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SCIENCE INSTITUTE

EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

JWST MIRI Development

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January 11, 2025

AAS Pipeline Workshop



The Mid-Infrared Instrument (MIRI)



Study the dusty, distant, and molecular universe at 5-28 microns

Modes:

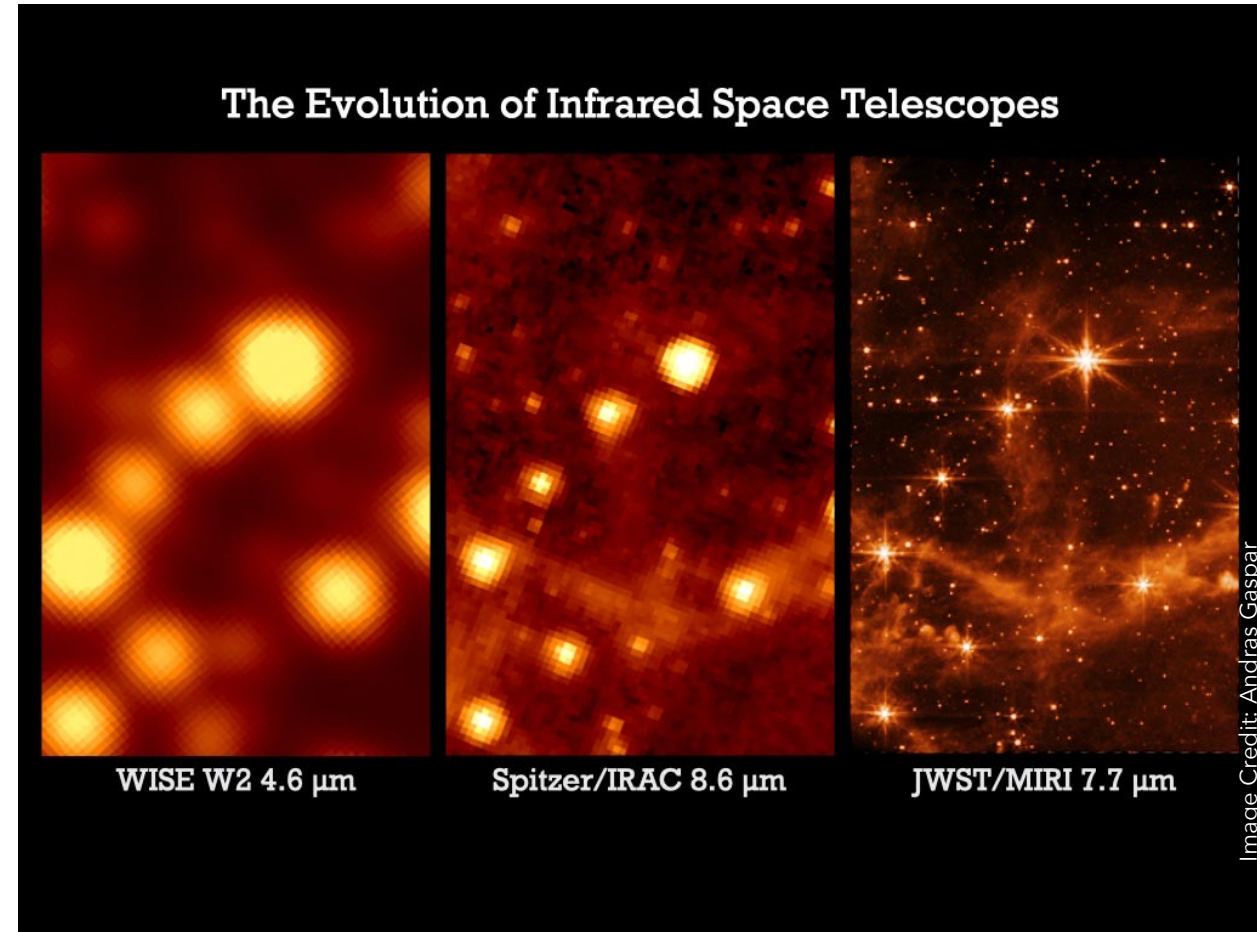
- Imaging
- Coronagraphy
- Low-resolution slit/slitless spectroscopy
- Medium-resolution IFU spectroscopy

Jointly developed by USA and European Consortium through ESA

Cryocooler keeps instrument at a constant 6 K

Performance overview: [Wright+23](#)

See also [Calibration Status](#) and [Known Issues](#) on JDOx



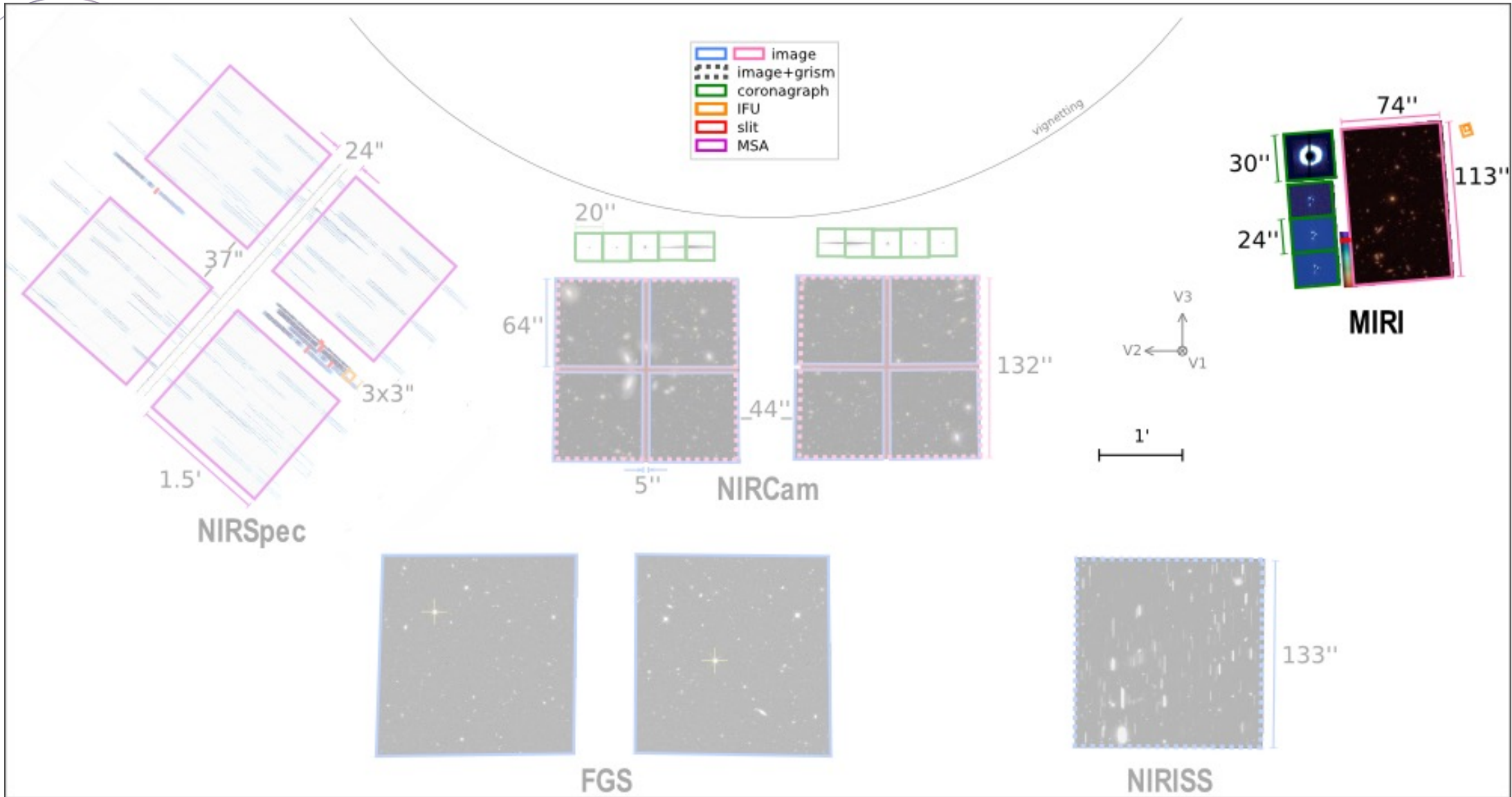


MIRI COMMISSIONING TEAM





MIRI in the JWST Instrument Plane



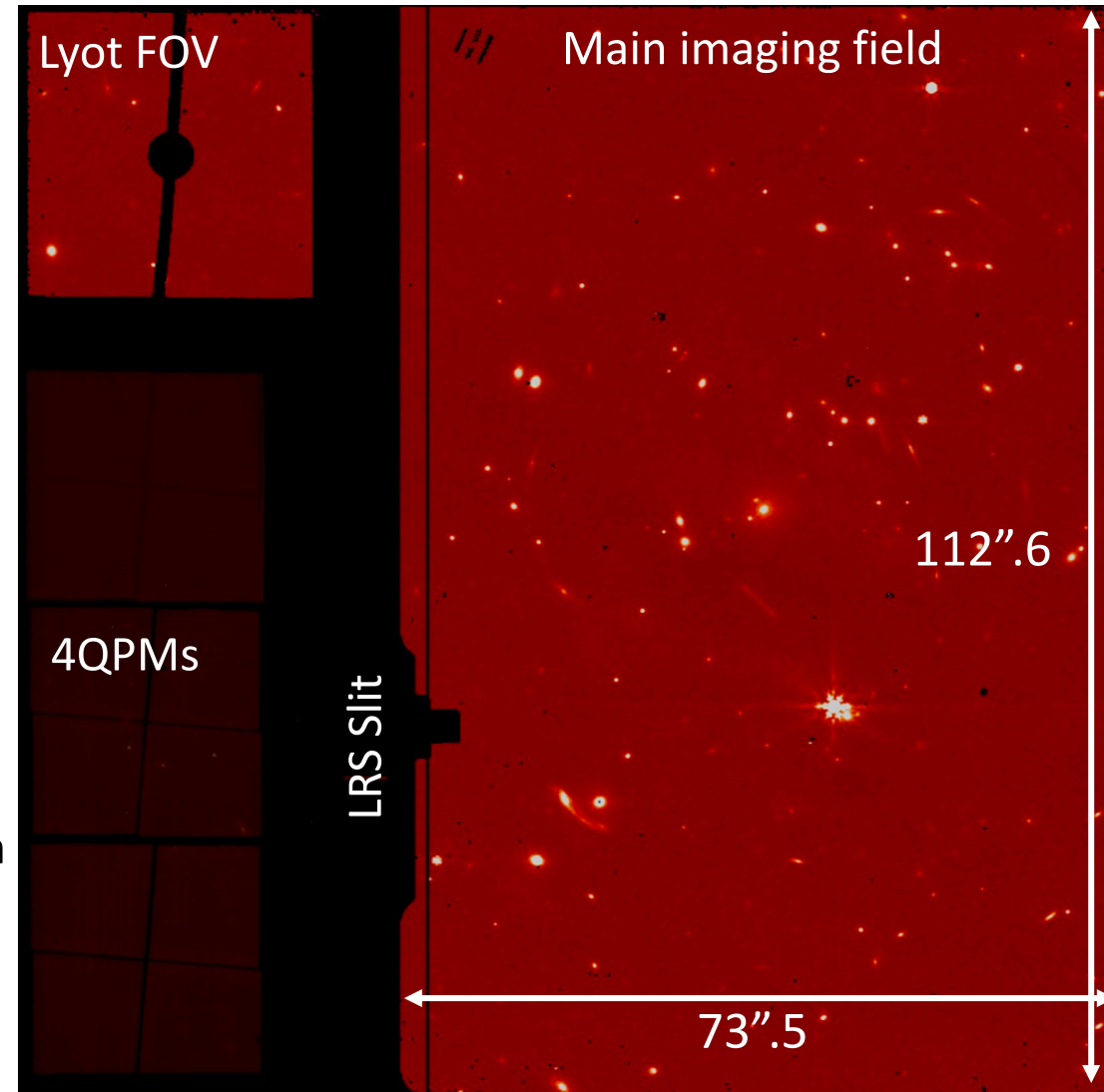


MIRI Imaging Calibration

Performance overview: See [Dicken+24](#) and [JDox](#)

Astrometric calibration:

- Typically good to 0.1-0.2 arcsec, although some cases early in the mission with 2 arcsec errors due to bad guide star catalog/ID (particularly in the Galactic center)
- Can typically be refined to ~ 0.01 -0.03 arcsec using the 'tweakreg' step in calwebb_image3
- This is important for creating mosaics, but doesn't always work well (some MIR wavelengths have mostly ISM and very few stars).
- See [Libralato+24](#) for details of distortion calibration



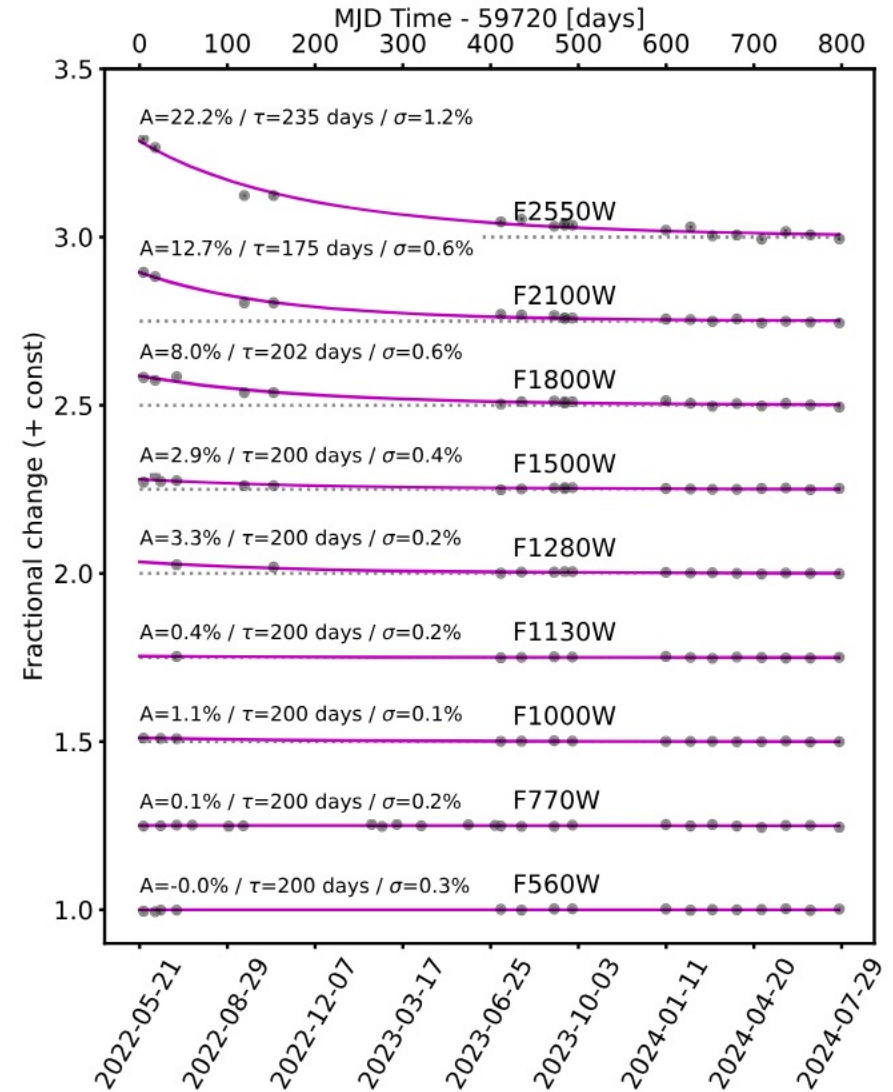
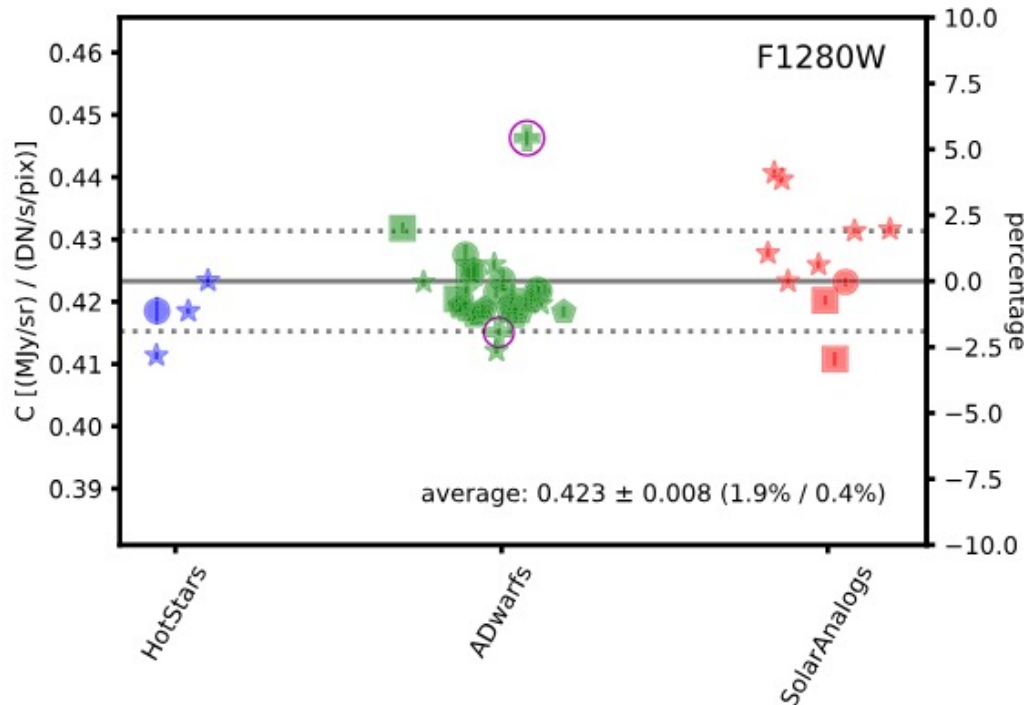
MIRI Imaging field, with coronagraphs + LRS



MIRI Imaging Calibration

Photometric calibration:

- See [Gordon+25](#)
- Typical flux calibration is $\sim 1\%$, dominated by differences between calibration stars.
- There is a time-dependent throughput loss, but this is automatically corrected by the pipeline.





MIRI Imaging Known Issues

Cruciform artifact:

- Scattering within the detector; adds to the PSF structure
- See [Gaspar+21](#) for details

Lyot background offsets:

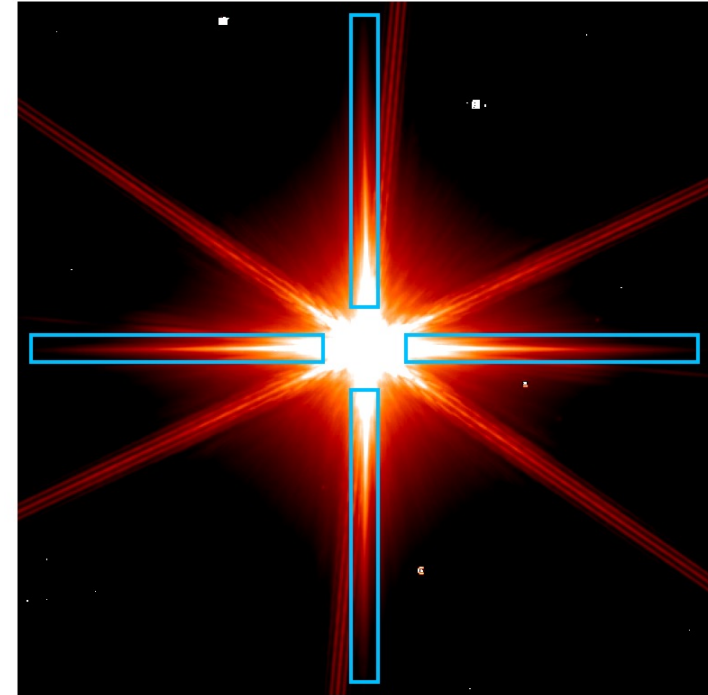
- Background in Lyot and main imaging field can differ slightly
- Can sometimes impact combined mosaics

Detector artifacts:

- Variable darks can produce striping, brighter-fatter effect, electronic cross-talk, reset effects. See [Morrison+23](#)
- Some scars and dead pixels– will be masked by pipeline.

Cosmic ray showers:

- Can affect very deep observations, but less significant than for MRS.



MIRI cruciform artifact



MIRI Imaging Pipeline Gotchas

Background subtraction:

- Background observations critical for long-wavelength observations (high thermal background)
- Default notebook doesn't accommodate this; will be updated post-AAS

Astrometric alignment can fail if too few stars in the field



MIRI Coronagraphy Calibration

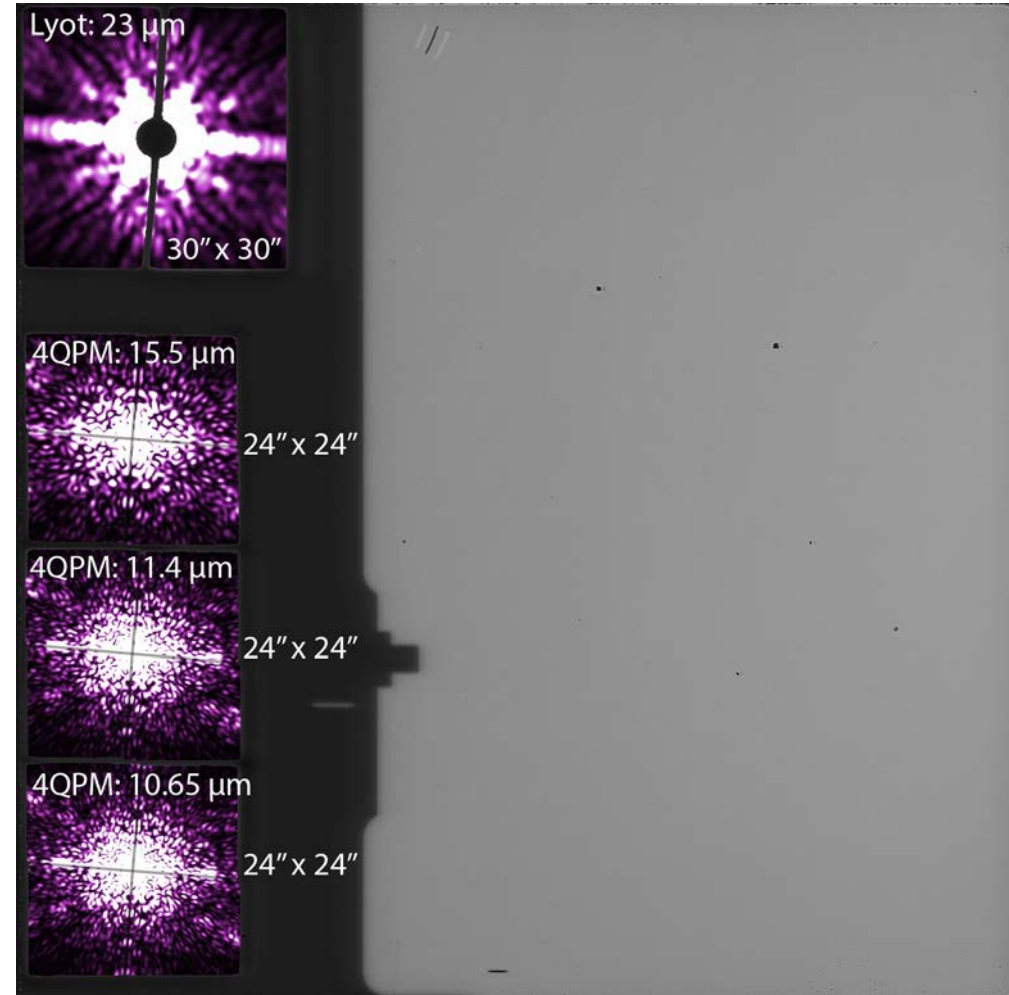
Performance overview: See [Boccaletti+22](#) and [JDox](#)

Photometric calibration:

- 3% or better

Contrasts:

- Raw contrast $1e-3$ or better within 1 arcsec, $1e-5$ or better beyond 5-6 arcsec
- Contrast $1e-5$ to $1e-6$ or better after reference star subtraction and processing.





MIRI Coronagraphy Known Issues

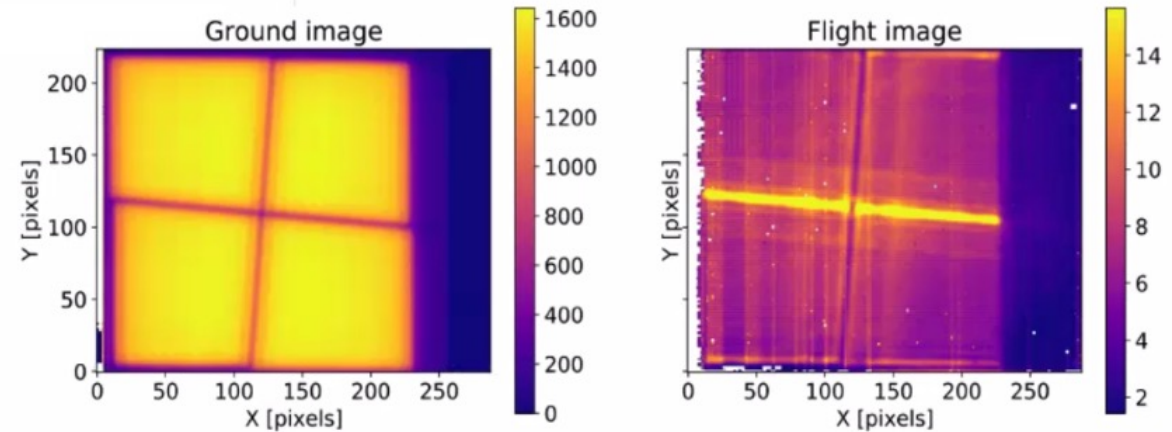
Glowsticks:

- Coronagraphic observations (and PSF reference observations) require dedicated backgrounds.

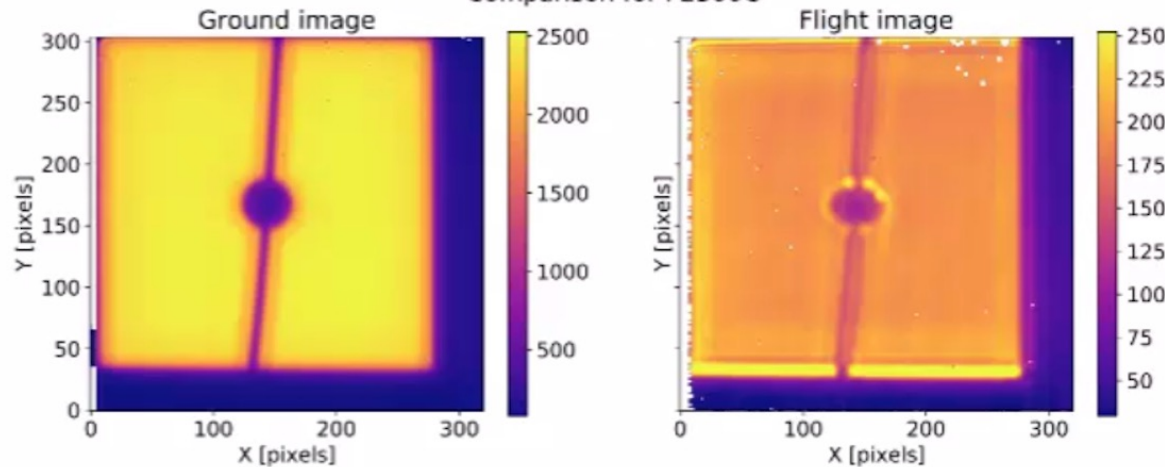
Edge brightening from straylight:

- Removed by dedicated backgrounds

Comparison for F1550C



Comparison for F2300C





MIRI LRS Calibration

Performance overview: See [Bouwman+23](#) and [JDox](#)

Wavelength calibration:

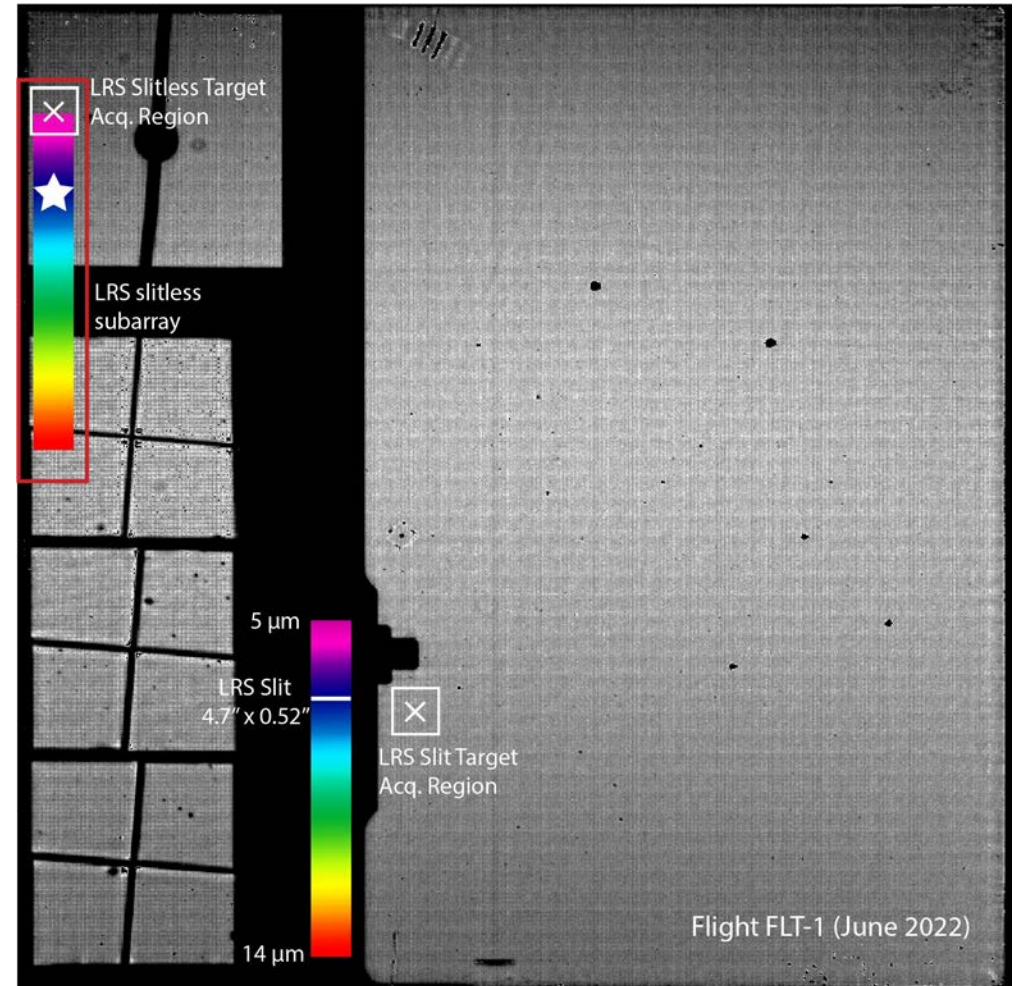
- Slit/slitless typically ± 20 nm (500 km/s)
- Potentially larger at 5 micron

Photometric calibration:

- Generally $< 2\%$, with some limitations from slit losses
- Lack of default background subtraction for some observing strategies

TSO spectrophotometric precision:

- 50 ppm or better after settling, background subtraction, 390 Hz noise correction.





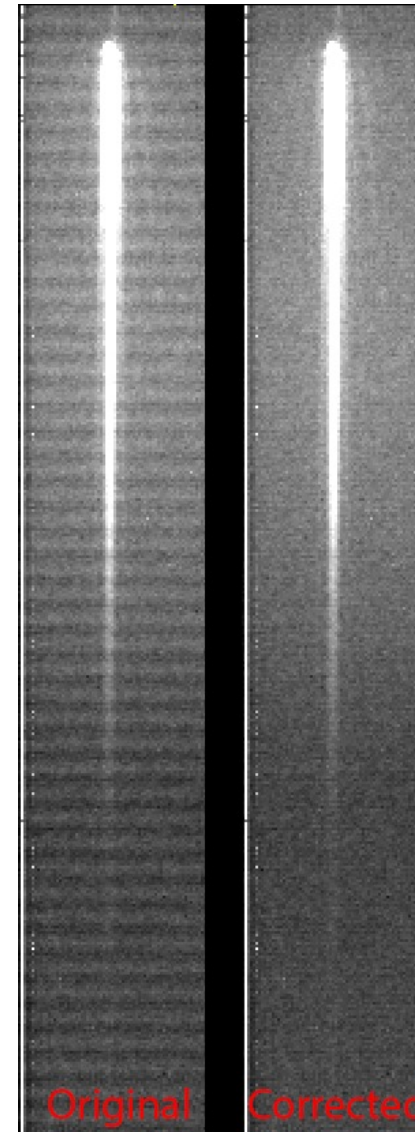
MIRI LRS Known Issues

Electromagnetic interference (EMI):

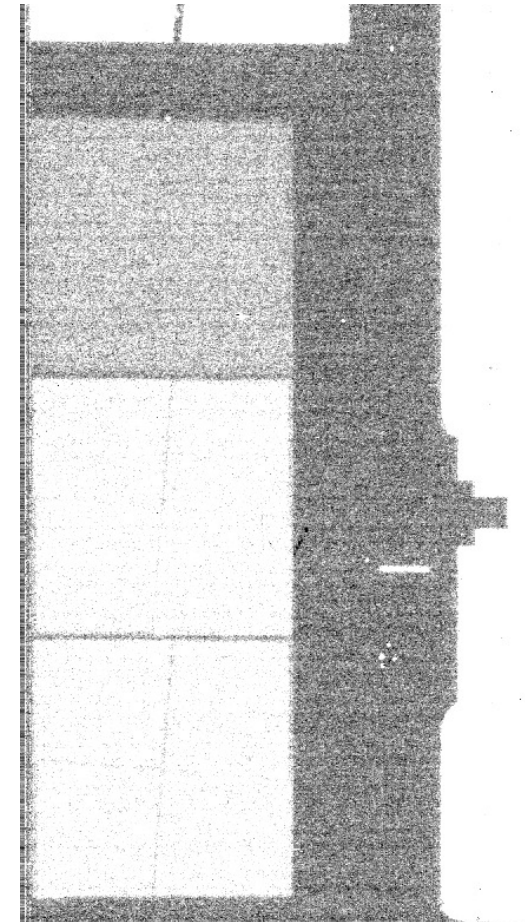
- 390 Hz noise in slitless subarray (significant)
- 10 Hz noise in full array (minor)

Scattered light:

- Bright sources near the slit in imaging field can contaminate the dispersed slit image



390 Hz noise



10 Hz noise



MIRI LRS Pipeline Gotchas

Electromagnetic interference (EMI):

- Pipeline correction, but only works at present for ngroups > 10

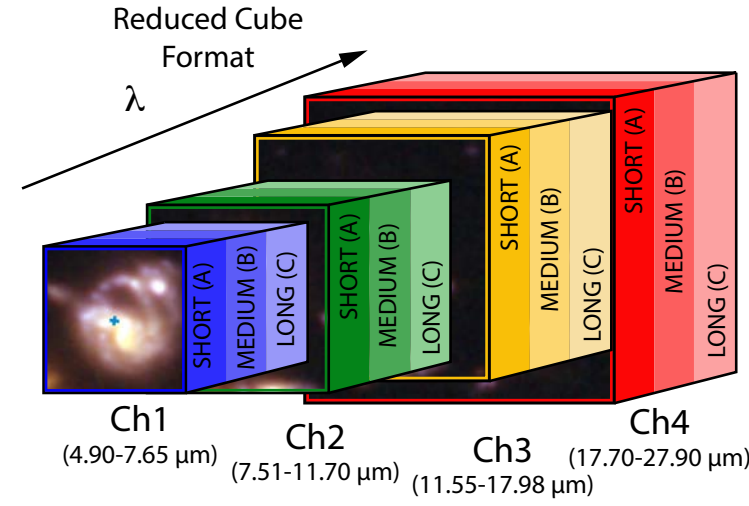
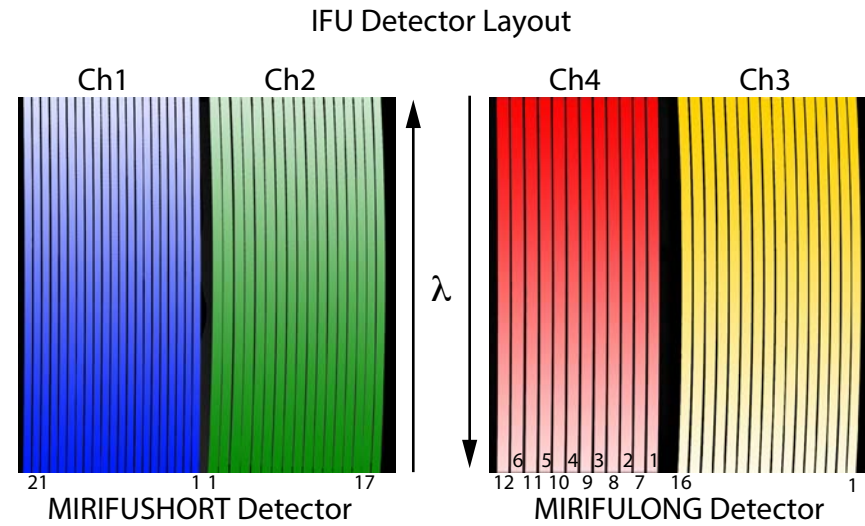
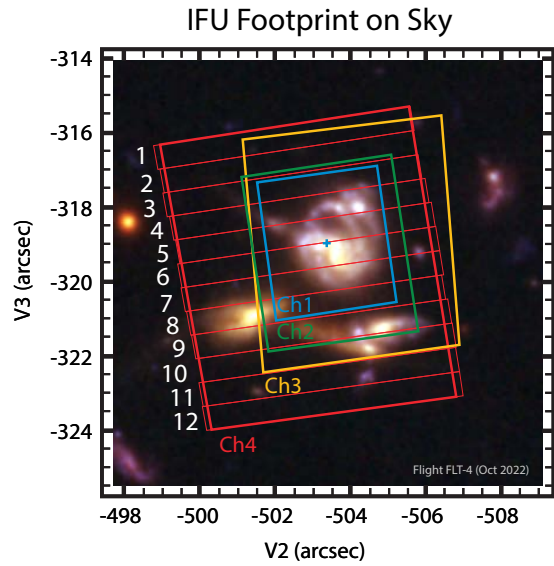
Background subtraction:

- Not currently performed by pipeline for all methods of observation

'Dropouts' in extracted spectra

- Due to bad pixels atop the bright center of traces
- Corrected by default in latest pipeline by 'pixel_replace' step interpolating values for missing data

MIRI MRS Calibration



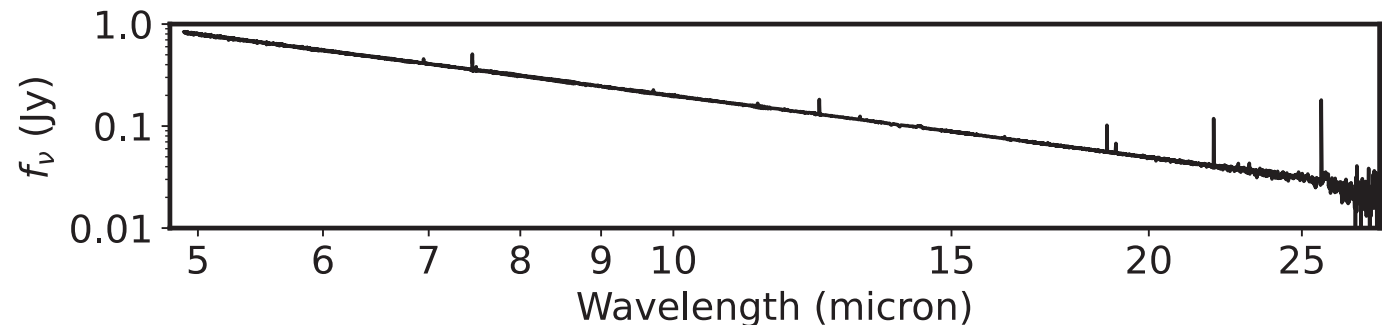
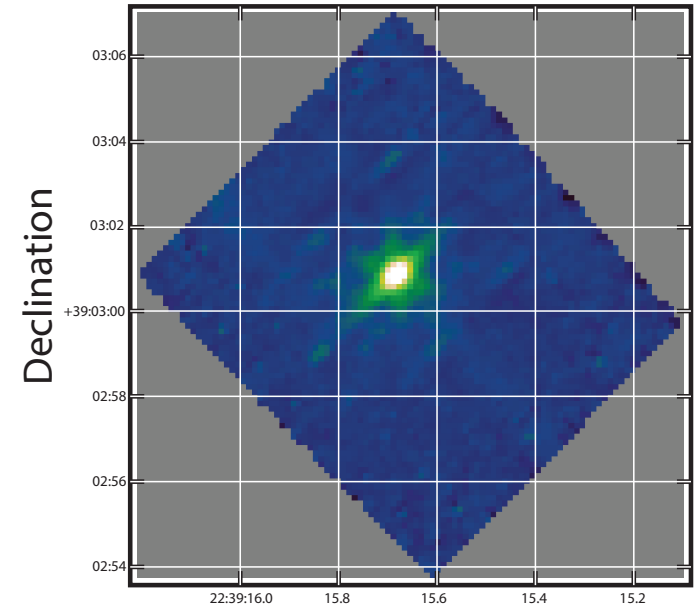
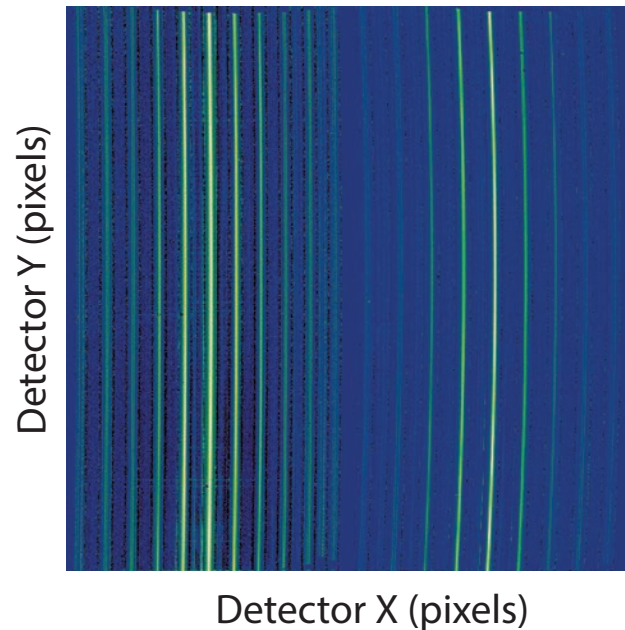
Slicer IFU with 12 spectral bands from 5-28 μm , spectral resolving power $R = 1300 - 3700$

Performance overview: See [Argyriou+23](#) and [JDox](#)



MIRI MRS Calibration

- Pipeline data processing creates calibrated 2-D dispersed data
- 2-D data built into 3-D data cubes using a variant of drizzle algorithm ([Law+23](#))
- Extract 1-D spectra (for point sources) from 3-D data cubes using conical aperture extraction, annular background subtraction, and aperture corrections at each spectral plane.
- Example data cube and spectrum for O9 V star 10 Lac.





MIRI MRS Calibration

Astrometric calibration:

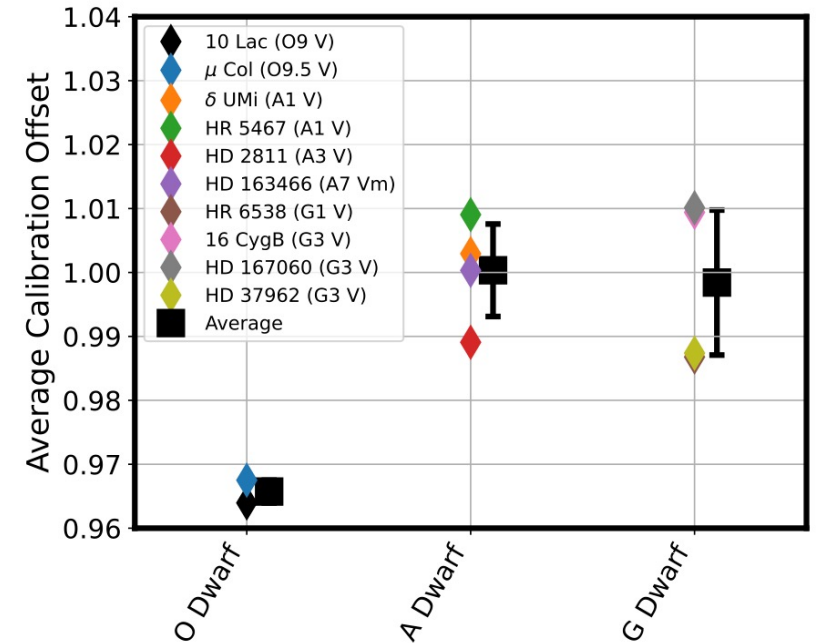
- Absolute astrometry good to about 0.3", relative to 0.03" (see [Patapis+23](#))

Wavelength calibration:

- Good to better than 10 km/s (see [Jdox](#) and [Argyriou+23](#))

Photometric calibration:

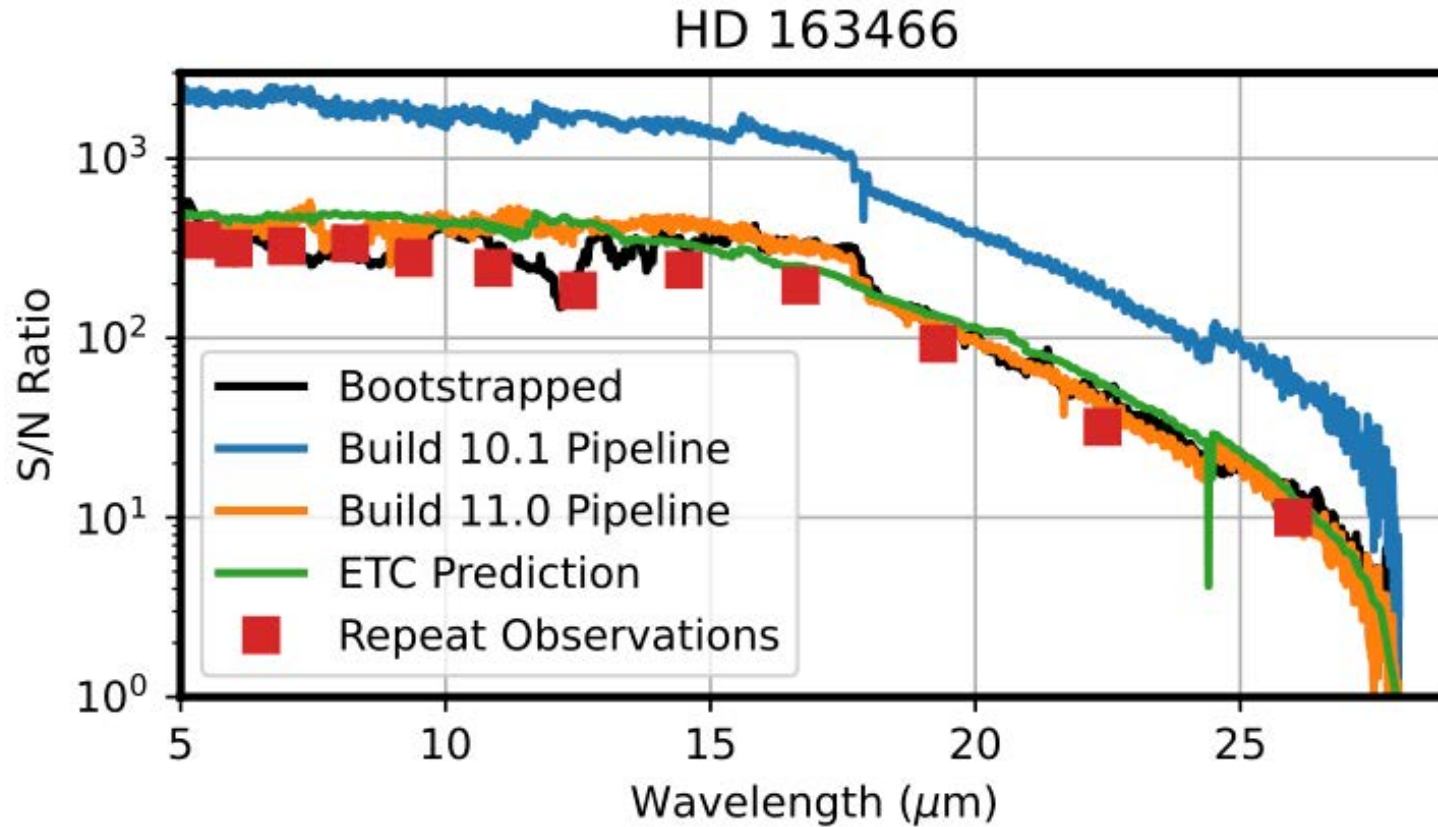
- Good to ~ 1% (see [Law+25](#)) below 24 microns
- Strong time dependent evolution in sensitivity (factor of 2 at longest wavelengths) automatically corrected by pipeline.



MIRI MRS vs Imager relative calibration



MIRI MRS Calibration



Uncertainties:

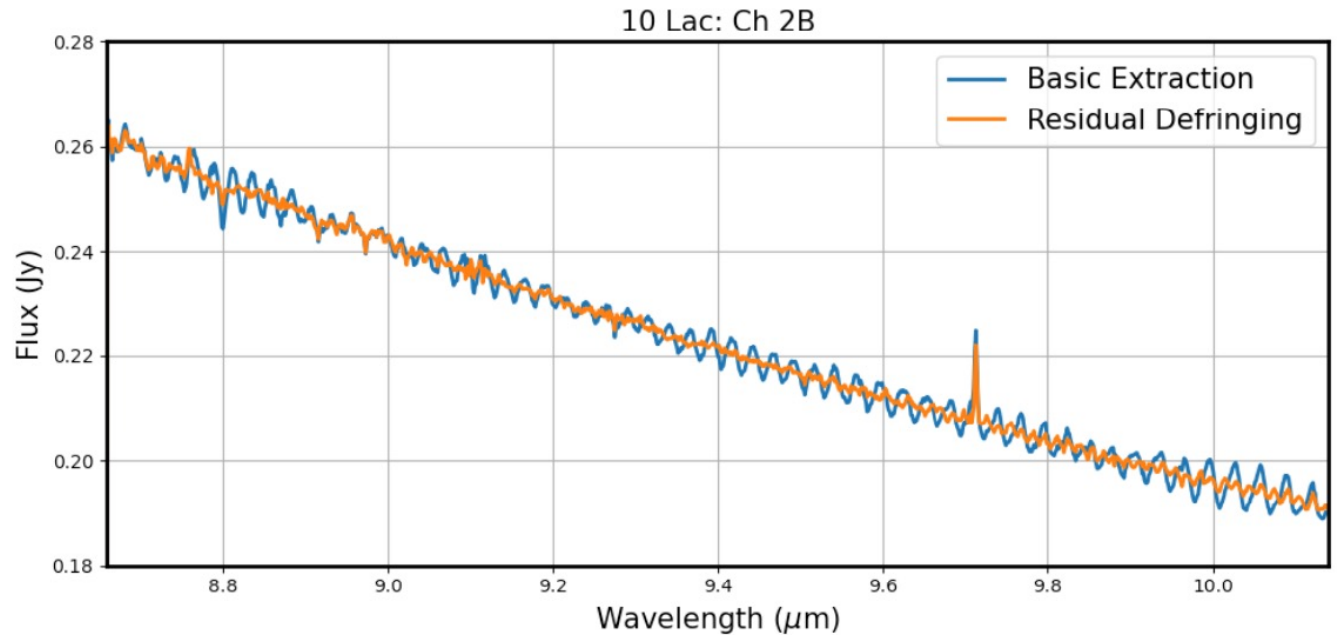
- Pipeline-estimated uncertainties fairly accurate in build 11.0 and later
- Spectral extraction accounts for cube spaxel covariance



MIRI MRS Known Issues

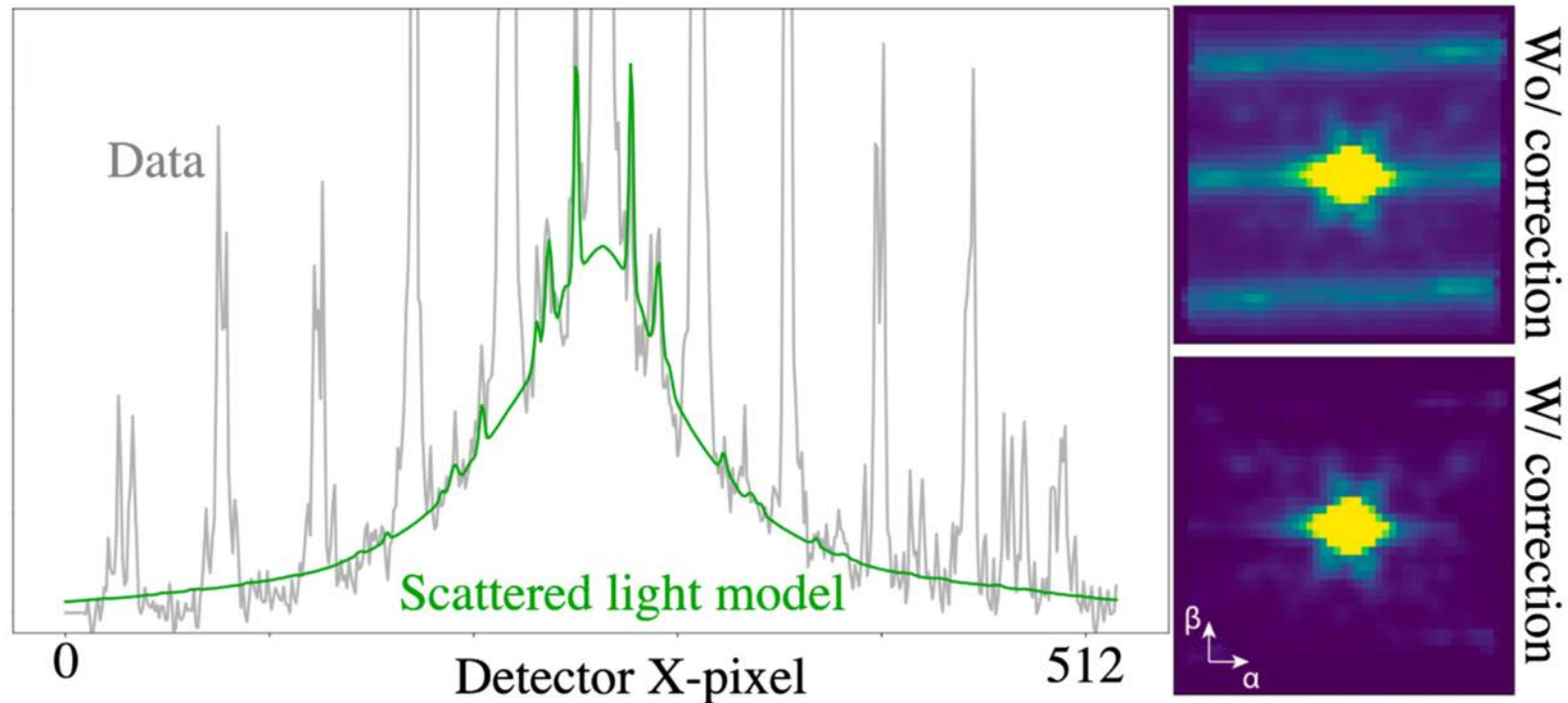
Fringing:

- Strong internal reflections within detector produce 30-40% scene-dependent fringes
- Few-percent residuals can remain in extracted spectra
- Turn on optional residual-defringing steps in pipeline





MIRI MRS Known Issues

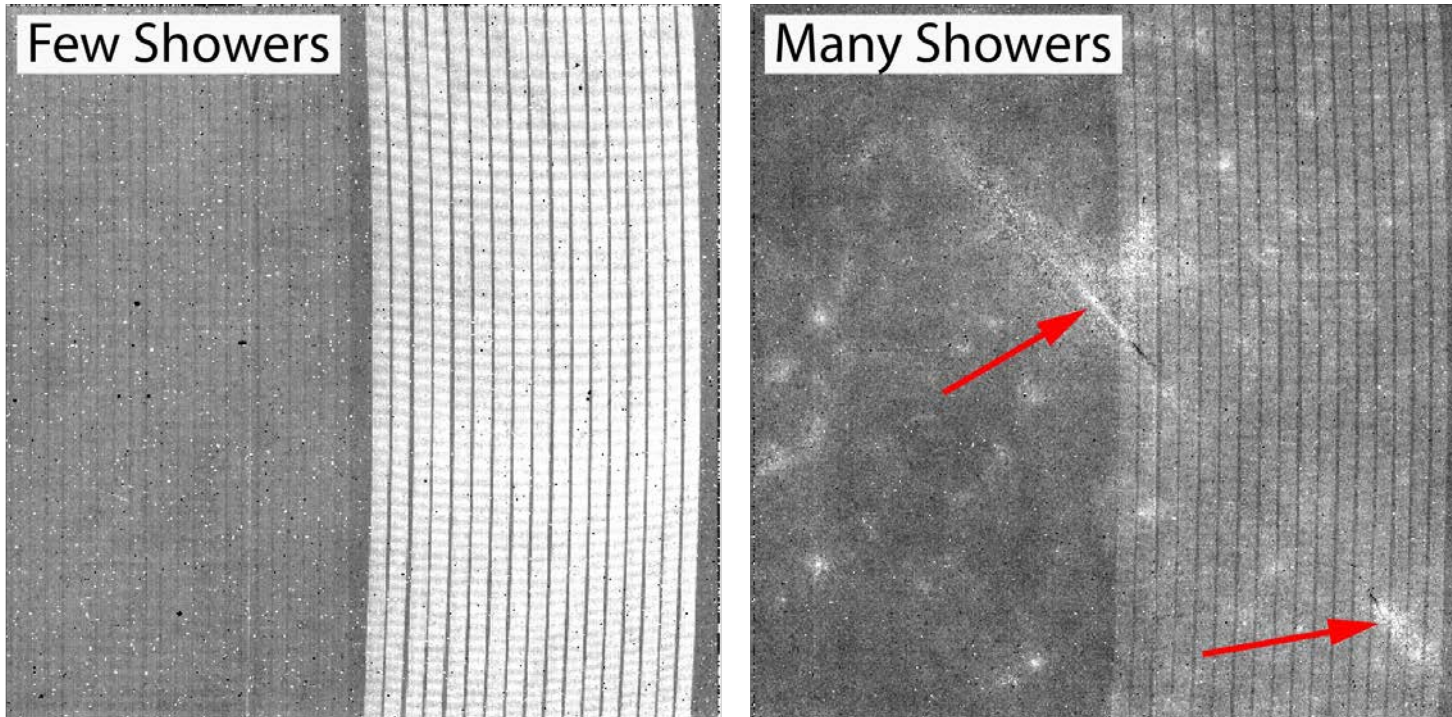


Cross-artifact:

- Interlacing of slices on detector means cross-artifact produces non-local streaks in the PSF
- Corrected by pipeline automatically in 'straylight' step, but residuals can remain



MIRI MRS Known Issues



Cosmic ray showers:

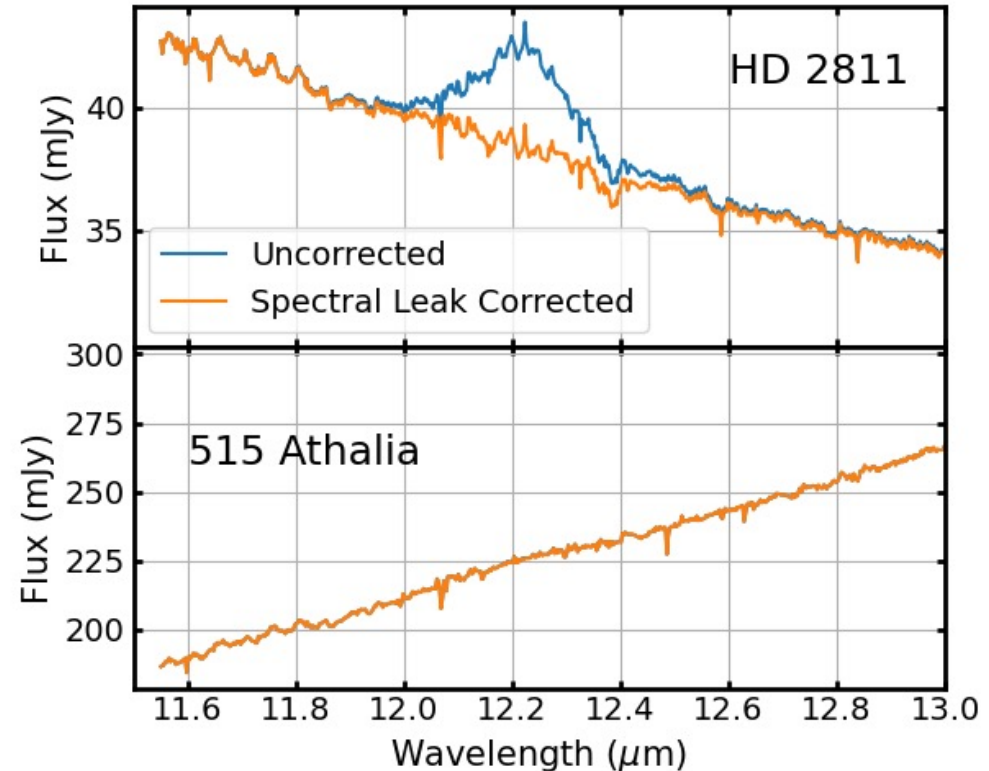
- Space 'weather' can create large blotches on detector that limit performance
- Partially corrected with 'find_showers' option to calwebb_detector1 jump step
- Correction on by default for build 11.2 and later (previously off)
- Additional corrections coming in build 11.3 (Spring 2025)



MIRI MRS Known Issues

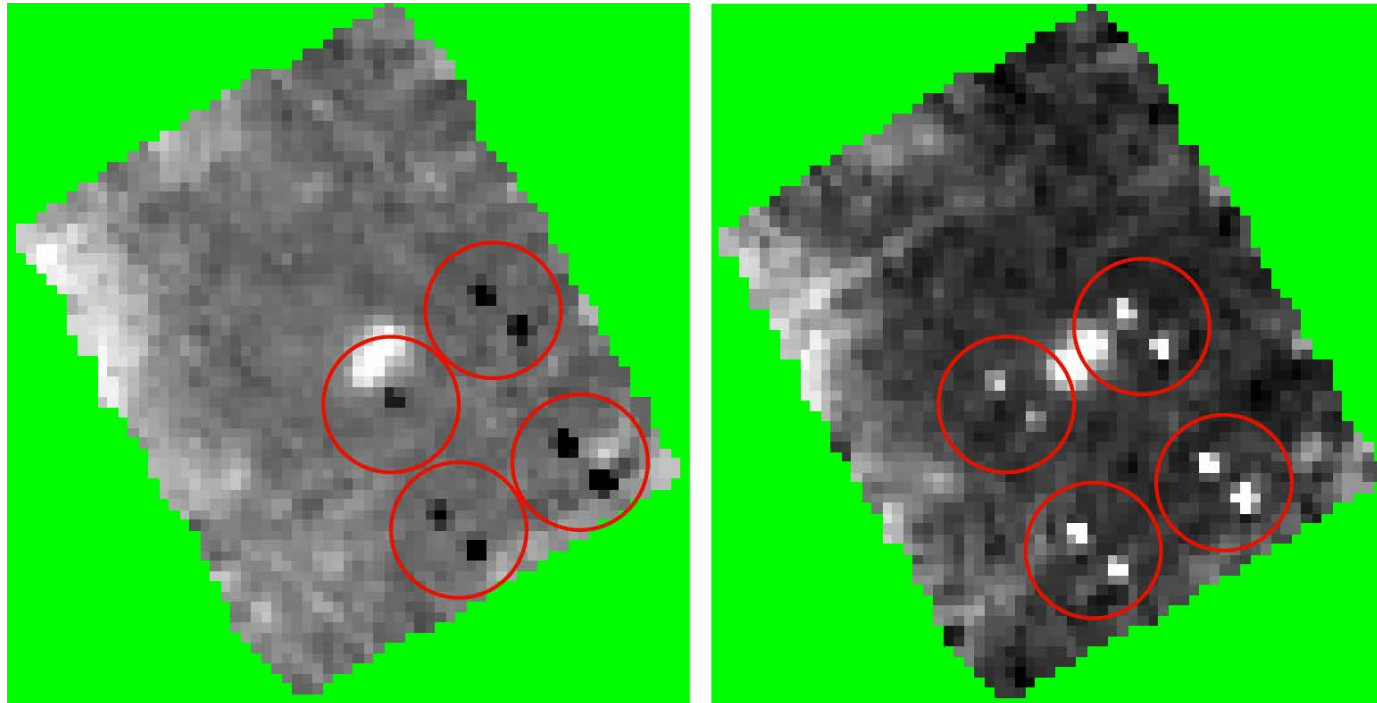
Spectral leak:

- A small fraction of 6 micron light leaks into the 12 micron regime at 2nd order
- Most noticeable for observations of blue sources
- Automatically corrected by pipeline for 1d extracted spectra if 6 micron data available
- No correction possible for IFU data cubes in general





MIRI MRS Known Issues



Bad pixels:

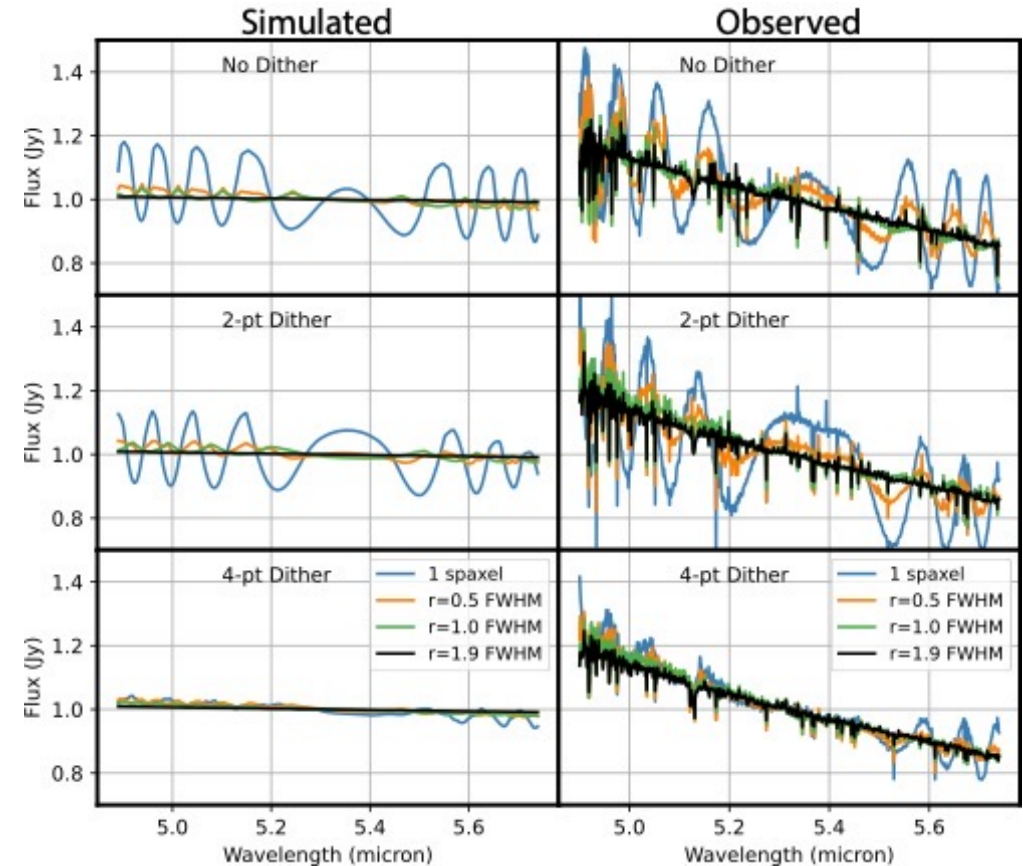
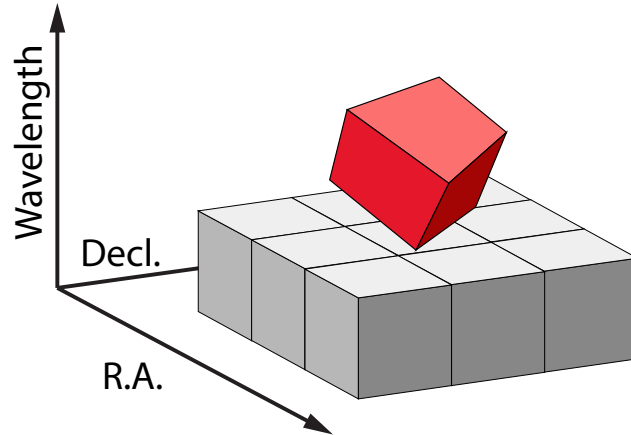
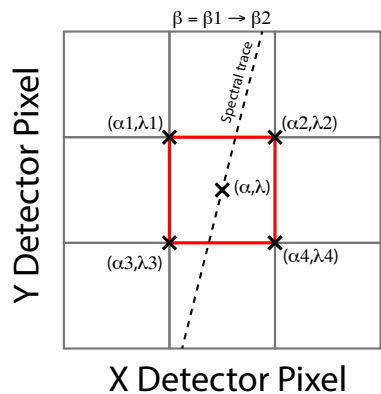
- Bad pixels are constantly evolving, and not all will be found/flagged by default
- Manifests as patterns of artifacts in data cubes
- Try using optional self-calibrated bad pixel detection if you have dedicated background observations.



MIRI MRS Known Issues

Resampling noise:

- Resampling detector pixels to cube spaxels can introduce ringing artifacts because not Nyquist sampled.
- Use 4-pt dithers, don't extract spectra from single spaxels.





MIRI MRS Pipeline Gotchas

Many optional steps that can improve performance for certain science cases. Pipeline notebook walks through most of these:

- Cosmic ray shower flagging in `calwebb_detector1` (automated in build 11.2+, optional in prior builds due to some bright-source failure cases)
- Background subtraction: dedicated background recommended in many cases, pipeline allows for pixel-based or model-based subtraction. Performance can be science-case specific, see JDox for guidance.
- Observations with dedicated backgrounds can benefit from optional self-calibrated bad pixel masking in `calwebb_spec2`.
- Spectra can be improved by optional `pixel_replace` step in `calwebb_spec3` (default in build 11.2+)
- Spectra can be improved by optional residual fringe correction in `calwebb_spec3` (beware if you have molecular features in the data though)
- Point-source spectra can be improved by auto-centroiding of sources (default, but could get confused if multiple sources)
- Point-source centroiding can change by up to 0.03'' between bands, combined with other factors can cause small discontinuities in extracted spectra.



What is the MIRI team working on now?

Improving understanding of detector systematics for TSOs

Imaging:

- Better flatfields (particularly long-wavelength)
- Understanding systematics in dark variability
- Improved subarray performance

LRS:

- Implementing wide-field slitless mode
- Improvements to wavelength calibration, background subtraction, slit throughput correction
- PSF-based spectral extraction

MRS:

- Better corrections for cosmic ray showers (limits faint performance)
- Better flatfields (limits bright performance)

Other issues may be relevant for certain science cases- send any questions to the MIRI team.