### Purpose of Test

- The primary purpose of this test was to trend the relative throughput of the JWST near-IR science instruments (NIRCam, NIRSpec, NIRISS, and FGS) as a way to monitor for any potential changes from system drifts, temperature changes, or other causes.
- These results also give the first relative throughput of the instruments in their flight-like configurations and can be used to verify and update model predictions.
- They can also be used for trending with the on-orbit throughputs that will be measured during commissioning.
- Data was obtained during Cryo-Vacuum testing of the Integrated Science Instrument Module (ISIM) at the Goddard Space Flight Center (GSFC) as part of 2 test procedures, the Initial Optical Baseline (IOB) December 29, 2018 and the Final Performance (FP) January 25, 2019 (which bracketed the SI1 testing in this Cryo-Vacuum test). The results will also be compared to a similar test from a previous Vacuum test). The results will also be compared to a similar test.

### Data Collection (IOB & FP)

#### Point Source Observations

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Observed Wavelength</th>
<th>Observed Flux</th>
<th>Exposure Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>NIRCam</td>
<td>1.6 µm</td>
<td>100 mJy/beam</td>
<td>1000 s</td>
</tr>
<tr>
<td>NIRSpec</td>
<td>1.6 µm</td>
<td>100 mJy/beam</td>
<td>1000 s</td>
</tr>
<tr>
<td>NIRISS</td>
<td>1.6 µm</td>
<td>100 mJy/beam</td>
<td>1000 s</td>
</tr>
<tr>
<td>FGS</td>
<td>1.6 µm</td>
<td>100 mJy/beam</td>
<td>1000 s</td>
</tr>
</tbody>
</table>

#### Spectral Observations

- Flux setting and temperature for each source is shown. NIRISS exposures were 1.1 to 1.3% clipped and NIRSpec exposures were 0.5 to 0.8% clipped by having to move the high speed mechanism to reach the Star. For these data sets, all sources were observed using the same exposure time and slit width.
- The same source and flux setting was used for each Science Instrument for a direct comparison 1.6, 1.5, 2.1, and 3.5 µm for all Science Instruments, and at 2.77 and 4.5 µm for NIRCam LW and NIRISS. The source was discounted but not blanked of the between exposures for the different instruments.

#### Data Reduction – point source data

1. Calibrated data (a slope fit the non-destructive read “up the ramp”) was used for this analysis. Notice, while these reductions subtract a dark image and divide by a flat field no linearity correction is applied.
2. The calibrated image is read in as is the data quality image. Pixels flagged as hot pixels in the data quality image are replaced by the average of the neighboring pixels in the image. Visual inspection, and peaking point location selection, showed that no hot pixels were inside the core of the PSF (where interpolation would not be accurate).
3. A background exposure treated in the same way is subtracted where applicable (FGS exposures, NIRSpec exposures using the Long Pass Filters, the LED35 and FAD5M exposures at 5%).
4. A column average of ~200 columns was taken on either side of the point source (several hundred pixels away) and then averaged and subtracted column by column in the data image to remove row by row differences in the bias.
5. Photometry was done using a Growth Curve (counts within concentric circular apertures centered on the Gaussian peak of the PSF). Background was measured from radius 22–30 pixels (typicaly) but was smaller for NIRSpec because of the small size of the imaging window (17-10 pixels).
6. A total number of DN was then selected within a radius of 15 pixels (NIRCam SW), 10 pixels (NIRCam LW, NIRISS), and 5 pixels (NIRSpec).
7. DN changed to e/cm2 - multiply the gain and divide by exposure time. The gain used were derived using data from the NIRCam, NIRISS, and FGS linearity tests. NIRSpec gain was derived from detector testing done at GSFC. Note: the uncertainty in the gain is the largest error in the ratio of the throughput of one SI to another.
8. Apply Aperture correction – Aperture corrections were derived using model images which take into account the source spectrum and all of the optical elements of the science instrument. These notables, zero background model images were treated in the same as the data images. The flux within this aperture from the source was measured compared to the total and a correction was derived. Typically the corrections were 5% for the blue bands and 10-15% for the red bands.
9. Apply correction for clipping due to off-nominal pupil – Corrections done using Code V models.
10. Apply correction for quantum yield effect for LD106 and LD155 data – Apply a correction for the quantum yield effect for LD106 and LD155 data.
11. Apply correction for different band pass – This applies the same correction that was used to cross check the SI1 module that the gain was the same for both.

### Data Reduction – spectral data

1. NIRSpec data was reduced to DN/e/cm2/second by Brian Kirkman of the NIRSpec team.
2. NIRCam and NIRISS data were reduced using the calibrated data and treated the same way as the point source data.
3. One dimensional spectra were extracted from the spectral images using a wide slit to make sure we get virtually all of the flux from the source. Background was measured in slits of the same size above and below the spectra, averaged and subtracted.
4. Wavelength Calibration for NIRCam and NIRISS – The fiber line long and short wave cutoffs were measured with the dispersions measured by the NIRCam and NIRISS teams.
5. The spectra were divided by the exposure time and the dispersion and multiplied by the gain to put the units into e/arcsec.

### Sources of Errors & Uncertainty

- The knowledge of detector gains are most likely the largest source of error in the ratio of the throughput of one SI to another. We estimate the error in the gain to be about 2% for NIRSpec and 5% for all other SIs detections. This is the reason for this case, when comparing results form the Initial Optical Baseline to the Final Performance (unless the gain has changed between them).
- Photon noise - The shot noise associated with the measurements of the detected number of DN within the selected aperture is a source of random error in each throughput and thus in the ratio.
- Determining the background to subtract has an inherent uncertainty. We estimate this from the growth curve for the point source data (as described above) and from the background extractions for the spectral data (as described above).
- A linearity correction may be needed – Although the effort was made in collecting the data to avoid going into the non-linear regime this was not always the case, especially for the Initial Optical Baseline LED35 data.
- Source Stability – Data taken for one SI at the start and end of each sequence shows that with the exception of the Initial Optical Baseline LED35 data the change was always less than 4% and usually less than 2% (the Initial Optical Baseline LED35 difference was 7.5%).
- The effect of the pupil offset – The Code V model computed corrections for the percent clipped amounted to less than 2% in all cases. Any error is therefore in computing the correction – a fraction of a small percentage.
- The model images may not match the actual PSF – This would produce an error in the derived aperture corrections – Probably a small error.
- The input spectra may not be known well enough – Producing an error in the correction for source clipping by the filters. This is especially a problem for LED35 [see the next panel].
- The quantum yield correction for lower wavelengths may be different from what we used – ~25 for 0.6 pm and 1.05 for 1.5

### Conclusions

1. **Bottom Line: Relative NIR throughput look good** – This test was conceived as a check to make sure that none of the near-IR Science Instruments has a gross problem (e.g. contamination, degradation of an optic). All comparisons show the relative throughput reasonably close to expectations (with the largest uncertainty for the LED3 5.5m comparison – the shape of the LED spectrum appears to change with flux in a way that explains the larger uncertainty for the LED3 data).
2. **Predictions of throughput (using an optical component model) are in reasonable agreement with what we observe** – This shows that the measured component curves are a fairly good representation of the actual response of each element and can be used to predict the system response.
3. **The Sensitivity Requirement for the ISIM** – There is a requirement that the Science Instruments for James Webb Space Telescope (JWST) reach certain sensitivity performance levels. These requirements are verified by a combination of instrument testing and analysis of the component efficiencies. The results of the throughput cross-calibration test show that the component efficiency curves as measured in the past are close to what is delivered science instruments. The results of this test serve as a cross check that the ISIM module meets the sensitivity requirements.

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