James Webb Space Telescope (JWST)

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JWST – the next great observatory

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

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

- **Segmented Beryllium Primary Mirror**
  - areal density 3 times less than HST
  - Technologies for JWST mirror manufacturing and polishing broadly applicable for future space telescopes
  - Must fold up to fit inside rocket fairing, breaking the limitation on mirror diameter

- **Composite structure to hold mirrors and instruments**
  - Behavior must be known to <40 nanometers (~1/10,000 of a human hair)
  - Must maintain this stability while being cooled over 400 degrees

- **Cryogenic Application Specific Integrated Circuit (ASIC)**
  - JWST ASIC already flying in space: Installed on Hubble Servicing Mission 4 to repair the failed Advanced Camera for Surveys (ACS) instrument

- **Micro-Shutters**
  - ~100,000 computer controlled shutters, each the width of a human hair
  - First Mirco-ElectroMechanical (MEMS) devise for science to be flown in space
  - Early research on MEMs devised for JWST helped develop analogous instrument for ground-based telescopes

- **Sunshield Membranes**
  - Lightweight deployable sunshield the size of a tennis court to passively cool JWST telescope and instruments
  - 5 thin separated membrane layers (each less than half the thickness of a piece of paper)
  - Providing a 500 F temperature difference (equivalent SPF of 1,000,000)

- **Advanced Near Infrared Detectors**
- **Advanced Mid-Infrared Detectors**
- **Cryo-cooler for Mid-Infrared Instrument**
- **Mirror Phasing and Control Software**
- **Heat Switches**
TECHNOLOGICAL ADVANCES

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

- **Segmented Beryllium Mirror**: Mirrors so smooth that if “stretched” to the size of the continental US largest deviation from perfection would be ~2 inches in height.

- **Advanced Near Infrared detectors**

- **Advanced Mid-Infrared detectors**

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

- **Mirror phasing and control**: 18 mirror segments computer controlled to operate as one mirror in space

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

- **Sunshield Membrane**: 5 thin membranes (each less than half the thickness of a piece of paper) protect the side in the extreme of cold space from the warm sunlit side [Equivalent Sun Protection Factor (SPF) of 1,000,000]
The Final Acceptance Test Completes a Decade plus Development Effort to Make JWST Mirrors

- **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**: Beryllium manuf. and process improvements

- **Subscale Beryllium Mirror Demonstrator (SBMD)**: 5 meter diameter,
  - OTE Optics Review (ODR): Beryllium Selected
  - Machining Facility Complete
  - Polishing Facility Complete
  - Cryo Testing Complete

- **Engineering Design Unit**
  - Technology Readiness Level-6 Demonstrated: All key requirements and environments demonstrated

- **PM Manufacturing of 18 segments**

- **OTE Optics Review**

- **Onset of James Webb Space Telescope**
  - 1996

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

- **5 meter diameter, Low Areal Density Mirrors**

- **1996 to 2014 Timeline**
Coated Primary Mirror Segment Assembly
Primary Mirror Assembly
Primary Mirror Composite

RMS: 23.2 nm
PV: 515.5 nm
## Mirrors Completed

<table>
<thead>
<tr>
<th>Mirror Element</th>
<th>RMS Surface Figure Error [nm]</th>
<th>Measured</th>
<th>Uncertainty</th>
<th>Total</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>18 Primary Segments (Composite Figure)</td>
<td></td>
<td>23.7</td>
<td>8.1</td>
<td>25.0</td>
<td>25.8</td>
</tr>
<tr>
<td>Secondary</td>
<td></td>
<td>14.5</td>
<td>14.9</td>
<td>20.8</td>
<td>23.5</td>
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<tr>
<td>Tertiary</td>
<td></td>
<td>17.5</td>
<td>9.4</td>
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<td>Fine Steering Mirror</td>
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<td>14.7</td>
<td>8.7</td>
<td>17.1</td>
<td>17.5</td>
</tr>
</tbody>
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01/26/2012
Flight Backplane Bonding Status

Status as of: 11/30/2011

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

PMBSS Center Section Assembly - in process

Center Section Assembly Locations

- Not Assembled
- Assembled
- Recently assembled since last PMR
Sunshield Template Membrane Work On-Going

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

- Template Layer 5 seamed and catenaries/fill regions installed. Currently getting edge features and grommets installed
- Template Layer 4 fully seamed
MIRI Cryo Cooler Overview

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

● Flight detector testing shows a degradation in pixel operability
  ■ Impacts NIRCam, NIRSpec, and FGS

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

● Decision for the detector swap will be in March 2012
ETU Detector Status

- Teledyne has recently completed testing Short Wave (SW) detectors fabricated for their ground-based astronomy customers.
  - Several of these SCAs were fabricated using new bake-stable process which will correct degradation issue seen on JWST detectors
    - Are similar to the JWST SW parts, thereby providing the first performance test of JWST-like parts using the new process
  - Test results show the new process does not appear to have any adverse effect on science performance

- Still on schedule to receive the first Mid-Wave and SW detectors in early January
  - Total of 22 SCAs to be delivered (Jan-April) for testing
    - Testing starts at Teledyne in Jan, then proceeds to University of Arizona and the GSFC Detector Characterization Lab in Feb.
New Optical Measurement Devices

- The need to accurately measure the shape of the JWST mirrors required significant improvements in wavefront sensing technology (Scanning Shack-Hartman Sensor)

- Has enabled a number of improvements in measurement technology for measurement of human eyes, diagnosis of ocular diseases and potentially improved surgery
  - Eye doctors can now get much more detailed information about the shape of your eye in seconds rather than hours
  - Four patents have been issues as a result of these innovations

Cryogenic ASIC

- JWST developed a low-noise, cryogenic ASIC to convert the analog signals from the near-IR detectors to digital

- Same design used on ASIC now being used in the Advanced Camera for Surveys which was repaired during the HST SM-4 servicing mission

- “future heritage”
Laser Interferometers utilizing High Speed Optical Sensors

- JWST needed to make measurements of mirrors and composite structures with nanometer precision in cryogenic vacuum chambers (with vibrations from pumping systems a constant problem)

- JWST provided 4D its first commercial contract to develop the PhaseCam interferometer system

- 4D Technology Corp has developed several new types of high-speed test devices that utilize pulsed lasers that essentially freeze out the effects of vibration

- 4D has gone on to generate over $30 M in revenue from a wide range of applications in astronomy, aerospace, semiconductor and medical industries based on the technologies developed for JWST
Implementing the New Baseline

- Completed the replan (9/23/2011) with an October 2018 launch date
  - Plan has adequate cost and schedule reserves consistent with ICRP recommendation
  - Additional $44M in FY11 was approved by Congress
  - FY12 budget approved by Congress with full funding for JWST
  - FY13 PBR fully funds the new baseline

- Recent Accomplishments
  - All flight optics have been cryo tested and meet requirements
  - Completed the Aft Optic System integration and alignment
  - Primary Mirror Backup Support Structure center section nearly complete (94% of bonding is complete)
  - Sunshield full scale Engineering Development Unit for layer #3 testing completed with good results
  - Instrument deliveries to GSFC begin in Spring 2012

- Brought back in work with additional FY11 funding and FY12 budget
  - Accelerated: Backplane Support Frame (BSF) by 4 months, completion of PMBSS by 4 months, start of Wings by 18 months, end of Flight Optics Integration by 4 months
  - Still have 13 month of funded schedule reserve on critical path

- Instrument deliveries slipped moving ISIM delivery to OTIS by 5 months (31 months to 26 months)
  - Even with Detector change out, still have 11 months slack for ISIM delivery to OTIS
  - ETUs for NIRSpec and NIRCam will be used in ISIM Cryo Test 1(all have flight hardware for CT 2+3)

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

**Primary Mirror Segments**: 100%

**Primary Mirror Support Structure**: 95%

**Science Instrument Module & Science Instruments**: 90%

**Sunshield Membranes**: 40%

**Secondary Supports**: 80%

**Spacecraft Bus**: 25%

**Secondary Mirror**: 100%

**Aft Optics System**: 100%

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

As of 1/13/2012
After testing of replacement detectors, the ISIM flow will be updated to show the detector change-out strategy.
Work-To-Go (FY12 to Launch and Commissioning)

- Backplane, Sunshield, Spacecraft (60%)
- Ground System (76%)
- ISIM (22%)
- System Level I&T (85%)
- Labor & Related Expenses (47%)
- Proj. Support (50%)
- Optical Telescope Element (21%)
- JSC Chamber A Modifications (30%)
- JPL Cryocooler (35%)
- Science & SWG (67%)

Relative proportion of project funding to-go
Optical telescope element Simulator (OSIM) Integration

On Track for Cryo Verification mid-April 2012

Status as of: 1/31/12
Telescope Assembly Ground Support Equipment

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

Ambient Optical Alignment Stand Complete

Landing a mirror onto backplane simulator

01/19/2012
Will be the largest cryo vacuum test chamber in the world
Center of Telescope Curvature Optical Test Equipment

- Pressure Tight Enclosure (PTE)
- Hexapod Actuator
- Multi Wavelength Interferometer (MWIF)
- Displacement Measuring Interferometers (DMIs)
- Null Assembly
- Beam Splitter and CASS Camera
- Hologram
BACKUP
James Webb Space Telescope (JWST) goes beyond Hubble and other space telescopes by seeing things that they cannot see...

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

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

- Optical Telescope Element (OTE) diffraction limited at 2 micron wavelength.
  - 25 m², 6.35 m average diameter aperture.
  - Instantaneous Field of View (FOV) ~ 9’ X 18’.
  - Deployable Primary Mirror (PM) and Secondary Mirror (SM).
  - 18 Segment PM with 7 Degree of Freedom (DOF) adjustability on each.
- Integrated Science Instrument Module (ISIM) containing near and mid infrared cryogenic science instruments
  - The Near-infrared camera functions as the on-board wavefront sensor for initial OTE alignment and phasing and periodic maintenance.
- Deployable sunshield for passive cooling of OTE and ISIM.
- Mass: ≤ 6530 kg.
- Data Capabilities: 471 Gbits on-board storage, 229 Gbits/day science data.
- Science Data Downlink: 32 Mbps.
- Life: 5 years [Designed for 11 years (goal) of operation].

Stowed Configuration