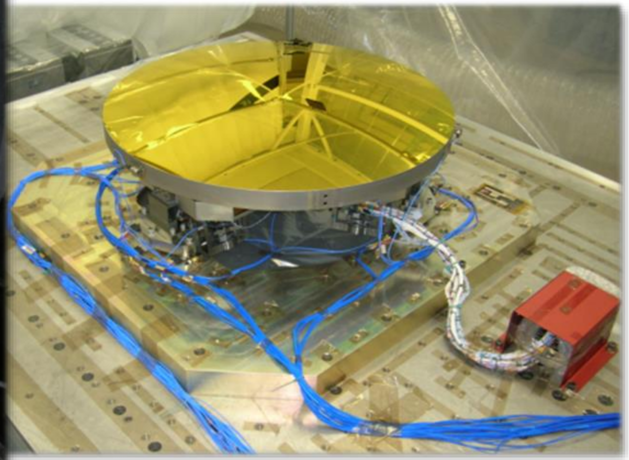
Flight SMA is Complete

SMA SFE: 19.8nm RMS SFE (including measurement uncertainty) vs. 23.5nm req’t

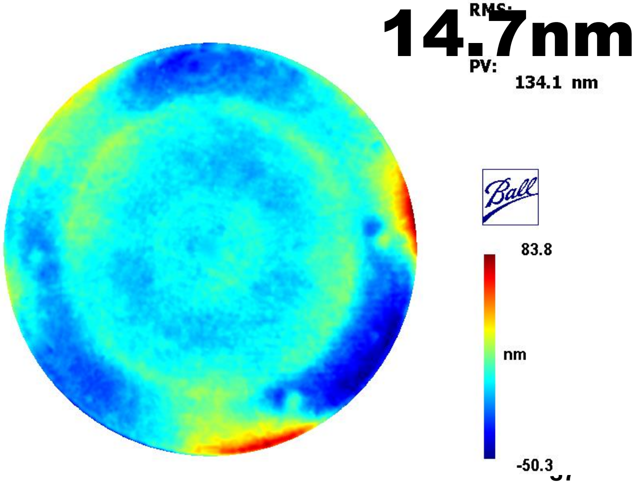
On convex mirror 0.7 meters in diameter.

One of the more challenging tasks on the program, and therefore, one of the more spectacular achievements.



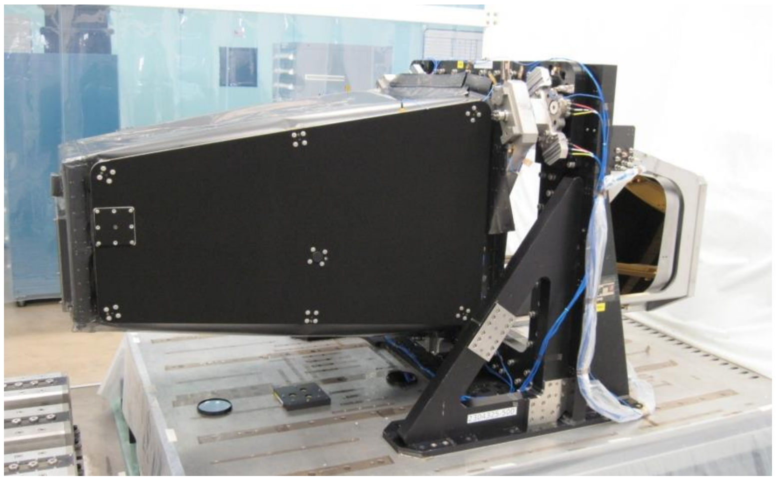


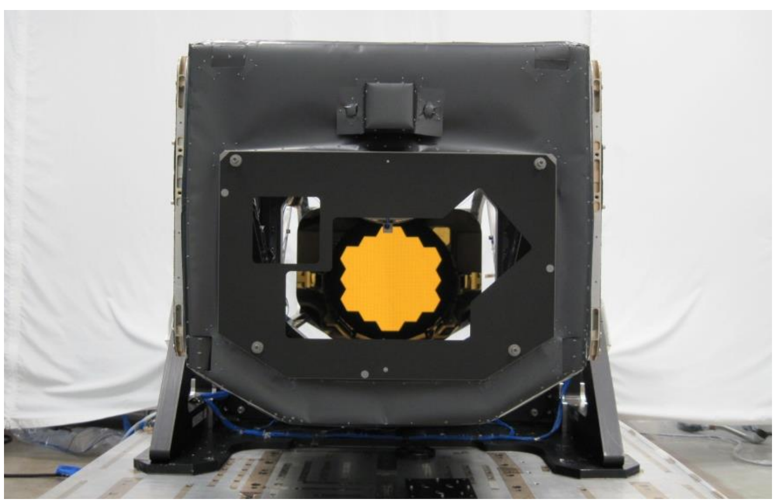
20K SMA Measured Surface Figure

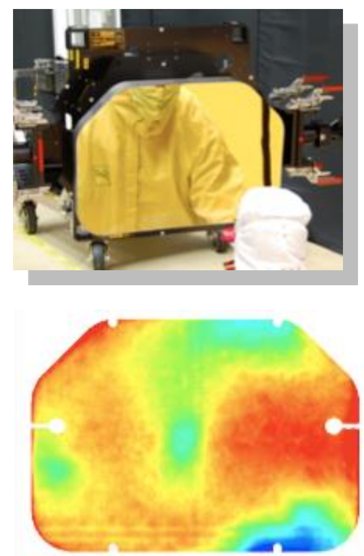


The fully integrated AOS

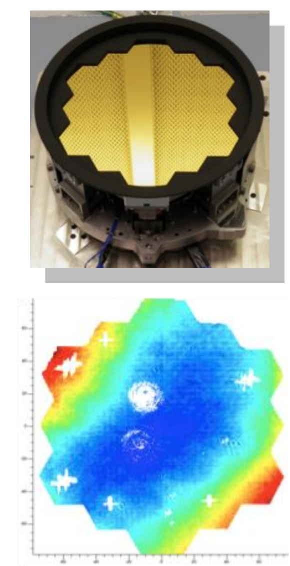
Mirror	Measured (RMS SFE)	Uncertainty (RMS SFE)	Total (RMS SFE)	Require-ment (RMS SFE)
Tertiary	18.1 nm	9.5 nm	20.5 nm	23.2 nm
Fine Steering	13.9 nm	4.9 nm	14.7 nm	18.7 nm







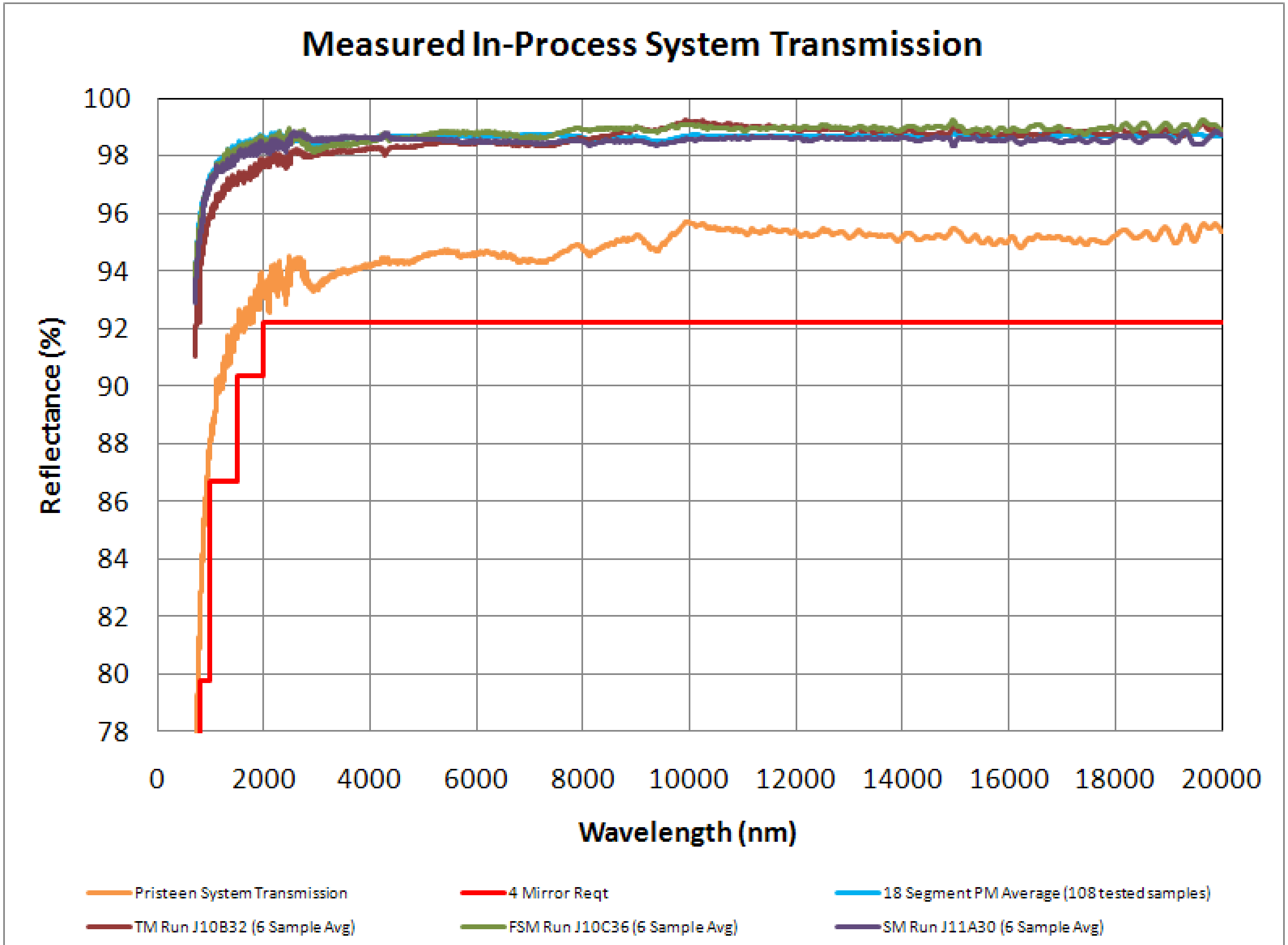
Tertiary Mirror



Fine Steering Mirror

38

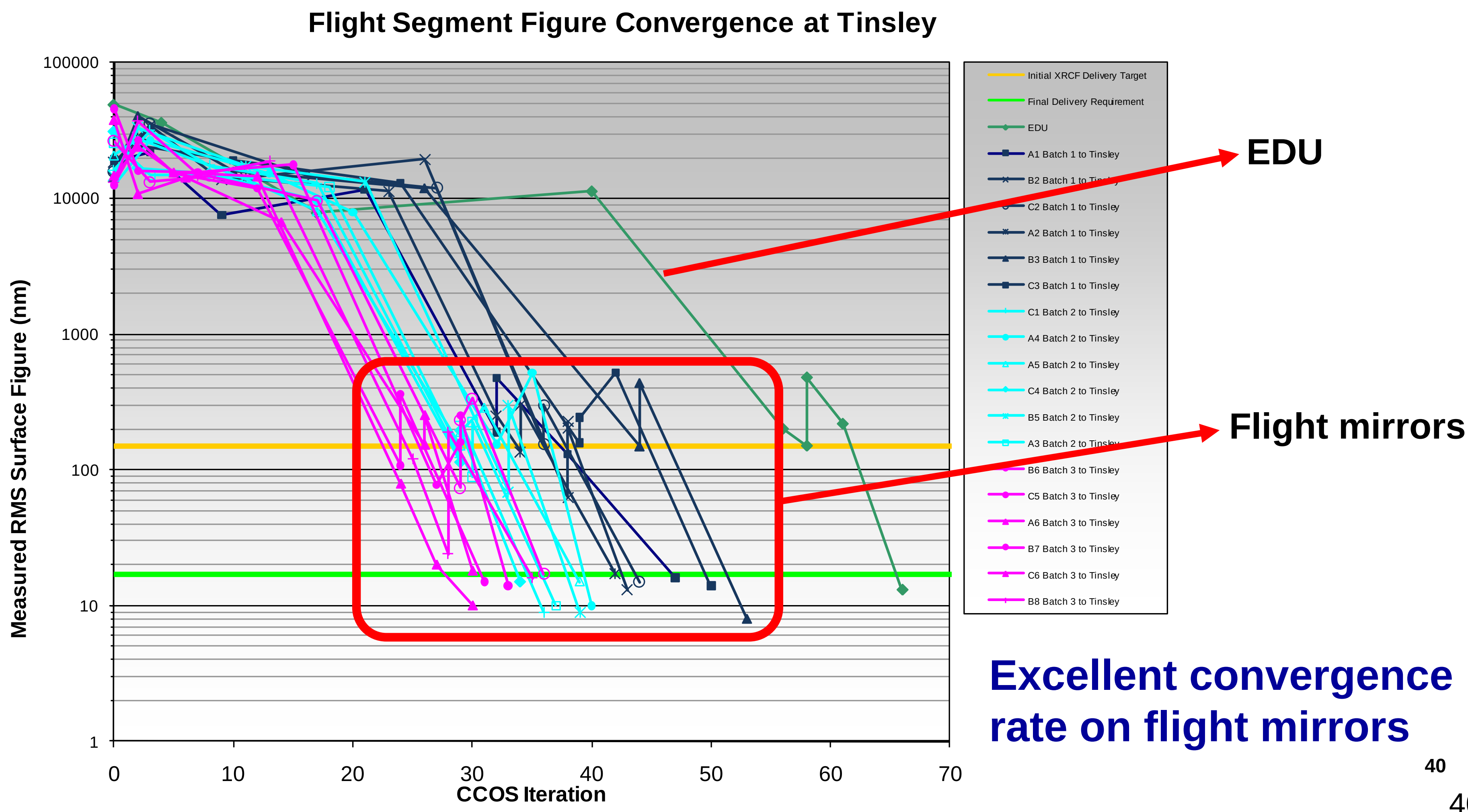
System transmission meets requirements



PMSA process durations improved with each production batch

Final batch CCOS iterations < ½ EDU iterations

So, the final batch completed months ahead of schedule.

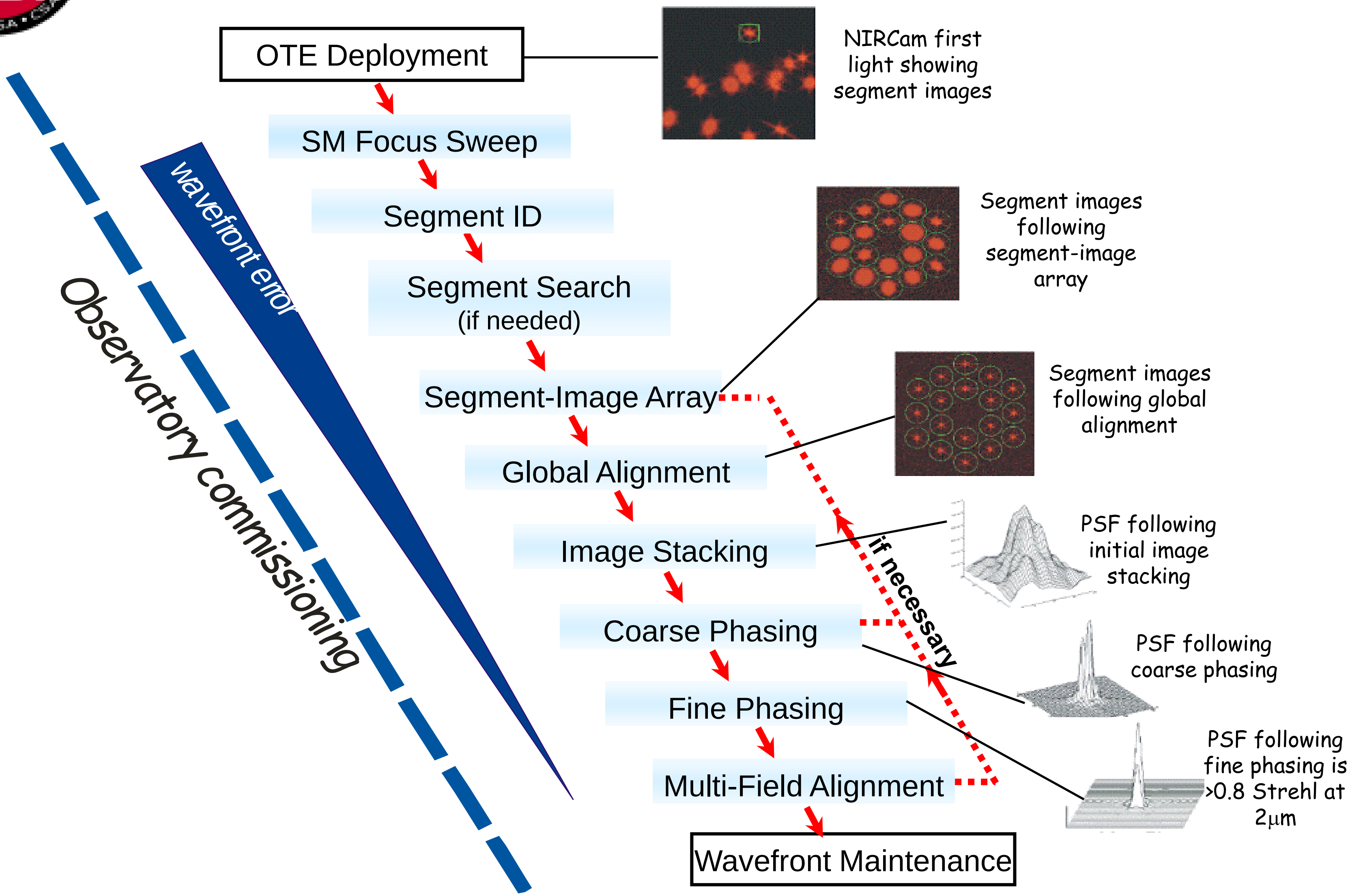


Excellent convergence rate on flight mirrors

Completed Mirrors in Storage

Wavefront Sensing and Control

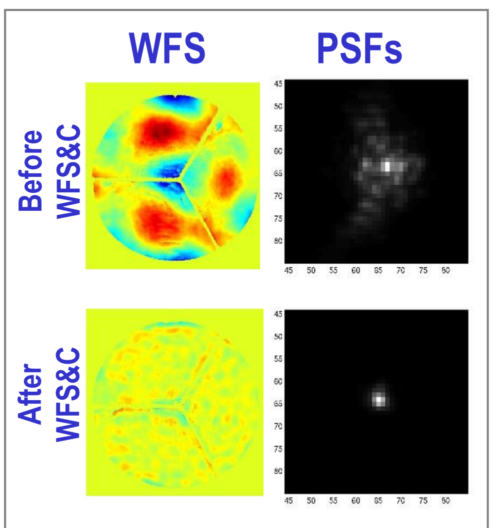
JWST Wavefront Sensing & Control Process

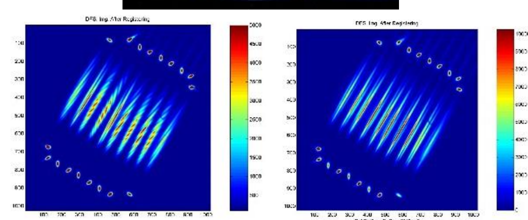


The viability of the JWST wavefront sensing and control approach was demonstrated subscale

- Wavefront Sensing and Control provides the software and algorithms used to align the telescope
- Techniques build on image based software and algorithms developed for HST Prescription Retrieval, ground telescopes, and on a large array of testbeds
- Early investments in WFSC proved the basic feasibility of the JWST segmented mirror approach through modeling and hardware demonstrations
- WFSC testbeds at the Goddard Space Flight Center (the Wavefront Control Testbed) and at Ball were used to develop JWST-specific technologies to TRL 4/5
- An experiment last July on the inner 18 segments of the Keck Telescope demonstrated the specific coarse phasing portion to be used on JWST (coarse phasing now at TRL-6)

JWST WCT-3 Testbed

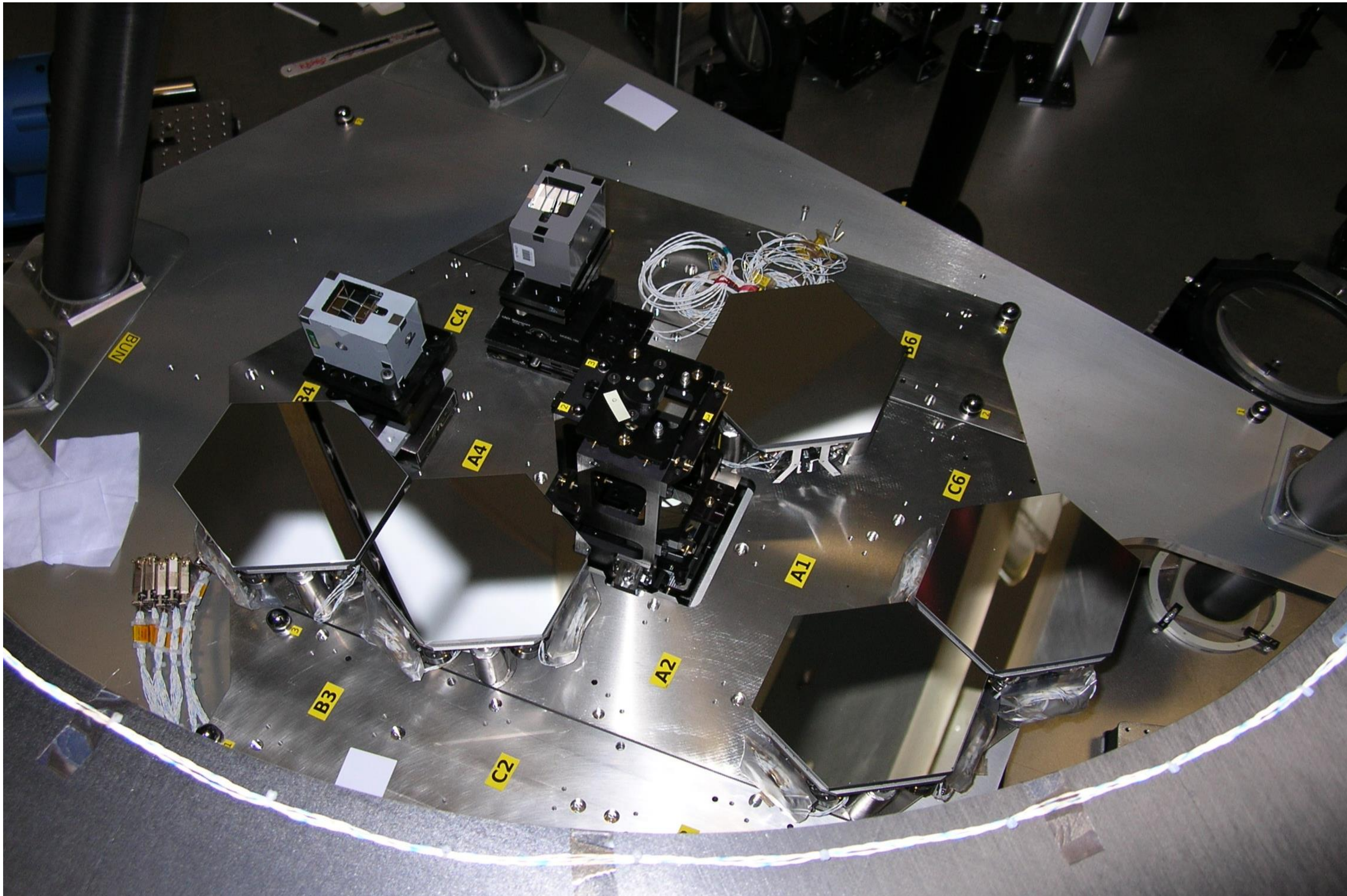




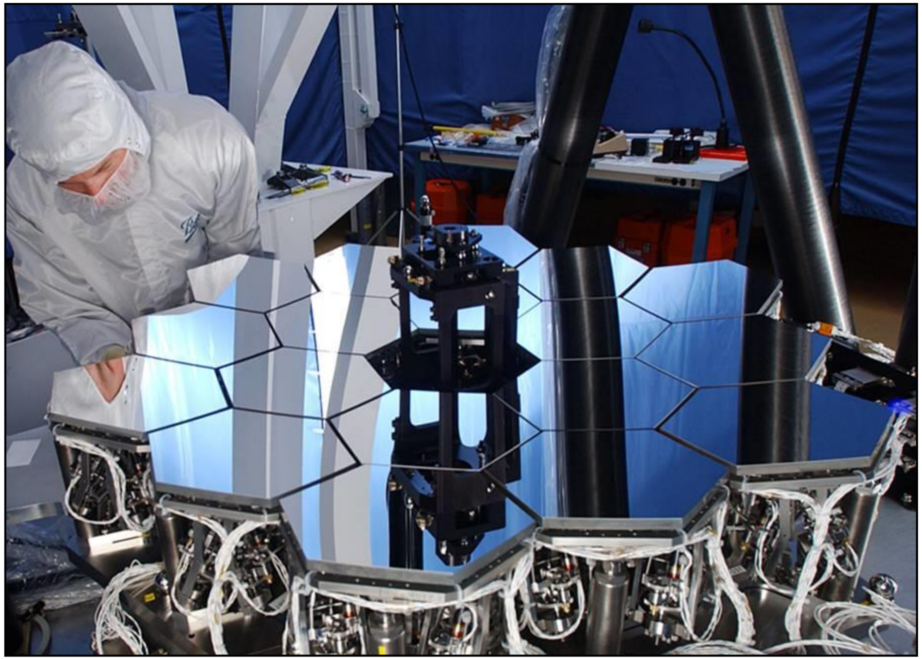
Initial errors
Max piston error=19 microns
Rms=5 microns

After correction
Max piston error=0.66 microns
Rms=0.18 microns

Ball WFSC Testbed with 5 Segments Installed



WFSC Development Plan – Testbed Telescope

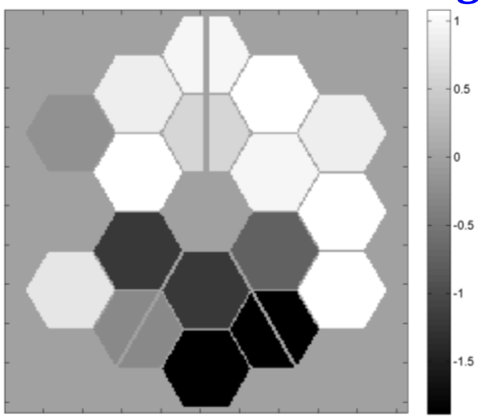


- WFSC Testbed Telescope is a 1/6th scale, fully functional model of the JWST telescope with performance traceable to JWST
- Testbed provides functionally accurate simulation platform for developing deliverable WFSC algorithms and software
- Algorithms have had initial check outs on the testbed
- Remaining WFSC TRL task is to demonstrate end-to-end wavefront sensing and control through final alignment

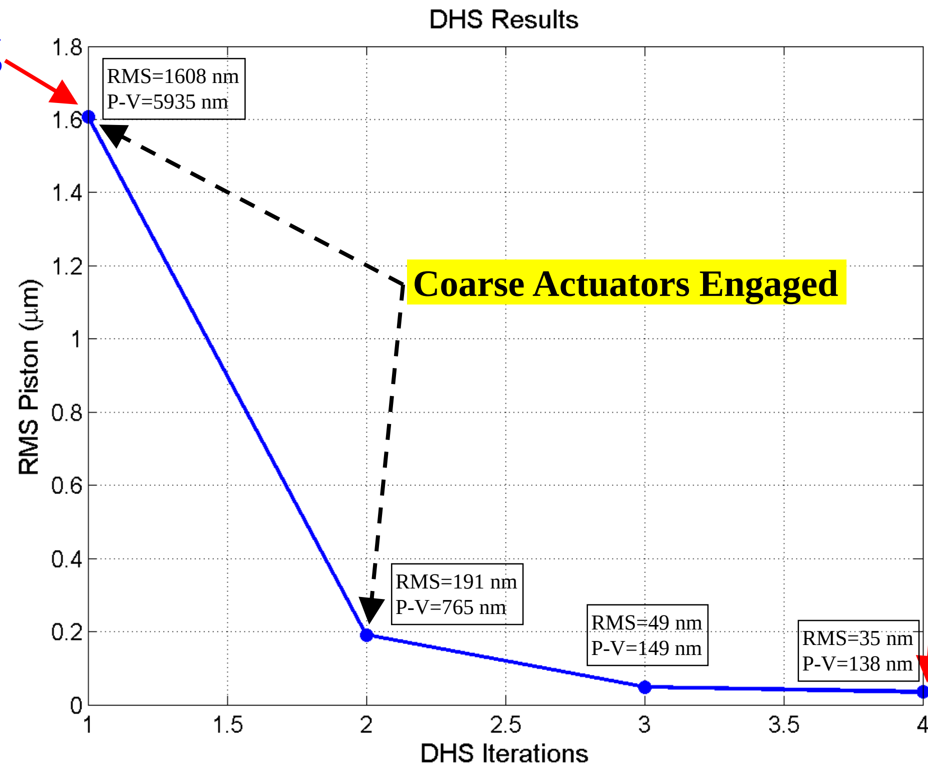
7. Coarse Phasing on the TBT

- Coarse phasing performed on the TBT using the DHS to detect segment-to-segment piston.

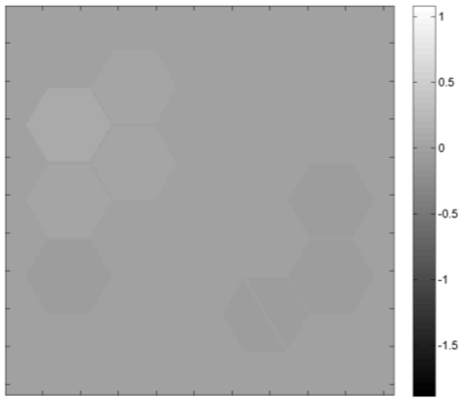
Before Coarse Phasing



Piston: RMS=1608 nm
P-V = 5935 nm



After Coarse Phasing



Piston: RMS= 35 nm
P-V = 138 nm

- Separate segment-to-segment piston values measured with DHS are consistent with the overall, reconstructed piston map to ≈18 nm (RMS)
- After Fine-Phasing: No 2π ambiguities occurred: confirmed by defocused PSFs at two wavelengths (1550 & 1900 nm)

8. Fine Phasing Convergence

Coarse Phasing → **Fine Phasing**

Repeatability Criteria Met:

Summary of Repeatability Results
(55nm requirement):

	GSFC/Dean Analysis	Ball/Acton Analysis
Median of Differences	**49 nm**	**50 nm**

Repeatability defined to be the median of the direct subtraction of controllable mode wavefronts of 6 December datasets.

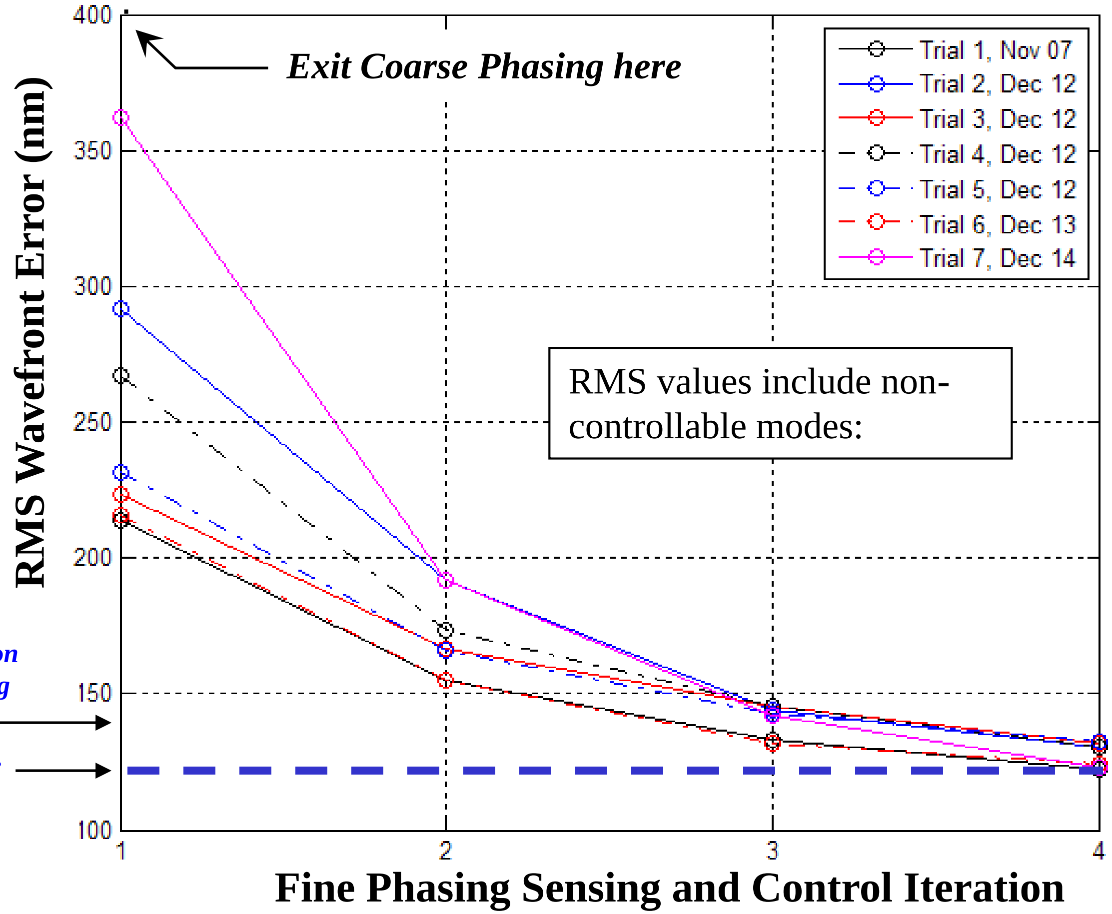
Table of Differences using the 6 phase maps:

	RMS Diff (nm)
rms (phase 1 - phase 2)	= 54.9731
rms (phase 1 - phase 3)	= 62.4567
rms (phase 1 - phase 4)	= 41.6916
rms (phase 1 - phase 5)	= 49.2951
rms (phase 1 - phase 6)	= 39.6658
rms (phase 2 - phase 3)	= 52.9011
rms (phase 2 - phase 4)	= 47.9891
rms (phase 2 - phase 5)	= 49.9841
rms (phase 2 - phase 6)	= 53.6143
rms (phase 3 - phase 4)	= 60.318
rms (phase 3 - phase 5)	= 62.2399
rms (phase 3 - phase 6)	= 49.3999
rms (phase 4 - phase 5)	= 48.822
rms (phase 4 - phase 6)	= 43.9319
rms (phase 5 - phase 6)	= 45.8155

median = 49.39 nm

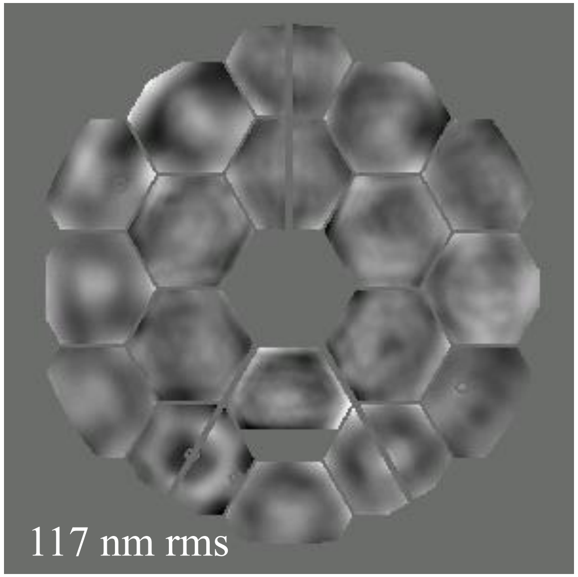
Equivalent RMS piston exiting coarse phasing from previous slide

Best Aligned Telescope (107nm) RSS'd With Typical Drift=118nm



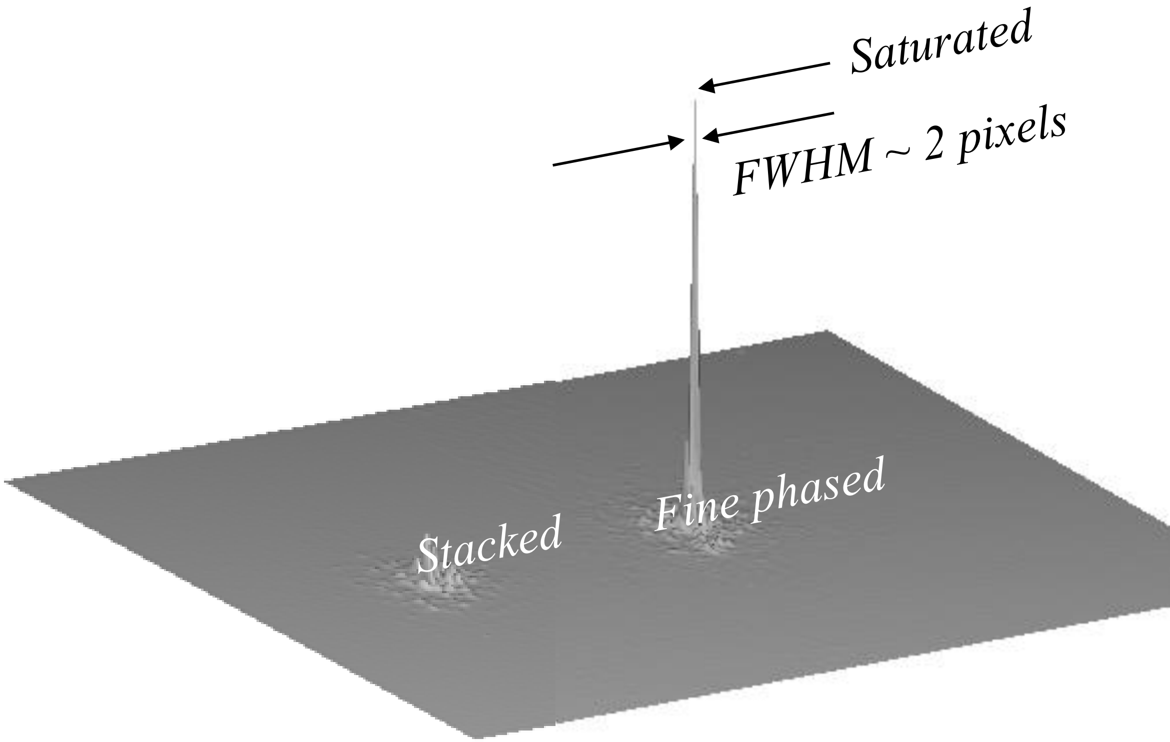
WFSC repeatability is well within the TRL-6 criterion

18 Segment Fine Phasing Demonstrated on JWST Testbed Telescope



•Double Pass Phase Retrieval estimate

- •~0.94 Strehl ratio (single pass at 1550 nm on TBT)
- •Flight requirement is >0.8 Strehl @ 2 µm



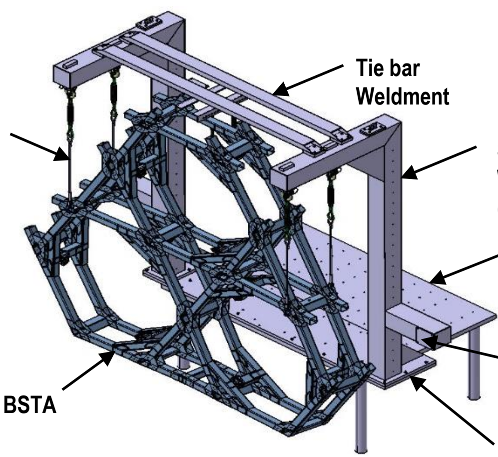
•Stacked Point Spread Function (left) contains random small tip/tilt and piston errors [Before]

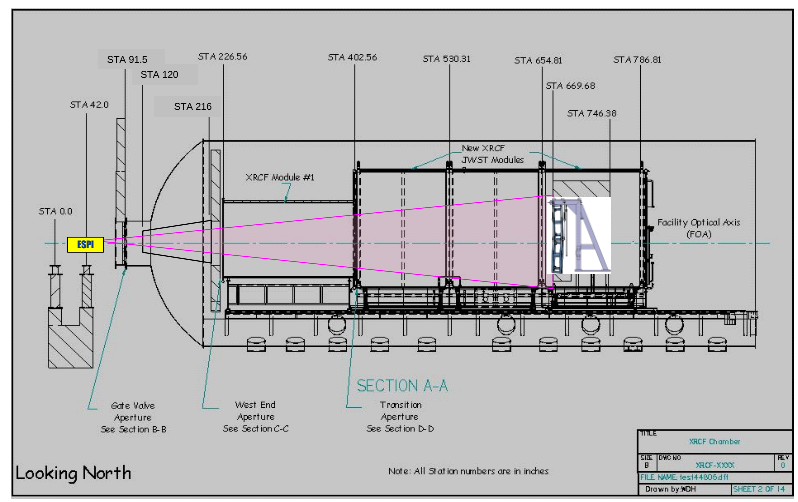
•Phased PSF clearly indicates coherent addition and success of closed loop fine phasing [After]

Lightweight Composite Structure (Backplane)

Backplane Stability Test Article to be used for cryo structure stability TRL-6 demonstration in the fall

- 1/6th full-scale portion of backplane
- Underwent cryogenic testing
  - Over operational ranges (hot to cold)
- Used ESPI to measure thermal distortions
- Demonstrated modeling and CTE testing approach and thus demonstrate our ability to predict backplane thermal stability



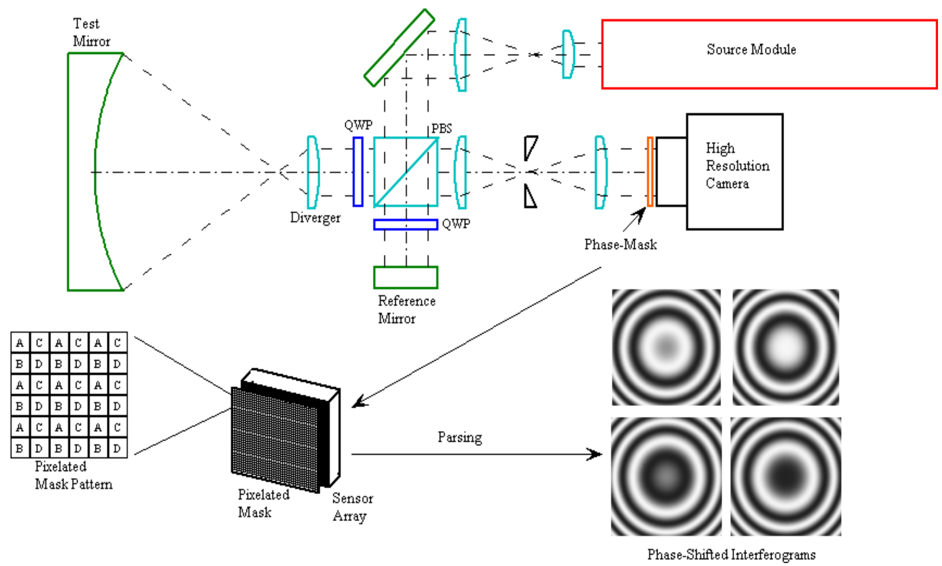


Test Configuration at XRCF

Metrology Tool Invented: Electronic Speckle Pattern Interometer

- **Instantaneous phase shifting interferometry is key to successfully test the large, deployable, JWST telescope at cryo**
- **Interferometer requirements:**
    - High sensitivity
    - Fast exposure time <100μs
    - Insensitivity to vibration
- **4D Technology developed two new interferometers:**
    - Multiple wavelength interferometer provides independent test of phasing of the Primary Mirror and the Telescope (more on this later)
    - Electronic Speckle Pattern Interferometer allows testing of deformations in large, diffuse structures to nanometer level at cryo (BSTA)
- **Pixelated phase mask that allows simultaneous capture of four phase shifted interferograms is the key feature in both interferometers.**

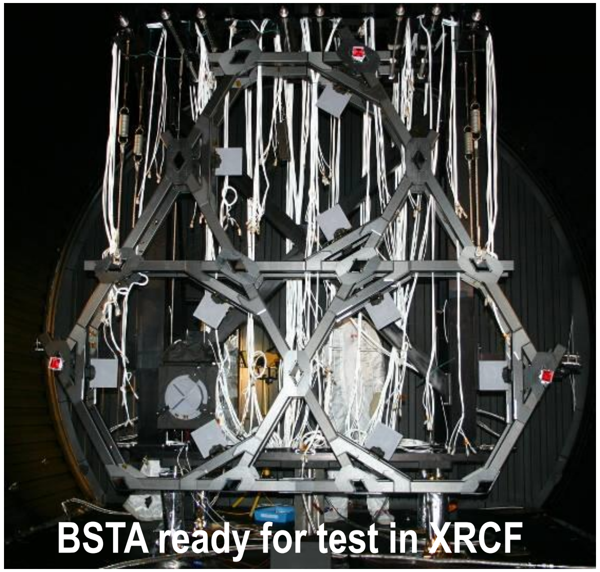
System Layout

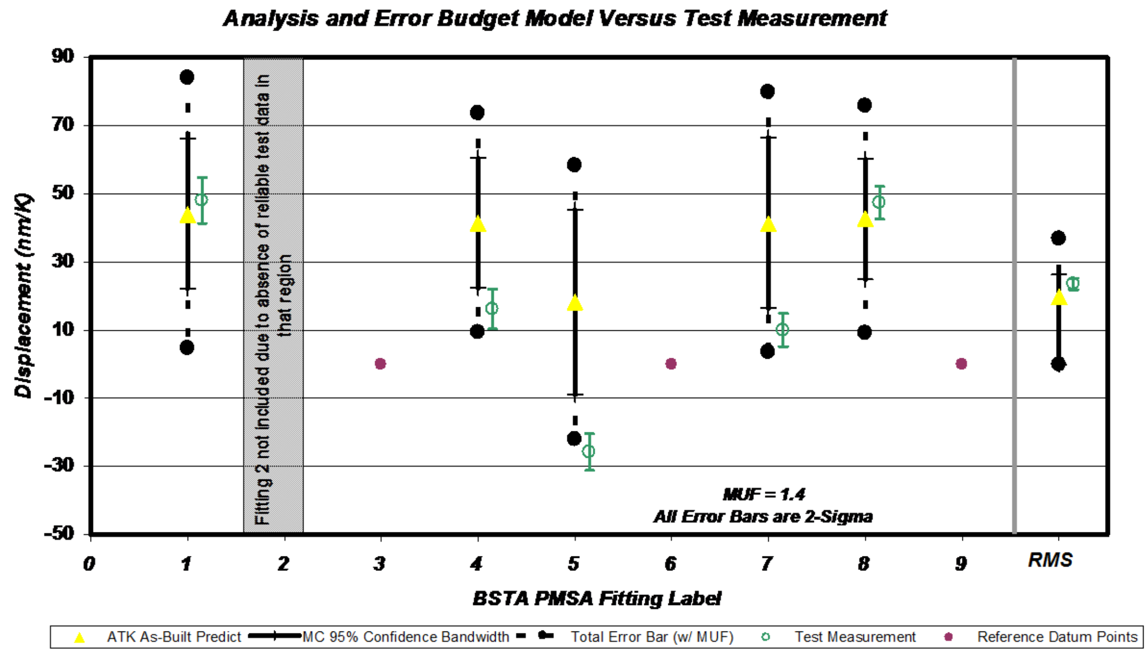


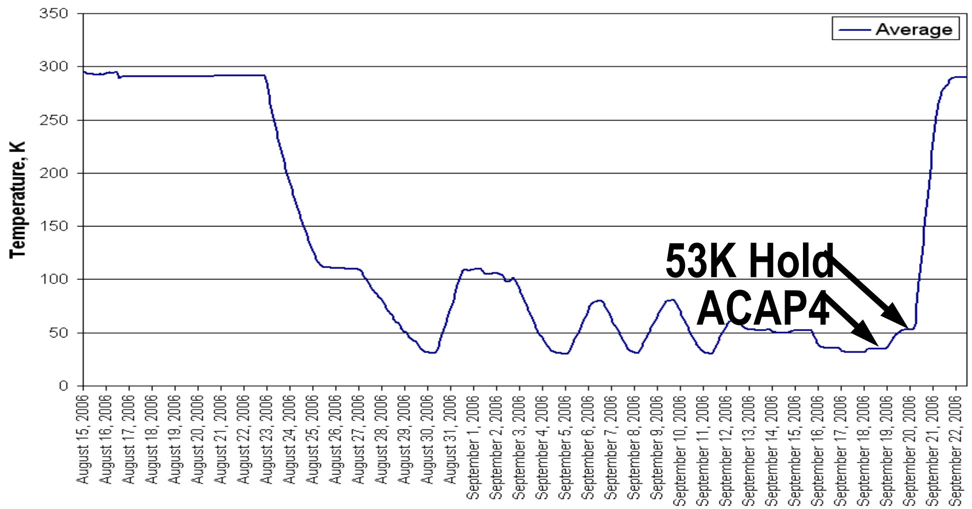
Four Phase-shifted Interferograms Captured Simultaneously

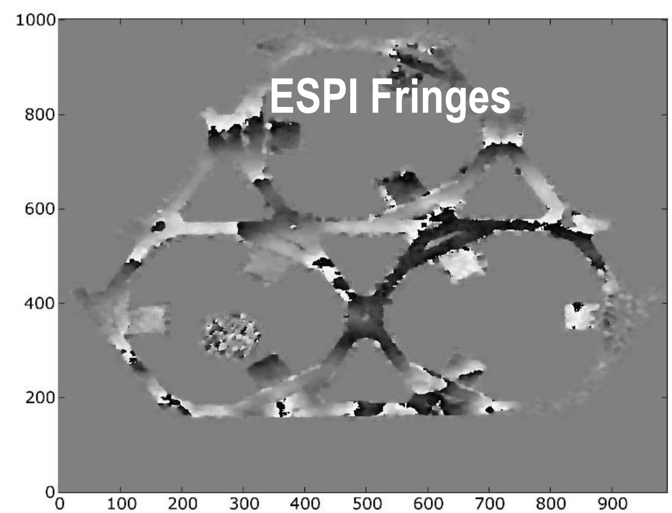
Electronic Speckle Pattern Interferometer

BSTA Results



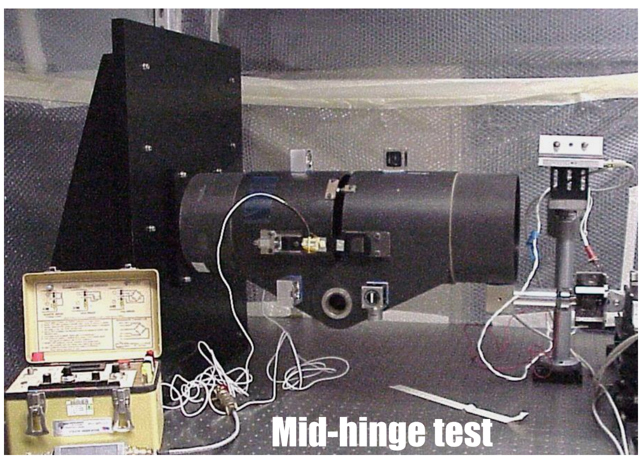


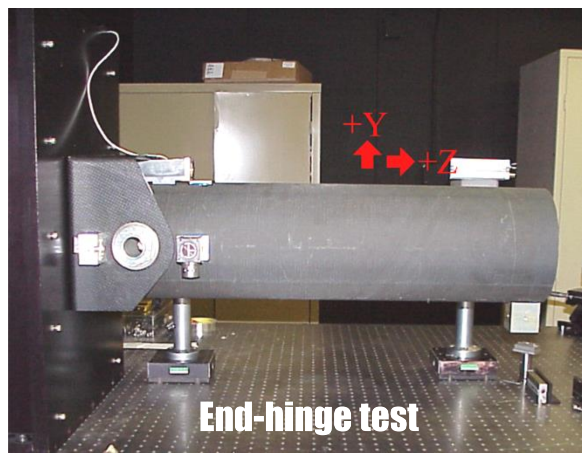




Microdynamic testing of all deployment latches completed

- Two types of SMSS hinge/latches and DTS tested
  - Wing latch was tested in 2000
- In all cases, no "nano lurches" were observed (with a noise floor of about 10nm) when loads were applied that were at least 10x greater than will be seen operationally


Mid-hinge test



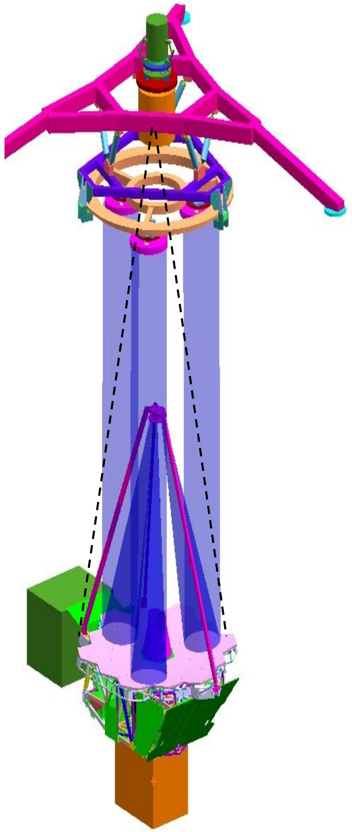
End-hinge test

Integration and Testing

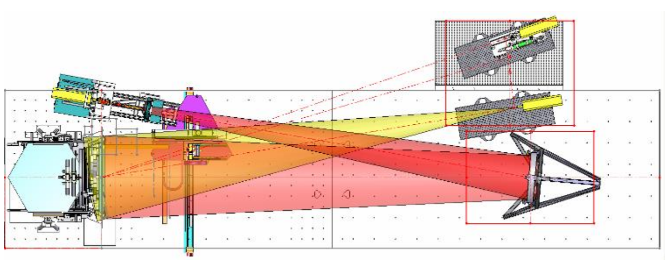
Avoiding a Hubble Error: Independent Testing

- The primary mirror segments have numerous cross checks built into the testing program
  - Ambient Primary Mirror Segment Level Testing using a CGH null at Tinsley and Ball
  - Ambient and Cryo measurements at the XRCF, made by Ball
    - Ball and Tinsley nulls designed and procured independently
  - Double Pass System level testing at JSC using the Autocollimating Flats, interferometery and PSF analysis
  - Center of Curvature Test at JSC using a null lens (made on all 18 mirror segments)
  - System optical alignment verification and secondary mirror testing are also important optical verification risks being managed via the risk management system.
- Cross checks also being employed on other optics and alignment
- In addition, an independent group of optical and telescope experts are reviewing test plans and key results (chaired by Duncan Moore, includes Jim Fienup)

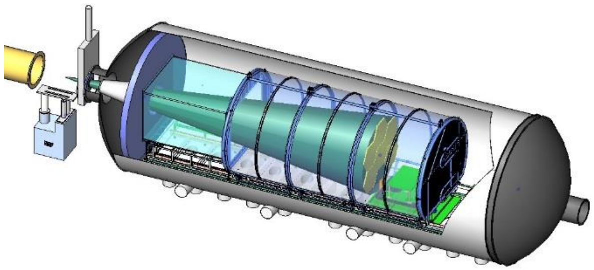
CoC Null Lens test



JSC System Test



Tinsley Ambient Configuration (Ball Config. Is Similar)

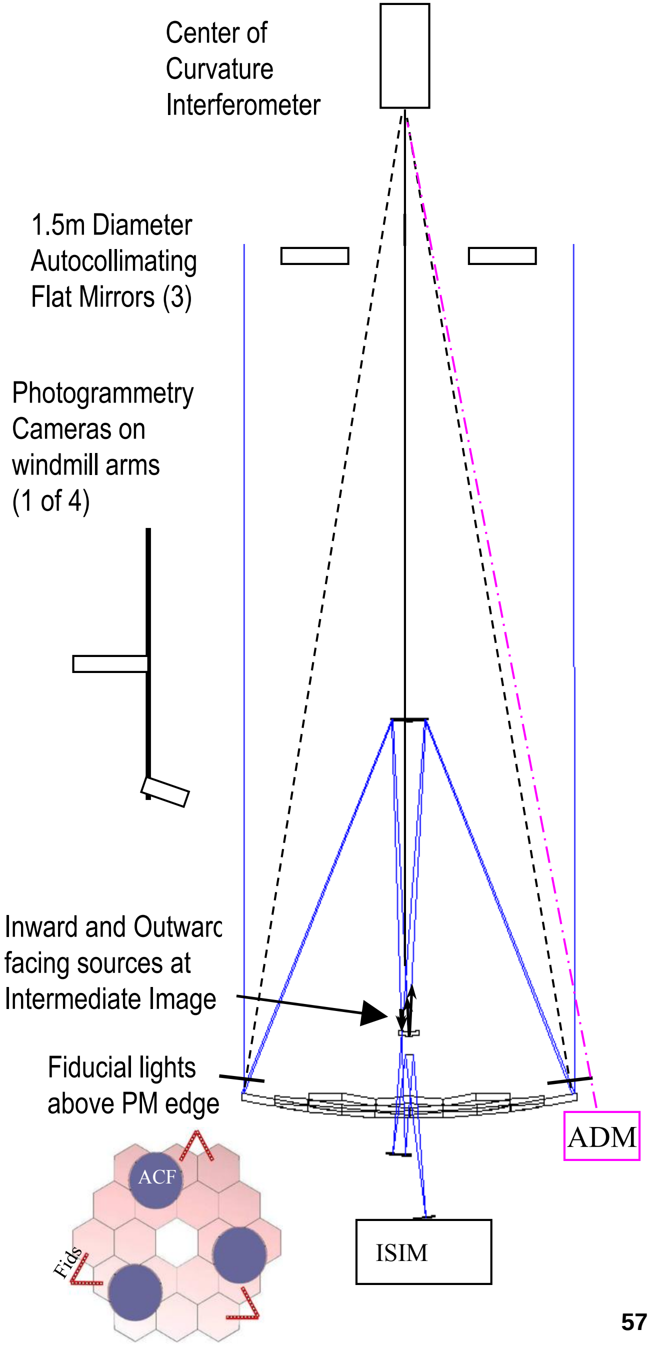


MSFC XRCF Cryogenic Configuration

JSC Optical Test Architecture

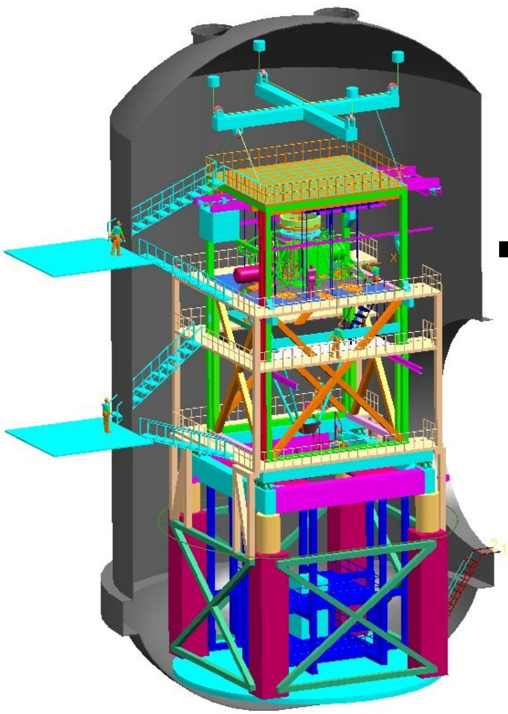
- Integrated Test Assembly supported from top of chamber with vibration isolation
- Center of Curvature Interferometer for PM WFE
  - Absolute Distance Meter (ADM) for axial distance
  - Alignment cameras for initial capture and setup
  - Displacement Measuring Interferometers (DMI) to monitor axial change during thermal distortion test
- Photogrammetry for position measurements
- Inward and Outward Facing Sources at PM-SM intermediate image for imaging to SI's
  - Direct to SI's "Half Pass"
  - End-to-End "Pass and a Half"
    - » Autocollimating Flat Mirrors
- Fiducial lights around PM for

  PM pupil alignment tests

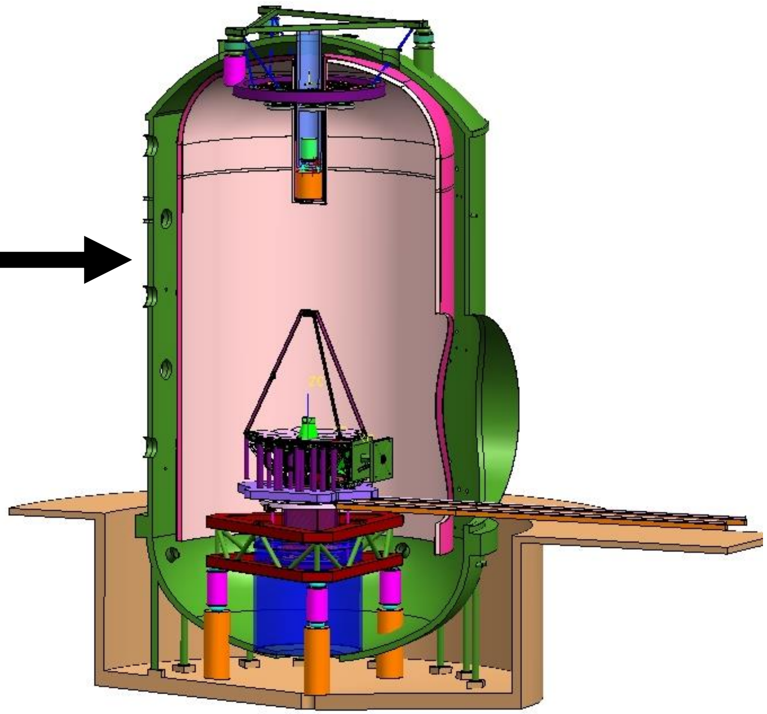


JSC Cup Up Configuration Removed Need for Expensive Metrology Tower

Old "Cup Down" Configuration Included Large Metrology Tower And Test Equipment Inside Shrouds



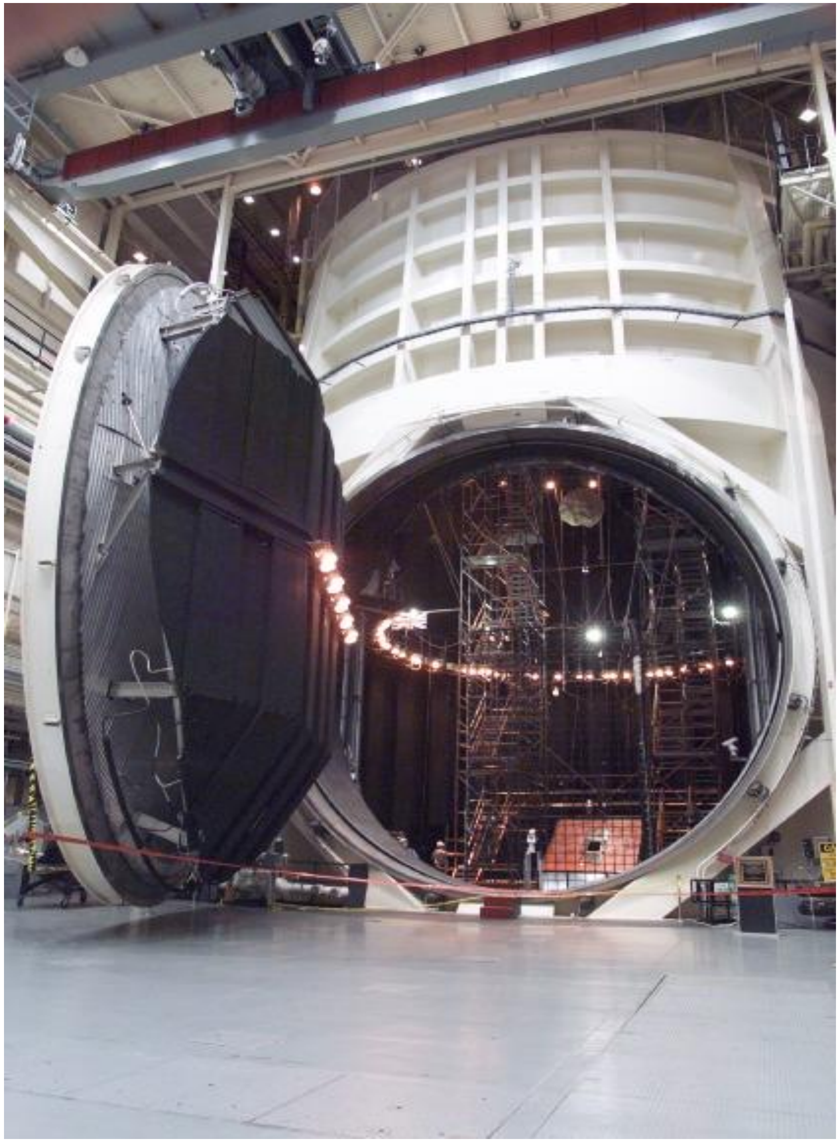
New "Cup Up" Configuration Eliminates Tower And Allows for Accessibility to Test Equipment From Top and Bottom of Chamber during testing



JSC Size, Accessibility, and Large Side Door Access Make it Well Suited for This Configuration

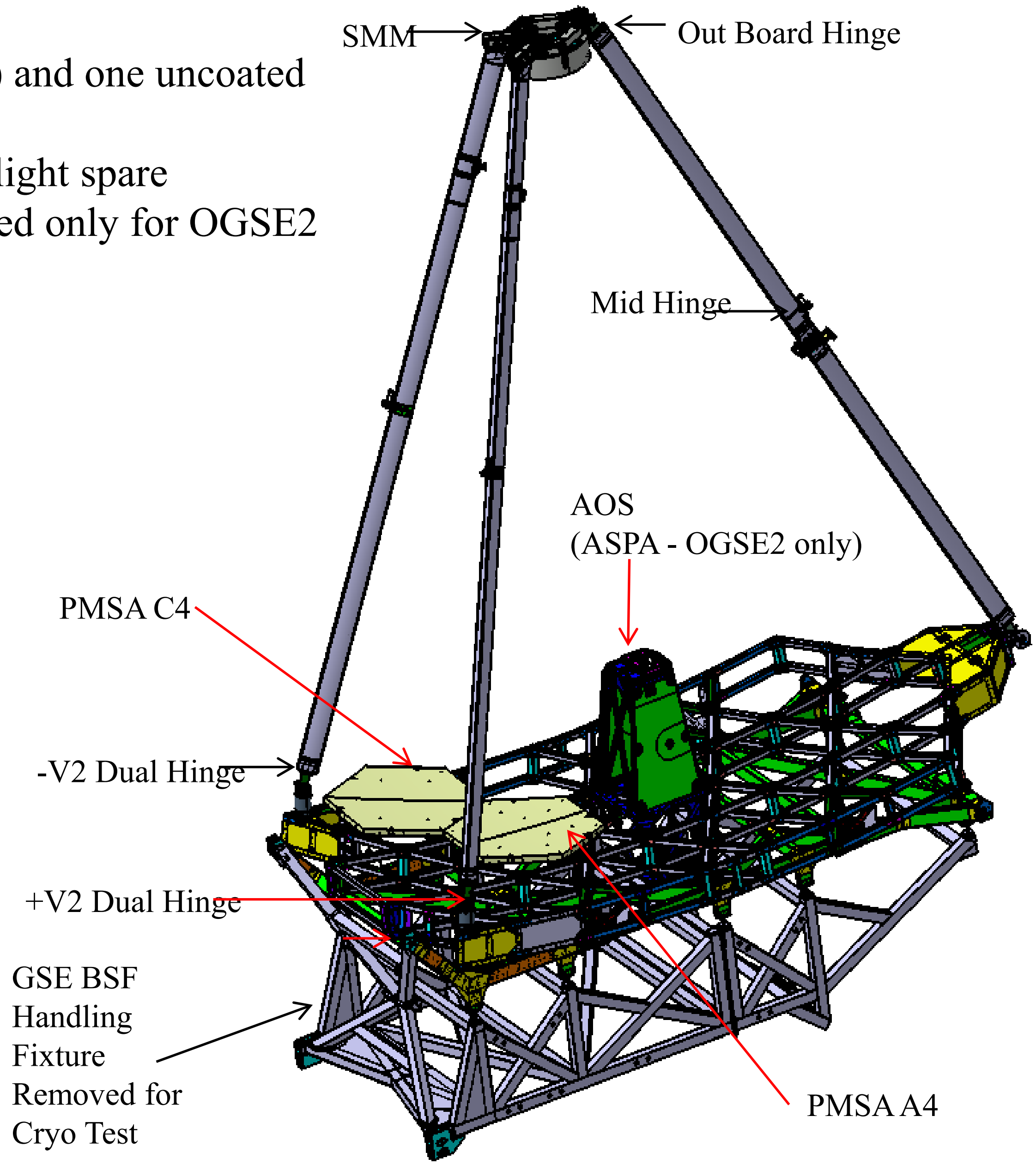
Cryogenic Testing Conducted in JSC Chamber A Thermal Vacuum Facility

Chamber A was used for Apollo landers and already includes Nitrogen and Helium systems. Plan is to upgrade it with a new Helium Inner Shroud.



Pathfinder Overview

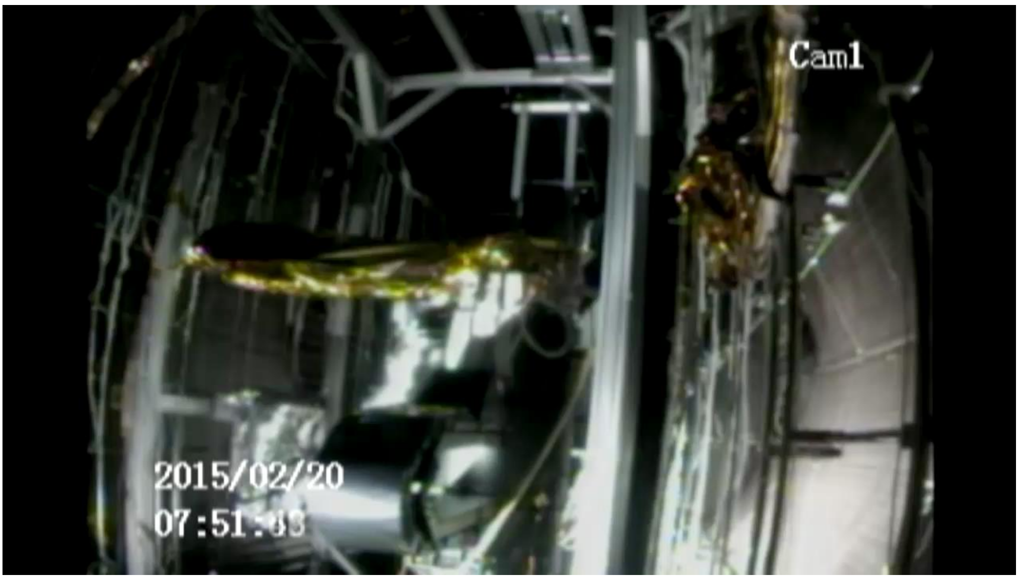
•Includes one coated PMSA (A4) and one uncoated PMSA (C4), flight spares
•Secondary Mirror is uncoated, flight spare
•AOS (flight) and ASPA are added only for OGSE2



Telescope and Pathfinder in Pictures

Telescope Pieces at Northrop Grumman

DTA deployment and Secondary Mirror Support Structure



May 2015


NORTHROP GRUMMAN
Wing Hinge Installation in
Redondo Beach


DTA
Installation

OTE Structure into Shipping Container

August 2015

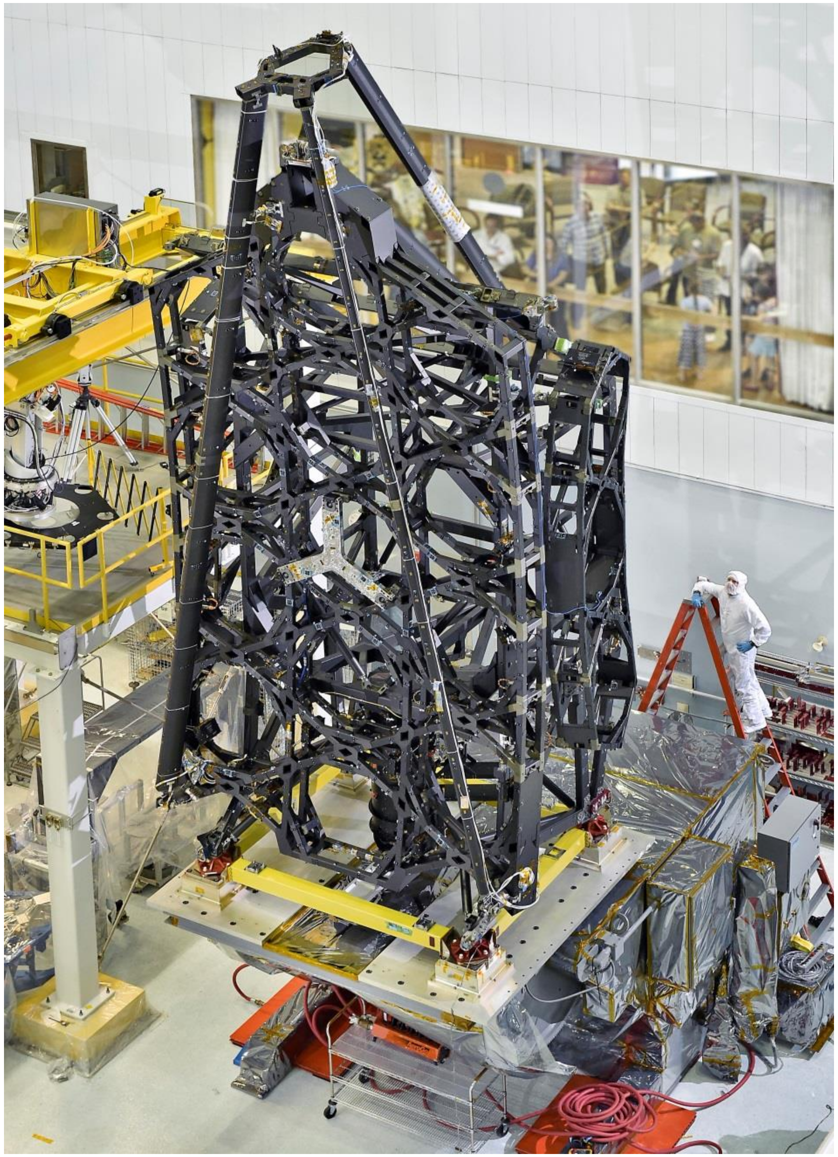
Welcome to GSFC (August 2015)

August 2015

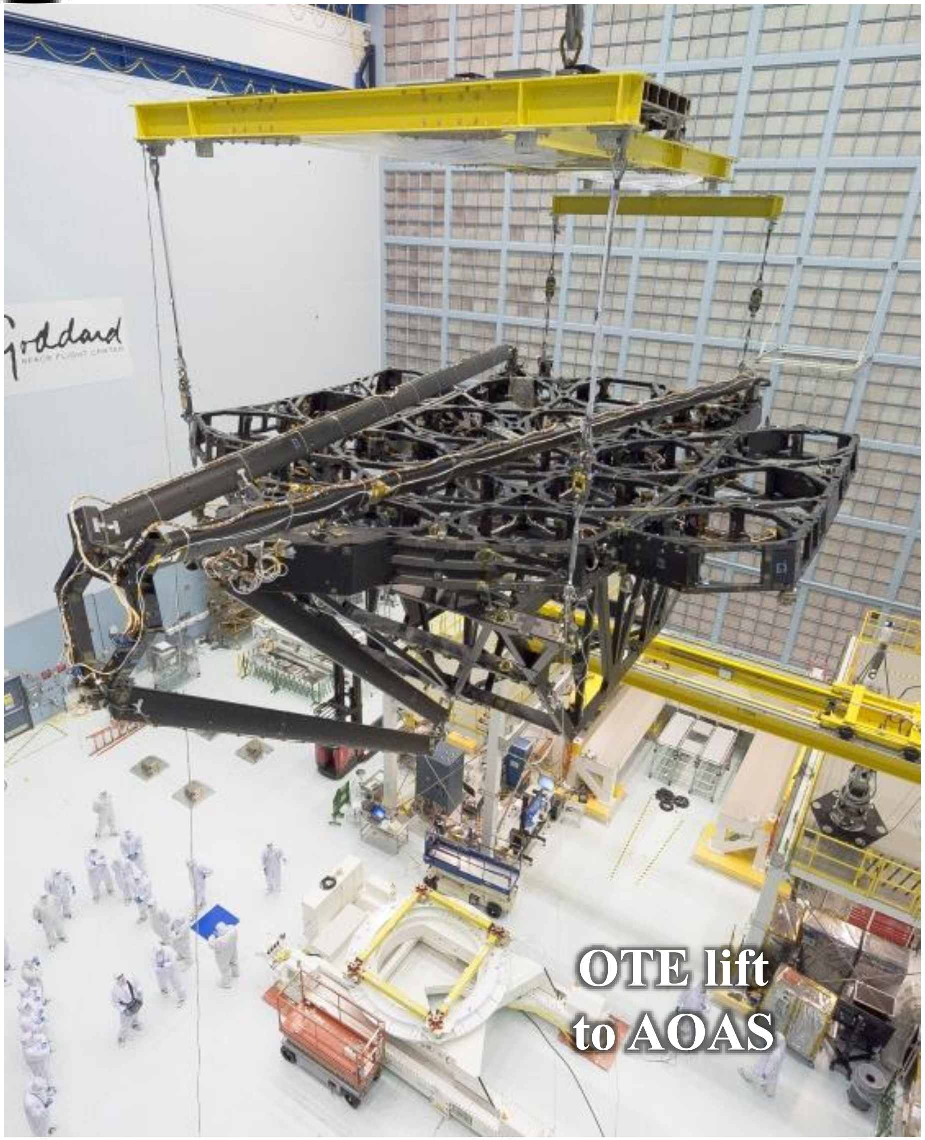

hubble.nasa.gov
OVERSIZE LOAD
NELSON
OTTAWA, OHIO
419-523-5321

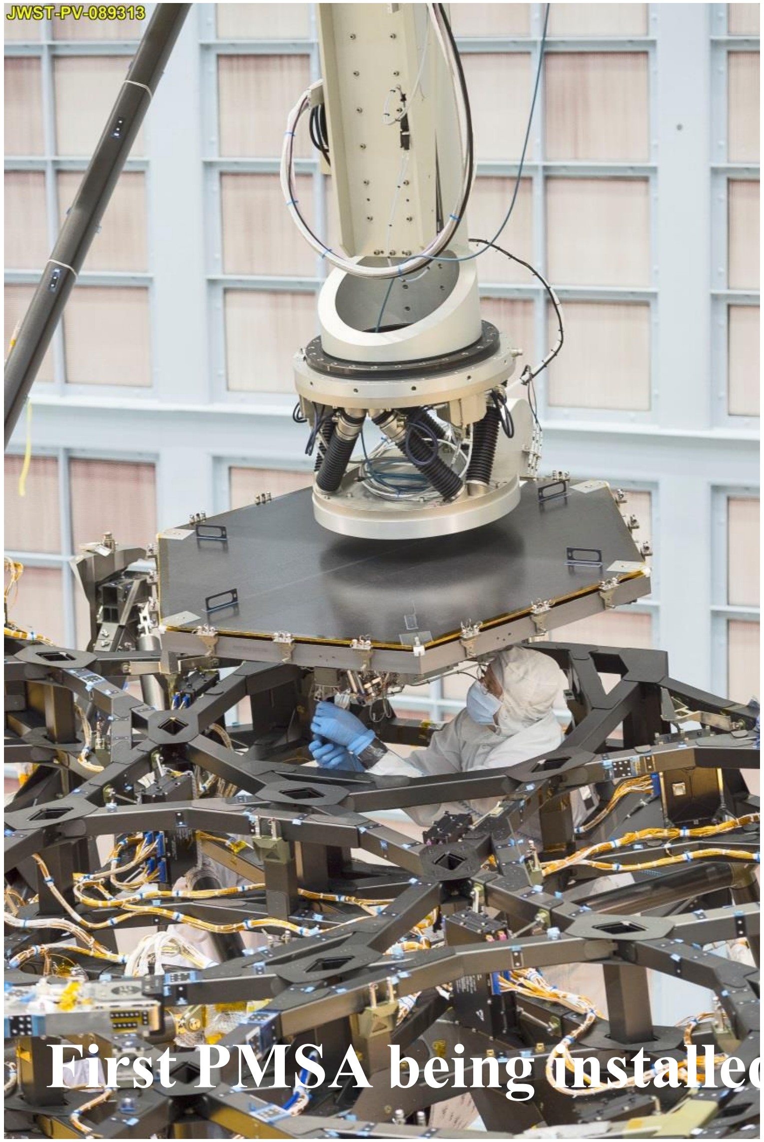
August 2015

- In SSDIF at GSFC



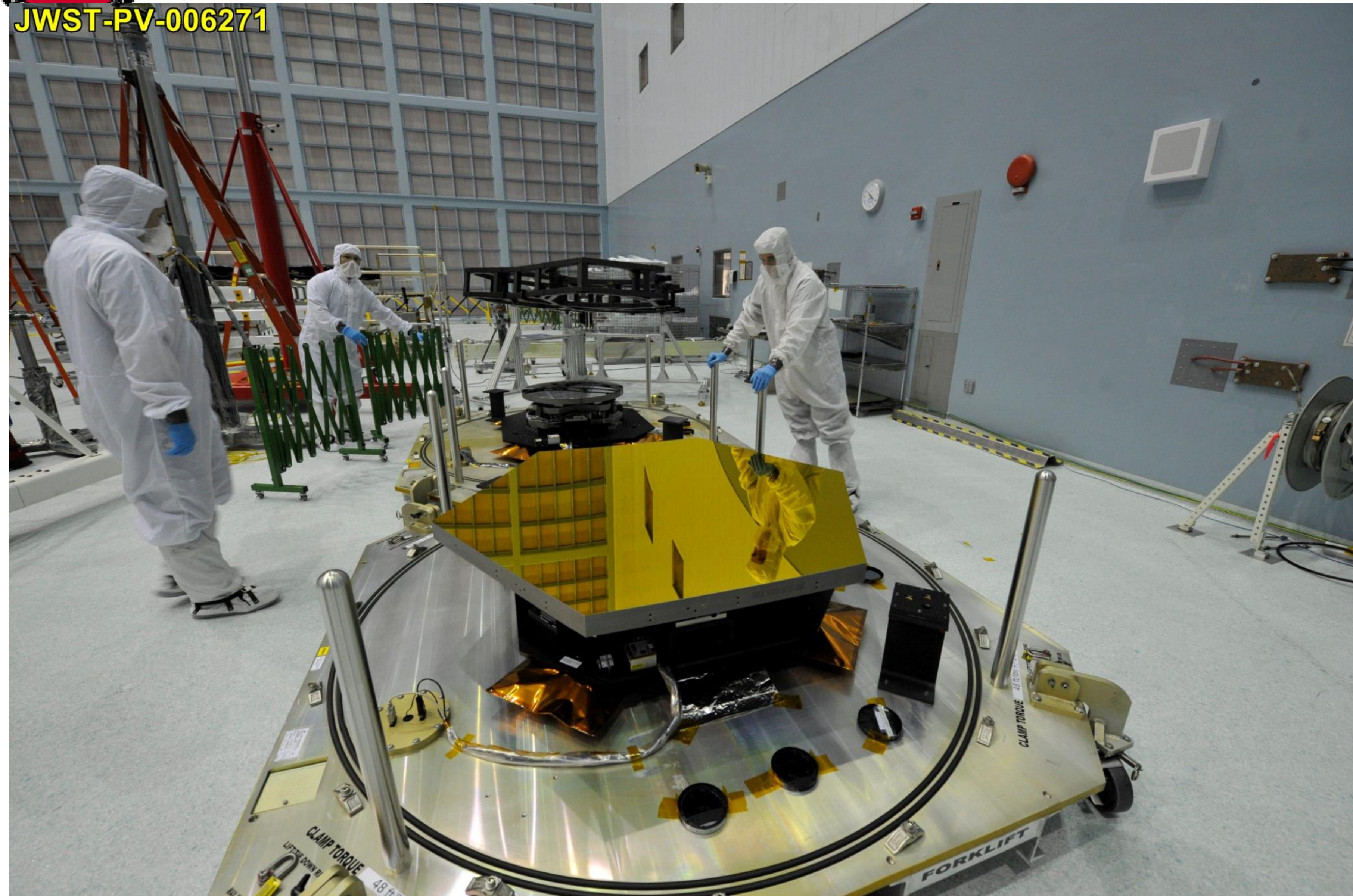
Mirror Installation (Nov ‘15 – Jan -16)





Pathfinder

Primary Mirror EDU and Secondary Mirror EDU in SSDIF: practice tests

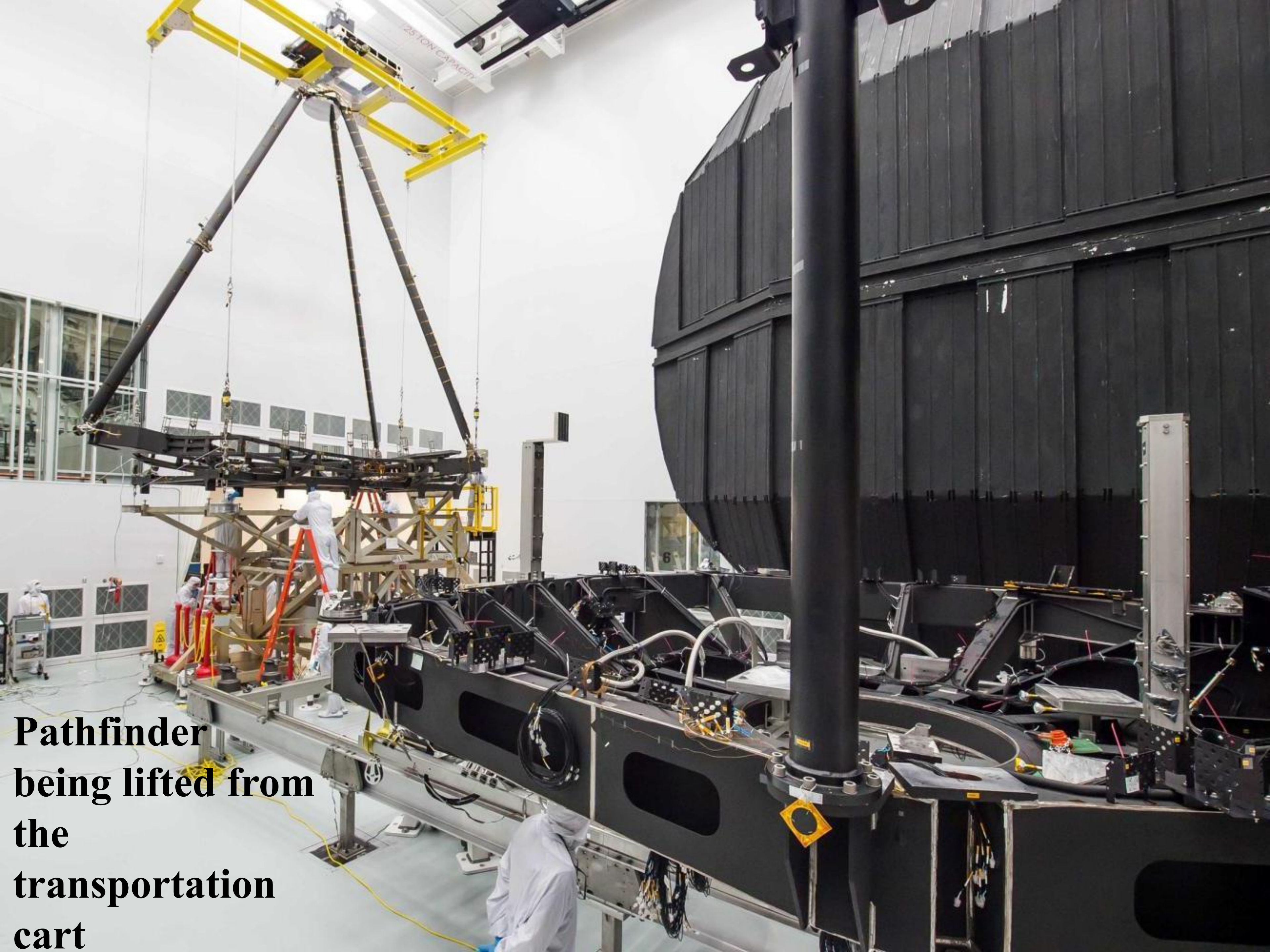


PMSA Processing in the GSFC CIAF

Every mirror was sent to the CIAF for CMM measurements before and after shimming (Roughly March to July for flight)

Performed final inspections


1-TON

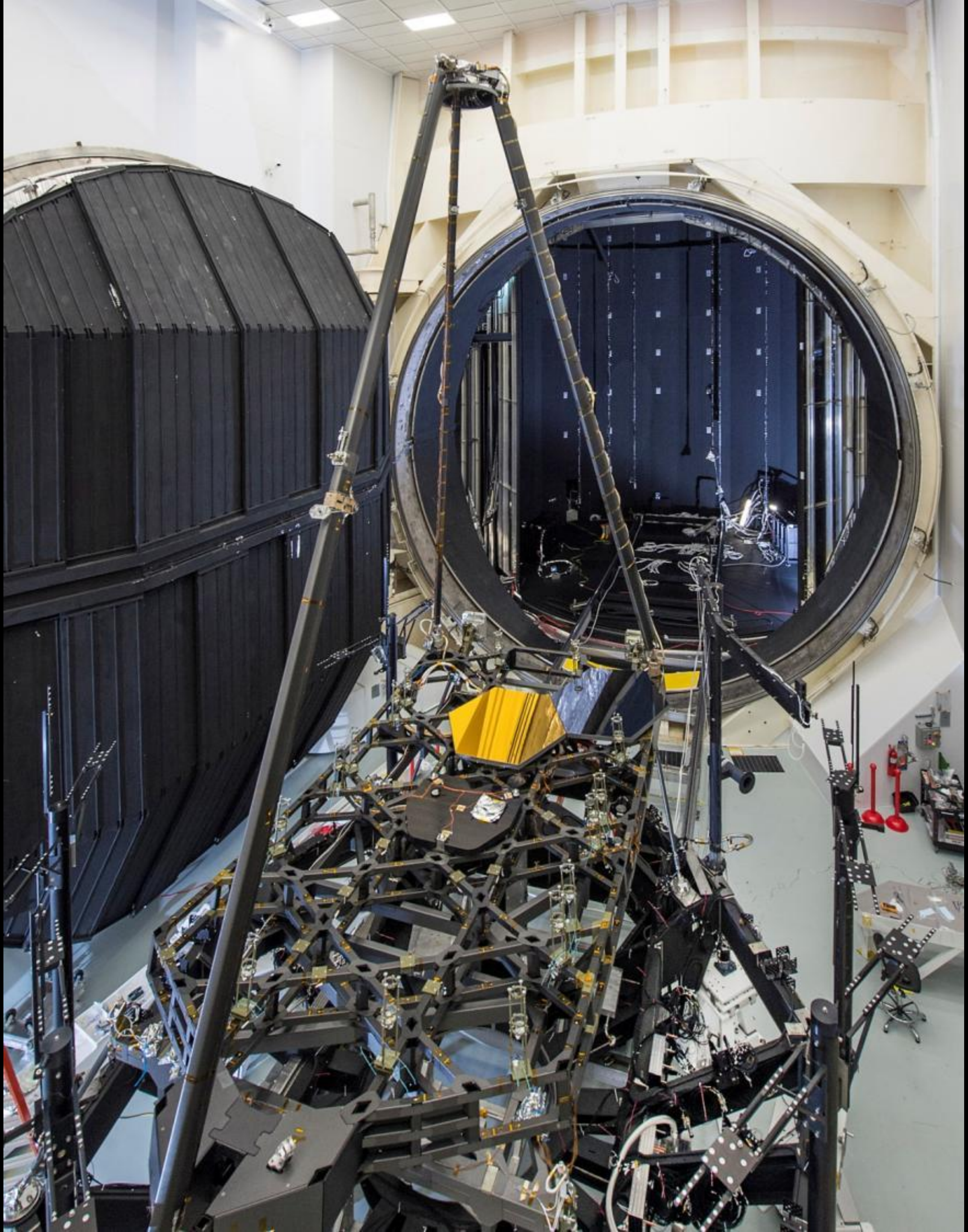


Pathfinder being lifted from the transportation cart

Pathfinder mounted to the HOSS as seen from inside the chamber

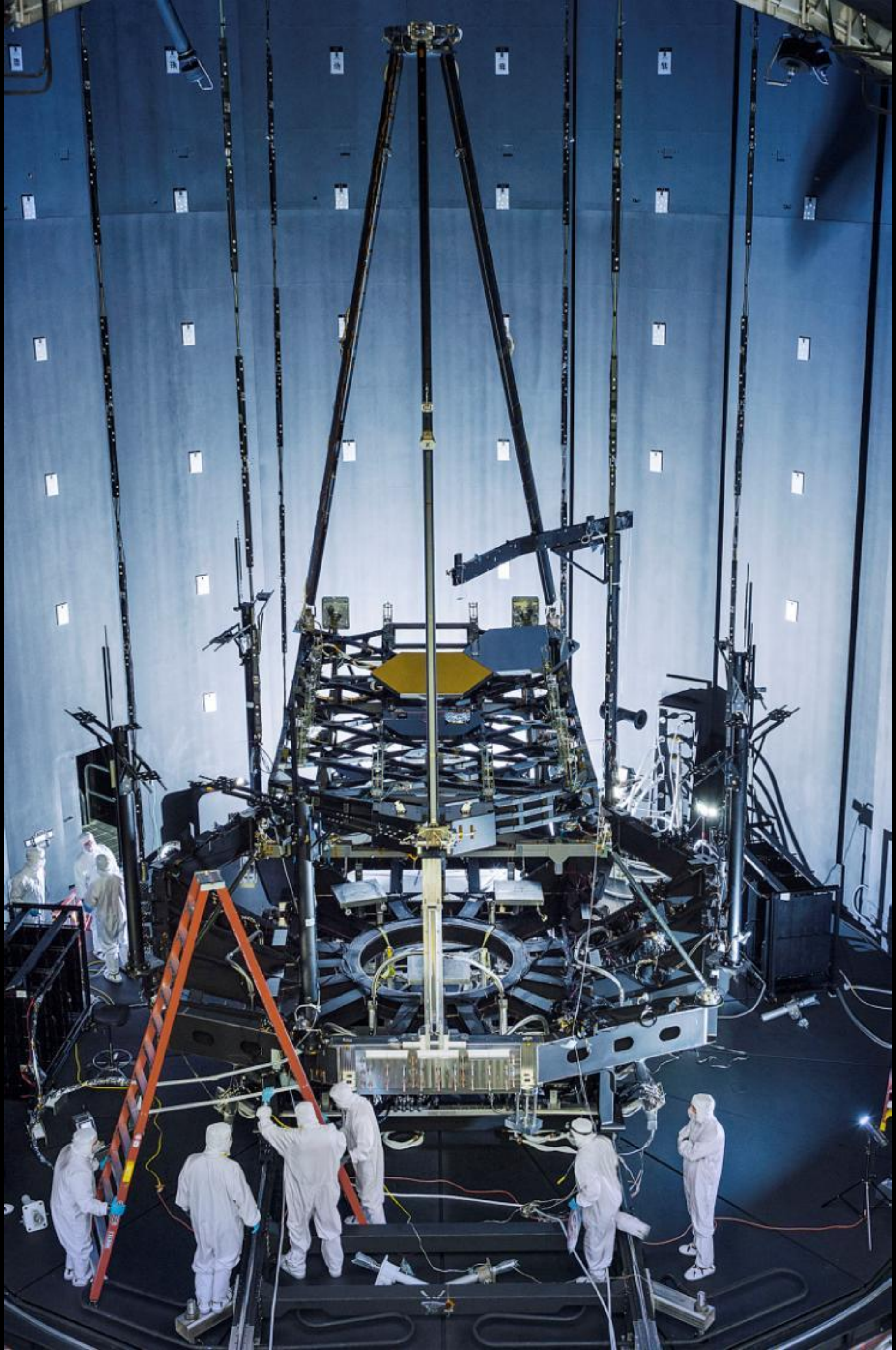
Pathfinder on the HOSS with the chamber in the background

Cleared the chamber door by 8"



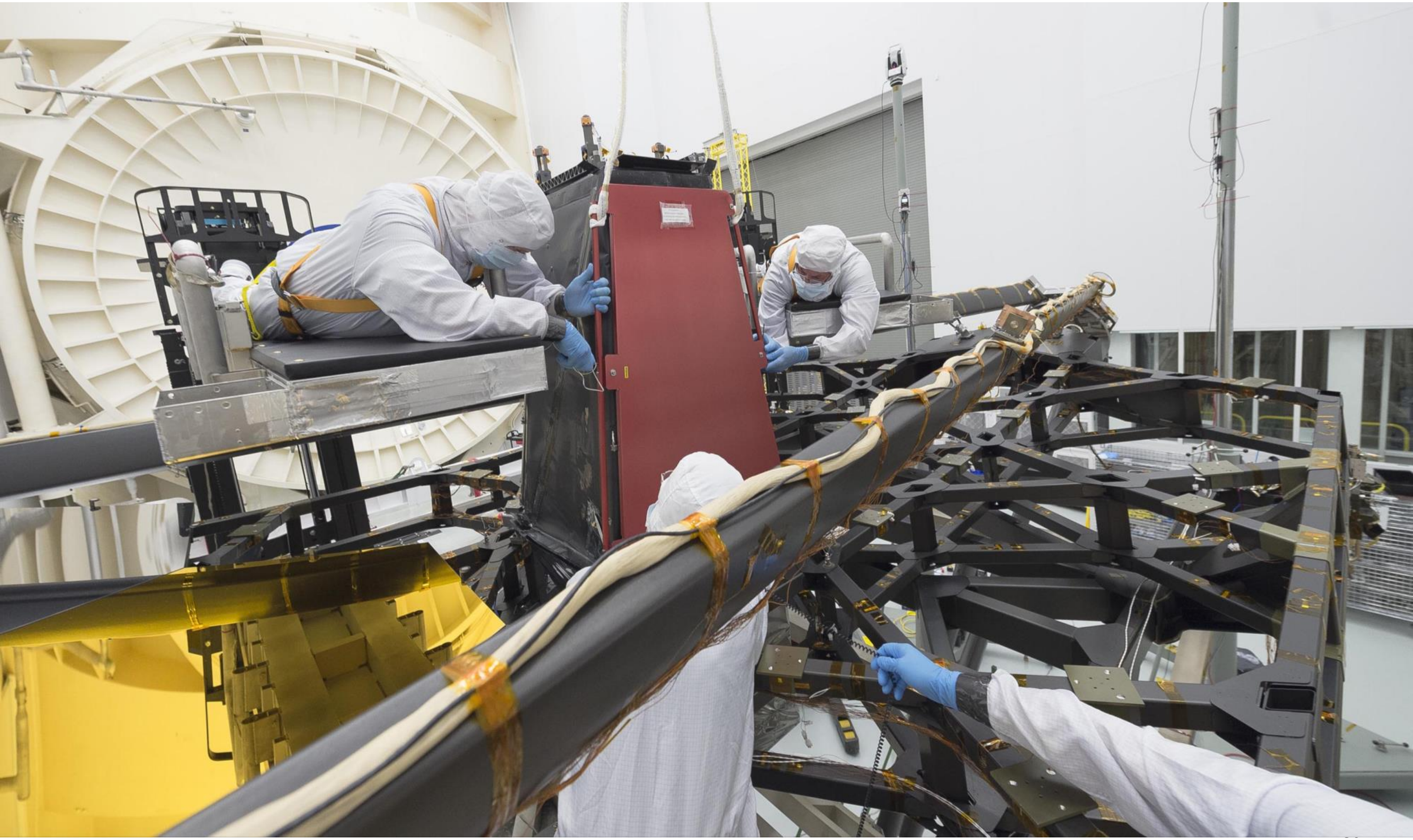
Pathfinder in the chamber.

Note the 12' step ladder for scale

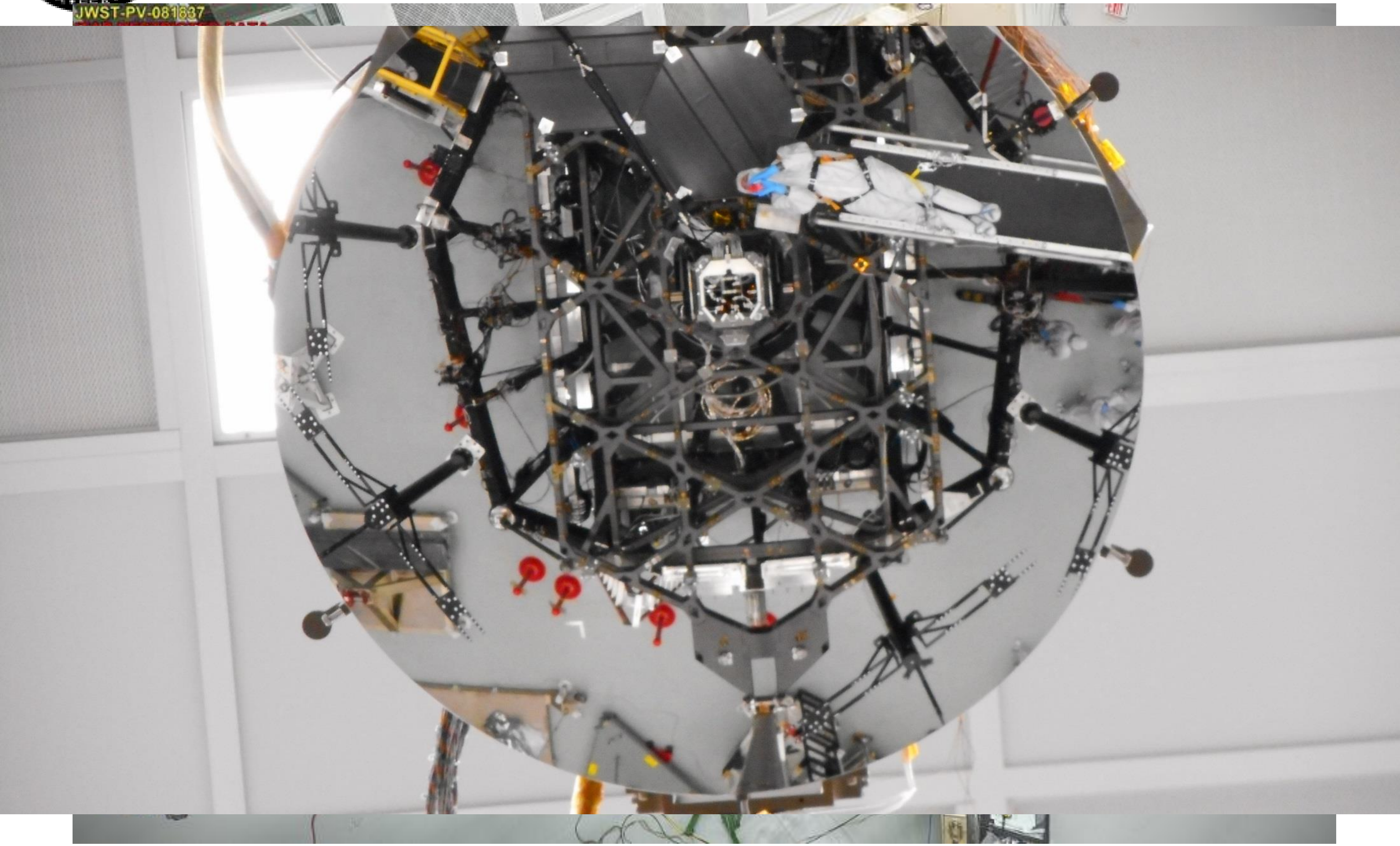


AOS in the OTIS Cleanroom at JSC, Metrology Preps

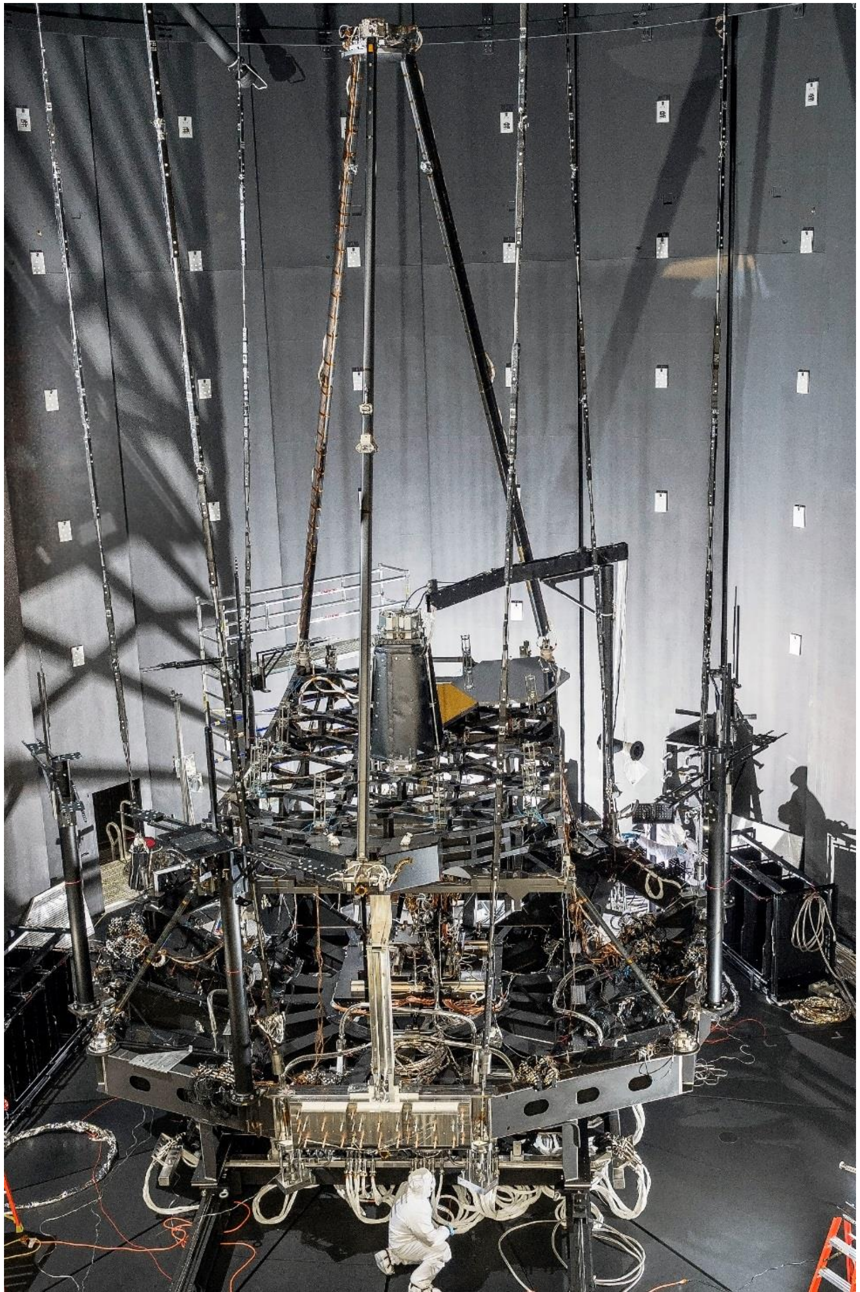
AOS Installation into the Pathfinder



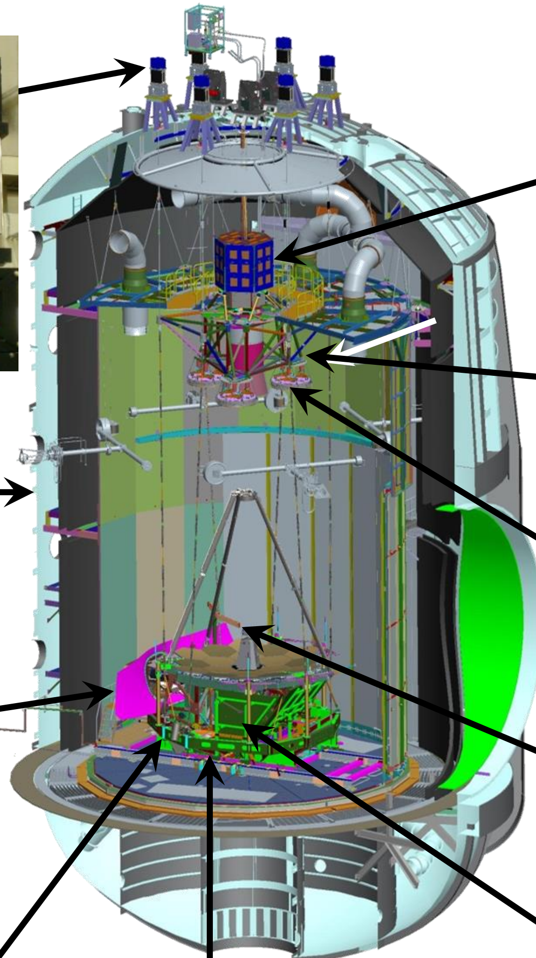
AOS on Pathfinder



Pathfinder in Chamber for OGSE2 (Sept '15)

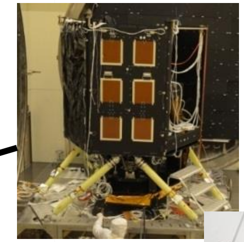


OTIS Test GSE Architecture

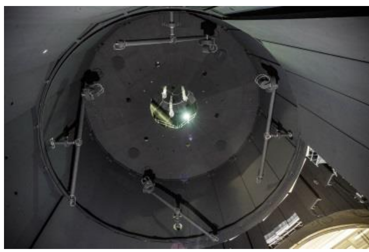


Chamber Isolator Units
Dynamically isolates OTIS Optical Test – Integration of 6 units complete

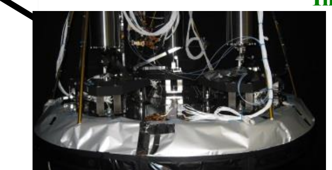
Cryo Position Metrology (CPM)
Photogrammetry System Integration Complete



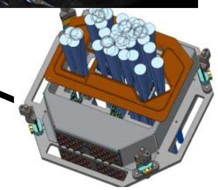
Center of Curvature Optical Assembly (COCOA)
- **Multiwavelength interferometer (MWIF), null, calibration equipment, coarse/fine PM phasing tools, Displacement Measuring Interferometer – Installed in Chamber**



USF Structural Frame – supports Metrology Installed in Chamber



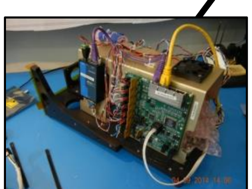
3 Auto collimating Flat Mirrors (ACFs)
1.5 M Plano for Pass and Half Testing
ACF 1 installed in Chamber A, ACF 4 and ACF 5 are complete,



AOS Source Plate Assembly (ASPA)
Testing complete at Ball
Delivered to JSC

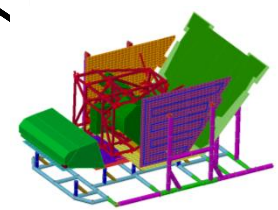
Space Vehicle Thermal Simulator (SVTS) and Sunshield Simulator
Third and final Pathfinder test planned this summer

Mag Damper Cryo Test Article Delivered



ADM
Testing complete at JHU
Delivered to JSC

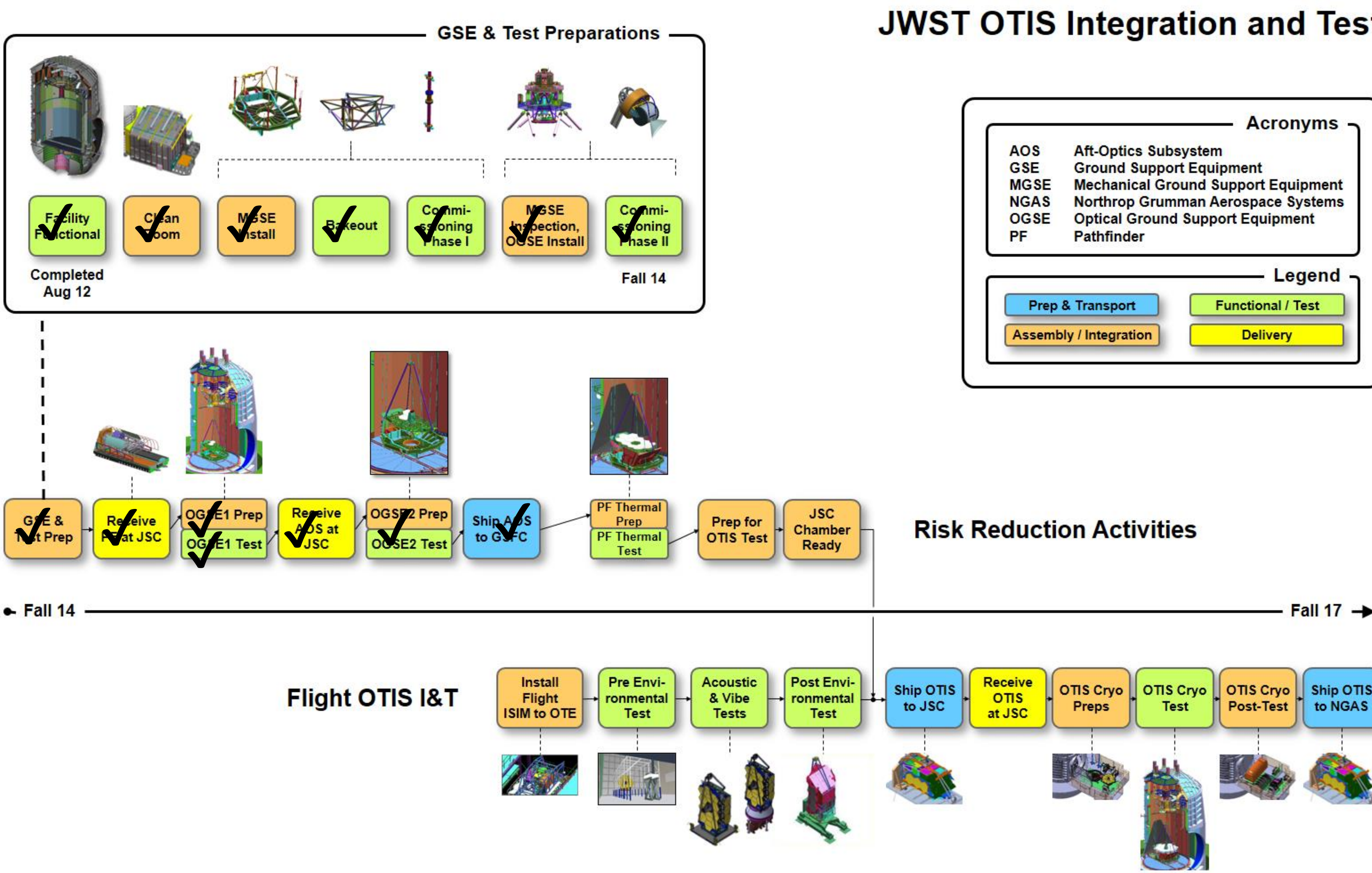
HOSS – Hardpoint Offloader Support Structure
In integration in Clean Room



Deep Space Edge Radiation Sink (DSERS)

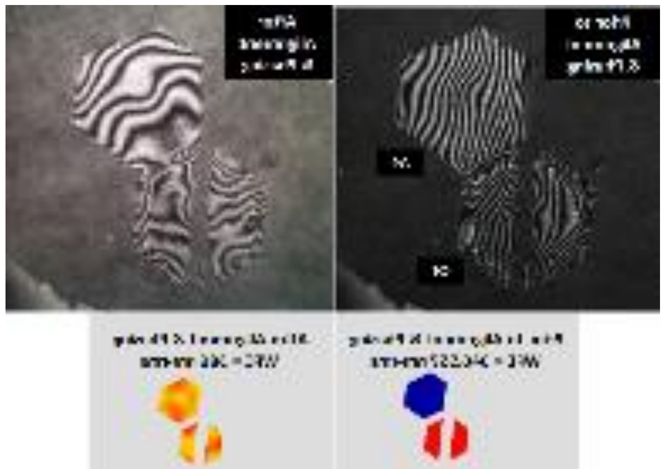
Frame integrated

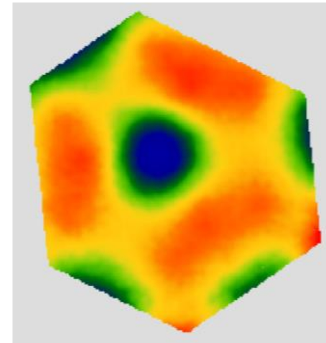
Where Are We In OTE-ISIM (OTIS Flow)

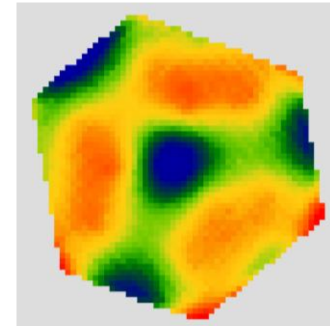


Pathfinder Early Results

Multi-Wavelength Phasing Using Synthetic Wavelengths



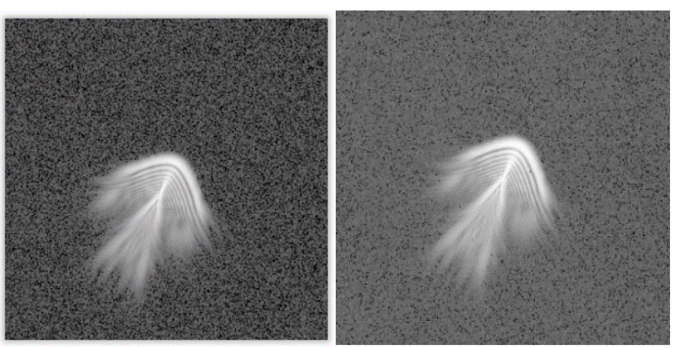




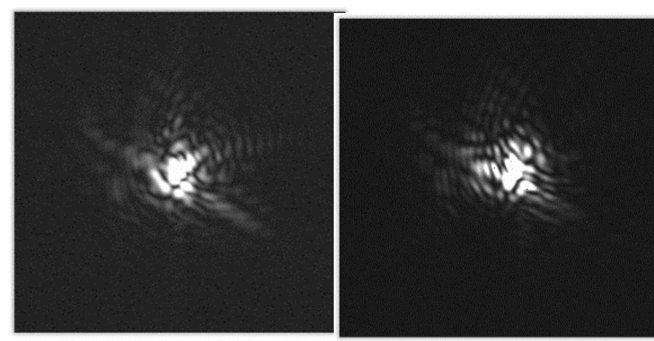
Measured RMS WFE = 211 nm

Modeled RMS WFE = 213 nm

Half pass Prediction vs. Data

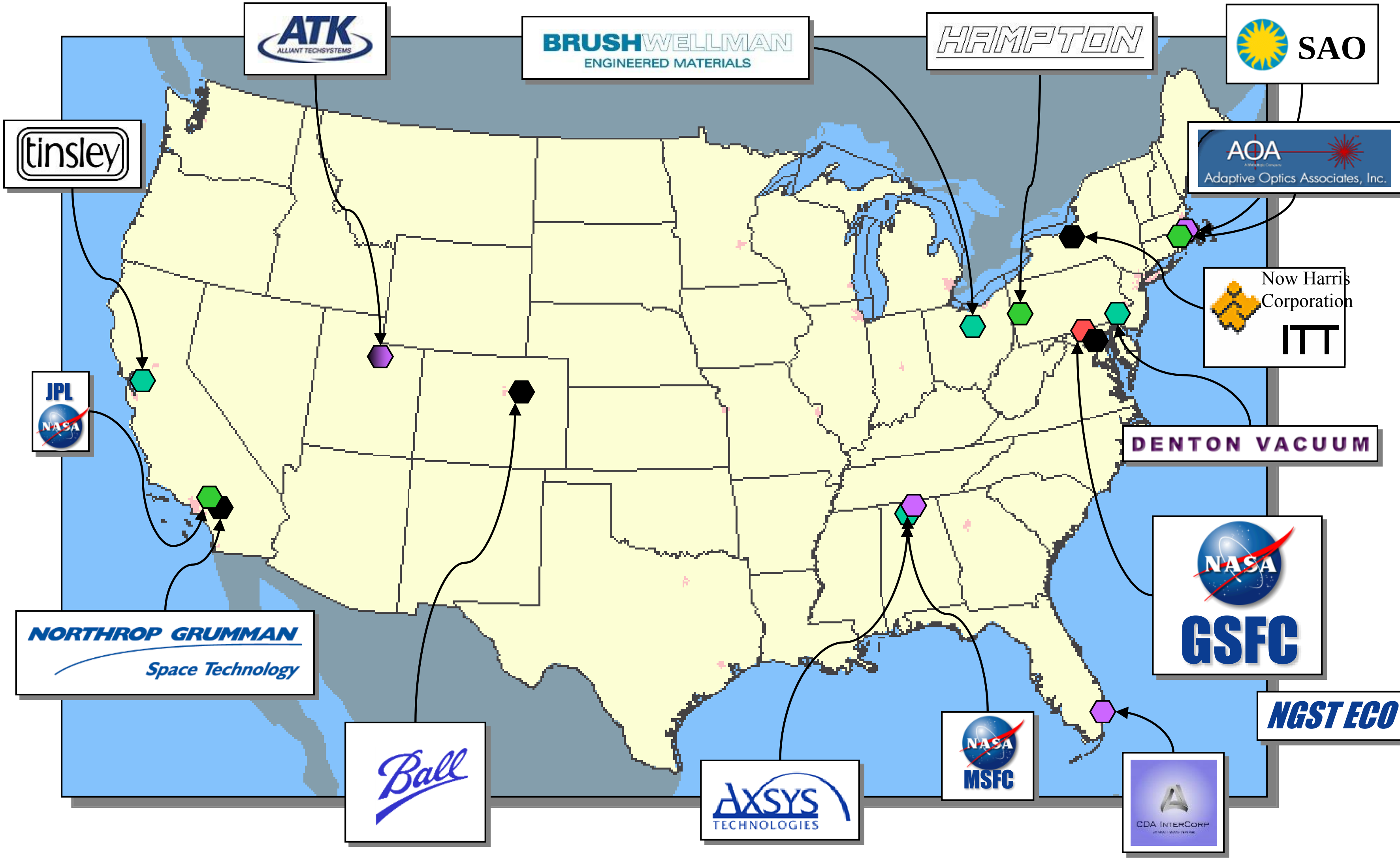


Pass and a Half Prediction Vs Data (“Stacked”)



The team

Telescope Team



NASA Project Office · JWST Prime Team · Beryllium Suppliers · WFS&C Suppliers/Associates · Other Suppliers/Associates

Looking Back: THANK YOU to the Incredibly Skilled and Dedicated Teams

National Aeronautics and Space Administration
Goddard Space Flight Center

OTE management team stable for 14 years!