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
October 12, 2016

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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 H$_2$ 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)

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

Thermal Region 1
- Components cooled to cryogenic temperatures

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

Thermal Region 3
- Components maintained at ambient temperatures

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

ISIM Electronics Compartment (IEC)

Spacecraft Bus
- Contains traditional "ambient" subsystems

OTE Deployment Tower

OTE Secondary Mirror

OTE Primary Mirror

OTE Backplane / ISIM Enclosure

Solar Array
Optical Telescope Element (OTE)

Secondary Mirror Support Structure (SMSS)

Primary Mirror Segment Assemblies (PMSA)

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

Aft Optics Subsystem

Secondary Mirror

Table 1: Key design parameters of the JWST and HST

<table>
<thead>
<tr>
<th>Performance Parameter</th>
<th>HST</th>
<th>JWST</th>
</tr>
</thead>
<tbody>
<tr>
<td>OTE Diameter (meters)</td>
<td>2.4</td>
<td>6.1 by 6.6</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>11600</td>
<td>6330</td>
</tr>
<tr>
<td>Output power at load input (watts)</td>
<td>2400</td>
<td>2079</td>
</tr>
<tr>
<td>Unobscured Aperture (sq meters)</td>
<td>4.5</td>
<td>25</td>
</tr>
<tr>
<td>Overall optical transmission (%)</td>
<td>45 to 25</td>
<td>62 to 43</td>
</tr>
<tr>
<td>Telescope field of view (arc min)</td>
<td>14.6 (radius)</td>
<td>18 by 9</td>
</tr>
<tr>
<td>Wavelength of diffraction limited performance</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Rayleigh radius (arc sec)</td>
<td>0.043</td>
<td>0.069</td>
</tr>
<tr>
<td>Telescope Strehl ratio (%)</td>
<td>80</td>
<td>80</td>
</tr>
<tr>
<td>Pointing accuracy without fine guidance (arc sec)</td>
<td>22</td>
<td>7</td>
</tr>
<tr>
<td>Pointing stability with fine guidance (arc sec)</td>
<td>0.007</td>
<td>0.007</td>
</tr>
<tr>
<td>Detector pixels (Mega Pixels)</td>
<td>25</td>
<td>66</td>
</tr>
<tr>
<td>Data volume (Gbits/day)</td>
<td>27</td>
<td>458</td>
</tr>
</tbody>
</table>

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

- Composite tube frame construction
- Two deployable Wings

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
JWST Mirror Development History

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

Onset NGST 1996

- AMSD

AMS-D Phase 1

AMS-D Phase 2

JWST Primary Optic Technology Selected - TRL 5.5

JWST Mirror Risk Reduction TRL 6

NAR

NMSD

AMSD Phase 1

JWST Monolithic Be Mirror Manufacturing

Brush Wellman Blank Production Completed (2008)

PM EDU Coated and Complete

EDU Ambient Polishing

Tinsley Large Optics Facility for JWST (2007)

2004

JWST Mirror Risk Reduction TRL 6

XRCF Cryo Testing (2009-2011)

2008

PM Segments Complete

2010

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\(^1\) (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

\(\Delta F\) has a direct relationship to \(\Delta T\) but is far easier to measure.

\(\Delta F\): Difference in frequency between transmitted and received signal.

\(-0.58\) Hz change is equivalent to 1 micron of range change [575 kHz/m x \(\Delta\text{Range}\)]

\(\Delta T\): Difference in time between transmitted and received signal,

\(-6.7 \times 10^{-16}\) sec is equivalent to 1 micron of range change [\(2 \times \Delta\text{Range} / c\)]

\(\Delta F\) is the frequency shift due to the modulation of the laser beam.

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
    - \( \frac{rV2}{rV3} \) 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
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)

Ambient Functional

CV3 Fall/Winter 2015/2016 → Delivery! March 2016
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

ISIM Structure (composite tubes and Invar joints)

Structure bonding at ATK (Utah)

Structure on kinematic mounts (from Harris)

Structure cryogenic metrology testing (PG)

Integration of science instrument optical assemblies
Characterizing & customizing the ISIM Structure
Cryogenic-vacuum test of Structure

- SES chamber
- LN2 shroud
- He shroud
- PG cameras and boom
- ISIM Structure
- Test support frame
- ITP+MATF
- Upper GESHA
- Vibration isolators
- Lower GESHA
- CAD image of cryo-set test

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 ($\lambda/\Delta\lambda$)</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>NIRCam</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>
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<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>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<tr>
<td></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></td>
<td>37</td>
<td></td>
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<tr>
<td>NIRSpec</td>
<td>Long Slits (5)</td>
<td>1.0 - 5.0</td>
<td>100, 1000, 2700</td>
<td>300 x 2500 max x 2, 400 x 4000 max, 100 x 2000 max</td>
<td>0.10 slice width</td>
<td></td>
<td></td>
<td></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></td>
<td>2</td>
<td>8</td>
<td>HgCdTe / 2048 x 2048</td>
<td>37</td>
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<tr>
<td>MIRI</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>
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<td></td>
<td>Low Res Slt</td>
<td>5 - 11</td>
<td>100</td>
<td>5&quot; x 0.5&quot;</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&quot; x 3.7&quot;</td>
<td>0.18 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></td>
<td>7.45 - 11.87</td>
<td>3000</td>
<td>4.7&quot; x 4.5&quot;</td>
<td>0.28 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></td>
<td>11.47 - 18.24</td>
<td>3000</td>
<td>6.2&quot; x 6.1&quot;</td>
<td>0.39 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></td>
<td>17.54 - 28.82</td>
<td>2250</td>
<td>7.1&quot; x 7.7&quot;</td>
<td>0.65 slice width</td>
<td>1</td>
<td>1</td>
<td>Si:As / 1024 x 1024</td>
<td>7</td>
</tr>
<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>1</td>
<td>4</td>
<td>HgCdTe / 2048 x 2048</td>
<td>40</td>
</tr>
<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>0.066 / 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
Fully integrated ISIM (SIs, Structure, etc.)
Gravity release alignment test
ISIM Cryo-Vacuum Test Configuration

- SES chamber
- LN2 Shroud
- He shroud
- ISIM
- OSIM
- Vibration Isolation Supports
- Fold Mirror 3 Tip/Tilt
- Gimbal Assembly
- Alignment Diagnostic Module
- OSIM Primary Mirror
Absolute alignment of OSIM’s optical output

OSIM cryo-vac test configuration
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 (diverger)

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 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 ~6μm 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

Cryo-Vac Testing of the JWST ISIM: R. Kimble/GSFC
CV3 in a Nutshell: The As-Run Timeline

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

3 Cycles over Operating Range

Turn OFF MIRI Detectors

Warm Flanks - Warming EFP

Coldup

Test End
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

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

Thermal Control

COOL DOWN

I EC EB Cycle - 3 Cycles over Operating Range

WARM UP

HR Load into OTE Test

Turn OFF MIRI Detectors

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-H-0

Stability Points

NIRCam

NIRSpec

FGS

NIRISS

St Mechanism Checks

St Structure Average

OSIM Shroud

ISIM Gradient

IC Rad Avg

OSS FPA Htr ON

MIRI <100K

NIRCam FPA OA

TB 1-C-0

2

3

NIRISS FPA Htr ON

Start Warm Up

MIRI CC Heat Load (Initial)

MIRI Detector Heaters Active

MIRI Detector Heaters Active

NIRspec=280K

MIRI Cold Detector Performance

Initial Flux Evaluation

MIRI FPA Performance

NIRCam Alignment

MIRI Performance

Optical Baseline

MIRI Performance

MIRI CC Heat Load

MIRI <200K

NIRCam Performance

OSS SI Characterization

MIRI Performance

NIRCam Guidance (ScS5213)

FGA Guide on Bad Pixel

NIRCam Performance

Warmup KDP

OSS SI

Power OFF SI’s

MIRI CC Decontamination

NIRISS/NC/Guider Darks

OSM + Si

Test Warm Up

KDP

NIRISS/NC/Guider Darks

NIRISS/NC/Guider Darks

OSS SI

OSS DTL

Final Optical Performance

Final Perf/ Prs

Stability Points

OSM Structure Average

FGS Bench

OSM Structure Average

FGS Bench

FGS

FGS

NIRISS FPA Htr ON

Start Warm Up

MIRI CC Heat Load

MIRI Detector Heaters Active

MIRI Detector Heaters Active

NIRspec=280K

MIRI Cold Detector Performance

Initial Flux Evaluation

MIRI FPA Performance

NIRCam Alignment

MIRI Performance

Optical Baseline

MIRI Performance

MIRI CC Heat Load

MIRI <200K

NIRCam Performance

OSS SI Characterization

MIRI Performance

NIRCam Guidance (ScS5213)

FGA Guide on Bad Pixel

NIRCam Performance

Warmup KDP

OSS SI

Power OFF SI’s

MIRI CC Decontamination

NIRISS/NC/Guider Darks

OSM + Si

Test Warm Up

KDP

NIRISS/NC/Guider Darks

NIRISS/NC/Guider Darks

OSS SI

OSS DTL

Final Optical Performance

Final Perf/ Prs

Key Decision Points

Start

Cooldown Decision

Cooldown End

End

Test End

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>
<thead>
<tr>
<th>Test</th>
<th>Start</th>
<th>End</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>11/10</td>
<td>6</td>
</tr>
<tr>
<td>2</td>
<td></td>
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</tr>
<tr>
<td>3</td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td></td>
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</tr>
</tbody>
</table>

### Tests / Tasks

- **Abbreviated Continuity**
- **System Functional Checks**
- **Outgassing Tests**
- **Target Monitoring**
- **Stability Checks**

### Key Decision Points

- **Abbreviated Continuity**
- **SES**
- **Pumpdown**
- **Outgassing Cart**

### Abbreviated Continuity

- **Abbreviated Continuity**

### System Functional Checks

- **MIRI Detector Heaters Active**
- **MIRI <200K**

### Outgassing Tests

- **FGS Subarray Darks**
- **FGS Bench**

### Target Monitoring

- **FGS Subarray Darks**
- **NIRCam**

### Stability Checks

- **FGS Subarray Darks**
- **NIRCam**

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**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.

PUPIL SHEAR

FOCUS

Defocus, OTE mm (NIRCam F212N)
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
JSC test layout

Chamber Isolation Assembly

COCOA

Upper Suspension Frame

ACF 3X

Telescope Rod Assembly

OTIS

HOSS

Ref. - JSC Chamber A

Ref. - OTIS and Thermal Sim(s).

L. Feinberg, AAS, Jan 2010
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?