JWST Calibration in Normal Operations

Greg Sloan
Lead, Cycle 1 and 2 Calibration Coordination Teams
Cycle 2 Calibration Coordination Team

NIRCam – Martha Boyer, Anton Koekemoer
NIRSpec – Nimisha Kumari, James Muzerolle
NIRISS – Kevin Volk, Andre Martel
MIRI – Greg Sloan, Stacey Bright
FGS – Sherie Holfeltz

Absolute flux calibration – Karl Gordon
**JWST calibration**

**Goal** – Enable the best possible science with the James Webb Space Telescope

**Means**

Generate and improve Calibration Data Products (pipeline input files)

Quantify performance (telescope, detectors, instrument modes)

Monitor changes in calibration, system performance, instrument health

Obtain reference data needed to troubleshoot likely challenges
JWST in a nutshell

18 primary mirror segments

18 detectors in focal plane

18* scientific observing modes

*Counting LRS slitless separately
JWST in a nutshell

18 primary mirror segments

18 detectors in focal plane

18* scientific observing modes

*Counting LRS slitless separately
Cycle 1 Cal plan – as of May 2021

All calibrations 1416 h

Prime time 682 h

All parallels 734 h
## By calibration type

<table>
<thead>
<tr>
<th>Cal type</th>
<th>Prime (h)</th>
<th>Pure Parallels (h)</th>
<th>Slew parallels (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abs. fluxcal</td>
<td>262</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Darks</td>
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<tr>
<td>Flats</td>
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<td>Speccal</td>
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<tr>
<td>Performance</td>
<td>91</td>
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<td>218</td>
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</tbody>
</table>

### Prime time

**682 h**

### All parallels

**734 h**
Cycle 1 Cal – progress

After some updates:

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<th>Instr.</th>
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<tr>
<td>NRC</td>
<td>106</td>
<td>57</td>
</tr>
<tr>
<td>NRS</td>
<td>91</td>
<td>222</td>
</tr>
<tr>
<td>NIS</td>
<td>62</td>
<td>211</td>
</tr>
<tr>
<td>MIRI</td>
<td>151</td>
<td>243</td>
</tr>
<tr>
<td>Cross</td>
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<td>0</td>
</tr>
<tr>
<td>FGS</td>
<td>10</td>
<td>0</td>
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<tr>
<td>total</td>
<td>730</td>
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Most Cycle 1 Cal observations completed
Some placed on hold, some permanently

Reference files
Most now based on Commissioning data
Files based on C1C data coming online now

Cross-instrument calibration
Will tie photometric calibration with common standards in next 2 months

OTE is on a separate budget
Planning Cycle 2 Cal

Cycle 1 plan

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OTE is on a separate budget

Cycle 2

Prime observations
Assessing C1C and applying lessons learned
Some programs can be discontinued
Newly identified issues require new obs

Parallel observations
Not (yet) heavily utilized by GOs
The more we can do in parallel, the better
### Absolute flux calibration

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**Cross calibration**

- = Cross-instrument calibration
- = Absolute flux calibration

~300 h is ~40% of all prime cal time
That is a significant commitment
The challenge of calibration

\[ \vec{S}_T = \vec{S}_o \frac{\vec{C}_T}{\vec{C}_o} \]

\( \vec{S}_T \equiv \) true spectrum of science target

\( \vec{S}_o \equiv \) observed spectrum of science target

\( \vec{C} \equiv \) spectrum of calibrator
Philosophy of absolute flux calibration

Next-generation calibration
Our standards *tied* to Sirius via BD+60 1753 (A1 V; Rieke et al. 2022, AJ, 163, 45)

Cross-instrument by design
Standards observed by different instruments *tie* them together

Cross-mission calibration by design
All *JWST* standards observed by STIS on *HST*, many by *Spitzer*
Some *JWST* standards (white dwarfs) are also *HST* standards

Absolute Flux Calibration Expert Team
*Ties* *JWST* directly to the community through external team members

Ultimate test of all parts of the *JWST* pipeline
Observations of standard stars are the canary in the coal-mine
Objectives of absolute flux calibration

Calibrate all *JWST* instruments and modes

Calibrate *past* formal requirements
- imagers – 5%
- spectrographs – 10-15%
- coronagraphs – 5-15%

Correct for systematic errors in standards
- Need a minimum of *three classes* of stars – to test models
- Need several of each class – because each star is unique (weather)

Cross-calibration
- Between *JWST* instruments and with *HST* and *Spitzer*

Document clearly what we’re doing
- e.g., Gordon et al. (2022, *AJ*, 163, 267)
Rayleigh-Jeans units hide no sins

RJ units can be $\lambda^2 F_v$ or $\lambda^4 F_\lambda$
Standards for absolute flux calibration

Stars – Straightforward to model

Primary standards for HST, Spitzer, ground-based infrared observatories

A dwarfs

Primary standards for Spitzer

G dwarfs (Solar analogs)

Strong heritage in infrared
Used by Spitzer

Hot dwarfs

White dwarfs
Primary standards for HST
OB stars planned in Cycle 2

Flux density in Rayleigh-Jeans units
Abs fluxcal – the Cycle 1 plan

**Part 1** – A star in every filter, optical element, detector ...
   NIR instruments and MIRI imager – 3 stars – 1 star of each type
   MIRI MRS, LRS, coronagraph – 1 A dwarf and 1 G dwarf

**Part 2** – Building the sample
   Objective – 5 stars of each type, to beat down random and systematic noise
   After rejecting misbehaving standards, need a minimum of 3 of each type
   Fewer bad standards = lower systematic noise
   More stars = lower random noise

**Part 3** – Repeatability
   Observe 1 star with a monthly cadence on each detector
Abs fluxcal – general results

Still in Cycle 1, and already looking good

Repeatability
~0.5% (1-sigma)

Variations between full and subarrays
1–4%

Scatter between standards
Generally <2%
Some filters (e.g. MIRI F560W) show more scatter
4 bright standards (for MIRI) below model predictions

New reference files based on Cycle 1 standards are on the way
Abs fluxcal – an example from MIRI imager

The diagram illustrates the calibration factors for different subarrays (FULL, BRIGHTSKY, SUB256, SUB128, SUB64) and categories (HotStars, ADwarfs, SolarAnalogs) for the F1280W filter. The current calibration factor is indicated by the horizontal line at 0.45. The subarray-corrected and original data points are shown for various flux levels. The under investigation area highlights specific data points that are currently being analyzed.
LRS slit

Integrate spectra (in RJ units) from 5.6 to 8.0 um

<table>
<thead>
<tr>
<th>Target</th>
<th>LRS/CALSPEC</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD+60 (1033)</td>
<td>0.9996</td>
</tr>
<tr>
<td>BD+60 (1536)</td>
<td>1.0106</td>
</tr>
<tr>
<td>HD 180609</td>
<td>1.0168</td>
</tr>
<tr>
<td>GSPC P330-E</td>
<td>1.0403</td>
</tr>
<tr>
<td>J1757132</td>
<td>1.0289</td>
</tr>
</tbody>
</table>

**Good news:** See above

**Under investigation:**
Deviations from models
Absolute flux calibration is arbitrary

Calibration tied to average of HD 2811, HD 37962, HD 167060
Abs fluxcal – planning for Cycle 2 Cal

**Part 3** – Repeatability
- Plan – 1 star per month on each detector
- Cycle 1 – Planned cadence disrupted by some observing failures
- **Cycle 2** – Continue with 1 star per month on each detector

**Part 2** – Building the sample
- Objective – 5 stars of each type, to beat down random and systematic noise
- Cycle 1 – 3 stars of each type
- **Cycle 2** – 3 stars of each type, but with new stars

**Part 1** – A star in every filter, optical element, detector ...
- Cycle 1 – Had 3 stars in NIR, 2 stars in MIR
- **Cycle 2** – Just 1 star per element, to be selected by the abs flux cal team