James Webb Space Telescope Project (JWST) Overview

Mitra Dutta,
ASIC Program Manager
NASA JWST Project

21-May-08
**Why build an Infrared Telescope?**

JWST designed to collect data in this region.
How to win at Astronomy (Size counts)

Big Telescopes with Sensitive Detectors In Space

Sensitivity Improvement over the Eye

Adapted from *Cosmic Discovery*, M. Harwit
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
- Launch NET June 2013 on an ESA-supplied Ariane 5 rocket to Sun-Earth L2
- 5-year science mission (10-year goal)

www.JWST.nasa.gov
JWST Full Scale Model at the GSFC
## JWST vs HST - Specifications

<table>
<thead>
<tr>
<th></th>
<th>JWST</th>
<th>HST</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mirror</strong></td>
<td>6.5 meter deployable Primary Mirror</td>
<td>2.4 meter Primary Mirror</td>
</tr>
<tr>
<td><strong>Orbit</strong></td>
<td>L2 orbit (1.1 year)</td>
<td>LEO orbit (95 minutes)</td>
</tr>
<tr>
<td><strong>Coverage</strong></td>
<td>0.6 to 27 microns coverage</td>
<td>0.1 to 2.5 microns coverage</td>
</tr>
<tr>
<td></td>
<td>- Near Infrared Camera (NIRCam)</td>
<td>- Faint Object Camera (FOC)</td>
</tr>
<tr>
<td></td>
<td>- Near Infrared Spectrometer (NIRSpec)</td>
<td>- Wide Field/Planetary Camera (WF/PC)</td>
</tr>
<tr>
<td></td>
<td>- Mid-Infra-Red Instrument (MIRI)</td>
<td>- Space Telescope Imaging Spectrograph (STIS)</td>
</tr>
<tr>
<td></td>
<td>- Fine Guidance Sensor (FGS)</td>
<td>- NICMOS</td>
</tr>
<tr>
<td></td>
<td><strong>MIRI cryocooled to ~ 7K</strong></td>
<td><strong>NICMOS cryocooled to ~ 77K</strong></td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>64 milliarcsecond resolution</td>
<td>100 milliarcsecond resolution</td>
</tr>
<tr>
<td><strong>Life</strong></td>
<td>5 year life requirement</td>
<td>Launched in 1990</td>
</tr>
<tr>
<td><strong>Cooling</strong></td>
<td>MIRI cryocooled to ~ 7K</td>
<td>NICMOS cryocooled to ~ 77K</td>
</tr>
<tr>
<td><strong>Launch</strong></td>
<td>Tennis court size sunshield</td>
<td>Launched in 1990</td>
</tr>
<tr>
<td></td>
<td>Launch in 2013</td>
<td></td>
</tr>
</tbody>
</table>
JWST Observatory

Telescope

Primary Mirror (PM)
Secondary Mirror (SM)

Instrument module

Cold, space-facing side

Sunshield

Warm, Sun-facing side

Spacecraft Bus
The JWST mission architecture is optimized to enable key science requirements

- **JWST sees in the infrared because that is where its science is**
  - Light waves have been stretched by the expansion of space since the Big Bang. Visible light emitted by the first stars and galaxies has been shifted into the infrared by the time it reaches us.
  - Light from star and planet forming regions and from planets themselves is brightest in the infrared.

- **Large telescope optics collect and focus light**
  - With telescopes, size matters
    1. **Resolution** – objects of interest are far away and appear small. The bigger the aperture, the more detail you can see. We need to see details of structure to identify what we are observing.
    2. **Sensitivity** – objects of interest are far away and are faint. The bigger the aperture, the more light we gather and the fainter are the objects we can detect.

- **JWST’s telescope is lightweight and deployable so it can be launched economically**
  - The required size of the main mirror is wider than any available or practical launch vehicle. Making its telescope lightweight and deployable makes JWST’s large size feasible and affordable.

- **Telescope and Scientific Instruments are cold for sensitivity**
  - Infrared light is heat radiation. The telescope and the instruments (cameras and spectrometers) attached to it need to be cold so that their own warmth does not overwhelm the faint infrared signals they are trying to detect.
  - The detector chips at the heart of each instrument must be cold in order to function.

- **Sunshield allows the telescope and instruments to get cold**
  - The sunshield shades the telescope and instruments from the Sun, allowing them to radiate their heat to the extreme coldness of deep space and become very cold themselves

- **L2 is an ideal place for an infrared observatory**
  - The Sun-Earth L2 point is far enough away from the warm Earth to provide a benign thermal environment and enable efficient operations, yet close enough for easy launch and communications
The science payload is integrated to avoid duplication of common science instrument systems

ISIM is:
- The JWST Science Instruments
- Associated Infrastructure: Structure, C&DH, & FSW

Region 1
Science Instrument Optics Assemblies
- Near Infrared Camera (NIRCam)
- Near Infrared Spectrograph (NIRSpec)
- Mid Infrared Instrument (MIRI)
- Fine Guidance Sensor and Tunable Filter (FGS/TF)
- Optical Bench Structure
- Radiators and support structure (NGST-supplied)

Region 2
- Focal Plane Electronics (FPE)
- Instrument Control Electronics (ICE, MCE)
- ISIM Remote Services Unit (IRSU)

Region 3
- ISIM Command & Data Handling (ICDH) Electronics
- MIRI Cryocooler Electronics
**Instrument Overview**

- **Fine Guidance Sensor (FGS)**
  - Ensures guide star availability with >95% probability at any point in the sky
  - Includes Narrowband Imaging Tunable Filter Module
  - CSA provided

- **Mid-Infra-Red Instrument (MIRI)**
  - Distinguishes first light objects; studies galaxy evolution; explores protostars & their environs
  - Imaging and spectroscopy capability
  - 5 to 27 microns
  - Cooled to 7K by Cyro-cooler
  - Combined ESA/JPL contributions

- **Near Infra-Red Camera (NIRCam)**
  - Detects first light galaxies and observes galaxy assembly sequence
  - 0.6 to 5 microns
  - Supports Wavefront Sensing & Control
  - Univ. of AZ - LMATC instrument

- **Near Infra-Red Spectrograph (NIRSpec)**
  - Measures red shift, metallicity, star formation rate in first light galaxies
  - 0.6 to 5 microns
  - Simultaneous spectra of >100 objects
  - Resolving powers of ~100 and ~1000
  - ESA provided with NASA Detectors & Micro shutter
JWST Roles and Responsibilities

- **GSFC**
  - Management & Systems Engineering
  - NIRSpec Micro-Shutter and Detector Subsystems
  - ISIM C&DH Electronics/Software
  - ISIM Structure and Thermal Subsystem
  - ISIM-level I&T

- **European Space Agency/European Consortium**
  - NIRSpec Instrument
  - MIRI OBA (Optical Bench Assembly) and I&T

- **Canadian Space Agency**
  - FGS including FGS/TF

- **University of Arizona**
  - NIRCam Instrument (Lockheed Martin ATC is Prime)

- **JPL**
  - MIRI Management & Systems Engineering
  - MIRI Detector Subsystem, Dewar, and Flight Software

**JWST Prime Contractor Team (NGST, Ball, Kodak, ATK)**
- ISIM Enclosure & Interface-related GSE

- **Space Telescope Science Institute**
  - Instrument Support for Flight and Science Operations

- **Teledyne Imaging Sensors**
  - NIR Detectors & ASIC

- **Raytheon Corporation**
  - MIR Detector
An on-line space simulation chamber enables JWST cryogenic testing

<table>
<thead>
<tr>
<th></th>
<th>JSC Chamber A</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chamber size</strong></td>
<td>55' diam, 117' high</td>
</tr>
<tr>
<td><strong>Existing Shrouds</strong></td>
<td>LN2 shroud, GHe panels</td>
</tr>
<tr>
<td><strong>Chamber Cranes</strong></td>
<td>4x25t fixed, removable</td>
</tr>
<tr>
<td><strong>Chamber Door</strong></td>
<td>40' diam</td>
</tr>
<tr>
<td><strong>High bay space</strong></td>
<td>~102'Lx71'W</td>
</tr>
</tbody>
</table>
The JWST will utilize an existing transportation system

U.S. Air Force Space Cargo Transportation System (SCTS)
The JWST is designed to utilize standard Ariane 5 launch service contributed by ESA.
Sun-Earth L2 is a location in space where gravities of the Sun and Earth combine to form a local equilibrium point which follows the Earth around the Sun

JWST will orbit about the L2 point, roughly 1.5 million kilometers from the Earth

- All major heat sources are on one side of the observatory, (Sun, Earth, Moon)
- This allows the sunshield to constantly shade the telescope and instruments to enable passive cooling to cryogenic temperatures
JWST Launch-to-Orbit Conceptual Timeline
(Note: Timeline sequence of events is conceptual and is not drawn to scale.)

- **Mid-course correction maneuver 2** (if required) L+25 days
- **L2 orbit achieved** L+109 days
- **Launch from Kourou**
- **Telescope Deployment** L+4 days
- **Initiate ISIM testing and certification** L+113 days
- **Sunshield deployment** L+2 days
- **Mid-course correction maneuver 1B** L+24 hrs
- **JWST separation** L+25 min
- **Fairing separation** L+183 sec
- **Observatory available for ISIM activities** L+70 days
- **Observatory first light (ISIM at safe operating temp)** L+59 days
- **JWST separation** L+24 hrs
- **Earth Moon ~1,500,000 km**
- **L2**
- **~1,500,000 km**
- **~1,000,000 km**

JWST Launch-to-Orbit Conceptual Timeline
- Early emphasis on vigorous technology development to retire risk
  - All new technology development are already at TRL-6 and flight production started.

- JWST technology investments enable future science missions
  - TPF, SAFIR, SPIRIT, SPECS and CON X use technology developed by JWST
JWST technology readiness is measured against formal non-subjective criteria

- TRLs are used to systematically assess the maturity of technologies
  - NASA uses a nine step TRL scale (from NPR 7120.5C):

  - **TRL 1**: Basic principles observed and reported
  - **TRL 2**: Technology concept and/or application formulated
  - **TRL 3**: Analytical and experimental critical function and/or characteristic proof-of-concept
  - **TRL 4**: Component and/or breadboard validation in laboratory environment
  - **TRL 5**: Component and/or breadboard validation in relevant environment
  - **TRL 6**: System/subsystem model or prototype demonstration in a relevant environment (ground or space)
  - **TRL 7**: System prototype demonstration in a space environment
  - **TRL 8**: Actual system completed and “flight qualified” through test and demonstration (ground or space)
  - **TRL 9**: Actual system “flight proven” through successful mission operations

- NASA Management Handbook requires that mission-enabling technologies reach **TRL 6** before the Project is confirmed
Early ISIM technology investments have paid off

- **Infrared Detector Technologies:**
  - HgCdTe Detectors used for NIRCam, NIRSpec, and FGS
    - JWST funding significantly advanced the state-of-the-art as represented by the HST/NICMOS 256x256 arrays
      - Grew detector format by 64X to 2048x2048 pixels
      - Doubled wavelength coverage, pushing long-wave cut-off from 2.5 microns to 5.0 microns
      - Lowered dark current by 10X
  - SiAs Detectors used for MIRI
    - Pushed technology beyond the SIRTF/IRAC 256x256 arrays
      - Grew format 16X to 1024x1024 pixels

- **Cryogenic ASIC Technology for noise immunity:**
  - NIRCam, NIRSpec and FGS instruments use ASICs to digitize analog detector signal and send over 4 meter cable length maintaining ultra-low noise
    - “Cryo ASIC” essentially developed for JWST
      - Technology brought from TRL1 to 6 in five years with JWST funding and RSC support
Region 1 is cold (~40K) & has limited radiator area, therefore the ASIC power dissipation is important.
- Power predictions should be accurate to <1mW

JWST needs to survive ~5.5 years in L2 Orbit
- ASICs must be spaceflight qualified.

To meet JWST sensitivities, NIRCam, NIRSpec, and FGS must be very low noise, on order of 6-10 e- total.
- ASIC must meet or beat noise performance of baseline analog electronic design.

ASICs must meet JWST schedule.
- ETUs delivered ~Nov 05/Aug 06
- Flight ASICs ~May 06/ Mar 07

Without the ASIC, there is a ~4 meter cable run between Detectors and Electronics (A/D, clocks, etc), therefore EMI crosstalk is a concern.
- We’d like to define (quantify) the improvement in EMI immunity in ASIC vs non-ASIC solution.