Status of the James Webb Space Telescope (JWST) Observatory

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**JWST and its Precursors**

**HUBBLE**
- 2.4-meter
- $T \sim 270$ K
- $123'' \times 136''$
- $\lambda/D_{1.6\mu m} \sim 0.14''$

**JWST**
- 6.5-meter
- $T \sim 40$ K
- $132'' \times 164''$
- $\lambda/D_{2\mu m} \sim 0.06''$

**SPITZER**
- 0.8-meter
- $T \sim 5.5$ K
- $312'' \times 312''$
- $\lambda/D_{5.6\mu m} \sim 2.22''$
- $324'' \times 324''$
- $\lambda/D_{24\mu m} \sim 6.2''$

**Wavelength Coverage**

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>HST</th>
<th>JWST</th>
<th>Spitzer</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 $\mu$m</td>
<td>$\lambda/D_{1.6\mu m}$</td>
<td>$\lambda/D_{2\mu m}$</td>
<td>$\lambda/D_{5.6\mu m}$</td>
</tr>
<tr>
<td>10 $\mu$m</td>
<td>$\lambda/D_{2\mu m}$</td>
<td>$\lambda/D_{20\mu m}$</td>
<td>$\lambda/D_{5.6\mu m}$</td>
</tr>
<tr>
<td>100 $\mu$m</td>
<td>$\lambda/D_{20\mu m}$</td>
<td>$\lambda/D_{24\mu m}$</td>
<td>$\lambda/D_{5.6\mu m}$</td>
</tr>
</tbody>
</table>
JWST: How It Works

- Integrated Science Instrument Module (ISIM)
- 5 Layer Sunshield
- Solar Array
- Primary Mirror
- Secondary Mirror
- Spacecraft Bus
- Hot Side
- Sun
- Cold Side: ~40K
JWST’s Orbit: L2

- JWST will be launched by an Ariane 5 to an orbit around L2
  - Direct insert launch
  - L2 presents a thermally benign environment
  - Science operations: 24/7
Pointing

- predicted performance for offsets
- now using FSM offsets for <35 arcsec

|            |            | FOV Offsets - Small (0-0.5 arcsec) |   |   |  
|------------|------------|-------------------------------------|---|---|---
| MR-182     | OBS-194    |                                     | 5.0| 4.0| milli-arcsec |
| MR-181     | OBS-1685   | FOV Offsets - Medium (0.5 - 2.0 arcsec) | 20.0| 4.2| milli-arcsec |
| MR-374     | OBS-193    | FOV Offsets - Large (2-20 arcsec)   | 20.0| 4.6| milli-arcsec |
| MR-364     | OBS-1161   | FOV Offsets - XLarge (20-45 arcsec) | 90.0| 5.3| milli-arcsec |
# JWST’s Telescope

<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>18 PM Segments (Composite Figure)</td>
<td>23.6</td>
<td>8.1</td>
<td>25.0</td>
<td>25.8</td>
</tr>
<tr>
<td>Secondary</td>
<td>14.7</td>
<td>13.2</td>
<td>19.8</td>
<td>23.5</td>
</tr>
<tr>
<td>Tertiary</td>
<td>18.1</td>
<td>9.5</td>
<td>20.5</td>
<td>23.2</td>
</tr>
<tr>
<td>FSM</td>
<td>13.9</td>
<td>4.9</td>
<td>14.7</td>
<td>18.7</td>
</tr>
</tbody>
</table>
Predicted Image Quality

- **F115W**
- **F070W**
- **F200W**
- **F444W**

Diffraction Limited: Strehl > 0.8 (WFE ≤ 150 nm)

Log Scale

Linear Scale
Encircled Energy Stability
Stray Light Backgrounds
Telescope Structure

- Telescope structure complete and delivered to GSFC
Primary Mirror Integration

Ambient Optical Alignment Stand

Mirror Installation dry-run
Pathfinder Backplane

- The pathfinder is a backplane section with a secondary mirror support structure (SMSS)
  - Verify SMSS deployment

- Tests integration of primary mirror segment installation with two flight spare mirror segments, plus flight-spare secondary mirror

- Pathfinder is scheduled for three cryogenic tests during 2015 in Chamber-A at JSC
  - Verify optical test equipment
Phasing the Telescope

OTE Deployment / First Light (Image Mosaic)

SM Focus Sweep

Segment Identification

Segment Search

Segment-Image Array

Global Alignment

Image Stacking

Coarse Phasing (DHS)

Single Field Fine Phasing

Multi-Field Fine Phasing

Wavefront Monitoring & Maintenance

NIRCam First Light

After Segment-Image Array

After Global Alignment

After Image Stacking

After Coarse Phasing

After Coarse Phasing

After Image Stacking

After Global Alignment

After SF Fine Phasing

DHS (20 edges)

Pupil Imaging
Sunshield Membranes

- Five flight-like Template Membrane layers manufactured
  - Template layers tensioned to flight-like configuration
    - 3-D membrane shapes measured by Lidar
    - Critical for layer-to-layer spacing ➞ thermal performance
    - Edge alignment ➞ thermal performance & stray light
- Flight membranes under construction (#3 completed)

Tensioned to 3x flight tension for shape measurement by Lidar
(3x tension counteracts gravity sag)
Sky Background

- JWST should be zodi-limited at $\lambda < 10 \, \mu m$

  Background levels will include contribution from stray light

- NIR stray light is controlled by baffling and contamination control of optical surfaces e.g. OTE, baffles, & sunshield

- MIR stray light is controlled by thermal control of critical surfaces and contamination control of surfaces e.g.
Spacecraft Bus Structure Complete
Spacecraft-Telescope: Fit Check
Observing Constraints

- Field of Regard is an annulus with rotational symmetry about the L2-Sun axis, 50° wide.
- Sun angle constraints yield 35% instantaneous sky coverage.
  - Full sky coverage achieved over a sidereal year.
- Observations interrupted for:
  - Orbit maintenance
  - Station-keeping burns
  - Momentum management
  - Reaction desaturation burns

Diagram showing continuous coverage zones North and South, with the North Ecliptic Pole and 360° rotation towards the Sun.
JWST will be zodi-limited at $\lambda < 10 \, \mu m$

- Background levels include contributions from stray light
- NIR stray light is controlled by baffling and contamination control of optical surfaces e.g. OTE, baffles, & sunshield
- MIR stray light is controlled by thermal control of critical surfaces and contamination control of surfaces:
  - primary mirror, sunshield & structures
- Near-IR ($< 5 \, \mu m$) stray light predictions meet requirements
- In mid-IR 10 $\mu m$ and 20 $\mu m$ meet requirements
JWST’s Science Instruments

**WFSC**  
Deep, wide field imaging

**Coronagraphic Imaging**  
Multi-Object, IR spectroscopy

**Multi-Object, IR spectroscopy**

**IFU spectroscopy**

**IFU spectroscopy**

**NIRCam**  
Mid-IR, wide-field Imaging

**NIRSpec**  
Mid-IR, wide-field Imaging

**FGS/NIRISS**

**MIRI**

**Moving Target Support**

**Near-IR imaging**

**High Contrast Imaging**

**Mid-IR Coronagraphic**

**Fine Guidance Sensor**

**Slitless Spectroscopy**

**IFU spectroscopy**

**Long Slit spectroscopy**
Observatory Sensitivity: Imaging

- Point source detected at 10 sigma for a $10^4$ s integration
Observatory Sensitivity:

Low resolution (R~100) spectroscopy, point source

$\frac{f_v}{\text{detected at SNR}=10} \text{ in } 10^4 \text{s}$ (Jy)

$10^{-3}$

$10^{-4}$

$10^{-5}$

$10^{-6}$

$10^{-7}$

$10^{-8}$

$1 \mu m$

$10 \mu m$

$\text{Spitzer IRS}$

$\text{Hubble grisms}$

$\text{WFC3}$

$\text{ACS}$

$\text{NIRISS}$

$\text{NIRSpec}$

$\text{MIRI}$

$\text{JWST}$

www.stsci.edu/jwst/science/sensitivity
Observatory Sensitivity

- Line flux that can be detected at $10\sigma$ for a point source in $10^4$ s
In addition, the color-coding of Figure 1 indicates the location and responsible organization (NASA, Northrop Grumman, ITT Exelis, or ESA/Ariane) for each of the principal I&T activities.

The sequence shown depicts the typical hierarchical process by which such a complex system is developed, with lower level elements developed and tested in parallel, then integrated into higher level assemblies and tested again, e.g.: Science Instruments; four Science Instruments + Electronics + Structure; ISIM; ISIM + OTE; OTIS; OTIS + Spacecraft Element; Observatory.

Philosophically, the JWST I&T program strives to verify performance requirements at the most appropriate level of assembly, attempting to identify problems at the lowest level of assembly possible (when they are easiest to fix), while providing independent cross-checks of key requirements at the higher levels of test to confirm that nothing went wrong in the assembly process.

In this paper, we focus on the upper half of the flow shown in Figure 1, the integration and test of the Science Instruments in the ISIM Element, of the Optical Telescope Element, and of the combined OTIS system, culminating in the end-to-end optical and thermal test in the cryo-vacuum chamber at JSC.

Space precludes comparable discussion of the Sunshield and Spacecraft I&T; some information on those vital portions of the JWST observatory can be found in Clampin and Bowers (2012) in this volume.

2. I&T OF THE INTEGRATED SCIENCE INSTRUMENT MODULE (ISIM)

2.1 ISIM and its cryo-test configuration

The Integrated Science Instrument Module, shown schematically in Figure 2, is comprised of the four JWST Science Instruments (NIRCam, NIRSpec, FGS/NIRISS, and MIRI), the ISIM structure that holds them (these elements operating at 35-40K, except for the MIRI, which is cooled by a two-stage mechanical cooler to a focal plane temperature of <7K), the ISIM Electronics Compartment (IEC) that houses (at room temperature) control electronics for the Science Instruments, and the OTIS cryocooler.
How Do We Test the Telescope?

- Cryogenic Optical Test will be conducted at JSC’s Chamber A

- Goals of Cryogenic Optical Test
  - **Optical workmanship** - check on assembly of the telescope e.g. mechanical interference
  - **Optical alignment** - are we inside the capture range of the telescope’s active optics?
  - **Thermal balance** - will the telescope cool to 40K?
OTIS Test Preparations

Chamber Isolator Units

Cryo Position Metrology

Center of Curvature Optical Assembly
Dry Run testing w/Chamber-A

1) First dry run test- phasing mirrors

2) Dry run imaging with flight AOS

3) Test thermal monitoring equipment
Prior to Alignment & Phasing

After Alignment & Phasing

Prior to Alignment & Phasing
WFE = 346,557 nm-rms

After Alignment & Phasing
WFE = 386 nm-rms
Overall Commissioning Schedule

Month 1 | Month 2 | Month 3 | Month 4 | Month 5 | Month 6
---|---|---|---|---|---
Observatory Deployments

Telescope Phasing

Observatory & Instrument Commissioning

- Phased Instrument power-on with Temp.
- Observatory check-out & calibrations
  - Attitude control, acquisition, thermal ....
- Instrument check-out and calibration
JWST will do transformational science and change our view of the Universe
Where To Follow JWST

Web pages
www.jwst.nasa.gov

Social Media
webbtelescope.org

Webcam
www.jwst.nasa.gov/webcam.html

ibook ➔ itunes
(iBook for JWST free on iTunes, search for "James Webb Space Telescope")