JWST from below*
An overview of the construction of the James Webb Space Telescope, interesting metrology, and cryogenic-vacuum testing

University of Richmond
Richmond, Virginia
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Outline

- About NASA, about me
- Introduction to the James Webb Space Telescope and its mission
  - Hardware status
  - Measurement innovations --- many physicists work in the area of “metrology”
- Optical Telescope Element (OTE)
- Science Instrument (SI) and Integrated Science Instrument Module (ISIM)
- The focus of this talk is ISIM

**JWST construction is well underway**

**NASA needs you!**
What is NASA?

- US Government’s civilian “space department”
- Partners with industry and academia, but in-house work, too
- Space exploration
  - Human space flight and exploration
  - Robotic exploration
  - Astronomy and other space science
- Earth science
  - Weather
  - Climate change
- Airplane research
- NASA works closely with companies, universities, and other countries
- We are living in a “golden age” for astronomy and space science!
- We are on the cusp of a new golden age for human space flight!
Who is this guy…?

- Born: Richmond, Virginia
- High school: Gettysburg, Pennsylvania
- College: BS, University of Richmond, Richmond, Virginia, 1994
  - Major: Physics (Dr. Vineyard, Incomplete Fusion of $^{28}\text{Si}$ and $^{24}\text{Mg}$ Nuclei)
  - Minor: Mathematics
  - University of Muenster, Muenster, Germany (Westfaelische Wilhelms-Universitaet Muenster)
- Graduate school: University of Virginia, Charlottesville (Johns Hopkins University, Baltimore, and NASA Goddard Space Flight Center, Greenbelt)
  - MA: Astronomy (populations of very hot stars)
  - PhD: Astronomy (instrumentation, hot star populations, stellar atmospheres)
- Titles:
  - Optical physicist/engineer, NASA Goddard Space Flight Center (~17 years)
  - Optical Engineering Lead, JWST science instruments and instrument + telescope assembly
  - Group Leader, Alignment, Integration, and Test Group, Optics Branch
- What I do: Build instruments with astronomers (telescopes, cameras, spectrometers) --- I typically work on the construction/testing/calibration part of a given project.
- Why I work at NASA: NASA’s science work is strongly driven by an agenda that address questions like “how did we get here” and “are we alone in the universe” and topics like the health of our planet --- this is a peaceful, high-karma undertaking that can keep one motivated and focused. This job keeps me learning (challenging; excellent colleagues).
- Hobbies:
  - Part-time teaching: Optics for graduate students in Applied Physics (Engineering for Professionals, Whiting School of Engineering, Johns Hopkins University)
  - Sailing, swimming, running
How I got to NASA Goddard and what I do there

- Interest in working for NASA in space exploration from a young age (early elementary school)
- Always a big science fiction fan
- Started to narrow my focus in high school toward physics

College:
- Undergraduate research in particle physics at U. of R.
  - Small school; one-on-one attention; excellent preparation for graduate school in physics
  - Lots of student research opportunities (good background for grad school and industry jobs)
  - Liberal arts background has been invaluable (writing, leadership, language, etc.)
- Summer student at NASA Kennedy Space Center (saw multiple Shuttle and rocket launches; worked on manned space flight “life science” projects) --- undergrad is a great time to try different fields

Graduate school (Master’s):
- Funded by NASA and teaching
- Worked on NASA’s Astro-1 and 2 Space Shuttle missions (ultraviolet telescopes flown in space)
- Taught undergraduate astronomy classes with professors (teaching assistant)
- Taught an undergraduate astronomy class at a community college

Graduate school (PhD):
- Funded by NASA through a contract to JHU to build an ultraviolet telescope / satellite
- Worked on optical testing, assembly, ground testing, ground test software, ground test electronics, etc. for NASA’s Far Ultraviolet Spectroscopic Explorer (FUSE) mission
- Worked on science data from hot stars and galaxies of hot stars

After working closely with NASA engineers and scientists from GSFC, encouraged to apply for an engineering opening at NASA GSFC after graduation from UVa
Astro-1 & 2 Space Shuttle missions
Figure 42: FUSE spectra (solid line) and absorption line fits (dotted line) used to determine the C and Si abundances listed in Table 9. Note the location of the Lyman transitions of H₂ used to help correct the wavelength scale for S III and S IV.
Ground-based, infrared spectrometer
Future telescope mission studies/concepts (e.g., Terrestrial Planet Finder)
James Webb Space Telescope (JWST)
JWST is a general astrophysics mission

- JWST will operate in a manner similar to HST to enable a wide range of science investigations proposed by astronomers world-wide
- General Observer community will drive science investigations
- Four science themes define the development of technical requirements for JWST:
  - First light and reionization: Identify the first bright objects in the early Universe and follow ionization history
  - Galaxy formation and evolution: Shed light on how galaxies and dark matter evolved to present
  - Star formation in our galaxy: Study the birth and early development of stars
  - Planetary systems: Observe the physical and chemical properties of solar systems (including our own)
**Integrated Science Instrument Module (ISIM)**
- Located inside an OTE provided ISIM Enclosure
- Contains 4 Science Instruments (NIRCam, NIRSpec, MIRI, FGS / TF)

**Thermal Region 2**
- Components maintained at ambient temperatures on cold side of the observatory

**ISIM Electronics Compartment (IEC)**

**Thermal Region 1**
- Components cooled to cryogenic temperatures

**Optical Telescope Element (OTE)**
- 6 meter Tri-Mirror Anastigmatic
- 18 Segment Primary Mirror

**Sunshield (SS)**
- 5 layers to provide thermal shielding to allow OTE and ISIM to passively cool to required cryogenic temperatures

**Solar Array**

**OTE Primary Mirror**

**OTE Secondary Mirror**

**OTE Deployment Tower**

**Spacecraft Bus**
- Contains traditional “ambient” subsystems

**OTE Backplane / ISIM Enclosure**

**Thermal Region 3**
- Components maintained at ambient temperatures
Optical Telescope Element (OTE)

Secondary Mirror Support Structure (SMSS)

Primary Mirror Segment Assemblies (PMSA)

Secondary Mirror

Primary Mirror (~6.5m diameter, segments ~1.5m tip-to-tip)

Aft Optics Subsystem

Primary Mirror Backplane Assembly (PMBA) and Backplane Support Frame (BSF)

- Composite tube frame construction
- Two deployable Wings

<table>
<thead>
<tr>
<th>Table 1: Key design parameters of the JWST and HST</th>
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</thead>
<tbody>
<tr>
<td><strong>Performance Parameter</strong></td>
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<tr>
<td>---------------------------</td>
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<tr>
<td>OTE Diameter (meters)</td>
</tr>
<tr>
<td>Mass (kg)</td>
</tr>
<tr>
<td>Output power at load input (watts)</td>
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<tr>
<td>Unobscured Aperture ( sq meters)</td>
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<tr>
<td>Overall optical transmission (%)</td>
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<tr>
<td>Telescope field of view (arc min)</td>
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<tr>
<td>Wavelength of diffraction limited performance</td>
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<tr>
<td>Rayleigh radius (arc sec)</td>
</tr>
<tr>
<td>Telescope Strehl ratio (%)</td>
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<tr>
<td>Pointing accuracy without fine guidance (arc sec)</td>
</tr>
<tr>
<td>Pointing stability with fine guidance (arc sec)</td>
</tr>
<tr>
<td>Detector pixels (Mega Pixels)</td>
</tr>
<tr>
<td>Data volume (Gbits/day)</td>
</tr>
</tbody>
</table>

Greenhouse, SPIE, 2015
Structure stability: Backplane Stability Test Article (BSTA) and speckle interferometry

- Structure required to be stable to ~nm level over temperature excursions
- BSTA developed as test article representative of portion of structure
- Vibration-insensitive Electronic Speckle Pattern Interferometry (ESPI) developed to measure nm-level changes in large, non-specular, mechanical surfaces over time, temperature, etc. by tracking speckle motion on the surface
- GSFC and STScI personnel
- Partnership with 4-D Technology, ATK, NGAS, and NASA MSFC
- B. Saif et al., Applied Optics 46 and 47, 2007

Fig. Electronic Speckle Interferometry of PM

ESPI-BSTA test configuration at NASA MSFC
NASA HST, Chandra, SIRTF Lessons Learned
- TRL 6 by NAR
- Implement an active risk management process early in the program (Early investment)

JWST Primary Optic Technology Selected - TRL 5.5
Axsys Machining Facility

Onset NGST 1996

Tinsley Large Optics Facility for JWST (2007)

Brush Wellman Blank Production Completed (2006)

XRCF Cryo Testing (2009-2011)

Technology Readiness Level 6 Demonstrated

PM Segments Complete
PM EDU Coated and Complete
EDU Ambient Polishing

L. Feinberg, AAS, Jan 2010
Primary mirror segments tested at NASA MSFC in XRCF chamber (Chandra/AXAF)

Ball Aerospace & Technology Corp.
Secondary mirror testing

L. Feinberg, AAS, Jan 2010
Ambient metrology tools: Laser trackers & radars and theodolites

Laser tracker\(^1\) is used to measure targets and surfaces
- Interferometric measurements of change in distance
- “absolute distance meter” measures range (from time of flight) based upon signal modulation (polarization; 780 nm)
- Operated with Spatial Analyzer\(^2\) software, which includes Unified Spatial Metrology Network (USMN; bundling) routine --- greatly improved uncertainty
- Its target is a spherically mounted retro-reflector (SMR)
- Uncertainty ~0.005--0.025 mm (1-sigma)
- LT may be used with T-Cam / T-Scan / T-Probe accessories to measure envelopes, surfaces, tooling holes

Theodolites are used to measure angles via auto-collimation
- Operated manually, data is analyzed with GSFC-developed software
- Autocollimation: Target is a specular flat mirror (cube)
- Uncertainty ~2 arc-sec (1-sigma) for a single measurements, >5 arc-sec (1-sigma) for a collection of measurements

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1. Leica Geosystems AG, Heerbrugg, Switzerland, metrology.leica-geosystems.com
Laser radar (LIDAR) is used to measure targets and surfaces

- Laser is modulated in frequency; return beam suffers a modulation shift with time of flight & range (1.55 um)
- Operated with Spatial Analyzer software
- Its target is diffuse surface (mechanical surface; matt finish), reflective tooling ball, specular mirror, or high-quality tooling hole
- Uncertainty ~0.015 mm in range (1-sigma), ~0.015 mm per meter in azimuth and elevation (1-sigma)
- Laser Radar scans much faster than Laser Tracker with T-Probe
- USMN-compatible
- At ambient, used for:
  - Used for prescription and alignment measurement for large optics (radius, aperture, etc.)
  - Envelope scans
  - Tooling ball targets on large assemblies
  - Large mirror prescription
- Cryogenic use:
  Measurement through a chamber window

1. Nikon Metrology, Brighton, Michigan and Manassas, Virginia
OTE build-up at NASA Goddard (Harris Corp. & GSFC)

- Mirror metrology
- Integration and alignment
Integrated Science Instrument Module (ISIM)

- Housed behind the primary mirrors
- Aligned to exit pupil and focal surface of telescope

Four Instruments on ISIM
- Near-Infrared Camera (NIRCam)
- Near-Infrared Spectrometer (NIRSpec)
- Mid-Infrared Instrument (MIRI)
- Near-InfraRed Imager and Slitless Spectrograph (NIRISS)
ISIM alignment and performance parameters

Misalignments and resulting performance errors

- **V1 changes best focus**
- **V2/V3 changes boresight**
  - 1 mm shift = 1.56 arcsec shift in sky angle, 1/6th of 10.2 arcsec requirement
  - **V2/V3 yields SI entrance pupil shear vs OTE exit pupil**
    - 1 mm shift = 0.66% shear, 1/5th of 3.1% requirement
    - V2/V3 alignment errors < 0.05 mm
  - Rotation about V2 or V3 shears the SI entrance pupils vs the OTE exit pupil
    - 1 arcmin error = 0.59% shear
    - rV2/rV3 alignment errors < 0.2 arcmin
- **Rotation about V1 yields pupil clocking (and field-clocking)**
  - However, alignments of individual pupil wheel elements dominate the errors in pupil clocking
ISIM Calibration

Reference A

Reference B

Secondary Mirror

Pupil Select Mechanism (PSM)
& Pupil Translation Mechanism (PTM)

Fold Mirror 3 Gimbal Assembly

NIRSpec

Pupil imaging Module (PIM)

Alignment Diagnostic Module (ADM)

Fold Mirror 1

Fold Mirror 2

Primary Mirror (PM)

Source Plate Mechanism (SPM)

Optical Bench (OB)
JWST ISIM integration and test flow chart

**CV1-RR**
Summer/Fall 2013

**Integration of Full-Up ISIM**

**CV2**
Summer 2014

### Science Instrument Final Upgrades

**FGS:**
- Detector arrays
- Electronics boards

**NIRISS:**
- Detector array
- Grisms
- Dual Wheel motors

**MIRI:**
- Flight HSA
- Electronics boards

**NIRCam:**
- 3 of 10 detector arrays
- Electronics boards

**NIRSpec:**
- Detector arrays
- MicroShutter Array
- Electronics board

### Environmental Testing

- Vibration (ISIM Prime, Harness Radiator, IEC separately)
- Acoustics (together)
- EMI/EMC (together)

**CV3**
Fall/Winter 2015/2016

**Delivery!**
March 2016

**Ambient Functional**
Cryogenic metrology tools

Photogrammetry is used to measure target positions
• Customized system developed for NASA/GSFC
• Uses COTS camera* housed in custom canister that holds the camera in ambient temperature and pressure environment within a larger vacuum chamber and cryogenic environment
• Operated with V-STARS* software
• Its target is a retro-reflective surface with a precision mask
• Targets measured from many vantage points to determine location via triangulation
• Uncertainty ~0.010 mm (1-sigma; highly dependent on test configuration)

Alignment Diagnostic Module (ADM)
• Leica Absolute Distance Meter measures the positions of retro-reflectors
• Alignment telescope with custom reticule measures back-illuminated pin hole or fiber positions or autocollimates on specular flat mirrors
• Sights along optical axis of OSIM
• Enables in situ 6 DoF alignment measurements of OSIM components, GSE, and ISIM Structure
• Internal components held at ambient temperature and pressure

*Geodetic Systems Inc., Melbourne, Florida

Characterizing & customizing the ISIM Structure
Cryogenic-vacuum test of Structure

OSIM (shown for reference only; not actually present or needed in test)
Science instruments (SIs; various scales)

- Near-Infrared Camera (NIRCam)
- Near-Infrared Spectrograph (NIRSpec)
- Fine Guidance Sensor (FGS)
- Near-Infrared Imager and Slitless Spectrograph (NIRISS)
- Mid-Infrared Instrument (MIRI)
## Key Instrument Characteristics (as of Mar 06)

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Channel/Mode</th>
<th>Wavelength (microns)</th>
<th>Typical Spectral Resolution (λ/Δλ)</th>
<th>FOV</th>
<th>Angular Resolution (arc sec)</th>
<th>Number of Sensor Chip Arrays</th>
<th>Mega Pixels</th>
<th>Detector Type / Format</th>
<th>Detector Temp (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>NIRCam</strong></td>
<td>Shortwave</td>
<td>0.6 - 2.3</td>
<td>4,10,100</td>
<td>2.2’ x 2.2’ each of 2 modules</td>
<td>0.032 / pixel</td>
<td>8</td>
<td>34</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>Longwave</td>
<td>2.4 - 5.0</td>
<td>4,10,100</td>
<td>2.2’ x 2.2’ each of 2 modules</td>
<td>0.065 / pixel</td>
<td>2</td>
<td>2</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<tr>
<td><strong>NIRSpec</strong></td>
<td>Multi-Object Spec</td>
<td>1.0 - 5.0</td>
<td>1000</td>
<td>see FOV</td>
<td>2</td>
<td>8</td>
<td>37</td>
<td>HgCdTe / 2048 x 2048</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Long Slits (5)</td>
<td>1.0 - 5.0</td>
<td>100, 1000, 2700</td>
<td>0.28 slice width</td>
<td>1.0 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td></td>
<td>IFU</td>
<td>0.7 - 5.0</td>
<td>2700</td>
<td>3 x 3 arc-sec</td>
<td>1.11 / pixel</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td><strong>MIRI</strong></td>
<td>Imager</td>
<td>5 - 27</td>
<td>4-6</td>
<td>1.9’ x 1.4’</td>
<td>0.11 / pixel</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Low Res Slit</td>
<td>5 - 11</td>
<td>100</td>
<td>5’ x 0.5’</td>
<td>see FOV</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
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<tr>
<td></td>
<td>Med Res IFU</td>
<td>4.87 - 7.76</td>
<td>3000</td>
<td>3.7’ x 3.7’</td>
<td>0.18 slice width</td>
<td>1</td>
<td>4</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
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<tr>
<td></td>
<td></td>
<td>7.45 - 11.87</td>
<td>3000</td>
<td>4.7’ x 4.5’</td>
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<tr>
<td></td>
<td></td>
<td>11.47 - 18.24</td>
<td>3000</td>
<td>6.2’ x 6.1’</td>
<td>0.39 slice width</td>
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<td></td>
<td></td>
<td>17.54 - 28.82</td>
<td>2250</td>
<td>7.1’ x 7.1’</td>
<td>0.65 slice width</td>
<td>1</td>
<td>8</td>
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<tr>
<td></td>
<td>FGS-TF</td>
<td>1.6 - 2.5, 3.2 - 4.9</td>
<td>100</td>
<td>2.2’ x 2.2’</td>
<td>0.065 / pixel</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
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<tr>
<td></td>
<td>FGS-Guider</td>
<td>0.8 - 5.0</td>
<td>0.7</td>
<td>2.3’ x 2.3’ each of 2 modules</td>
<td>0.069 / pixel</td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
</tbody>
</table>
Detector and MEMS micro-shutter technology

- Light
- Semiconductor absorber layer
- Indium interconnects
- Silicon readout integrated circuit (ROIC)
Fully integrated ISIM (SIs, Structure, etc.)
Gravity release alignment test
Absolute alignment of OSIM’s optical output

OSIM cryo-vac test configuration

Photogrammetry Cameras

BIA

ISIM Test Platform (ITP)

Upper GESHA

He Shroud Region

LN2 Shroud Region

Vibration Isolators (3)
Primary mirror

Concave mirror under test

Interferometer test beam (overfills mirror aperture)

Center of curvature of mirror and temporary location of tooling ball target (dashes) used for alignment of the interferometer

Transmission sphere (divergent)

Interferometer instrument located with focus of diverger at center of curvature

LR beam focused on surface of mirror and specular return

LR instrument located close to center of curvature
ISIM Element in SES Chamber

ISIM and the IEC within their test cryo-panels, all mounted on the test integration fixture.

The OSIM telescope simulator, carefully closed out to keep the test environment dark out to \(~6\mu\text{m}\) wavelengths.
CV3 Top-Level Objectives

Key CV3 objectives:

- Verify the ISIM System in its final configuration after environmental exposure
- Provide a post-environmental performance baseline
- Obtain critical ground calibrations needed for science data processing in flight
CV3 in a Nutshell: The As-Run Timeline

[Diagram of timeline and test procedures involving MIRI, NIRCam, MSA, and OSM components, including thermal control, system functional checks, and performance tests.]
**CV3 in a Nutshell: The As-Run Timeline**

Oct 27, 2015 → Feb 12, 2016: 108 days around the clock

<table>
<thead>
<tr>
<th>Date</th>
<th>Test Description</th>
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<tr>
<td>11/10</td>
<td>Cooldown Decision</td>
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<tr>
<td>11/10</td>
<td>Abbreviated Continuity</td>
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<tr>
<td>11/17</td>
<td>Overview Test and Correction</td>
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<td>11/24</td>
<td>Test Warm Up</td>
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<tr>
<td>11/25</td>
<td>Final Optical Performance</td>
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<td>11/26</td>
<td>Final System Functional Checks</td>
</tr>
<tr>
<td>12/1</td>
<td>Test End</td>
</tr>
</tbody>
</table>

**Tests/Tasks**

- Abbreviated Continuity
- System Functional + Fault Mgmt (Vac)
- ISSM Amb Metrology
- SI Stability Points
- Thermal Balance Points
- Final System Functional Checks
- Cooler Down

**Key Decision Points**

- Test Warm Up
- Final Optical Performance
- Final System Functional Checks
- Cooler Down

**Abbreviations**

- OSS: Optical Systems Engineering
- SI: Structural Integrity
- NIRCam: Near Infrared Camera
- NIRISS: Near Infrared Imaging Spectrograph
- MIRI: Multi-mirror Infrared Instrument
- NIRSpec: Near Infrared Spectrograph
- FGS: Fine Guidance System

**Timeline**

- Oct 27, 2015 → Feb 12, 2016: 108 days around the clock

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**Diagram Details**

- Timeline with various phases and milestones.
- Key events and checkpoints highlighted.
- Diagram includes multiple test phases and decision points.

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**Graphical Representation**

- Graph showing temperature changes over time.
- Plot of system performance metrics.

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**Thermal Control**

- Thermal Balance Points
- Thermal Control
- Key Decision Points

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**Tests/Tasks**

- Test Start
- Cool Down Decision
- Cool Down End
- Final System Functional Checks
- Test End

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**Abbreviations**

- OSS: Optical Systems Engineering
- SI: Structural Integrity
- NIRCam: Near Infrared Camera
- NIRISS: Near Infrared Imaging Spectrograph
- MIRI: Multi-mirror Infrared Instrument
- NIRSpec: Near Infrared Spectrograph
- FGS: Fine Guidance System

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**Graphical Elements**

- Temperature graphs for various components.
- Timeline representation with markers for key events.
- Graphs showing data trends over the timeline.
CV3 in a Nutshell: The As-Run Timeline

~1 Week at Ambient Vacuum: Outgassing + System Functional
CV3 in a Nutshell: The As-Run Timeline

~2.5 weeks to cool down safely and cleanly
CV3 in a Nutshell: The As-Run Timeline

7 weeks at “cold op” temperatures
CV3 in a Nutshell: The As-Run Timeline

2 weeks at “warm op” temperatures
**CV3 in a Nutshell: The As-Run Timeline**

**ISIM Cryo-vac Test #3 As Run Timeline 4/4/2016**

<table>
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<th>Tests / Tasks</th>
<th>Phase</th>
<th>Phase</th>
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<td>Thermal Balance Points</td>
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<td>TB 1-C-0</td>
<td>TB 1-H-0</td>
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<td>TB 1-H-0</td>
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<td>TB 0-C-0</td>
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</table>

**Tests / Tasks**

- **Initial Flux Evaluation**
- **Comprehensive Performance Test**
- **MIIR CC Heat Load**
- **OSM MAT/FAT/ET**
- **Target Monitoring**
- **FGA Guide on Bad Pixel**
- **OSM FPA Htr**
- **NIRISS/NC/Guider Darks**
- **FGA ODT Test**
- **HR Load into OTE Test**
- **Warm up to 2nd (Warm) Plateau**
- **Start Warm Up**

**Thermal Balance Points**

- **TB 1-C-0**
- **TB 1-C-1**
- **TB 1-H-0**
- **TB 1-H-1**
- **TB 0-C-0**
- **TB 0-C-1**
- **TB 0-H-0**
- **TB 0-H-1**

**Key Decision Points**

- **Start Warm Up**
- **OSM DITL**
- **Initial Flux**
- **Final Optical Performance**
- **MIRI Cold Detector**
- **High Priority Tests**
- **Final Perf/Prs**
- **Power Off St’s**
- **MIRI CC Decontamination**
- **SES Re-Press**

**Abbreviations**

- **AM Ambient Checks**
- **CCH Contamination Region**
- **MIRI Detector Heaters Active**
- **MIRI <200K**
- **FGS/NC/NS Dark Count Test (OSS)**
- **SES Pumpdown**
- **OSM Short Detection**
- **FGS Solar Darks**
- **OSM Amb Metrology**
- **Thermal Control**
- **FGS/NC/NS Dark Count Test (OSS)**
- **FGS Solar Darks**
- **OSM Short Detection**

**Notes**

- **NERSC 200K**
- **Add Heaters to MIRI**
- **Close MIRI CCC**

**System Turn-On**

- **NERSC 140K**
- **Add Heaters to MIRI**
- **Close MIRI CCC**

**Time Frame**

- **10/27**
- **11/3**
- **11/10**
- **11/17**
- **11/24**
- **12/1**
- **12/8**
- **12/15**
- **12/22**
- **12/29**
- **1/5**
- **1/12**
- **1/19**
- **1/26**
- **2/2**
- **2/9**
- **2/16**

**2 weeks for safe warmup and final ambient vacuum functional**
Test Went Very Well

- The test campaign ran extremely smoothly overall and accomplished all of its significant goals
- Thoroughly exercised ISIM instruments and systems: >25,000 images (>8 TB) collected
Afterward, we attached ISIM to OTE ("OTIS")
Next test: OTE+ISIM, NASA JSC, Chamber A

- Isolation System
- Down Rods
- Upper Suspension Frame (USF)
- Telescope Tension Rods
- Space Vehicle Thermal Simulator (SVTS) by NG
- Hardpoint Offloader Support System (HOSS)
- Center of Curvature Optical Assembly (COCOA)
  - COCI (MWL interferometer, null, calibration equipment)
- Autocollimating Flat Mirrors (ACF Assembly)
  - 3 ACFs (actuated motion)
  - Rogue Path
    - Cryo Position Metrology
    - Fiber fed PM Lights
- LN2 and Helium Cryogenic Shrouds
- Optical Telescope Element (OTE Integrated Science Instrument Assembly (ISIM) – (OTIS)

L. Feinberg, AAS, Jan 2010
L. Feinberg, AAS, Jan 2010

Ref. - JSC Chamber A

Ref. - OTIS and Thermal Sim(s).
Monitor JWST’s progress and learn about its science

- www.nasa.gov
- www.jwst.nasa.gov
- http://www.jwst.nasa.gov/science.html
NASA needs you

- Internships:  [https://intern.nasa.gov/](https://intern.nasa.gov/) (Student Opportunities; OSSI)
- Co-operative education (co-op; “Pathways”; BS--PhD)

  **Engineering Student Trainee - NASA Pathways Intern**
  Vacancy Announcement Number: GS16I0015
  Pay Plan, Series, and Grade: GS- GS-0899-4/5/6/7/9/11
  Code: 220, 360, 550, 560, 580, 590
  Duty Station: Greenbelt, MD
  Closing Date: 10/03/2016

  **Engineering Student Trainee - NASA Pathways Intern**
  Vacancy Announcement Number: GS16I0016
  Pay Plan, Series, and Grade: GS- GS-0899-4/5/6/7/9/11
  Code: 250, 580, 590
  Duty Station: Wallops Island, VA
  Closing Date: 10/03/2016

- Civil servant jobs

  **Research Astrophysicist, AST, Atmospheres and Ionospheres**
  Vacancy Announcement Number: GS16D0080
  Pay Plan, Series, and Grade: GS-1330-13
  Code: 693
  Duty Station: Greenbelt, MD
  Closing Date: 09/29/2016

  **Research Space Scientist, AST, Planetary Studies**
  Vacancy Announcement Number: GS16D0084
  Pay Plan, Series, and Grade: GS-1330-12
  Code: 691
  Duty Station: Greenbelt, MD
  Closing Date: 09/29/2016

- “Contractor” jobs (industry, academia)
Questions?