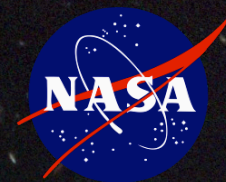
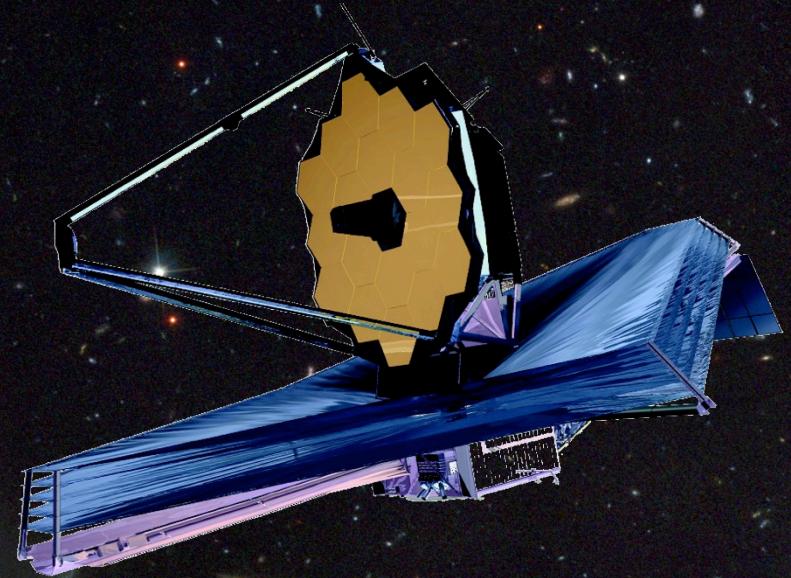


The James Webb Space Telescope



Jonathan P. Gardner

NASA's Goddard Space Flight Center

<http://jwst.gsfc.nasa.gov>

Space Science Reviews, 2006, 123/4,

485



JWST "movie trailer":

<http://svs.gsfc.nasa.gov/goto?10565>

James Webb Space Telescope

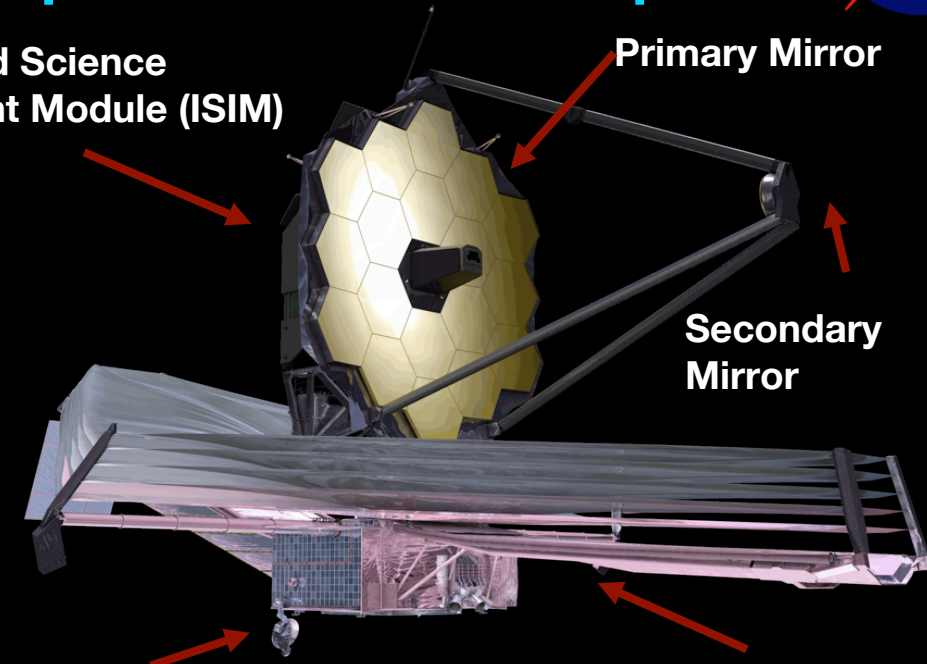


- 6.6m Telescope
- Launch in 2014 to L2.
- Successor to Hubble & Spitzer.
- Demonstrator of deployed optics.
- 4 instruments: 0.6 to 28.5 μm
- Passively cooled to $<50\text{K}$.
- Named for 2nd NASA Administrator

Integrated Science
Instrument Module (ISIM)

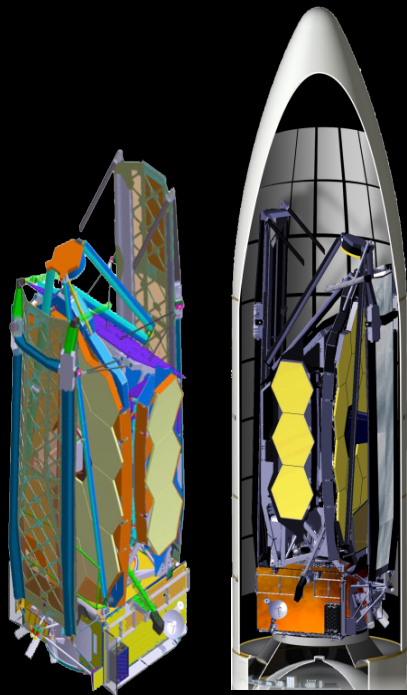
Primary Mirror

Secondary
Mirror



Spacecraft Bus

5 Layer Sunshield

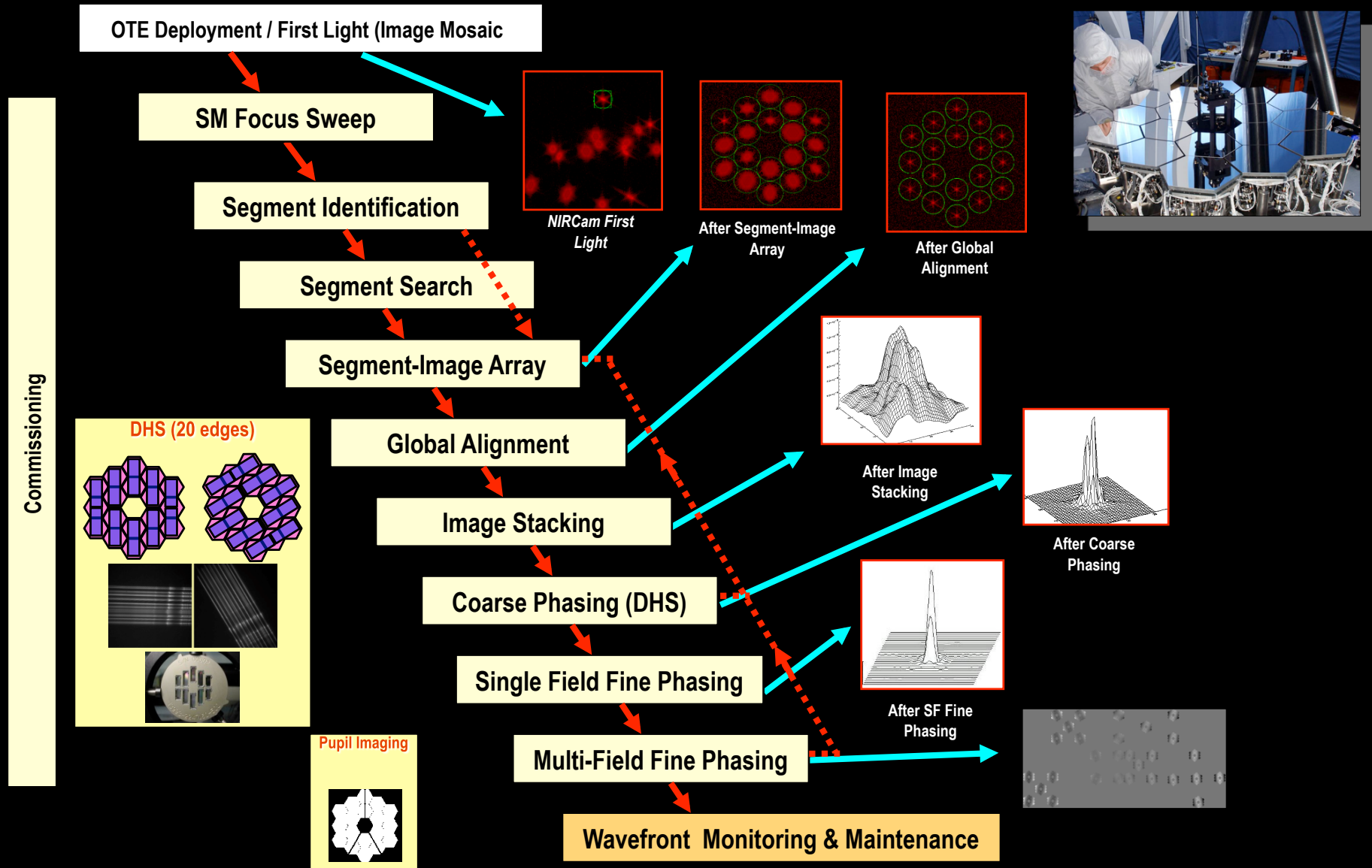


- Complementary to ELT, ALMA, SKA, IXO, etc
- NASA + ESA + CSA: 14 countries
- Lead: Goddard Space Flight Center
- Prime: Northrop Grumman
- Operations: STScI
- Senior Project Scientist:
Nobel Laureate John Mather

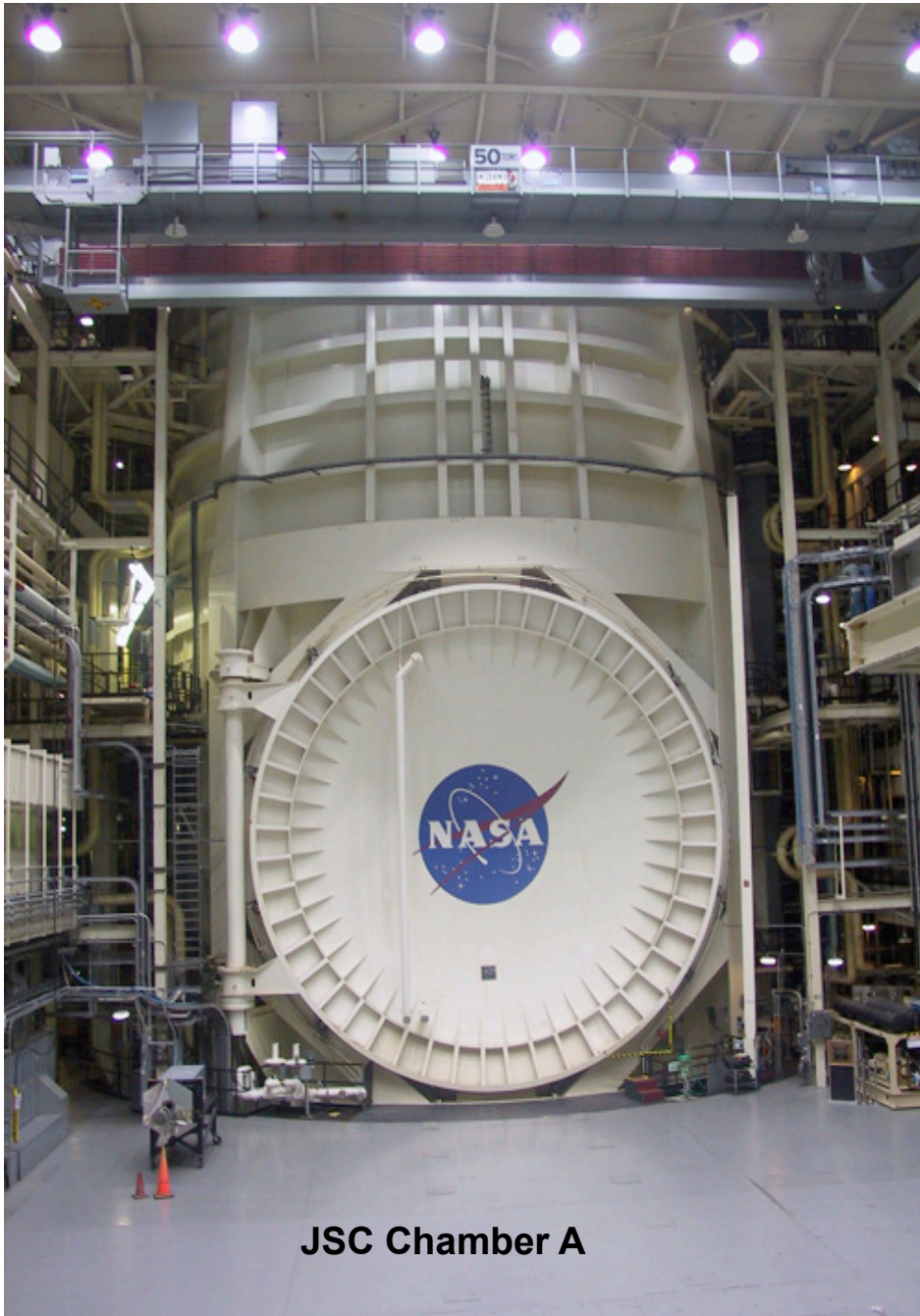




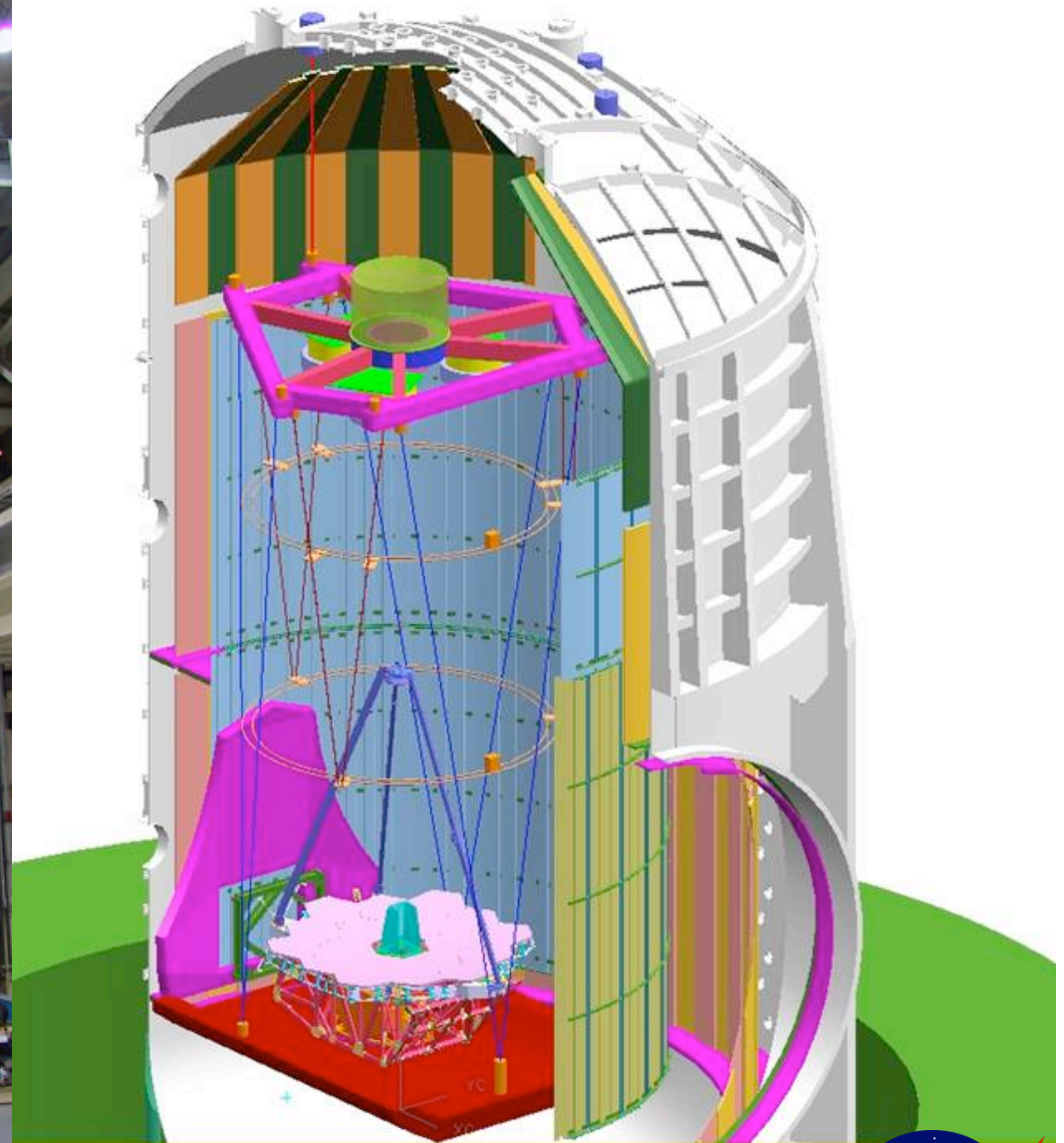
WFSC



Observatory level cryo-vacuum testing will occur at JSC



JSC Chamber A



Near-Infrared Camera

- Broad, Medium and Narrow-band imaging
- 0.6 to 5.0 mm
- 10 square arcmin
- Two bands at once
- Coronagraphy



LOCKHEED MARTIN



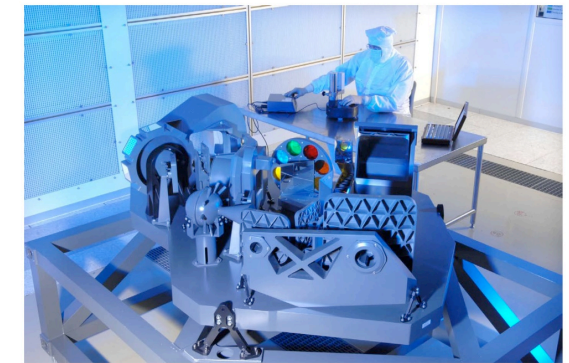
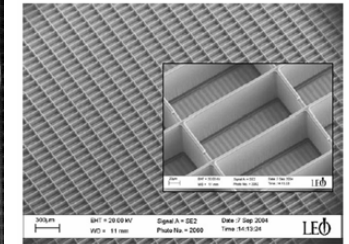
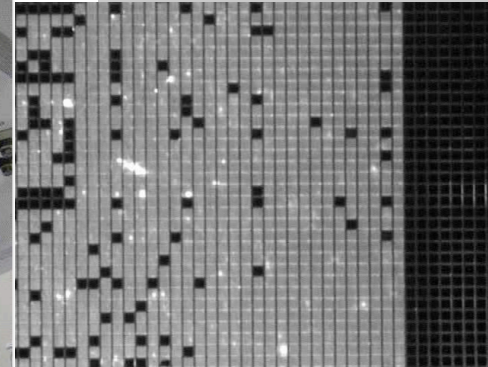
Fine Guidance Sensor and Tunable Filter Imager

- Imaging at ~1% bandwidth
- $1.6 < \lambda < 4.9 \mu\text{m}$ (with gap)
- 5 square arcmin



Near-Infrared Spectrograph

- Multi-Object Spectroscopy
- 10 square arcmin
- R=100, 1000 & R=3000

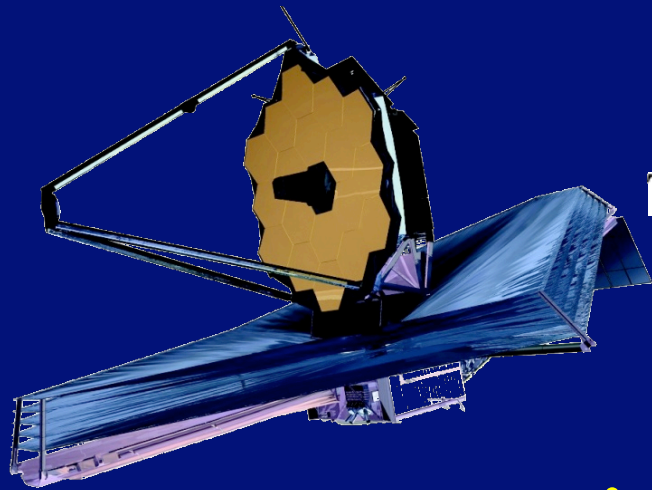


Jet Propulsion Laboratory
California Institute of Technology

Mid-Infrared Instrument

- Broad-band Imaging
- $5 < \lambda < 27 \mu\text{m}$
- R=3000 Integral Field
- Coronagraphy
- Cryocooler to 7K

Operations

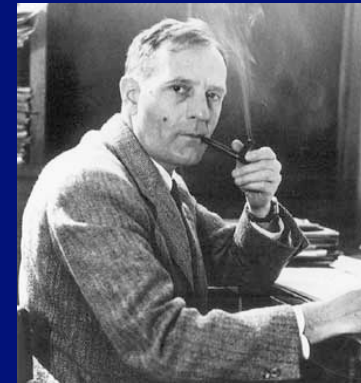


JWST at L2



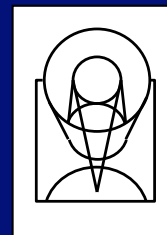
DSN

THE ASTROPHYSICAL JOURNAL



Astronomer

- STScI has been designated as Science Operations Center
- GO, Legacy/Treasury and GTO programs similar to HST



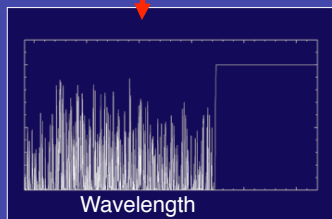
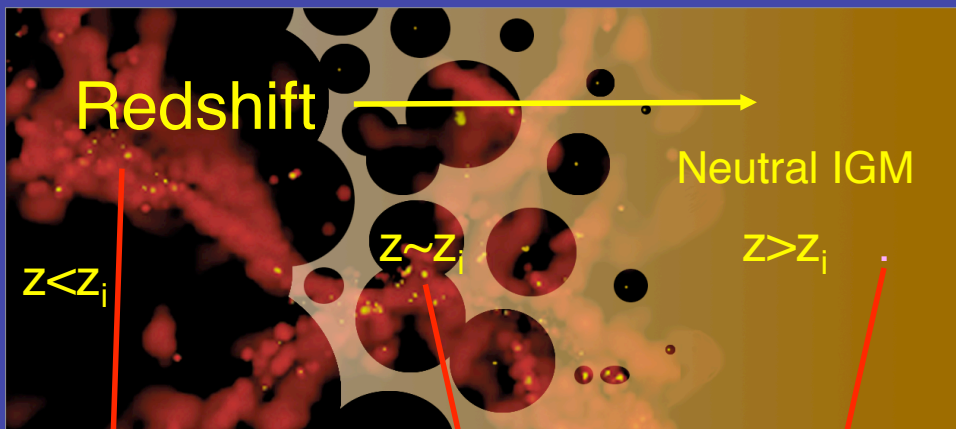
STScI



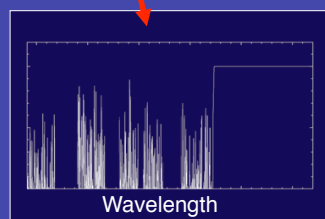
TAC

End of the dark ages: first light and reionization

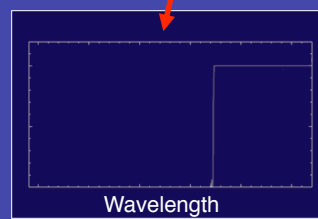
- What are the first galaxies?
- When did reionization occur?
 - Once or twice?
- What sources caused reionization?



Lyman Forest Absorption



Patchy Absorption



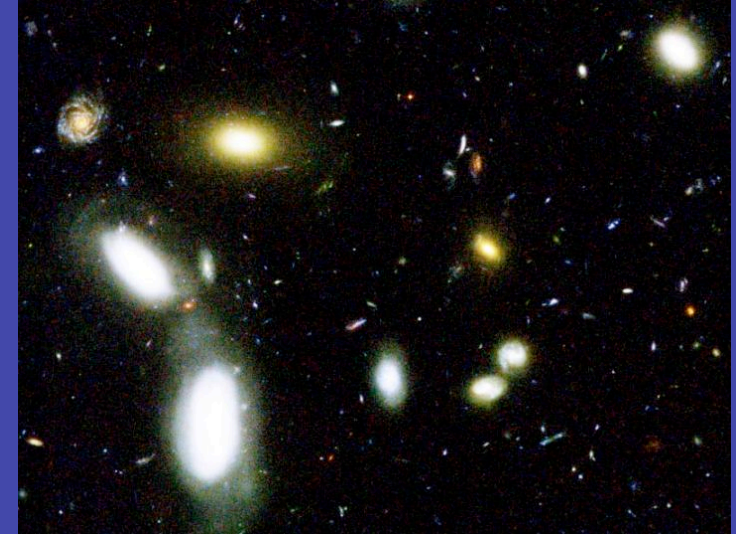
Black Gunn-Peterson trough



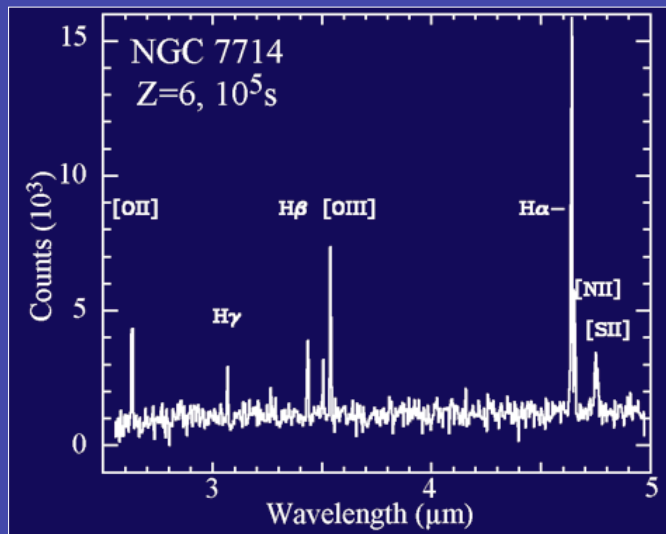
- Ultra-Deep NIR survey (1.4 nJy), spectroscopic & Mid-IR confirmation.
- QSO spectra: Ly- α forest
- Galaxy spectra: Balmer lines (2×10^{-19} ergs/cm²/sec)

The assembly of galaxies

- Where and when did the Hubble Sequence form?
- How did the heavy elements form?
- Can we test hierarchical formation and global scaling relations?
- What about ULIRGs and AGN?



Galaxies in GOODS Field



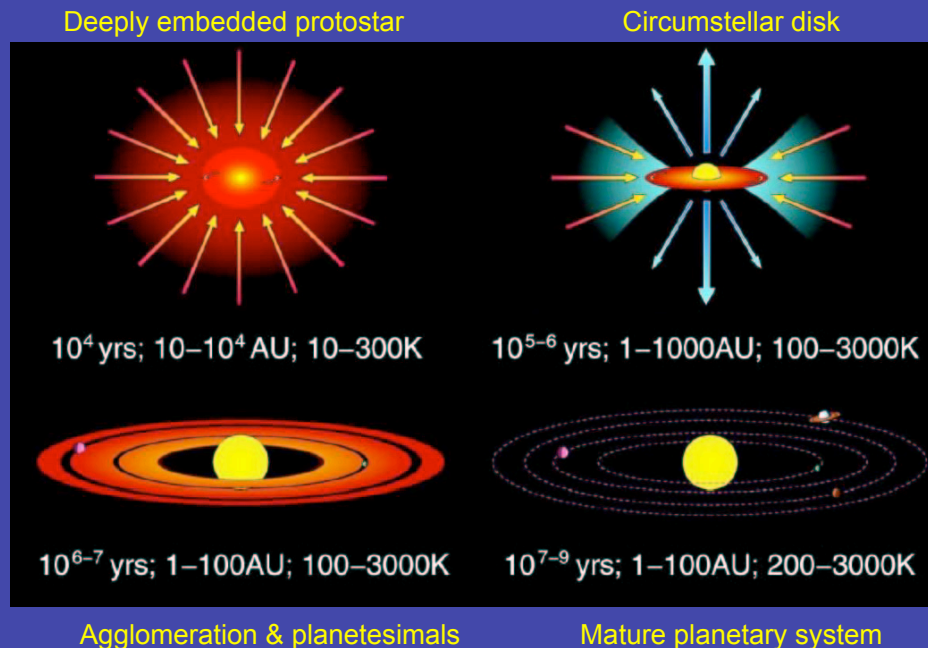
- Wide-area imaging survey
- $R=1000$ spectra of 1000s of galaxies at $1 < z < 6$
- Targeted observations of ULIRGs and AGN

Birth of stars and protoplanetary systems

- How do clouds collapse?
- How does environment affect star-formation?
 - Vice-versa?
- What is the low-mass IMF?



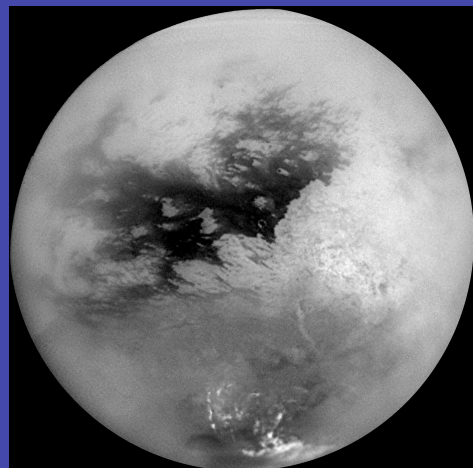
The Eagle Nebula
as seen in the infrared



- Imaging of molecular clouds
- Survey “elephant trunks”
- Survey star-forming clusters

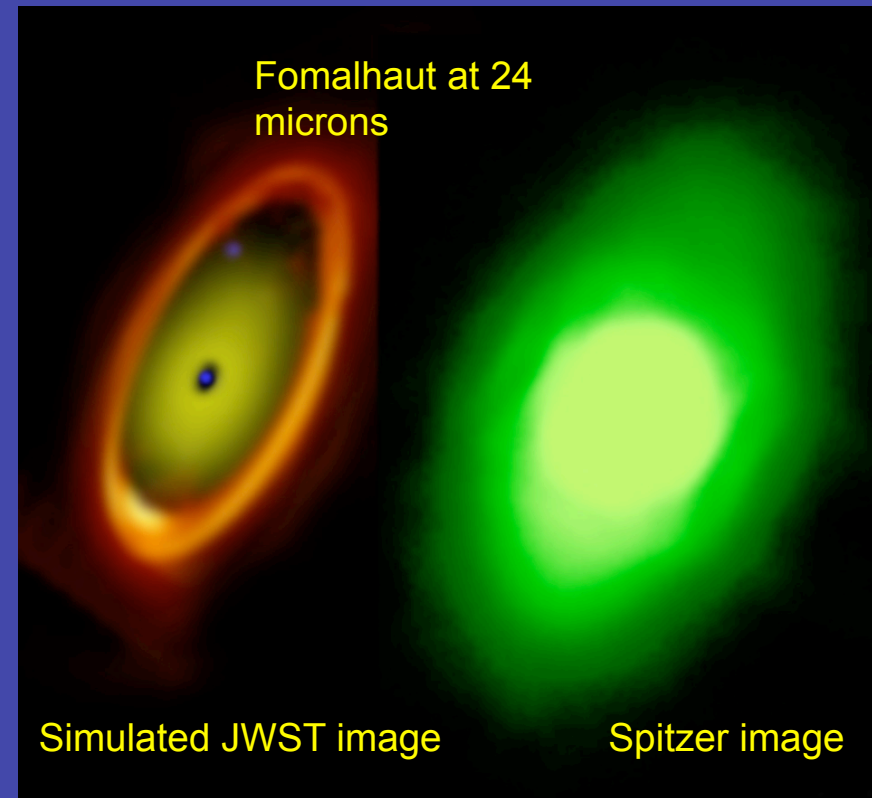
Planetary systems and the origins of life

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



Titan

- Extra-solar giant planets
 - Coronagraphy
- Spectra of circumstellar disks, comets and KBOs
- Spectra of icy bodies in outer Solar System



Schedule



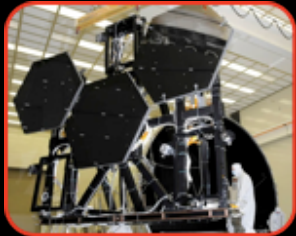
- 1989 – Next Generation Space Telescope Workshop
- 1995 – HST and Beyond (Dressler Report)
- 2000 – Decadal Survey
- 2002 – Contract with Northrop Grumman signed
- 2007 – Technology ready
- 2008 – Confirmation: start Phase C/D (construction)
- 12-16 April 2010: Mission Critical Design Review
- 2010-2011 – Instruments completed.
- 2014 – Launch
- 2015 – Cycle 1 observations begin.
- ~2024 – Out of fuel = end of mission.



JWST: Under Construction



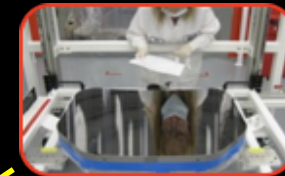
Primary Mirror Segment



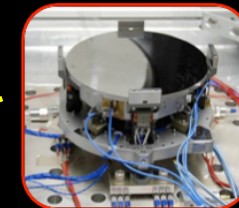
Aft Optics System



PM Flight Backplane

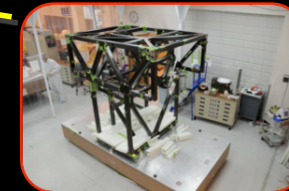


Tertiary Mirror



Fine Steering Mirror

ISIM Flight Bench



Mid-boom Test



IC&DH unit ETU



Pathfinder Membrane



Membrane Mgmt

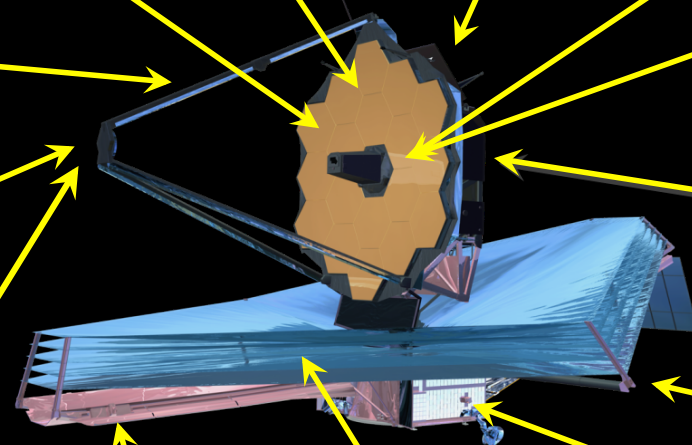
SMSS Pathfinder Strut



SM Hexapod

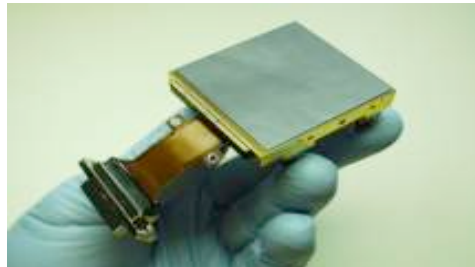


Secondary Mirror Segment

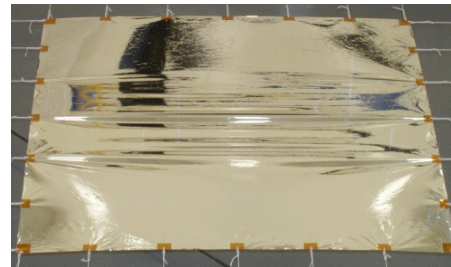




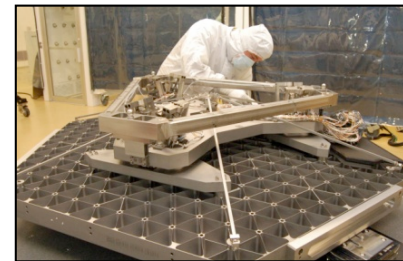
JWST Mission-Critical Technologies Demonstrated to TRL-6 in 2007



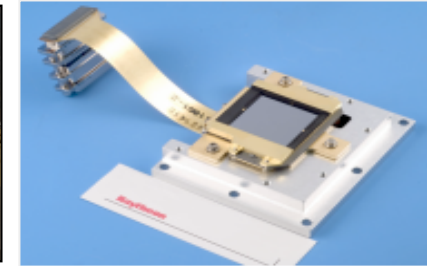
Near Infrared Detectors
April 2006 ✓



Sunshield Material
April 2006 ✓



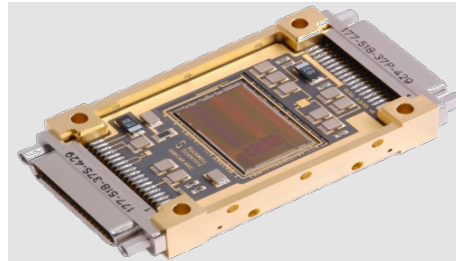
**Primary Mirror Segment
Assembly**
June 2006 ✓



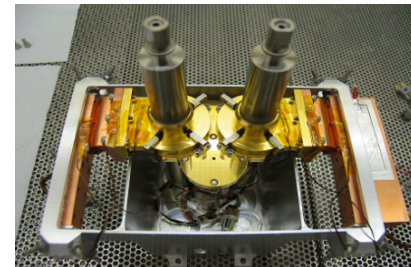
Mid Infrared Detectors
July 2006 ✓



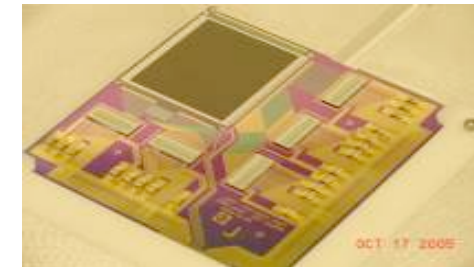
Cryo Cooler
March 2007 ✓



Cryo ASICs
August 2006 ✓



Heat Switches
November 2006 ✓

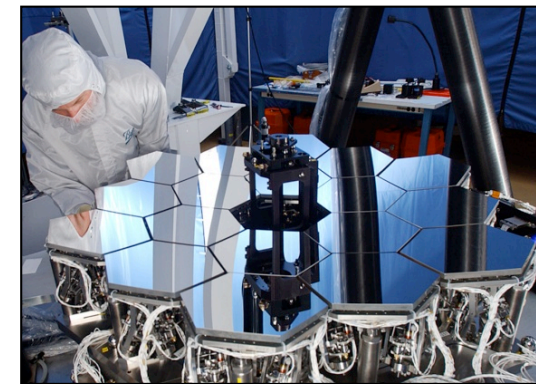


Microshutter Arrays
December 2006 ✓

**JWST Passed
Technology Non-
Advocate Review in
January 2007;
PDR in April 2008**



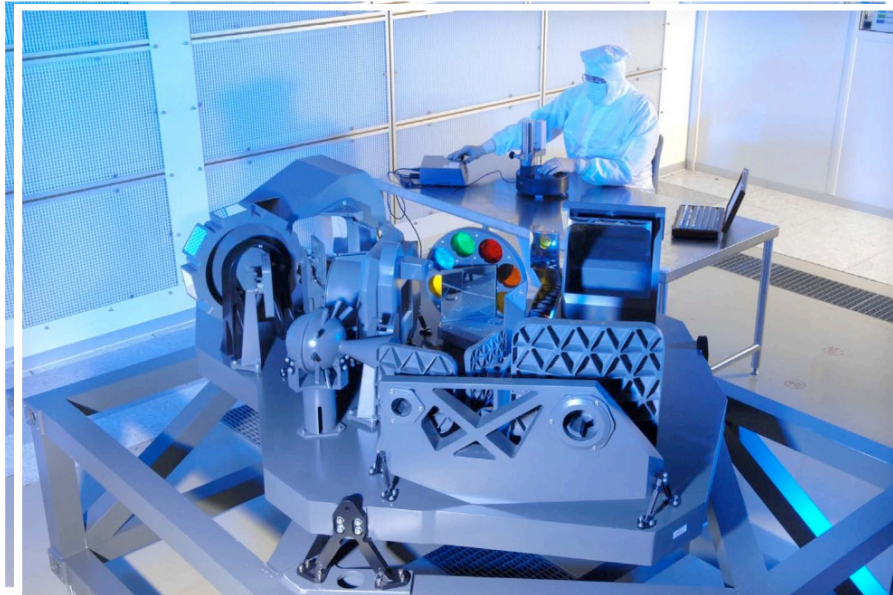
Large Precision Cryogenic Structure
December 2006 ✓



Wavefront Sensing & Control
December 2006 ✓



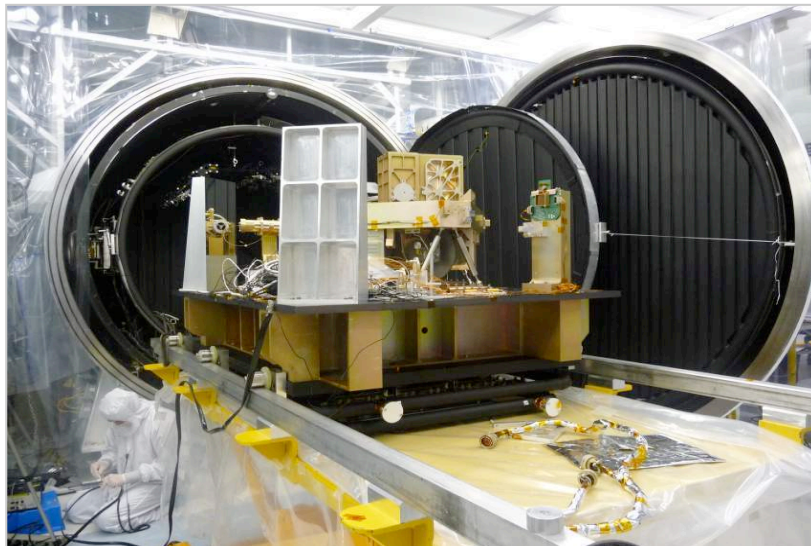
JWST Instrument Engineering, Verification and Development Models



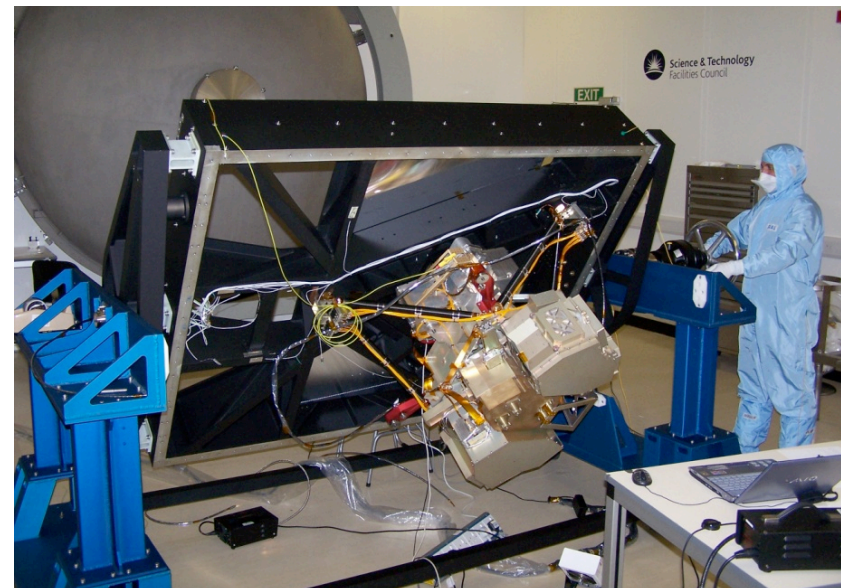
NIRSpec Development Model



NIRCам ETU OBA with Mass Simulators



FGS Engineering Model



MIRI Verification Model



Cooler end-to-end Integrated Functional Test



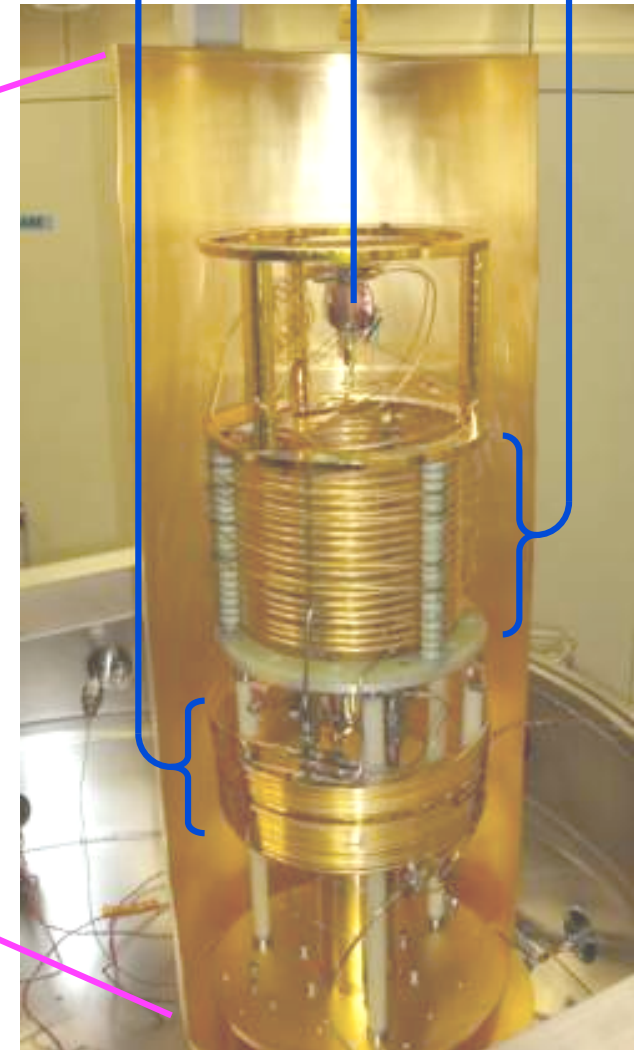
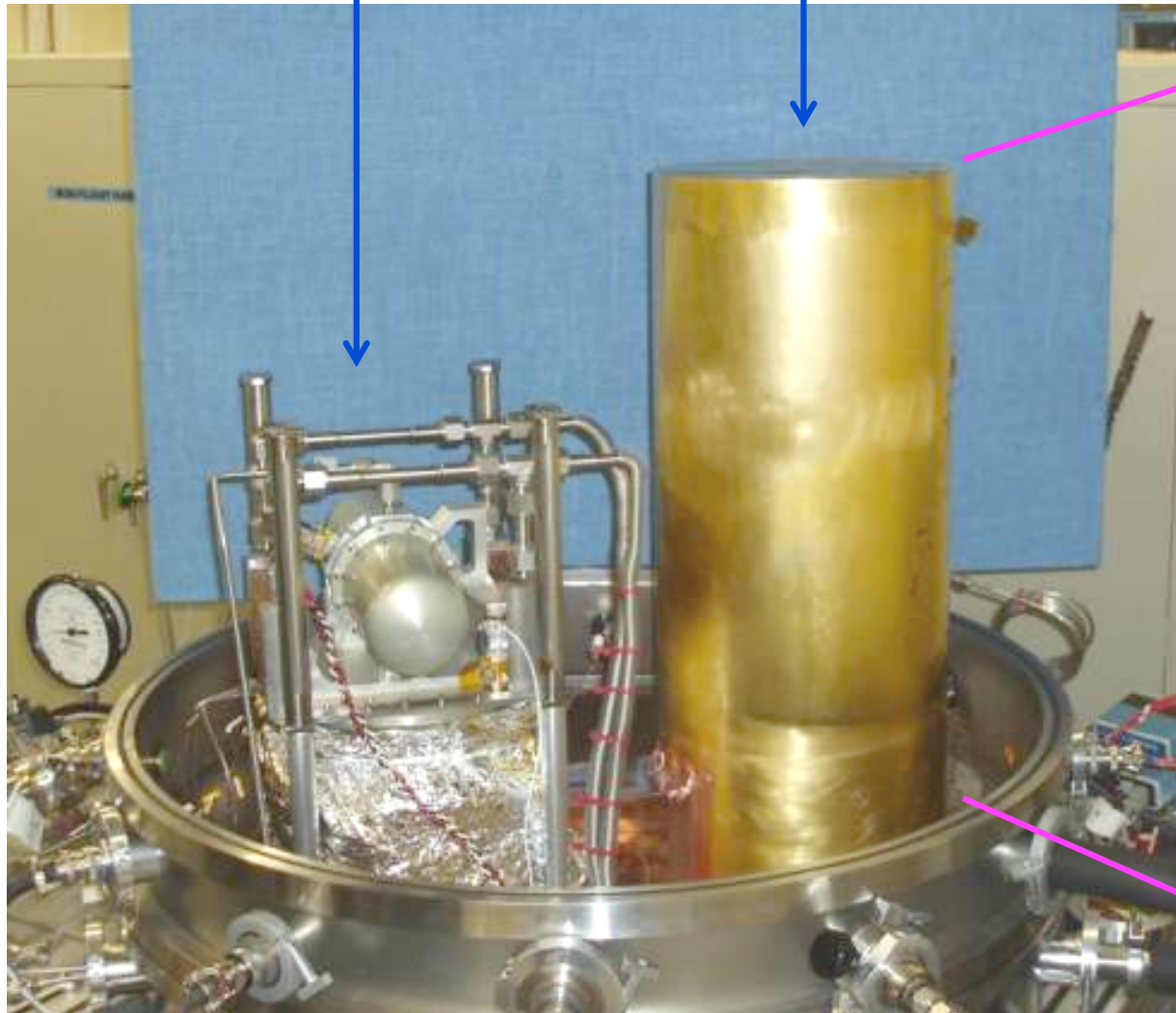
Pre-Cooler
Subassembly

CHA & CTA
with environmental shield

RLDA

6K HX

CHA/ HSA



Images courtesy of NGST



ISIM Flight Structure at GSFC





Live update every 60 seconds <http://www.jwst.nasa.gov/webcam.html>.

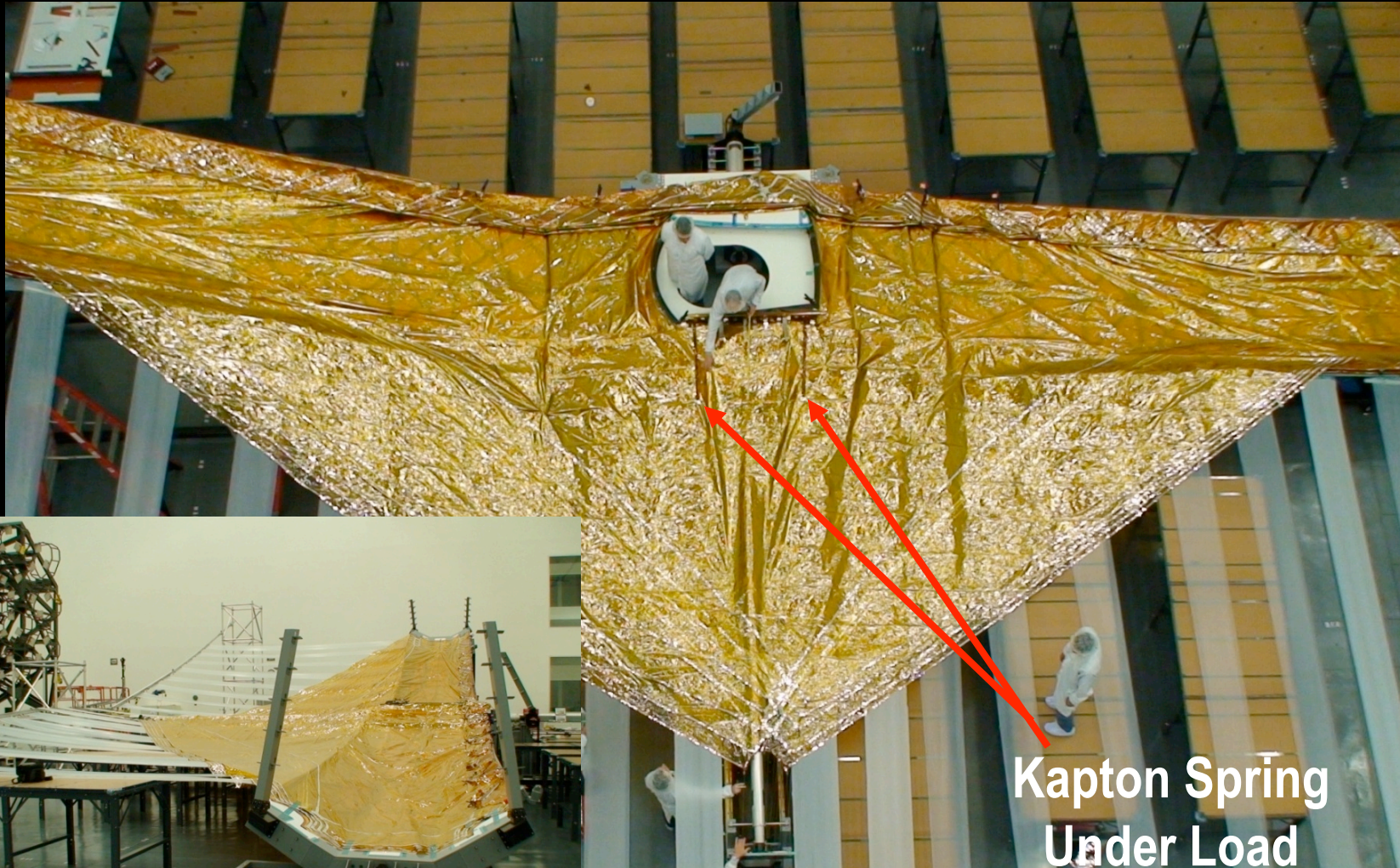


1/3rd Scale Sunshield





Sunshield Deployment Testing



JWST Mirror Fabrication

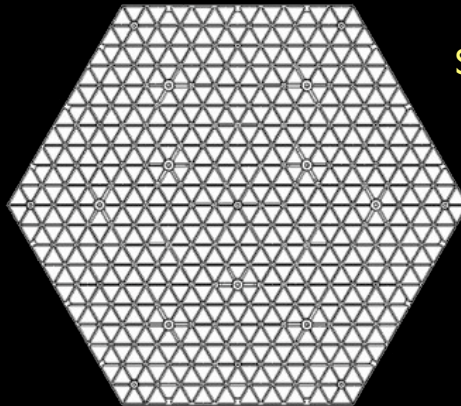


- JWST Mirrors made of beryllium
- Lightweight and stable at 40 K
- Brush-Wellman

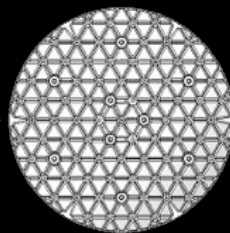
Raw Be billet (two mirrors)



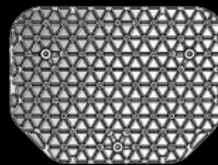
Primary mirror segment



Secondary mirror

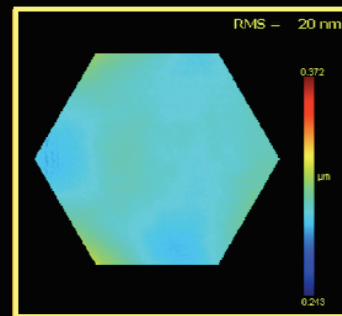


Tertiary mirror

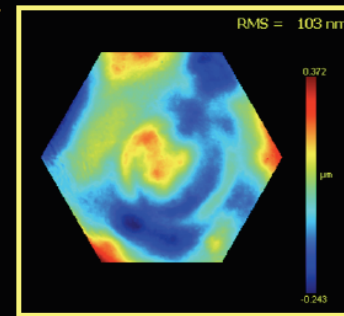


- Machined & lightweighted by Axsys
- 92% material is removed

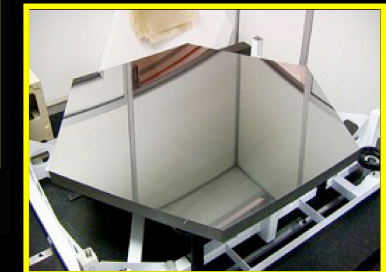
- Mirrors polished at Tinsley
- Segment cryo-figure: 20 nm



Cryo-surface figure



Ambient

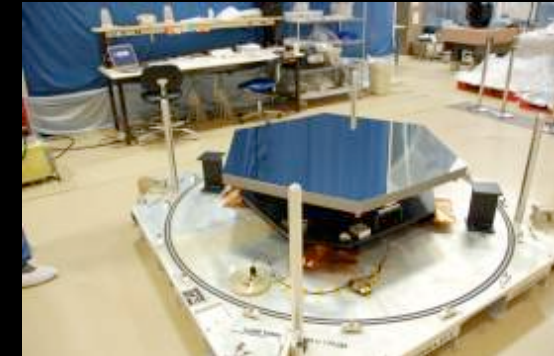




EDU Mirror Cryo-Polish Complete

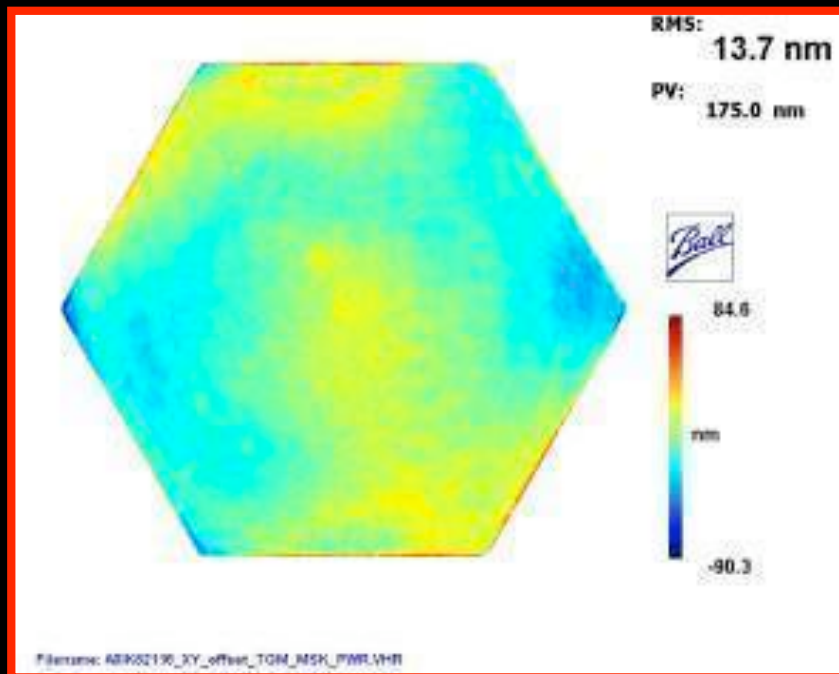


- Primary Mirror EDU-mirror has completed cryo polishing and meets all specifications
- Mid Frequency Tinsley Spec: 20nm RMS
- High Frequency Tinsley Spec: 7nm RMS
- Edges are significantly better than AMSD

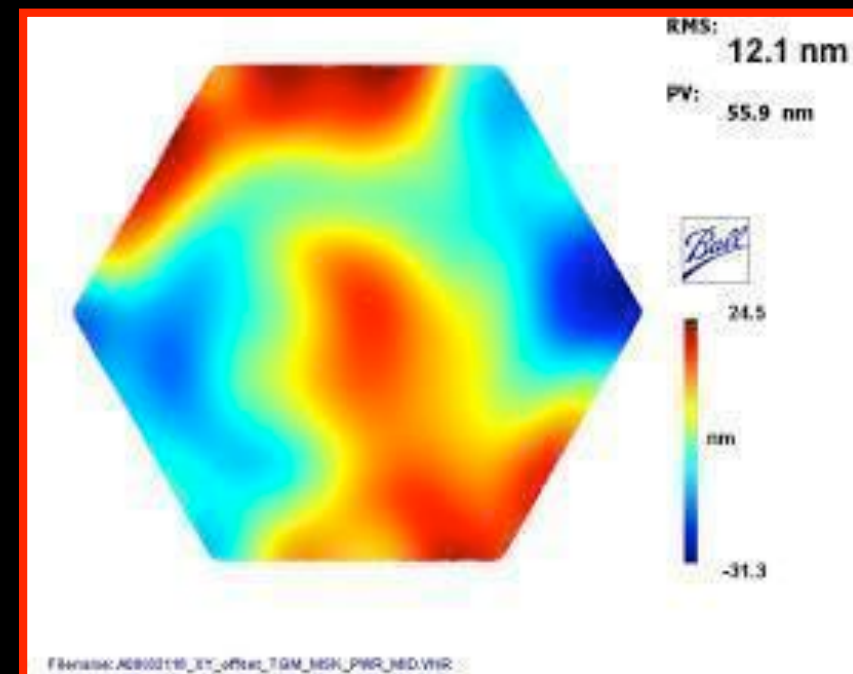


Total Surface Error

Hit Map, Radius, Decenter, and Clocking Removed



Mid-Frequency





Flight Mirror Cryogenic Testing



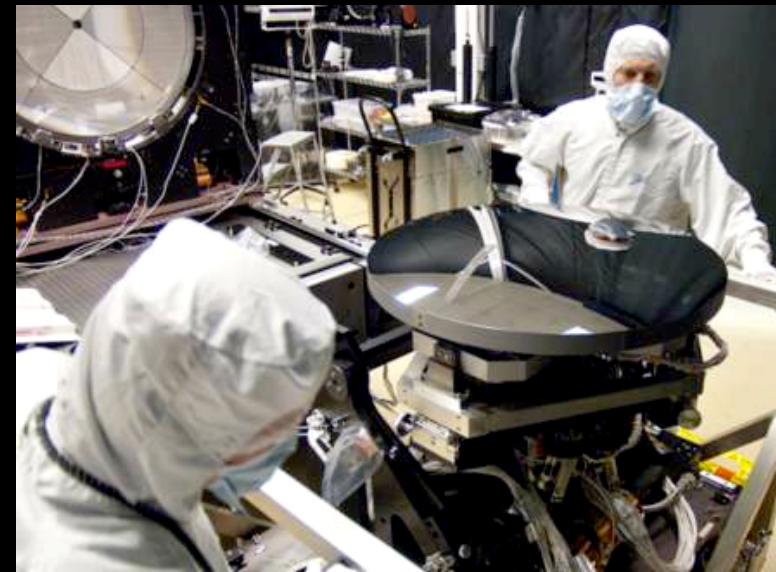
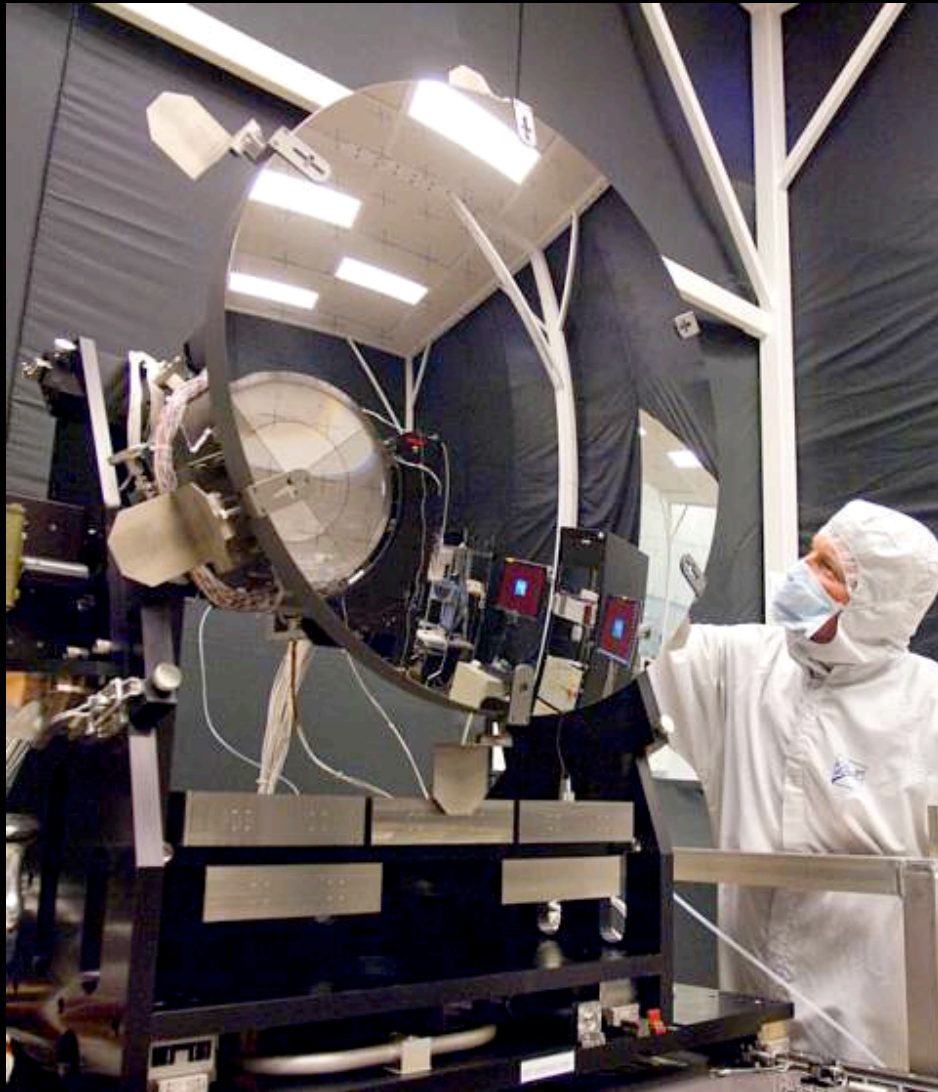


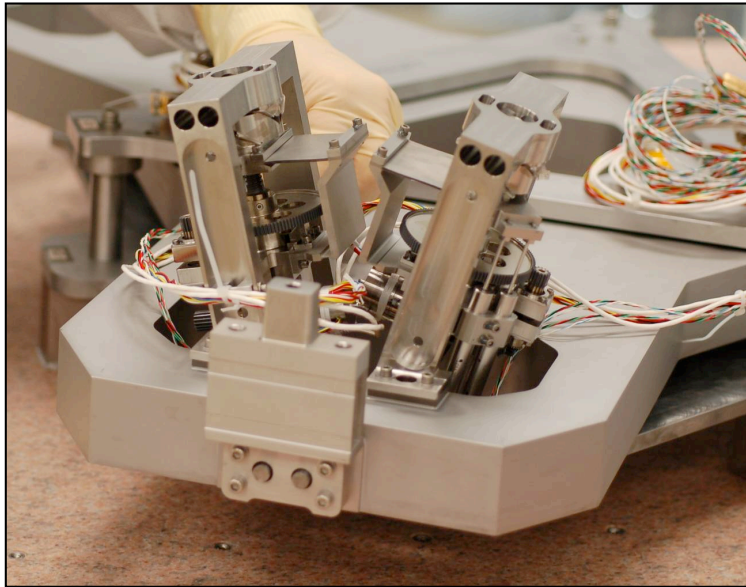
Flight Mirror Cryogenic Testing



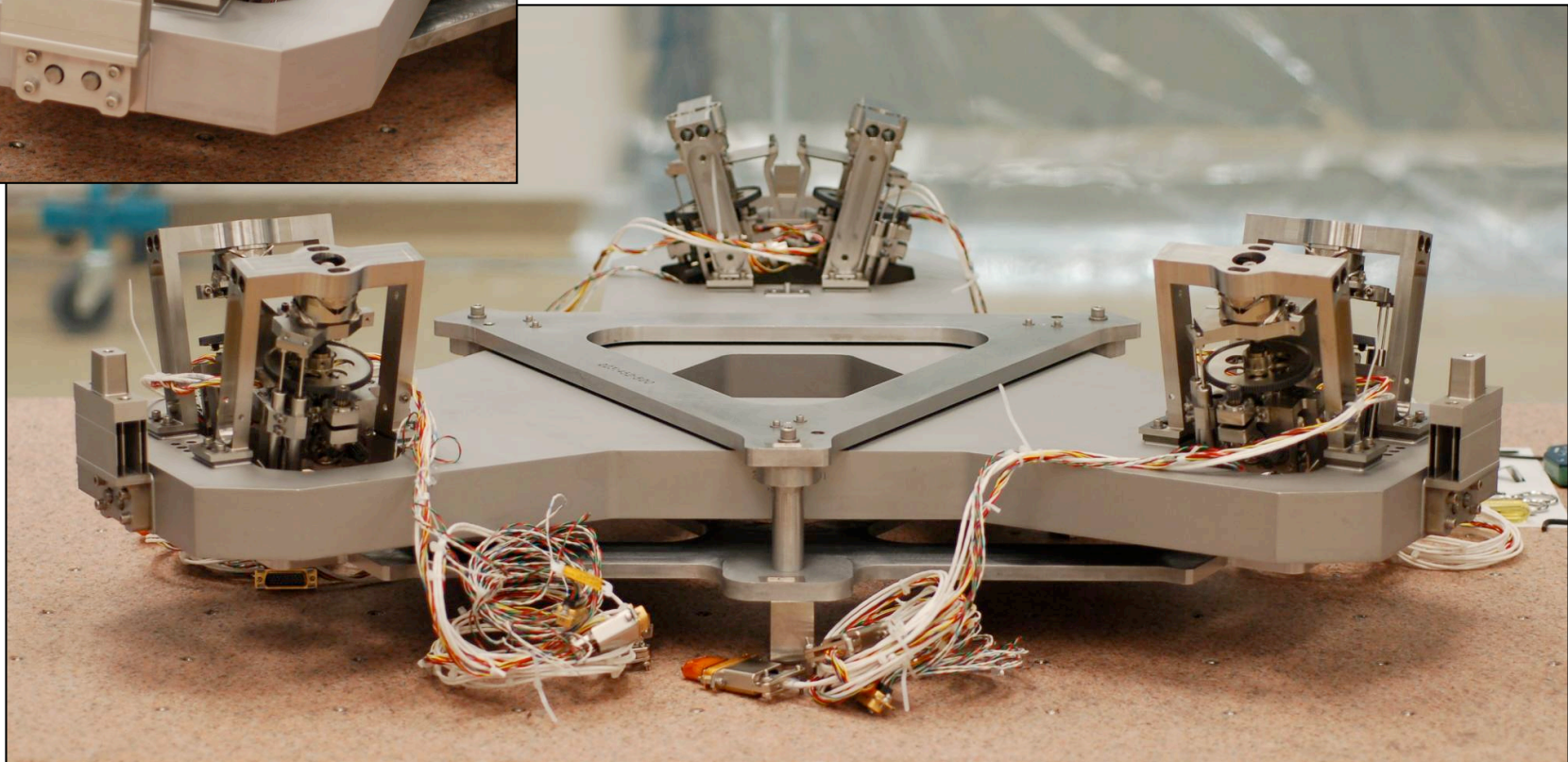


Secondary Mirror Assembly Progress





Build-up of the first flight segment Hexapod to Delta Frame Assembly completed; this assembly includes the actuators that can adjust the shape and position of each Primary Mirror segment



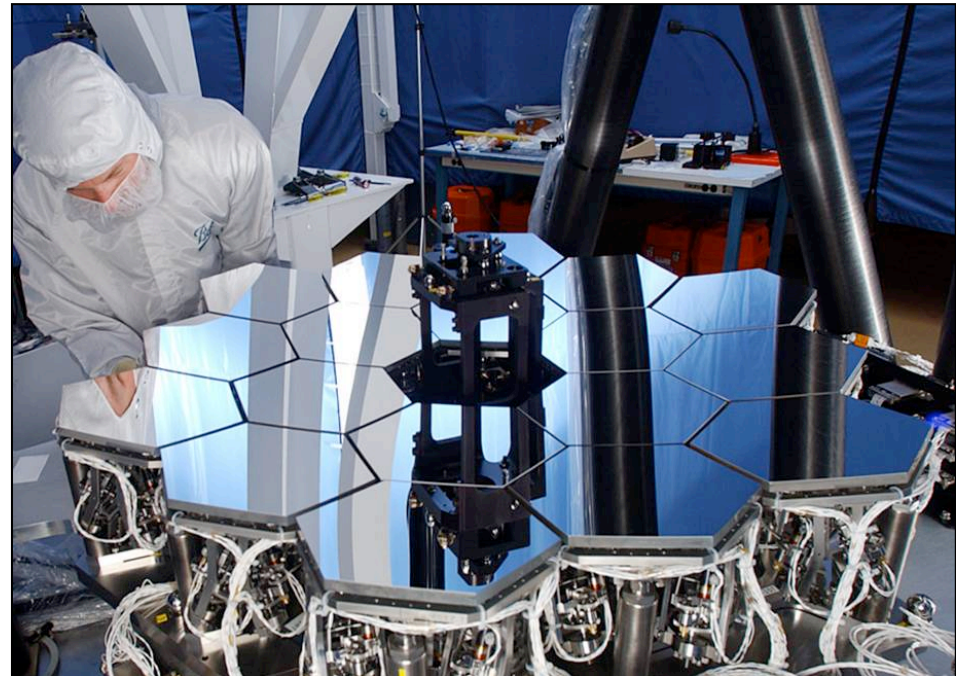
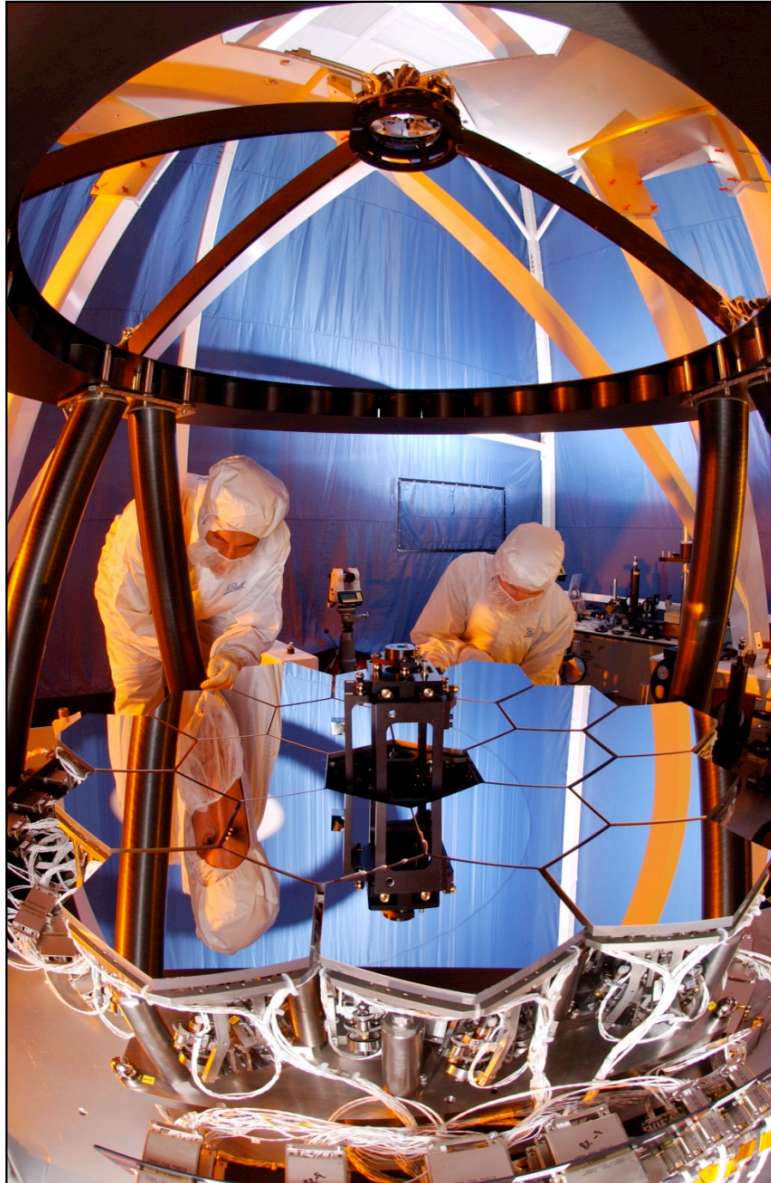


Pathfinder Backplane Bonding Completed





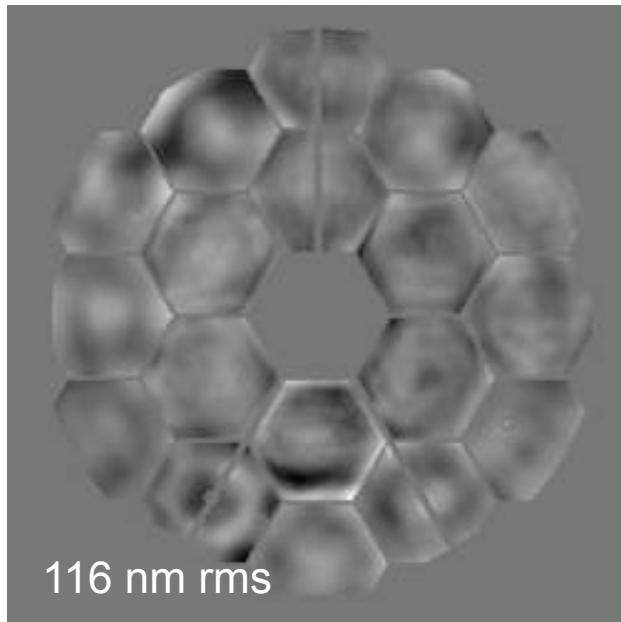
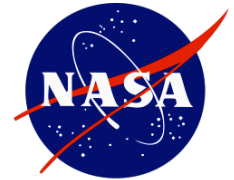
Wavefront Sensing and Control Development Plan – Testbed Telescope



- **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 are being checked out on the testbed**
- **Demonstrated end-to-end wavefront sensing and control through final alignment**



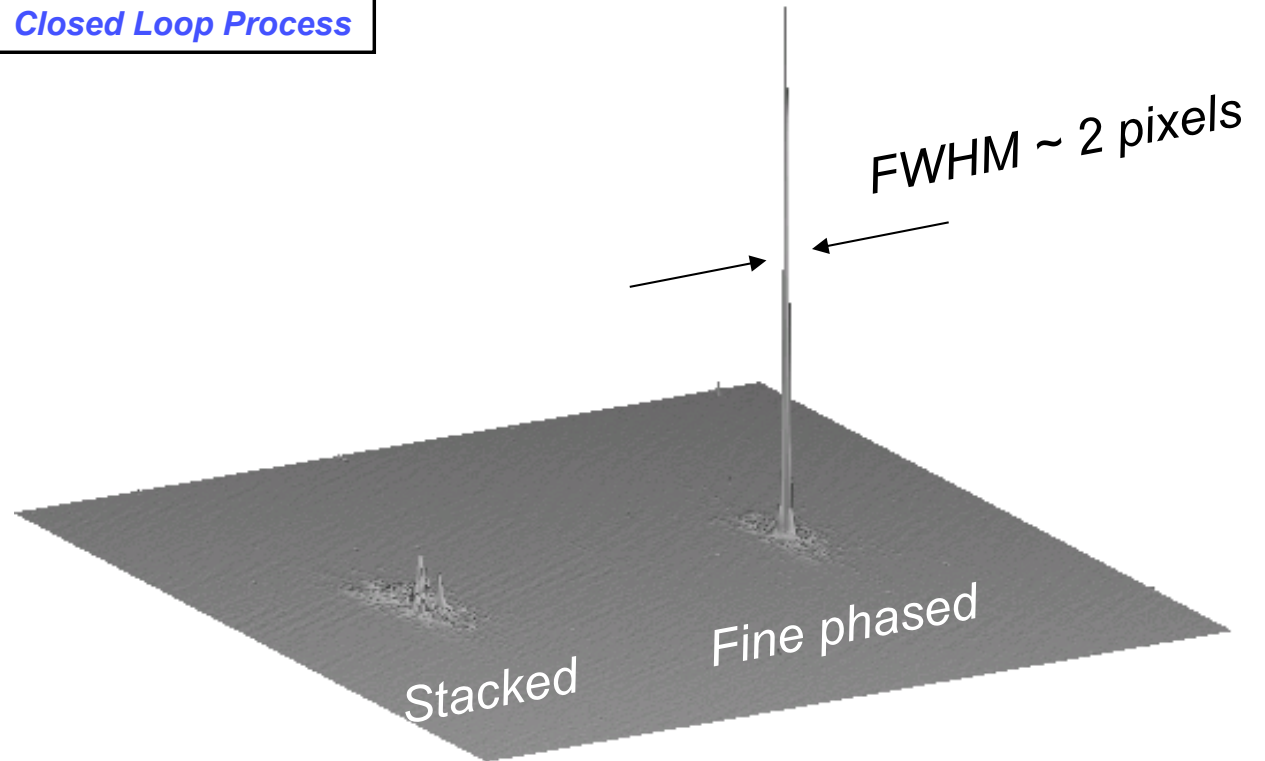
Fine Phasing on JWST Testbed Telescope Clearly (repeatedly) Demonstrates Coherent Image Addition



116 nm rms

- Double Pass Phase Retrieval Estimate
- ~0.95 Strehl ratio
- (single pass at 1550 nm on TBT)
- Flight requirement is >0.8 Strehl @ 2micron

Closed Loop Process

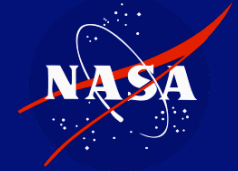


Full 18-segment run completed
8 Oct PM (SC Source)

- 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)



Want to Learn More about JWST?



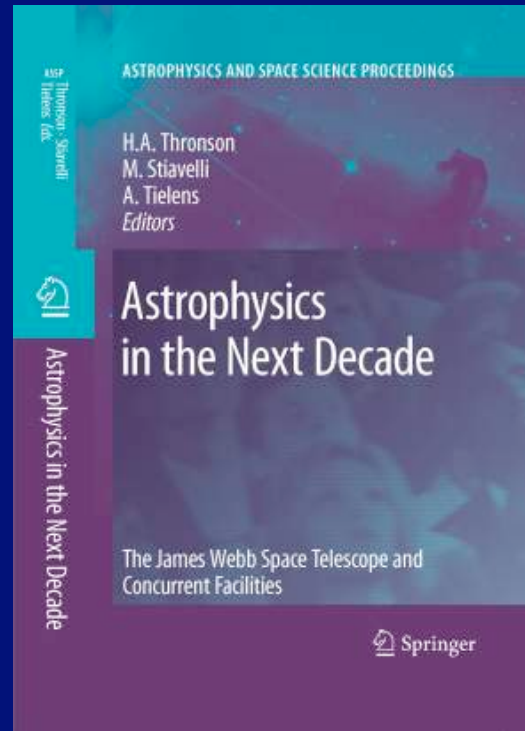
THE JAMES WEBB SPACE TELESCOPE

JONATHAN P. GARDNER^{1*}, JOHN C. MATHER¹, MARK CLAMPIN²,
RENE DOYON³, MATTHEW A. GREENHOUSE¹, HEIDI B. HAMMEL⁴,
JOHN B. HUTCHINGS⁵, PETER JAKOBSEN⁶, SIMON J. LILLY⁷, KNOX S. LONG⁸,
JONATHAN I. LUNDINE⁹, MARK J. MCCABE¹⁰, MATT MOUNTAIN¹¹,
JOHN NELLA¹², GEORGE H. RIEKE¹³, MARCIA J. RIEKE¹³,
HANS-WALTER RIX¹⁴, ERIC P. SMITH¹⁵, GEORGE SONNEBORN¹⁶,
MASSIMO STIAVELLI¹⁷, H. S. STOCKMAN¹⁸, ROGER A. WINDHORST¹⁸ and
GILLIAN S. WREGHITT¹⁷

¹Laboratory for Observational Cosmology, Code 665, Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.
²Laboratory for Exoplanet and Stellar Astrophysics, Code 667, Goddard Space Flight Center, Greenbelt, MD 20771, U.S.A.
³Département de Physique, Université de Montréal, C.P. 6128 Succ. Centre-ville, Montréal, Québec, Canada H3C 3J7
⁴Space Science Institute, 4750 Walnut Avenue, Suite 205, Boulder CO 80301, U.S.A.
⁵Herzberg Institute of Astrophysics, 5071 West Saanich Road, Victoria, British Columbia, Canada V9E 2E7
⁶Astrophysics Division, RSSD, European Space Agency, ESTEC, 2200 AG Noordwijk, The Netherlands
⁷Department of Physics, Swiss Federal Institute of Technology (ETH-Zürich), ETH Honggerberg, CH-8093 Zürich, Switzerland
⁸Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218, U.S.A.
⁹Lunar and Planetary Laboratory, The University of Arizona, Tucson, AZ 85721, U.S.A.
¹⁰Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany
¹¹School of Physics, University of Exeter, Stocker Road, Exeter EX4 4QL, U.K.
¹²Northrop Grumman Space Technology, 1 Space Park, Redondo Beach, CA 90278, U.S.A.
¹³Steward Observatory, University of Arizona, 933 North Cherry Avenue, Tucson, AZ 85721, U.S.A.
¹⁴Max-Planck-Institut für Astronomie, Königstuhl 17, Heidelberg D-69117, Germany
¹⁵NASA Headquarters, 300 E Street Southwest, Washington, DC 20546, U.S.A.
¹⁶Department of Physics and Astronomy, Arizona State University, Box 871504, Tempe, AZ 85287, U.S.A.
¹⁷Astronomy Technology Centre, Royal Observatory, Blackford Hill, Edinburgh EH9 1HU, U.K.
¹⁸*Author for correspondence, E-mail: jonathanp.gardner@nasa.gov

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Abstract. The James Webb Space Telescope (JWST) is a large (6.6m), cold (<50K), infrared (IR)-optimized space observatory that will be launched early in the next decade into orbit around the second Earth-Sun Lagrange point. The observatory will have four instruments: a near-IR camera, a near-IR multi-object spectrograph, and a tunable filter imager will cover the wavelength range, $0.6 < \lambda < 5.0 \mu\text{m}$, while the mid-IR instrument will do both imaging and spectroscopy from $5.0 < \lambda < 29 \mu\text{m}$. The JWST science goals are divided into four themes. The key objective of The End of the Dark Ages: First Light and Reionization theme is to identify the first luminous sources to form and to determine the ionization history of the early universe. The key objective of The Assembly of Galaxies theme is to determine how galaxies and the dark matter, gas, stars, metals, morphological structures, Space Science Reviews (2006) 123: 485–606
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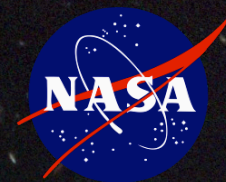
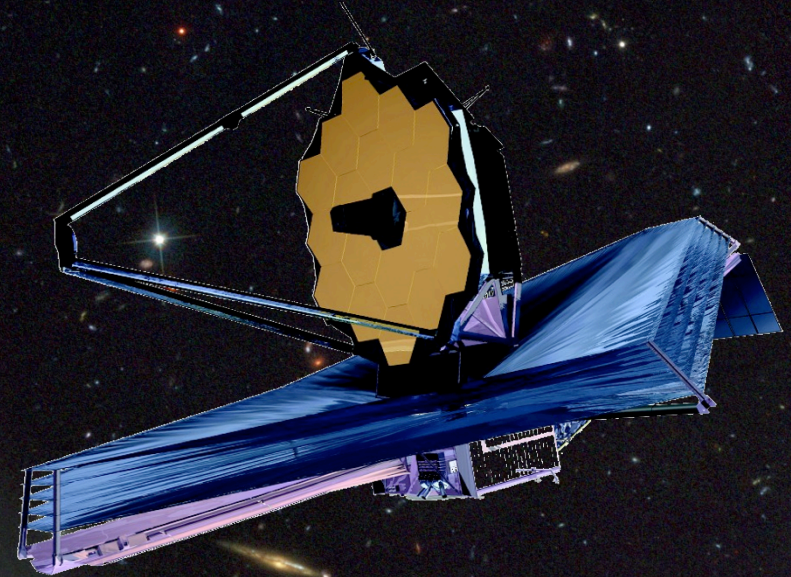
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The James Webb Space Telescope



Jonathan P. Gardner

NASA's Goddard Space Flight Center

<http://jwst.gsfc.nasa.gov>

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