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

Very first light: atoms w/electrons microwave became transparent

Big Bang/Inflation was incredibly fast

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

First light – Atoms come together Supernova from first collapsed stars, etc??

JWST is designed to observe formation of the first galaxies
Looking back, seeing the Edge of Time
(cosmic light horizon)

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](http://www.JWST.nasa.gov)
OTE Architecture Overview

Secondary Mirror Support Structure (SMSS)

Aft Optics Subsystem (AOS)

OTE Electronics
- Cold Junction Box
- Cold Multiplexer Units

Thermal Management Subsystem (TMS)
- Honeycomb Panel Roof Radiators
- Honeycomb Panel +/- V2 Radiators
- ISIM Enclosure (MLI)
- Parasitic Tray Radiator

Secondary Mirror Assembly (SMA)

Primary Mirror Segment Assemblies (PMSA)

Primary Mirror Backplane Assembly (PMBA)
- PM Backplane Support Structure (PMBSS)
- PM Backplane Mechanism

Thermal Management Subsystem (TMS)
- Deployable “Batwings”
- Fixed Diagonal Shield
- Deployable Stray-Light “Bib”

Deployment Tower Assembly (DTA)
Three Mirror Anastigmat Optical Design Provides a Wide Field-of-View

- 1.32 meters flat to flat
- 6.6 meters flat to flat

- V3 (anti-spacecraft)
- V1 → V2

- 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

Beryllium Primary Mirror Segment

Sunshield Membrane

Near-Infrared Detector

Mid-Infrared Detector

μShutters

Cryocooler

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

Onset of James Webb Space Telescope

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

AMSD Phase 1: 8 Mirror Designs
AMSD Phase 2: 3 mirrors developed
AMSD Phase 3/Six Sigma Study
Be manuf. and process improvements

Engineering Design Unit.
PM Manufacturing of 18 segments
Cryo Testing
Polishing Facility Complete

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

Subscale Beryllium Mirror Demonstrator (S$BM$D): 5 meter diameter,
Low Areal Density Mirrors Identified as Key Enabling Technology for 25 Square Meter Space Telescope

Low Authority Beryllium

Medium Authority Glass (ULE)

OTE Optics Review (COR): Beryllium Selected

Medium Authority

PM Manufacturing of 18 segments
Cryo Testing
Polishing Facility Complete

Primary Mirror Segment Assemblies Complete

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

Machining Facility Complete

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

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

240
300
200
100
60
30
15

Areal Density (Kg/m²)
1980 1990 2000 2010

JWST Requirement

Mirror History

Mirror Technology Choices

~30 K minus Ambient

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

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

Actuator for radius of curvature adjustment
Secondary Mirror
Secondary Mirror Cryo-Optical Testing
Axsys Machining Facility

Dedicated facility and machining centers for JWST mirror production
## Beryllium Flight Mirror Machining Complete at Axsys Technologies

<table>
<thead>
<tr>
<th>Pathfinder</th>
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<td><img src="pathfinder8.png" alt="Image" /></td>
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<tr>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #1 (EDU-A / A1)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #2 (11 / B3)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #3 (12 / C3)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #4 (5 / A2)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #5 (6 / B2)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #6 (7 / C2)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #7 (13 / A4)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #8 (17 / B5)</td>
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<tr>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #9 (4 / C1)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #10 (16 / A5)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #11 (20 / B6)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #12 (15 / C4)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #13 (8 / A3)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #14 (22 / B7)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #15 (18 / C5)</td>
<td><strong>Done at Axsys!!</strong>&lt;br&gt;PMSA #16 (19 / A6)</td>
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Tinsley Built A New Large Optics Facility To Support the JWST Program
<table>
<thead>
<tr>
<th>Batch #1 (Pathfinder)</th>
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<th>Batch #2</th>
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<th>Batch #2</th>
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<td>PMSA #1 (EDU-A / A1)</td>
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<td>PMSA #5 (6 / B2)</td>
<td>PMSA #6 (7 / C2)</td>
</tr>
<tr>
<td>PMSA #7 (13 / A4)</td>
<td>PMSA #8 (17 / B5)</td>
<td>PMSA #9 (4 / C1)</td>
<td>PMSA #10 (16 / A5)</td>
<td>PMSA #11 (20 / B6)</td>
<td>PMSA #12 (15 / C4)</td>
</tr>
<tr>
<td>PMSA #13 (8 / A3)</td>
<td>PMSA #14 (22 / B7)</td>
<td>PMSA #15 (18 / C5)</td>
<td>PMSA #16 (19 / A6)</td>
<td>PMSA #17 (3 / B1) (TRL6 PMSA)</td>
<td>PMSA #18 (21 / C6)</td>
</tr>
</tbody>
</table>
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.
Testing at XRCF
Tertiary Mirror
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

14.7nm RMS

PV: 134.1 nm
The fully integrated AOS

<table>
<thead>
<tr>
<th>Mirror</th>
<th>Measured (RMS SFE)</th>
<th>Uncertainty (RMS SFE)</th>
<th>Total (RMS SFE)</th>
<th>Requirement (RMS SFE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tertiary</td>
<td>18.1 nm</td>
<td>9.5 nm</td>
<td>20.5 nm</td>
<td>23.2 nm</td>
</tr>
<tr>
<td>Fine Steering</td>
<td>13.9 nm</td>
<td>4.9 nm</td>
<td>14.7 nm</td>
<td>18.7 nm</td>
</tr>
</tbody>
</table>
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.

Flight Segment Figure Convergence at Tinsley

Excellent convergence rate on flight mirrors
Completed Mirrors in Storage
Wavefront Sensing and Control
JWST Wavefront Sensing & Control Process

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

NIRCam first light showing segment images

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 2μm

Wavefront error

JWST Wavefront Sensing & Control Process

Observatory commissioning

wavefront error
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)
Ball WFSC Testbed with 5 Segments Installed
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.
End-to-End Commissioning

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 $2\pi$ ambiguities occurred: confirmed by defocused PSFs at two wavelengths (1550 & 1900 nm)
End-to-End Commissioning

8. Fine Phasing Convergence

Coarse Phasing ➤ Fine Phasing

Repeatability Criteria Met:

Summary of Repeatability Results (55nm requirement):

<table>
<thead>
<tr>
<th></th>
<th>GSFC/Dean Analysis</th>
<th>Ball/Acton Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median of Differences</td>
<td>49 nm</td>
<td>50 nm</td>
</tr>
</tbody>
</table>

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:

<table>
<thead>
<tr>
<th>RMS Diff (nm)</th>
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</thead>
<tbody>
<tr>
<td>rms (phase 1 - phase 2) = 54.9731</td>
</tr>
<tr>
<td>rms (phase 1 - phase 3) = 62.4567</td>
</tr>
<tr>
<td>rms (phase 1 - phase 4) = 41.6916</td>
</tr>
<tr>
<td>rms (phase 1 - phase 5) = 49.2051</td>
</tr>
<tr>
<td>rms (phase 1 - phase 6) = 39.6638</td>
</tr>
<tr>
<td>rms (phase 2 - phase 3) = 52.9011</td>
</tr>
<tr>
<td>rns (phase 2 - phase 4) = 47.9891</td>
</tr>
<tr>
<td>rns (phase 2 - phase 5) = 52.9841</td>
</tr>
<tr>
<td>rns (phase 2 - phase 6) = 53.6143</td>
</tr>
<tr>
<td>rns (phase 3 - phase 4) = 60.3118</td>
</tr>
<tr>
<td>rns (phase 3 - phase 5) = 62.2399</td>
</tr>
<tr>
<td>rns (phase 3 - phase 6) = 62.3999</td>
</tr>
<tr>
<td>rns (phase 4 - phase 5) = 48.8222</td>
</tr>
<tr>
<td>rns (phase 4 - phase 6) = 43.9319</td>
</tr>
<tr>
<td>rns (phase 5 - phase 6) = 45.8155</td>
</tr>
</tbody>
</table>

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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
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

Analysis and Error Budget Model Versus Test Measurement

[Graph showing data points and error bars]

- MUF = 1.4
- All Error Bars are 2-Sigma

BSTA PMSA Fitting Label

- ATK As-Built Predict
- MC 95% Confidence Bandwidth
- Total Error Bar (w/ MUF)
- Test Measurement
- Reference Datum Points

BSTA ready for test in XRCF

53K Hold

ESPI Fringes

Temperature, K

- Average
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
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, interferometry 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)
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
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 Test at Ambient

Backplane in Redondo Beach
DTA deployment and Secondary Mirror Support Structure
May 2015
OTE Structure into Shipping Container
August 2015
Welcome to GSFC (August 2015)
August 2015

- In SSDIF at GSFC
Mirror Installation (Nov ‘15 – Jan -16)

- OTE lift to AOAS
- First PMSA being installed
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
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)
Space Vehicle Thermal Simulator (SVTS) and Sunshield Simulator
Third and final Pathfinder test planned this summer

ADM
Testing complete at JHU
Delivered to JSC

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

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

Cryo Position Metrology (CPM)
Photogrammetry System Integration Complete

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,

USF Structural Frame – supports Metrology Installed in Chamber

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

HOSS – Hardpoint Offloader Support Structure
In integration in Clean Room

Deep Space Edge Radiation Sink (DSERS)
Frame integrated

Mag Damper Cryo Test Article Delivered
Where Are We In OTE-ISIM (OTIS Flow)

GSE & Test Preparations

- Facility Functional
- Cleanroom
- MGSE Install
- Reuse
- Commissioning Phase I
- MGSE Inspection, OGSE Install
- Commissioning Phase II

Fall 14

JWST OTIS Integration and Test

- Acronyms
  - AOS: Aft-Optics Subsystem
  - GSE: Ground Support Equipment
  - MGSE: Mechanical Ground Support Equipment
  - NGAS: Northrop Grumman Aerospace Systems
  - OGSE: Optical Ground Support Equipment
  - PF: Pathfinder

Legend

- Prep & Transport
- Functional / Test
- Assembly / Integration
- Delivery

Risk Reduction Activities

- Fall 14
- Fall 17

Flight OTIS I&T

- Install Flight ISIM to OTE
- Pre Environmental Test
- Acoustic & Vibe Tests
- Post Environmental Test
- Ship OTIS to JSC
- Receive OTIS at JSC
- OTIS Cryo Preps
- OTIS Cryo Test
- OTIS Cryo Post-Test
- Ship OTIS to NGAS
Pathfinder Early Results

Multi-Wavelength Phasing Using Synthetic Wavelengths

Half pass Prediction vs. Data

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

Measured RMS WFE = 211 nm

Modeled RMS WFE = 213 nm
The team
Looking Back: THANK YOU to the Incredibly Skilled and Dedicated Teams
OTE management team stable for 14 years!

Scott Texter

Charlie Atkinson/NGAS

Ritva Keski-Kuha

Bill Hayden

OTE + Project Mgt Visit Keck 2014