James Webb Space Telescope (JWST) Integrated Science Instruments Module (ISIM) Cryo-Vacuum (CV) Testing at GSFC

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28th Space Simulation Conference
NASA Goddard Space Flight Center (GSFC)
Topics

- JWST Mission Overview
- ISIM CV Test Campaign at GSFC
- Test Configuration
- CV1 Test Summary
- CV1 Chamber Performance
- Improvements in Path Forward to CV2 & CV3
- Summary
**JWST Mission Overview**

**Mission Objective**
- Study the origin and evolution of galaxies, stars & 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 AZ
  - Near Infrared Spectrograph (NIRSpec) – ESA
  - Mid-Infrared Instrument (MIRI) – JPL/ESA
  - Fine Guidance Sensor (FGS) – CSA

**Description**
- Deployable telescope w/ 6.5m dia segmented adjustable primary mirror
- Cryogenic temperature telescope and instruments for infrared performance
- Launch Oct 2018 on ESA-supplied Ariane 5 ECA rocket to Sun-Earth L2
- 5-year science mission + 2 years of data analysis
ISIM CV Test Campaign at GSFC

ISIM CV #1
Aug – Nov 2013

NIRCam
MIRI
NIRSpec

ISIM CV #2 & 3
June 2014 & Aug 2015
ISIM CV Overall Test Configuration

Chamber specifications
Volume: 27’ dia x 40’ high
Pumping speed
- 7 cryopumps: $2.1 \times 10^5$ l/s
- Turbomolecular pump: 6,000 l/s
Payload support: 40,000 lbs

- Nitrogen shroud
- Helium shroud
- ISIM hardware & support frames
- JWST OTE Simulator (OSIM)
- Vibration isolators
- Upper and Lower Supports Assembly
Nitrogen Volume Test Configuration

N$_2$ Volume Support Hardware Components
GSFC Equipment Support Hardware Assembly (GESHA): triangular Al structure to alleviate motion between two aligned systems
- Upper GESHA held at around 90K (-183°C)
- Lower GESHA: held at ambient temperatures to alleviate CTE induced strains

Vibration Isolators System (VIS): pneumatic system isolates test articles from chamber induced jitter sources
- Chamber vibration measured amplitudes of 1 milli-G in all axes at 20 Hz – VIS provides minimum attenuation of 40 dB to these levels
- VIS vertical natural frequency is 1.0-1.3 Hz
- VIS horizontal natural frequency is 0.4-0.6 Hz
Helium Volume Test Configuration

SIF & STMS Frame

HR Shroud (HR)

IEC Shroud (IEC LN₂ Panel)

He Shroud Specifications
- Dimensions 26’ dia x 15’ tall
- Provide 1000 W cooling capacity
- Cooling between 80K (-193°C) and 20K (-253°C)
- Five independently controlled shroud zones
- The other five helium zones are allocated to various parts of ISIM structure
ISIM CV1 Test Summary

- Pump-down: 08/29/2013 ~21:00
- Warm-up: 10/29/2013
- Open chamber: 11/11/13
- Total days under vacuum = 73 days
- Total consumables
  - LN₂ = 520K gallons
  - Helium = 20 bottles
Shrouds Temperature Performance

At steady state: Helium shroud achieved 24K ±1K
LN2 shroud maintained 182K ±3K (switched LN2 to GN2 Day 11: 9/10/13)
Chamber Vacuum Performance

- High vacuum was achieved using:
  - (qty 6) 65000 liter/sec cryopumps
  - (qty 1) 5000 liter/sec turbopump
- 1 (of 6) cryopumps left in reserve at all times

<table>
<thead>
<tr>
<th>Pressure (Torr)</th>
<th>Time since start</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.0 x 10^-5</td>
<td>29 hrs (1.2 days)</td>
</tr>
<tr>
<td>1.0 x 10^-5</td>
<td>35 hrs (1.5 days)</td>
</tr>
<tr>
<td>5.0 x 10^-6</td>
<td>46 hrs (1.9 days)</td>
</tr>
<tr>
<td>1.0 x 10^-6</td>
<td>108 hrs (4.5 days)</td>
</tr>
<tr>
<td>5.0 x 10^-7</td>
<td>128 hrs (5.3 days)</td>
</tr>
</tbody>
</table>
Chamber Vacuum Performance

Chamber pressure from pump-down to back-fill

JWST ISIM CV1 Full Pressure Data for Chamber 290

- Chamber Pressure IG-1
- He Skid Shut-Down

Pressure (Torr)

Days of Testing
Chamber Vacuum Performance

With cool-down, warm-up, & He skid shut-down pressure spikes omitted, normally $3 \times 10^{-7}$ Torr
Improvements for CV2 & CV3

- Helium skid reliability needed to be improved in order to reduce risk to flight hardware and to schedule
- Detection of helium leaks needed to be more stringent in order to verify MIRI head loads
# Helium Skid Reliability: Summary of Helium Skid Shutdowns

Total of six (6) helium skid shutdowns:
- **Cause #1**: low turbine bearing gas temperature alarm
- **Cause #2**: compressor oil level/temperature alarm

<table>
<thead>
<tr>
<th>#</th>
<th>Date</th>
<th>Cause</th>
<th>Action (back online)</th>
<th>Pressure Spike</th>
<th>Duration*</th>
<th>He Temp (Temp rise)</th>
<th>Duration**</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>09/10/13</td>
<td>#1</td>
<td>Re-start skid (&lt;1 hr)</td>
<td>$4.1 \times 10^{-6}$ Torr</td>
<td>4.0 hrs</td>
<td>52K (+16K)</td>
<td>11.2 hrs</td>
</tr>
<tr>
<td>2</td>
<td>10/05/13</td>
<td>#1</td>
<td>Re-start skid (&lt;1 hr)</td>
<td>$2.8 \times 10^{-4}$ Torr</td>
<td>5.3 hrs</td>
<td>42K (+15K)</td>
<td>8.5 hrs</td>
</tr>
<tr>
<td>3</td>
<td>10/15/13</td>
<td>#2</td>
<td>Re-start skid (&lt;0.5 hr)</td>
<td>$1.1 \times 10^{-4}$ Torr</td>
<td>1.1 hrs</td>
<td>33K (+9K)</td>
<td>14.0 hrs</td>
</tr>
<tr>
<td>4</td>
<td>10/19/13</td>
<td>#2</td>
<td>5-sec interlock to delay shutdown command</td>
<td>$9.3 \times 10^{-5}$ Torr</td>
<td>1.1 hrs</td>
<td>32K (+8K)</td>
<td>6.5 hrs</td>
</tr>
<tr>
<td>5</td>
<td>10/22/13</td>
<td>#2</td>
<td>Override compressor load/unload status</td>
<td>$9.2 \times 10^{-5}$ Torr</td>
<td>6.1 hrs</td>
<td>37K (+13K)</td>
<td>N/A</td>
</tr>
<tr>
<td>6</td>
<td>11/05/13</td>
<td>#2</td>
<td>Re-start skid (~1 hr)</td>
<td>$6.8 \times 10^{-6}$ Torr</td>
<td>2.1 hrs</td>
<td>N/A (warm-up)</td>
<td>N/A</td>
</tr>
</tbody>
</table>

*Duration for pressure to return to $5 \times 10^{-7}$ Torr

**Duration for helium shroud average temperature to return to temp before shut-down
Replace Dunham Busch Compressor
6 to 10 week delivery
Successfully installed & checked out May 2014

Old

New
Helium Leak Detection Improvement

- MIRI requirement: 6.2 K (-266.8°C) at the instrument
  - 2-stage cooler system
  - Accurate heat map required during environmental testing
- Issues encountered during CV1
  - Measured heat loads to cooler from MIRI higher than expected
  - Presumed cause is higher levels of helium in chamber
- Actions
  - Add RGA in STMS volume
  - Implement more stringent leak checking requirements
The chamber RGA detected helium levels of $5.0 \times 10^{-7}$ Torr.
Helium levels consistently detectable to levels of $1.0 \times 10^{-9}$ Torr (as opposed to $5.0 \times 10^{-7}$ in CV1)

Helium levels in ISIM volume slightly higher than in the $N_2$ chamber volume: consistently $<1.0 \times 10^{-8}$ Torr

The MIRI predicted thermal loads matched the measured within the prediction and measurement uncertainties
JWST ISIM RGA Data Reliability

- The need for a calibrated RGA is being investigated for CV3 testing as the total RGA pressure does not match the chamber ion gauge pressure readings: chamber RGA was ~2.5 x 10^-7 Torr higher
- Currently, qualitative statements can only be made using the RGA data

![JWST ISIM CV1 Difference in RGA vs. IG Pressures](chart.png)
Summary

• Successful CV1 test
  ▫ Dry run of test procedures and processes
  ▫ Achieved thermal requirements
  ▫ Identified facility performance improvements necessary

• Two notable facility improvements
  ▫ New helium skid compressor
  ▫ Additional helium shroud RGA

• Future investigation into improving confidence in RGA readings
Questions?
Back-Up Slides
Helium Skid Shutdown Cause #1: Low & high oil temperature interlocks (false readings)
Helium Skid Shutdown Cause #2: Low turbine bearing return temperatures
Helium Skid Issues #3: Unable to achieve 20K on refrigerator due to compressor loading mechanism malfunction
Helium Skid Issues #4: In-house air pressure fluctuations
House air pressure drops cause helium skid to warm up
Power Supply Operation

• All heater racks functioned as required for entire test duration
  ▫ 9 heater racks
  ▫ 14 LS-336s
• Only issue: heater circuit 8-2
  ▫ Control sensors failed
  ▫ Placed in local mode during the test
  ▫ Resolution: Fix broken wire
Power outages: Generators & UPS

- # of power outages: 1
- Operated seamlessly. B10 generator & Helium skid UPS
- Short commercial power outage experienced on 09/21/2013 (approx. 21:43).
  - Several heater racks needed to be manually reset, but no significant impacts to test hardware.
  - He skid operation not impacted.
  - After coming back online, CQCM heaters came on full power and CQCMs achieved >350K.
MIRI Air Leak
Helium Skid Issues #5: LN$_2$ purifier needed to be cleaned
Warm up heater begins to leak when cold
Causes differential pressure to increase
## Updated Predict

### Steady State Predict Versus Measured

<table>
<thead>
<tr>
<th>Thermal Load</th>
<th>Thermal Model Predict *</th>
<th>ISIM CV2 Measured (7/15/14 12:00PM UTC)</th>
<th>ISIM CV2 Measured (7/21/14 8:46AM UTC)</th>
<th>ISIM CV2 Measured (7/28/14 1:02PM UTC)</th>
<th>ISIM CV2 Measured (7/29/14 5:30PM UTC) **</th>
</tr>
</thead>
<tbody>
<tr>
<td>MIRI Thermal Shield</td>
<td>9.5 mW ± 2 mW</td>
<td>8.1 mW ± 7.5 mW</td>
<td>7.2 mW ± 7.5 mW</td>
<td>6.14 mW ± 7.5 mW</td>
<td>5.26 mW ± 7.5 mW</td>
</tr>
<tr>
<td>MIRI OM</td>
<td>17.6 mW ± 6 mW</td>
<td>25.9 mW ± 2.8 mW</td>
<td>30.6 mW ± 2.8 mW</td>
<td>23.12 mW ± 2.8 mW</td>
<td>19.27 mW ± 2.8 mW</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Boundary Conditions</th>
<th>Assumed Thermal Model (7/15/14 at 12:00PMUTC)</th>
<th>ISIM CV2 Measured</th>
<th>ISIM CV2 Measured</th>
<th>ISIM CV2 Measured</th>
<th>ISIM CV2 Measured</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISIM Conductive Temp at HSA feet (ISIM HKT-14)</td>
<td>35.91 K</td>
<td>35.91 K</td>
<td></td>
<td></td>
<td>34.74 K</td>
</tr>
<tr>
<td>ISIM Conductive Temp at MIRI feet (ISIM HKT-35/36/37)</td>
<td>32.79 K</td>
<td>32.79 K</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ISIM Radiative Temp (STMS T^4 * Area Weighted Avg)</td>
<td>Used actual measured STMS panel temps and includes other actual instrument temperatures</td>
<td>34.65 K</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- MIRI Shield Temp (Avg of Rails) | 29.53 K | 29.53 K |                   |                   | 30.5 K           |
- MIRI OM Temp | 6.31 K | 6.31 K | 6.2 K | 6.27 K |
- MIRI Detectors | OFF | OFF | ON | OFF |
- MIRI CQCM | OFF | ON | ON | OFF |

* See presentation note field for details on changes in predicted loads.
** At equilibrium on MIRI OM load however this is not the officially declared steady state data point.