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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

NIRSpec Known Issues and Ongoing Work

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AAS 245

JWST Pipeline Workshop 1/11/2025

Overview

- Brief overview of NIRSpec modes and pipeline processing
- General known issues and ongoing work
- Mode specific known issues and ongoing work
  - BOTS
  - IFU
  - MOS
  - FS

JWST Pipeline NIRSpec Overview

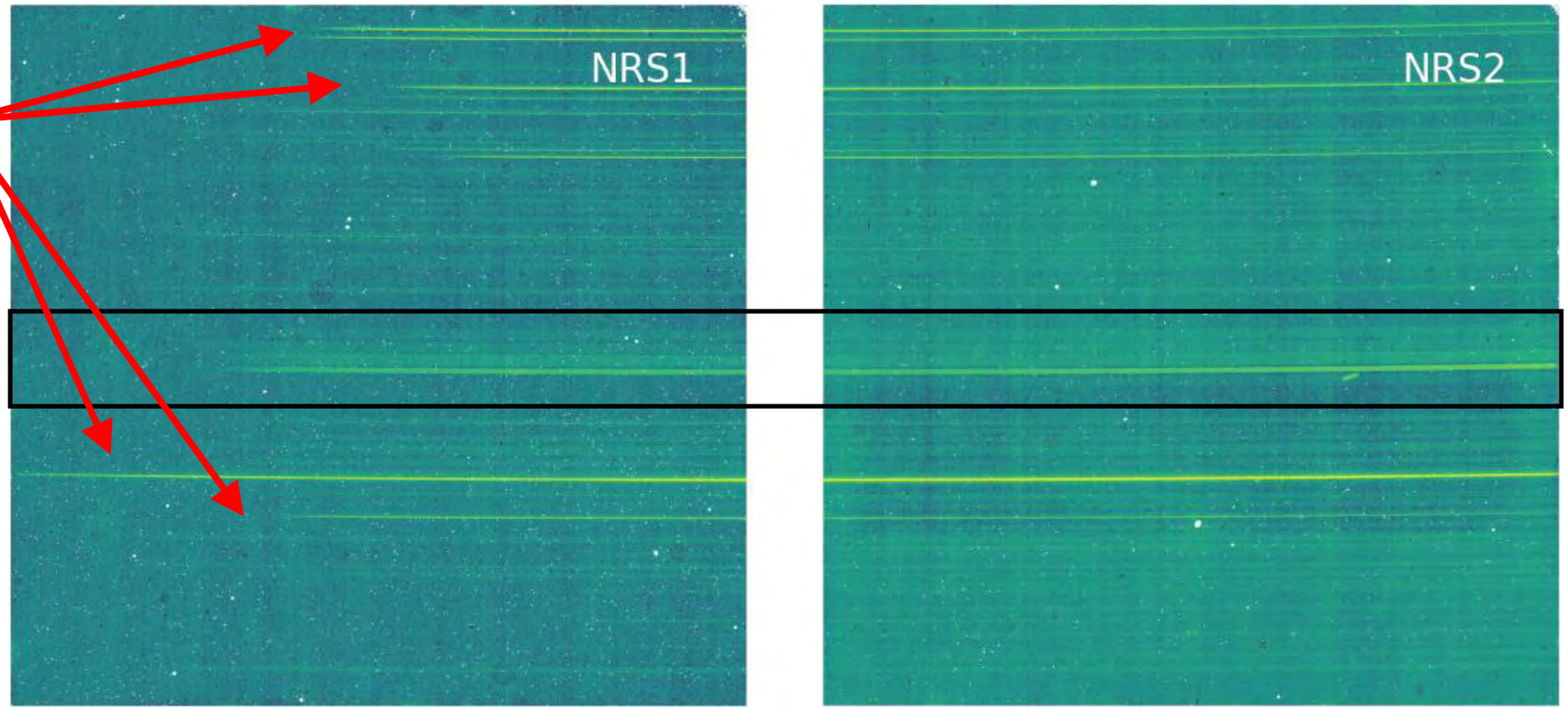
NIRSpec Modes Overview

NIRSpec has 4 observing modes, each of which has a different calibration and is handled slightly differently by the JWST pipeline.

- FS – Fixed Slit
  - Uses the 5 always open fixed slits
- BOTS – Bright Object Time Series
  - Uses the 1.6” square fixed slit (S1600A1) for stable time series observations
- IFU – Integral Field Unit spectroscopy
  - Uses an image slicer with 30 slices across a 3” x 3” field of view, that are projected on the NIRSpec detectors to observe spatially resolved spectral cubes
- MOS – Multi-Object Spectroscopy
  - Use a 3.6” x 3.4” FoV Micro-Shutter Array (MSA) to build custom configured slitlets to observe multiple objects

NIRSpec Modes Overview - IFU example

MOS G395H observation



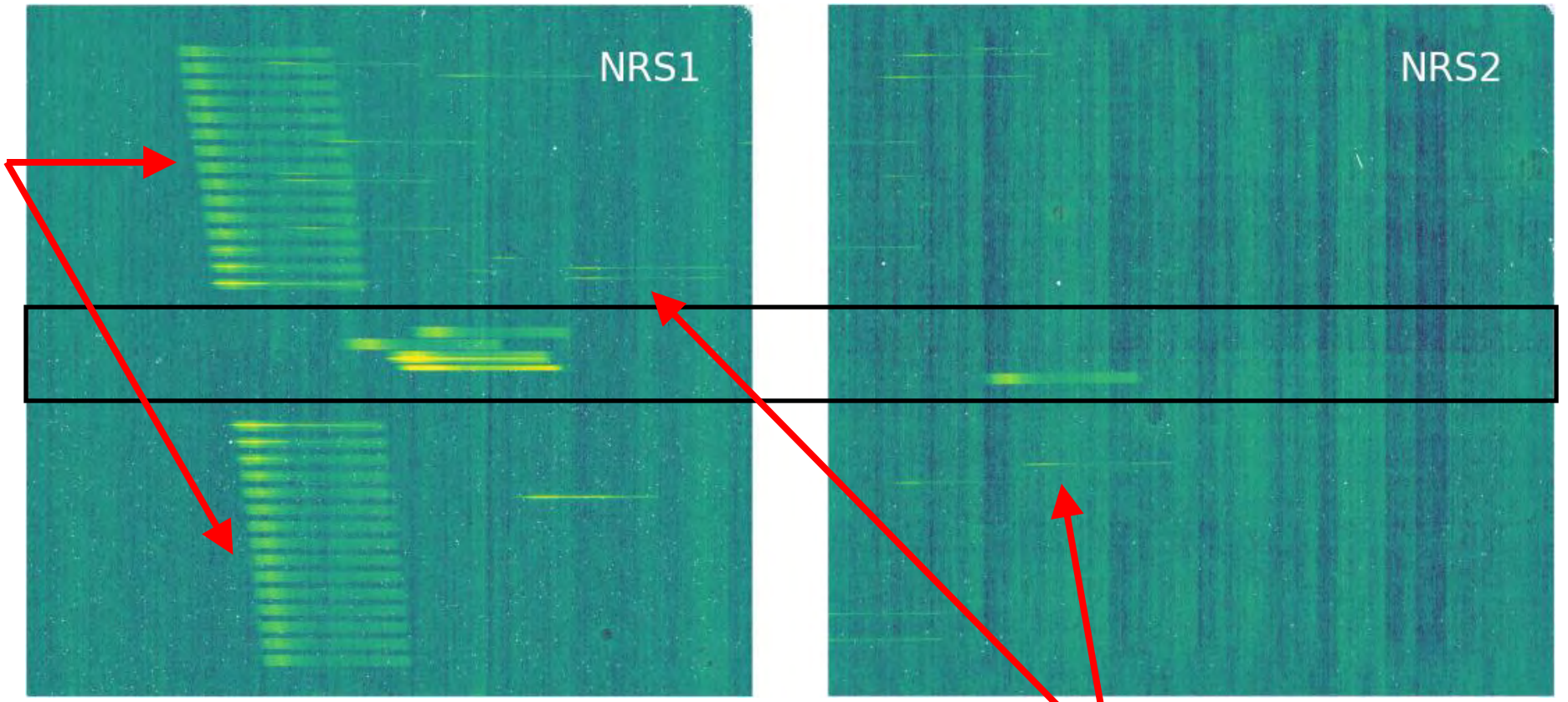
Open MOS slitlets

FS region

G395H light on NRS2

NIRSpec Modes Overview - IFU example

IFU PRISM observation



NIRSpec Pipeline Overview

- calwebb_detector1 – calculate rate images for each exposure/integration and correct for detector level effects → all modes process similarly
- calwebb_spec2 – performs individual exposure calibrations → some slight differences between modes
  - BOTS – uses rateints files as a starting point, no resampling
  - IFU – includes leakcal subtraction and 3D cube building
  - MOS – includes barshadow corrections
- Level 3 processing – combine multiple exposures into final source based products
  - BOTS – uses calwebb_tso3, produces x1dints and white light curves
  - FS, MOS – use calwebb_spec3, produces resampled s2d and x1d spectra
  - IFU – uses calwebb_spec3, produces s3d cubes and x1d spectra

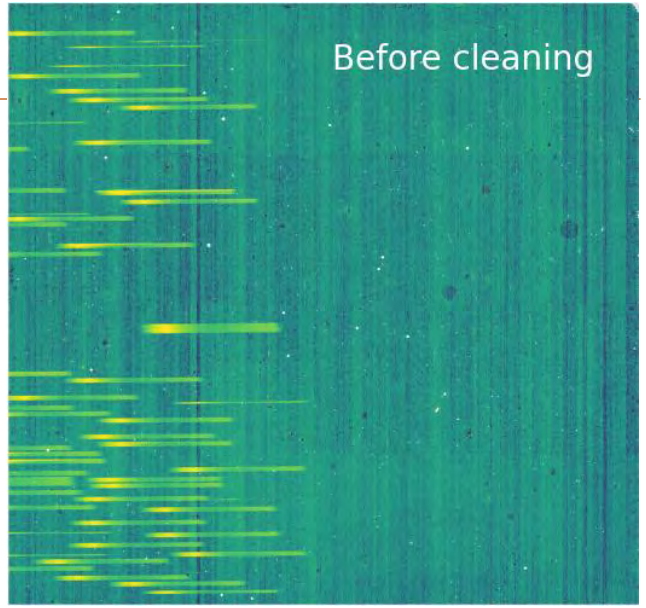
Known Issues – General

1/f Noise – Known Issue

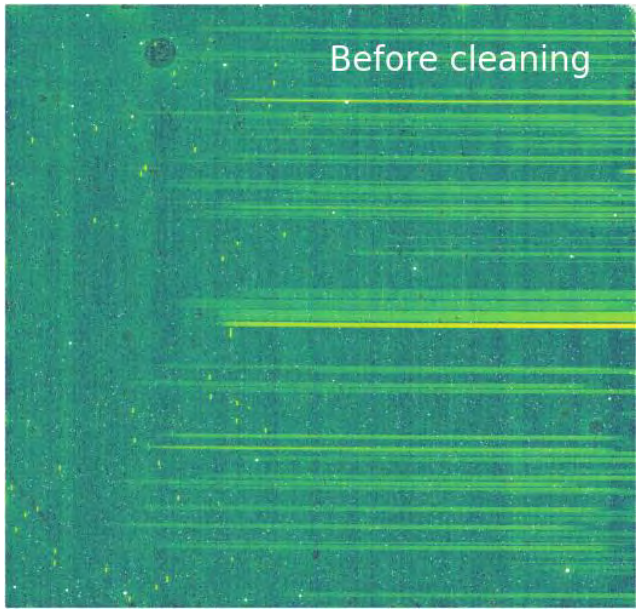
One issue that affects all NIRSpec data to some extent is the appearance of vertical striping due to correlated readout noise with a 1/f power spectrum, commonly referred to as 1/f noise.

- Fluctuations in readout amps can lead to correlated offsets in measured counts, which produce stripes in the fast readout direction (i.e., vertically on the NIRSpec detectors)
- NIRSpec's special full-frame readout mode IRS^2 reduces the presence of 1/f noise, but does not remove it entirely.

Traditional readout



IRS^2 readout



1/f Noise – Ongoing Work

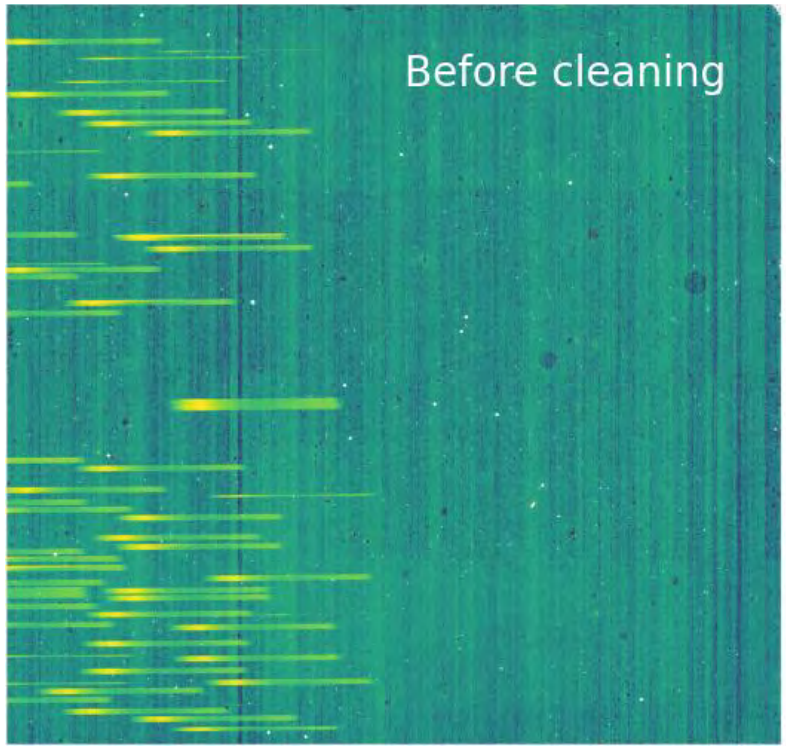
There are now multiple options in the JWST pipeline for cleaning 1/f noise, as of JWST pipeline versions 1.16.0 and later see: 1/f Noise page on JDox for more information.

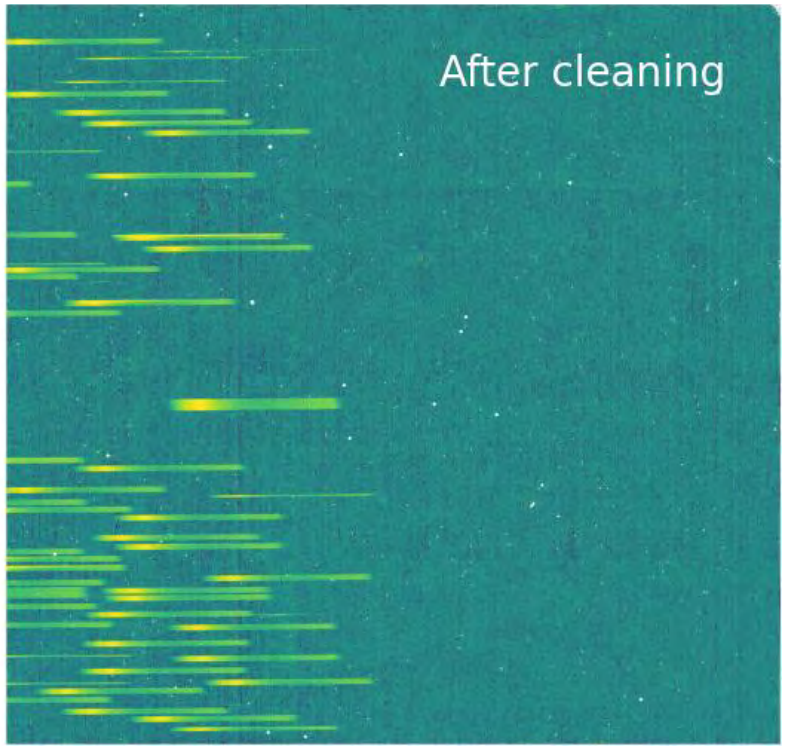
- There are two core algorithms that are implemented as 1/f cleaning options:
  - An FFT-based algorithm based on NSClean (Rauscher 2024).
  - A column-wise median correction based on the "image1overf" developed by Chris Willot.
- For NIRSpec data these options can be applied to either group data (using the clean_flicker_noise step in calwebb_detector1) or rate data (using the nsclean step in calwebb_spec2).
  - While the step names differ, the functionality is the same for the two steps.

1/f Noise – Ongoing Work

Investigations are ongoing into the optimal 1/f cleaning parameters for each NIRSpec mode.

- Optimal parameters will likely differ between modes and may differ between datasets.
- Currently 1/f cleaning is off by default, but available for re-processing.





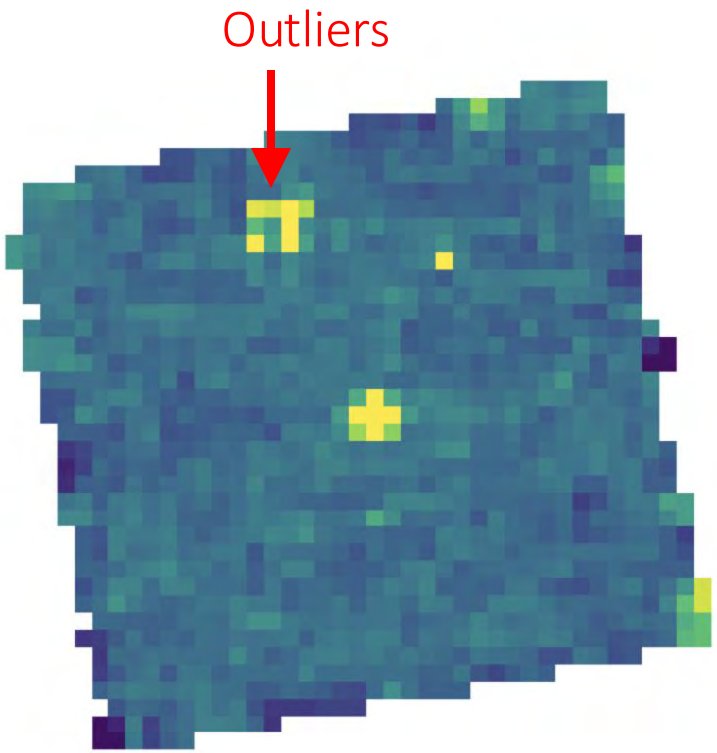
Residual Outliers – Known Issue

Another frequent issue affecting most NIRSpec data is the presence of residual outliers that have not been removed.

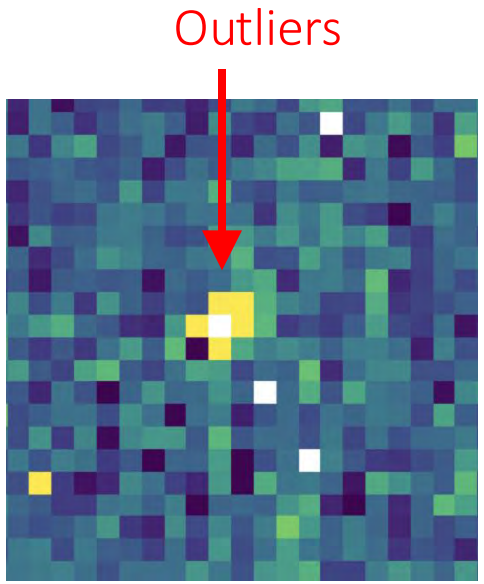
- Multiple steps/calibrations flag various outliers but some can be missed:
  - The bad pixel mask flags hot and dead pixels
  - Dark subtraction removes the higher dark rates in hot-pixel neighbors due to IPC-coupling
  - The jump step detects and flags CRs and snowballs
  - The outlier_detection step looks for outliers when combining multiple exposures (or integrations for BOTS observations).
  - Additional optional steps: pixel_replace (replace flagged pixels), badpix_selfcal (self-calibrate bad pixels)
- Remaining outliers may be missed or poorly flagged cosmic rays, snowballs, hot pixels and their neighbors, etc.

Residual Outliers – Known Issue

IFU example – bright outliers seen in a single wavelength slice but affecting multiple nearby spaxels.

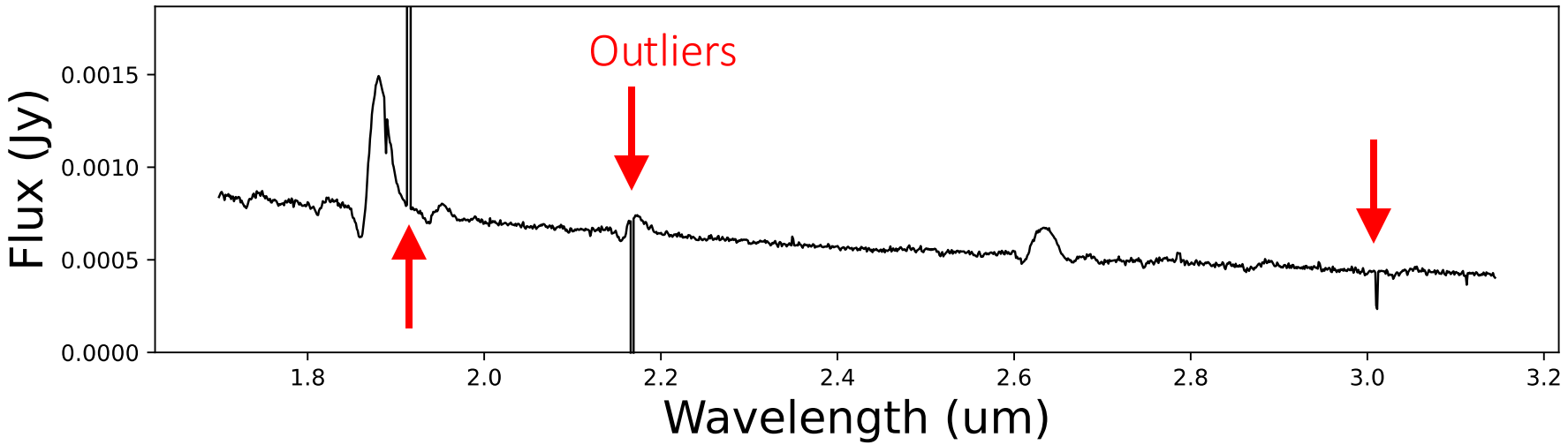


Cube slice



Rate file cutout

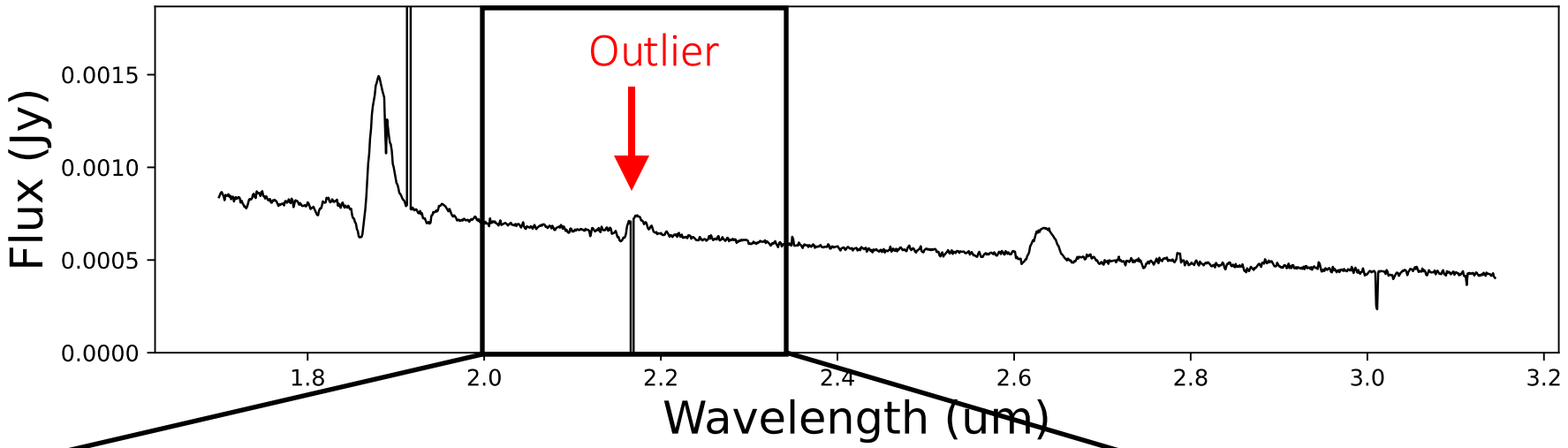
Residual Outliers – Known Issue



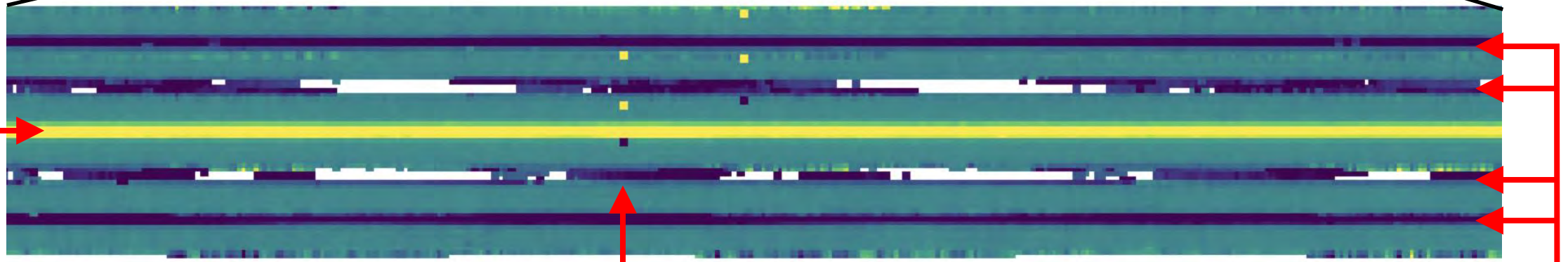
FS example – many outliers appear as very large positive or negative spikes (though some may be weaker and look similar to narrow emission/absorption features.

Residual Outliers – Known Issue

Often appear in a fixed location on the detector and will show up repeated in level 3 combined s2d spectra



Level 3 Combined and Resampled spectrum



Source

Outlier

Nod-subtracted source

Residual Outliers – Ongoing Work

A number of improvements were recently added, are planned, or will be investigated for future Builds, in order to reduce the number of outliers in final products:

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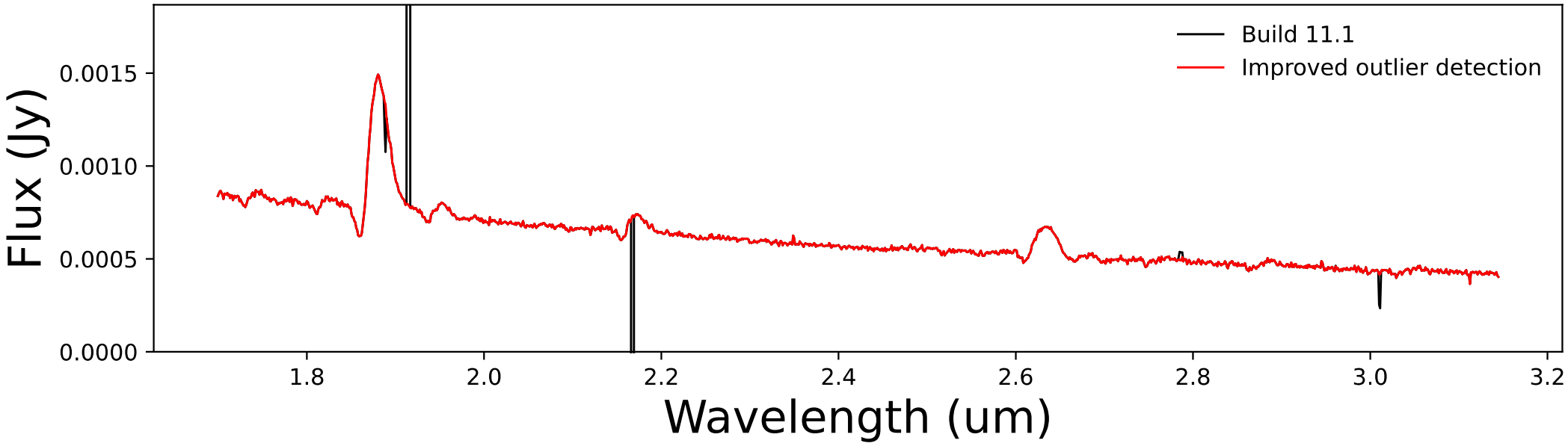
- Improvements to the outlier_detection step for MOS and FS data (planned for Build 11.2)



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- Improvements to the outlier_detection step for MOS and FS data (planned for Build 11.2)
- Delivering Cycle 2/3 dark and bad pixel mask reference files, which will provide updated hot pixel flagging (expected Build 11.3)

Additional Calibration efforts

Calibration work is ongoing. In addition to the mode specific calibrations in following slides, some ongoing calibration work includes:

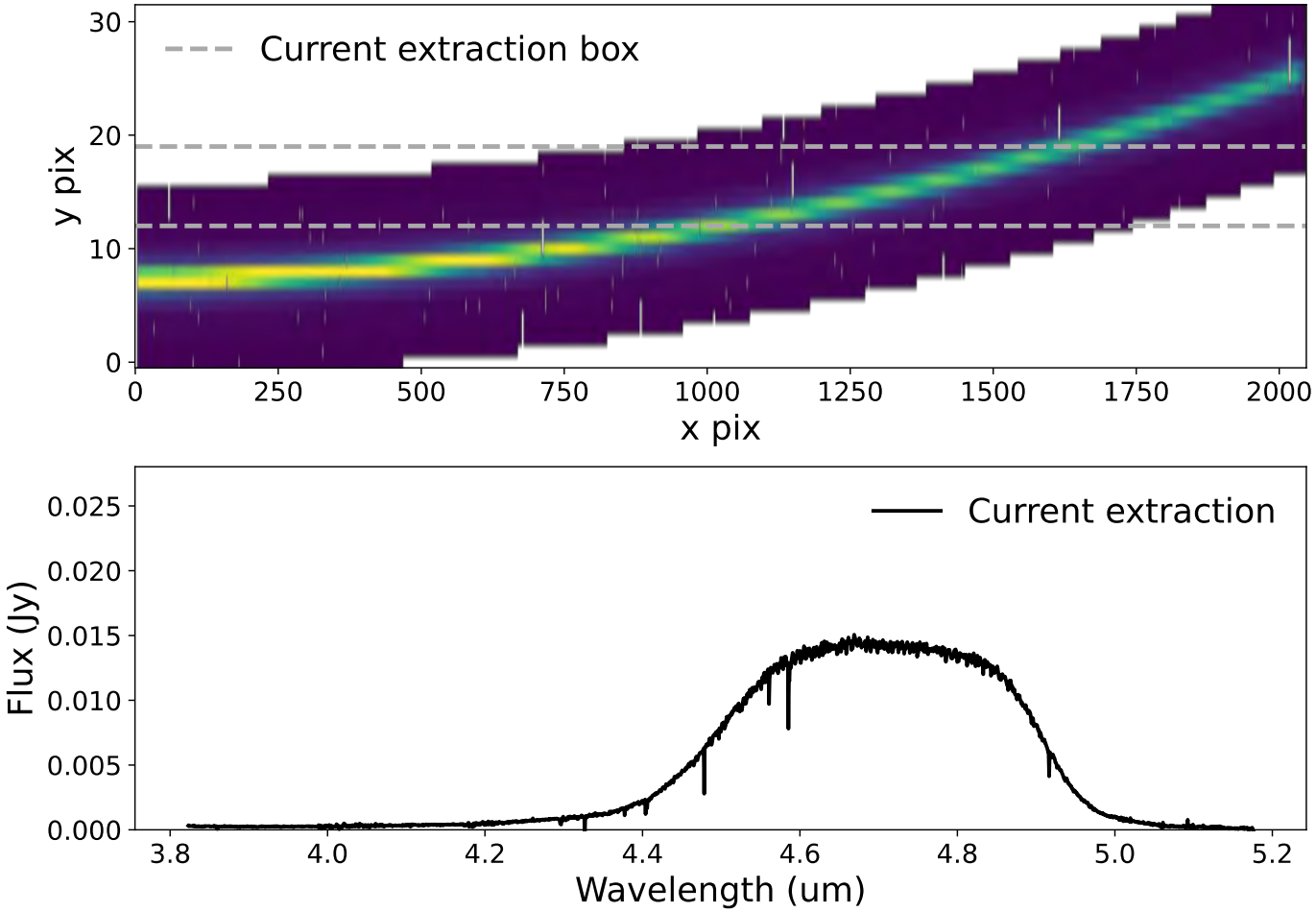
- New biases/darks/bad pixel masks for Cycle 2/3.
- Continued flux calibration work:
  - Most of the flux calibrations are done with a single calibration source, want to reduce systematics by combining multiple sources.
  - Comparisons between multiple sources (where possible) show ~2% differences in flux calibration
- Investigating Wavelength Calibrations:
  - Current wavelength calibrations are verified at a single field point (for IFU/MOS), wavelength calibration good to the nominal ~1/8th of a pixel
  - Looking into wavelength calibration across the MOS and IFU fields of view
  - Comparing wavelength calibrations between PRISM and gratings

Known Issues – BOTS

Missing BOTS Flux – Known Issue

Currently the rectangular extraction boxes used for 1D extraction are not suitable for BOTS data, which are not resampled.

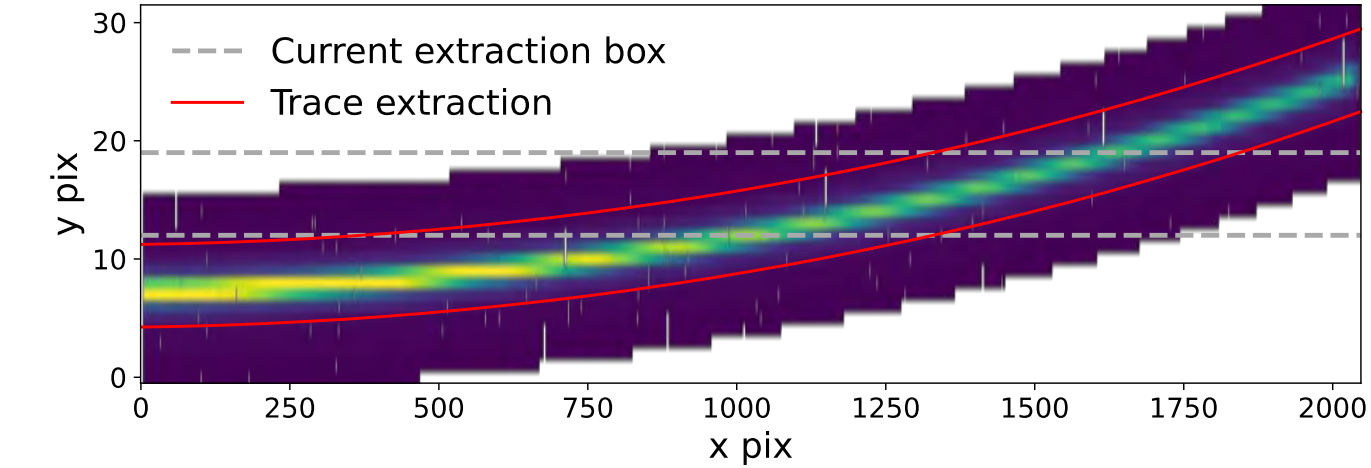
- Workaround 1: provide a polynomial defined source extraction through the src_coeff keyword in an extract_1d parameter reference file.
- Workaround 2: run a custom 1D extraction

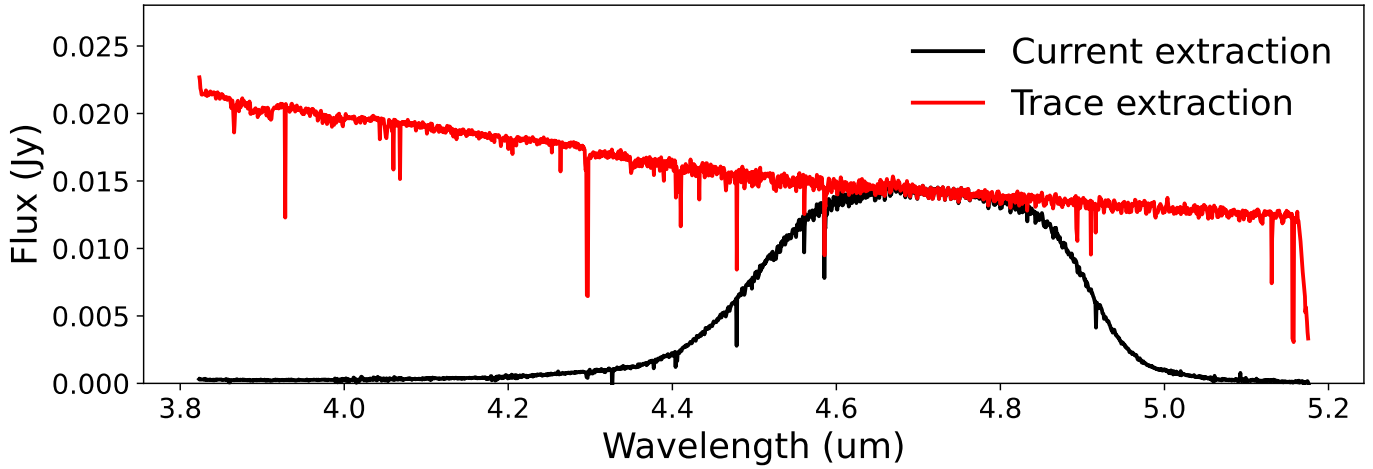


Missing BOTS Flux – Ongoing Work

Work is in progress to improve the default pipeline extraction.

- Currently working on updates to calculate a trace from the expected source positions and use a curved extraction box.
- Future improvement: implement an option for optimal/PSF.





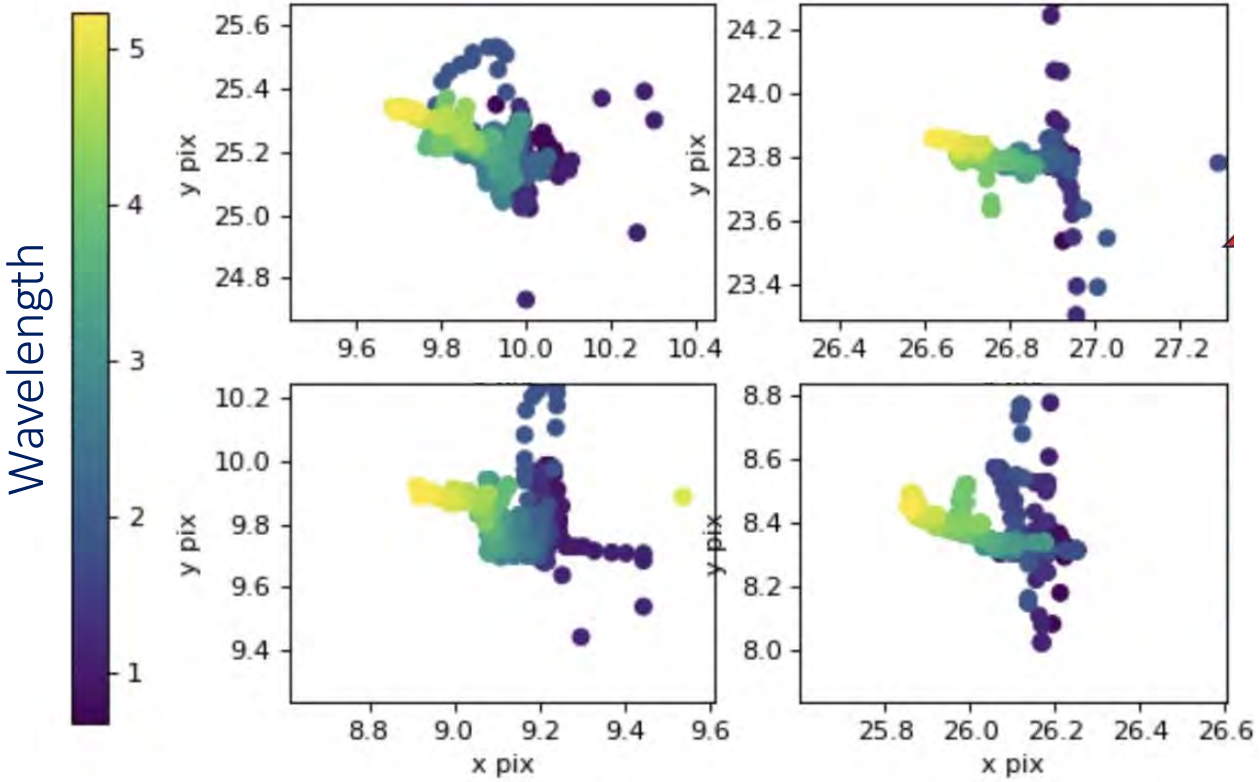
Known Issues – IFU

NIRSpec IFU spatial and spectral distortions – Known Issue

Distortions have been seen in both the spatial position of PSF centroids as a function of wavelength and line centers of emission lines in NIRSpec IFU cube data.

NIRSpec IFU spatial and spectral distortions – Known Issue

Point source centroid wanders with wavelength



Cross slice direction

Apparent kinematic shift in point source Brα line center (when none should be seen)

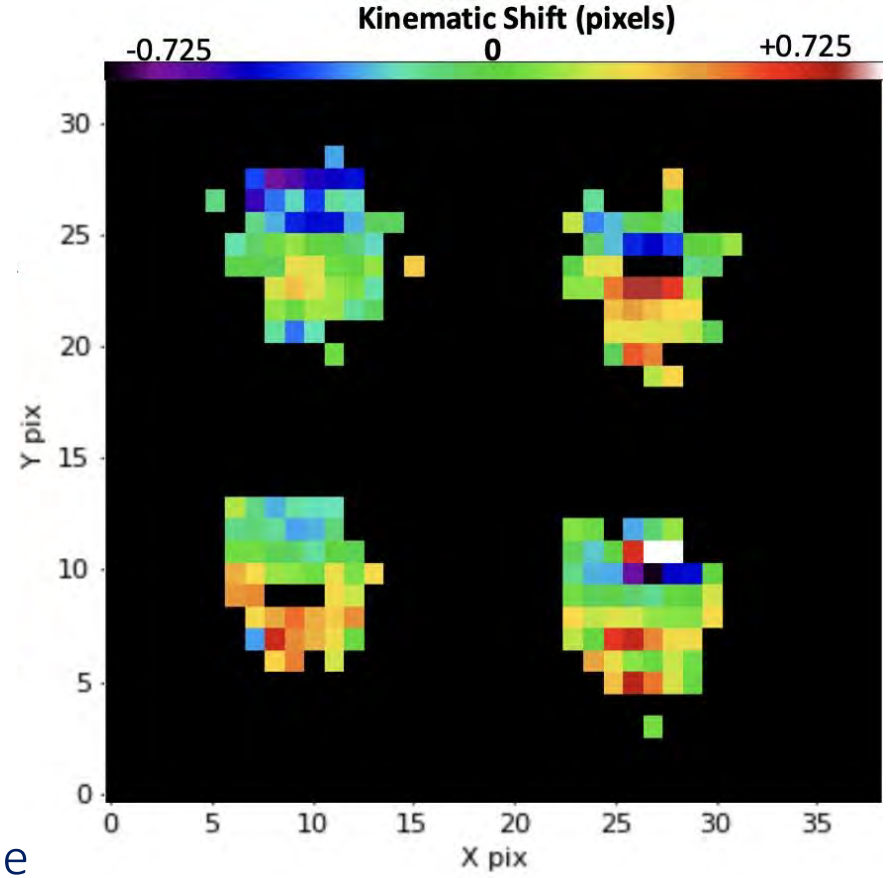


Image Credit: T. Beck JWST Techinical Memo (in prep.)

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- Spatial distortions:
  - Magnitude of the effect differs between filters/gratings
  - Extracting from single spaxels can have incorrect fluxes due to a slight wander in PSF centroids
  - Can affect resolved flux-ratio maps and fluxes from small aperture extractions
  - Slightly improved with an increased number of dither positions, but not entirely removed
- Spectral distortions:
  - Magnitude of the effect differs between filters/gratings
  - Can affect kinematic analyses of compact, but resolved, sources

NIRSpec IFU spatial and spectral distortions – Ongoing Work

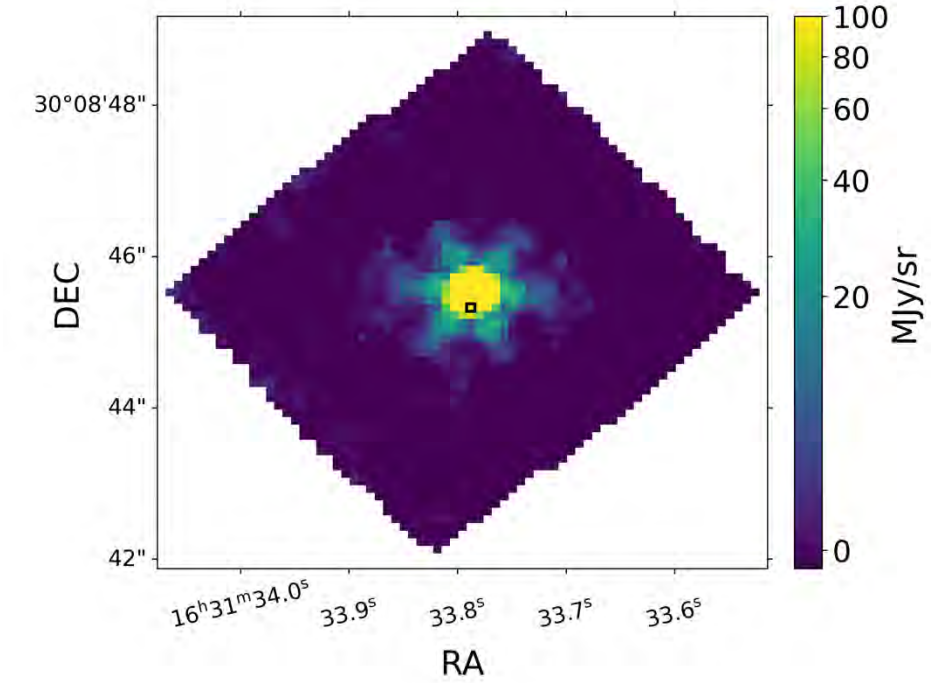
Both issues are currently under investigation, with two dedicated Cycle 3 IFU distortion calibration programs in progress to characterize and address the problems.

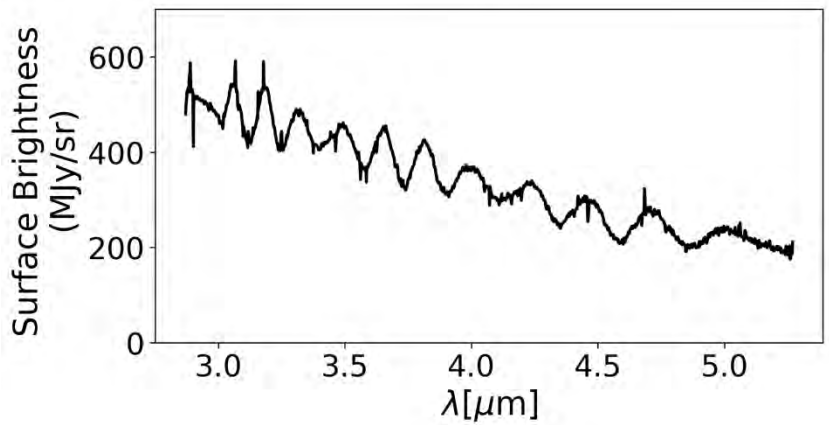
- Calibration programs: PIDs 6640 and 6641
- More information and mitigation plans will be released to the community once the root cause is identified.

Resampling errors when extracting individual spaxels – Known Issue

When using a sufficiently small extraction aperture or working with spectra from individual spaxels, ripples or ringing may be seen, particularly when analyzing spaxels near a point-source.

- These patterns are due to the resampling in cube – building
- Using larger apertures and more dithers reduces this resampling noise.





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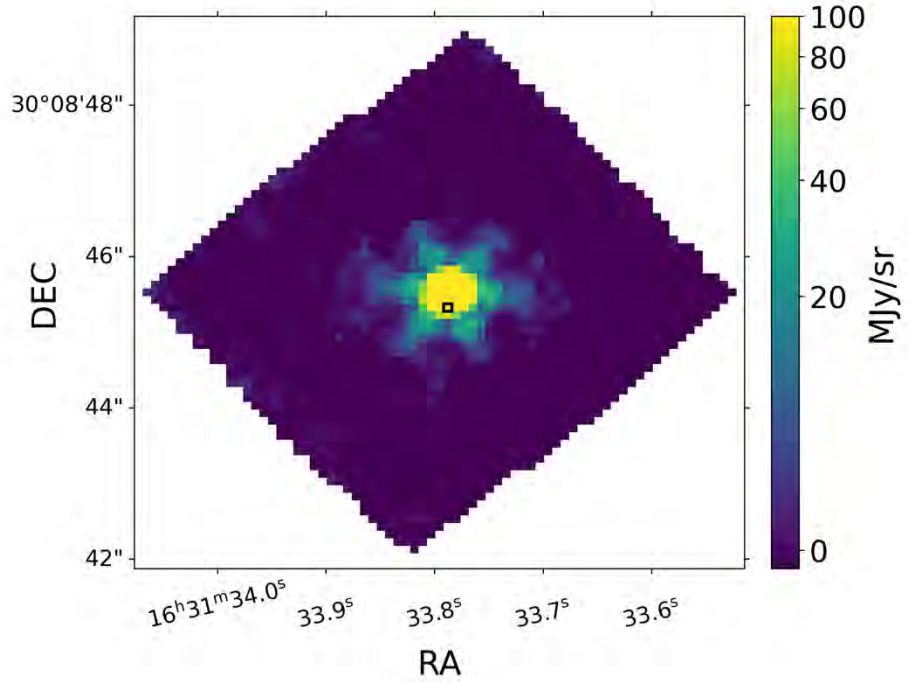
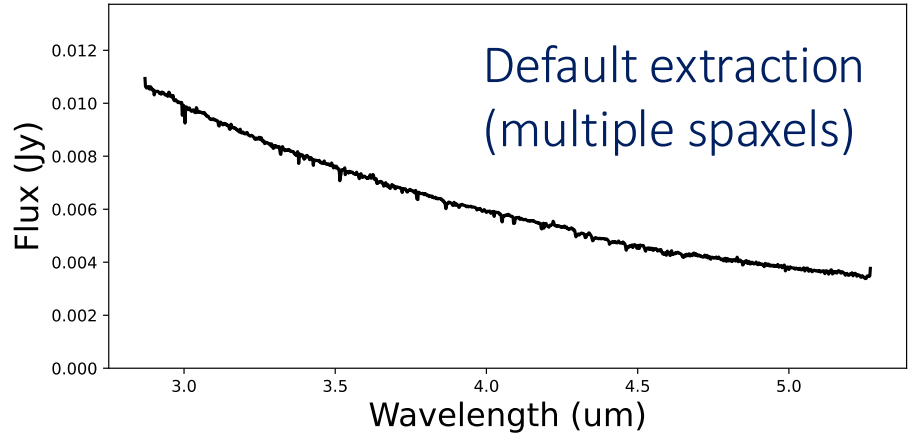




Known Issues – MOS

MOS Flux Calibration – Ongoing Work

The NIRSpec MOS mode is fairly complex to calibrate, so work is ongoing to continue to improve and refine various elements that contribute to MOS flux calibration.

- With ~ 4 x 171 x 365 individual shutters, it's not possible to calibrate each shutter separately
- Absolute flux calibration is done in a single 3-shutter slitlet. Field dependent throughput across the MSAs and detector related flat fielding expected to be corrected by separate calibrations.
- There are also shutter level throughput calibrations, i.e., pathloss (accounting for diffraction and slit losses) and barshadow (accounting for the bars between adjacent shutters)

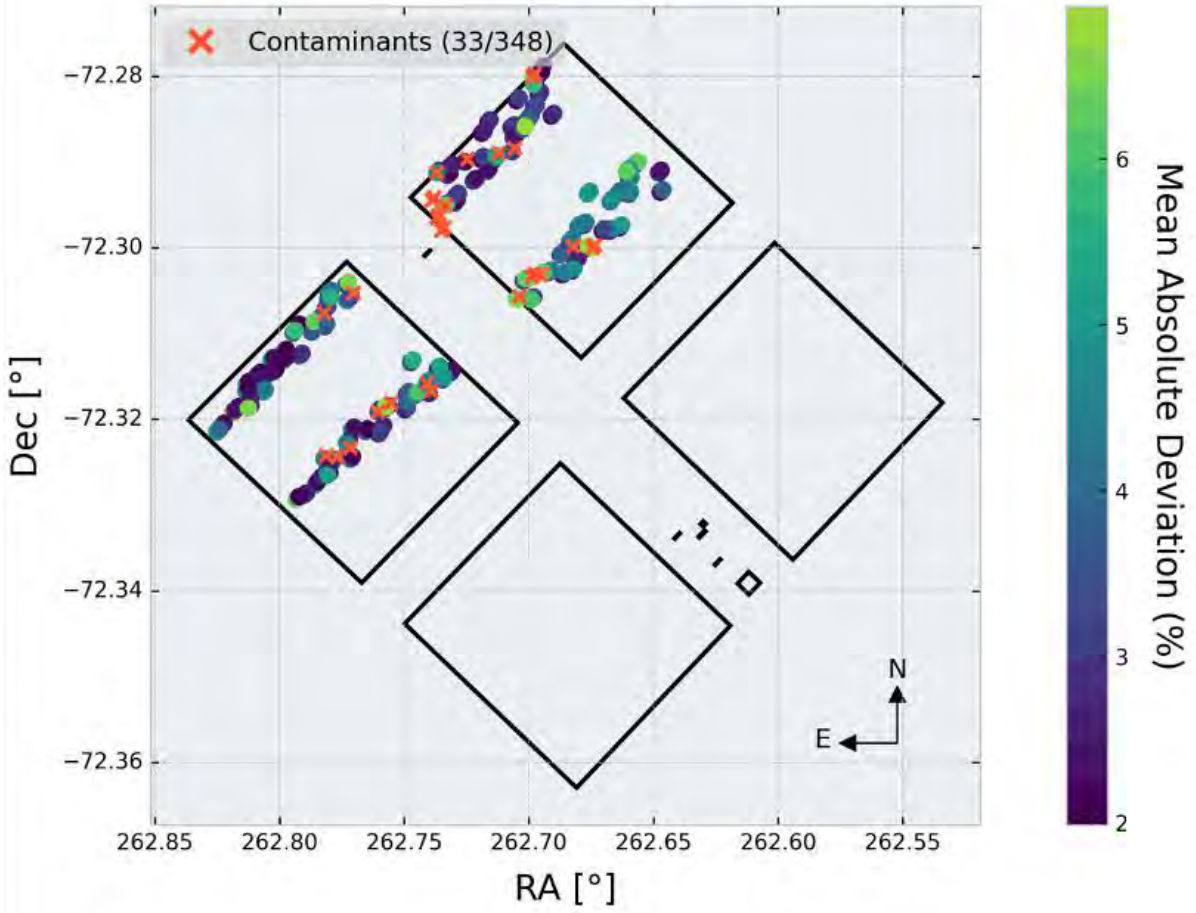
MOS Flux Calibration – Ongoing Work

Ongoing MOS flux calibration work:

- MOS flat fielding does not currently account field dependent throughput across the MSA plane.
  - Field dependent variations appear to be at or below the +/- 5% level.
  - Work to produce the necessary calibrations is underway.
- MOS Pathlosses are based on simulations (using in-flight PSF models).
  - Working on calculating relative MOS point-source pathlosses from in-flight data
  - Pathlosses for extended sources (non-point/non-uniform) require custom corrections accounting for source shape and size
- MOS barshadow corrections have a slightly incorrect profile – requires updating in the future.

MOS Flux Calibration – Ongoing Work

Flux variation in sky background slitlets



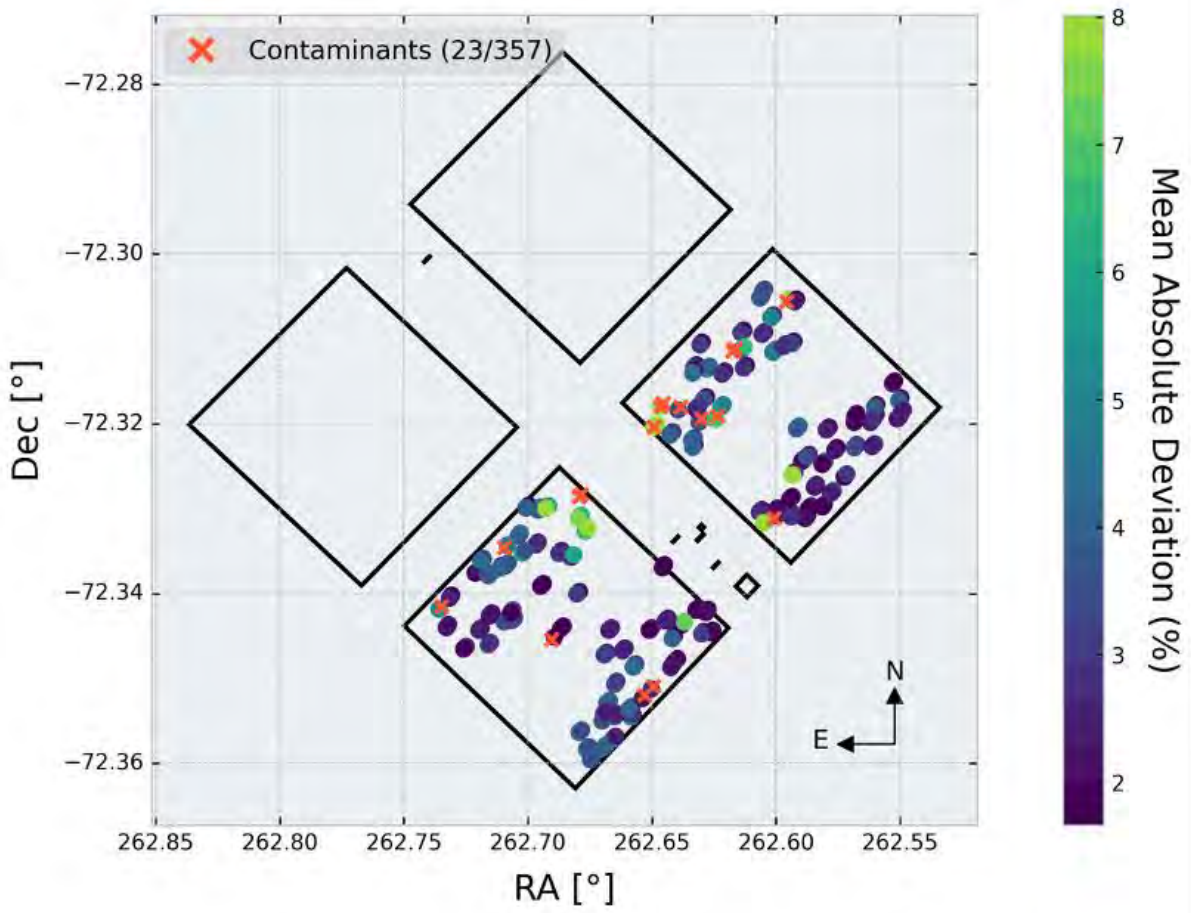


Image Credit: K. Glidic

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MOS Flux Calibration – Known Issue

MOS barshadow corrections have a slightly incorrect profile, leading to over- and under-correction on the edges of a shutter

3-shutter sky background slitlet
with barshadow corrections

Over-correction

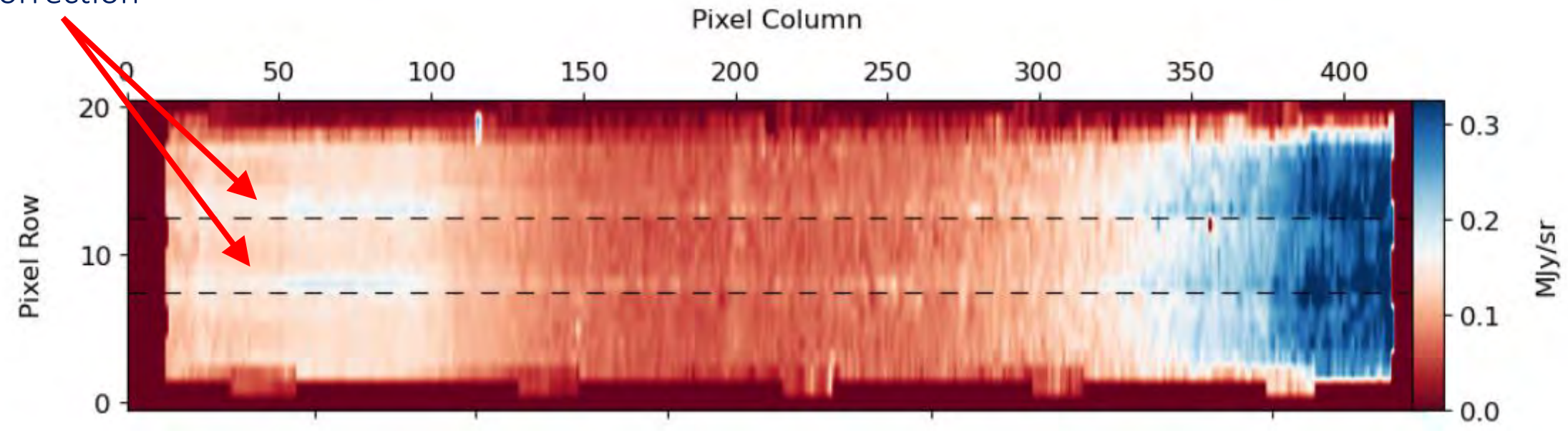


Image Credit: K. Glidic
Jwebbinar 33

Known Issues – Fixed Slit

Nod over-subtraction – Known Issue

For nodded data, nods are sufficiently close that the edges of the PSF overlap when performing nod subtraction for pixel-to-pixel background subtraction.

- Worst for S1600A1 (the shortest slit).
- Differs for each slit (and affects MOS) and nod pattern.
- Flux calibration is done using 3-pt nod for all slits (and MOS) except S1600A1 which is calibrated for no nods to be optimal for BOTS.

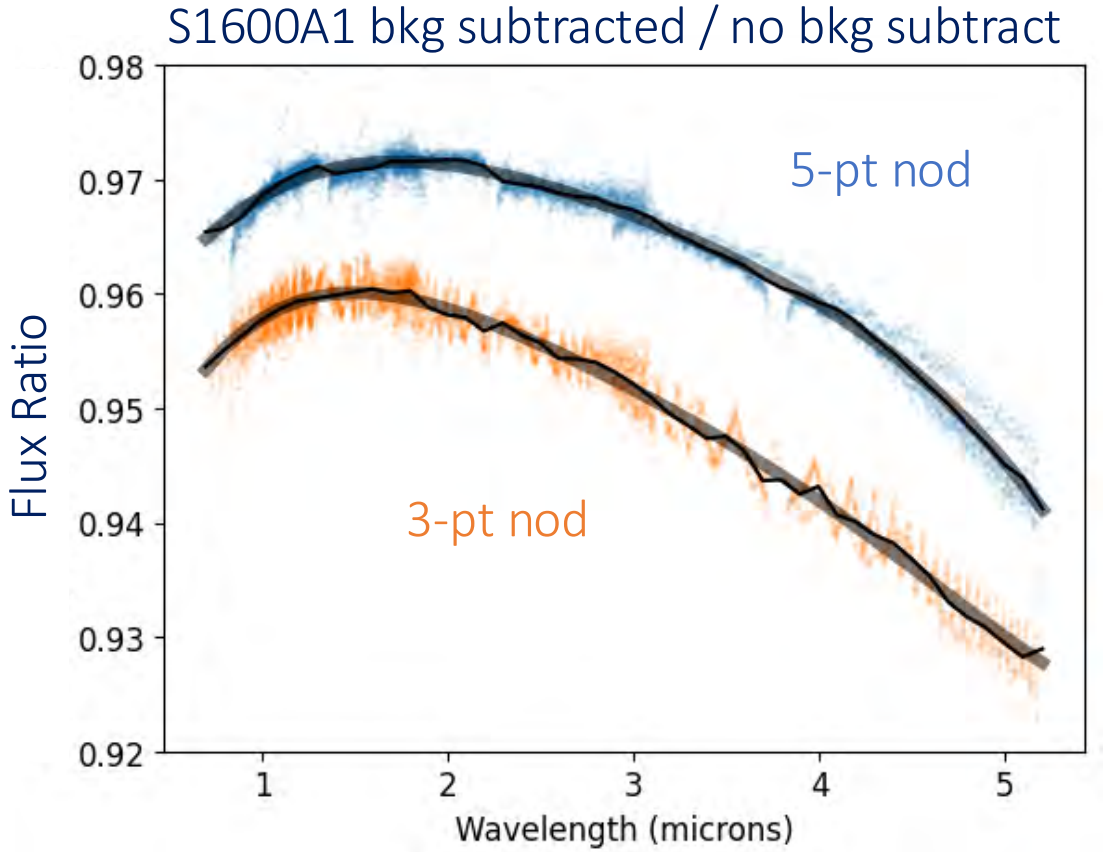
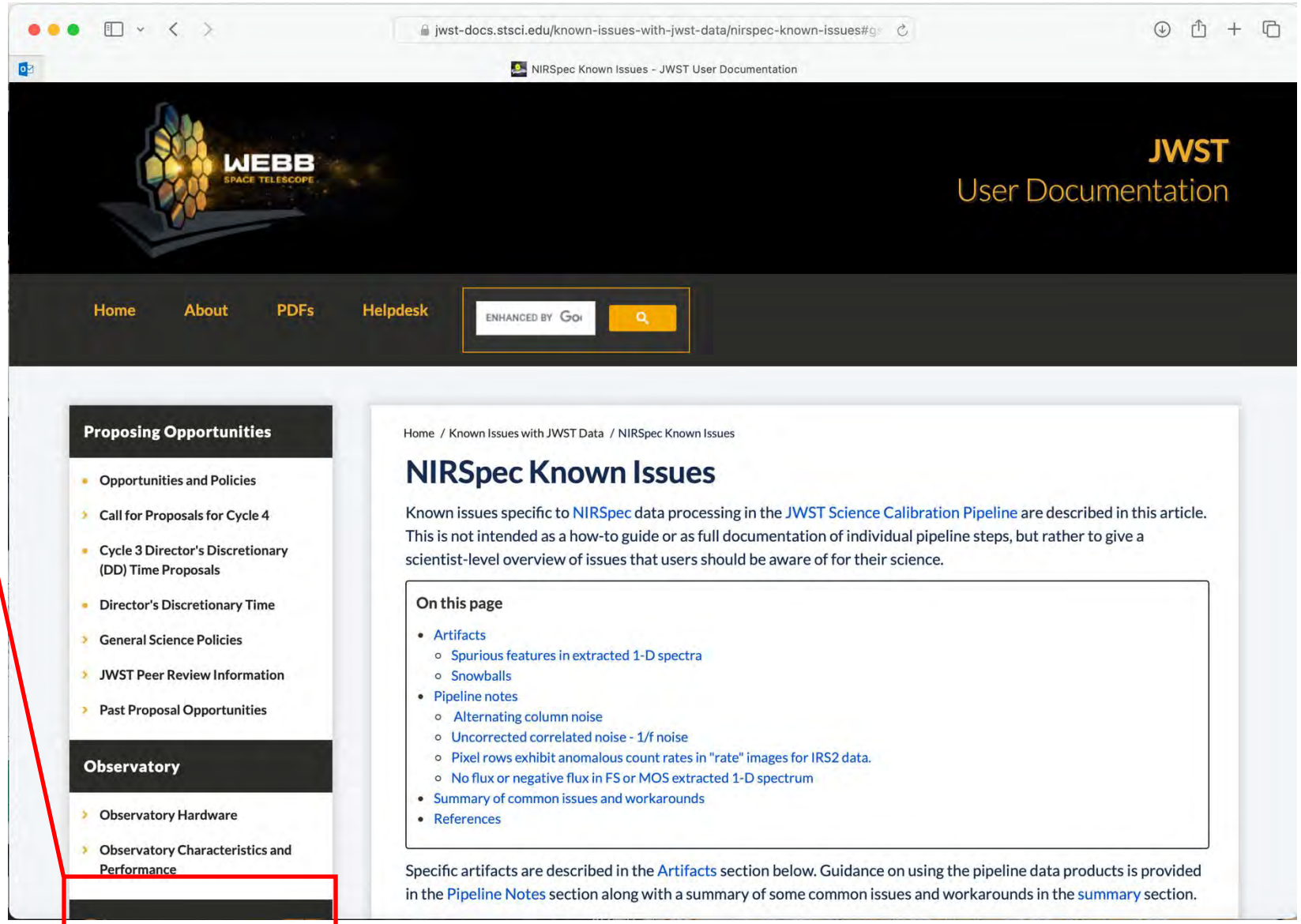


Image Credit: C Proffitt

Staying up to date with known issues

NIRSpec Known Issues



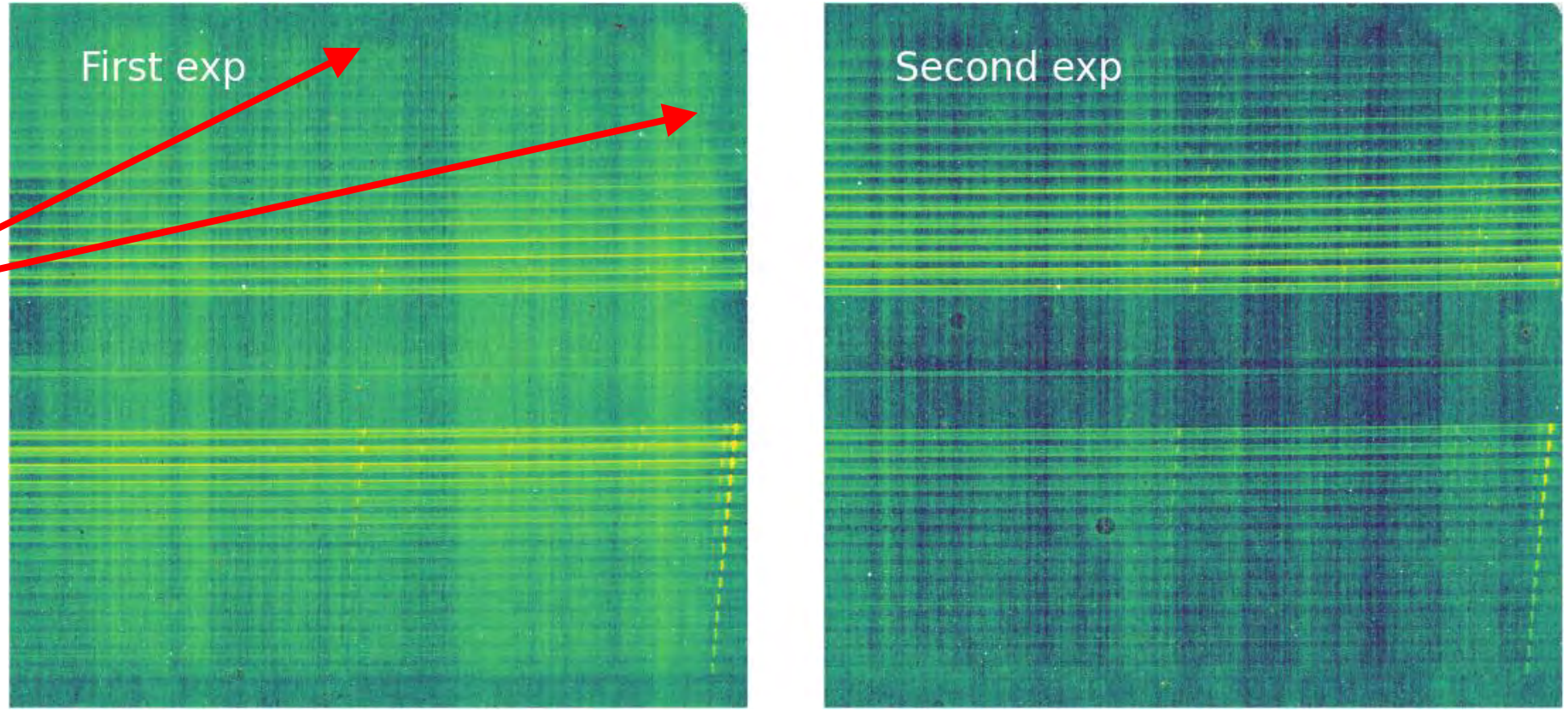
Questions?

Additional/Minor Known Issues

Picture Frame – Known Issue

Another correlated noise effect, the “Picture frame”, can be seen in some NIRSpec data and shows up most prominently in IRS^2 exposure following a read mode switch from traditional to IRS^2 (e.g., after target acquisition) due to higher thermal instabilities.

Picture frame



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- Affects the full frame, not simply the edges.
- Time varying
- Has a stronger signature when the detectors are thermally unstable, i.e., during mode switches, but is present at a lower level in all data.

Picture Frame – Ongoing Work

Currently there is no direct way to clean the picture frame effect, though it is partially addressed by the 1/f noise cleaning routines. Investigations are underway to explore options for addressing this.

World Coordinate System Offsets – Known Issue

WCS transforms are available in the header metadata for transforming from detector → "slit frame" → sky . SLIT_RA/DEC and projecting WCS often shows spatial offsets from known source positions.

- This does not affect the data reduction which relies on planned source positions (e.g., in MSA metadata files or known dither/nod offsets) and internal transformations
- Offsets are thought to be due to some combination of factors that aren't included in the telescope pointing (e.g., TA offsets, TA pointing errors, etc.)

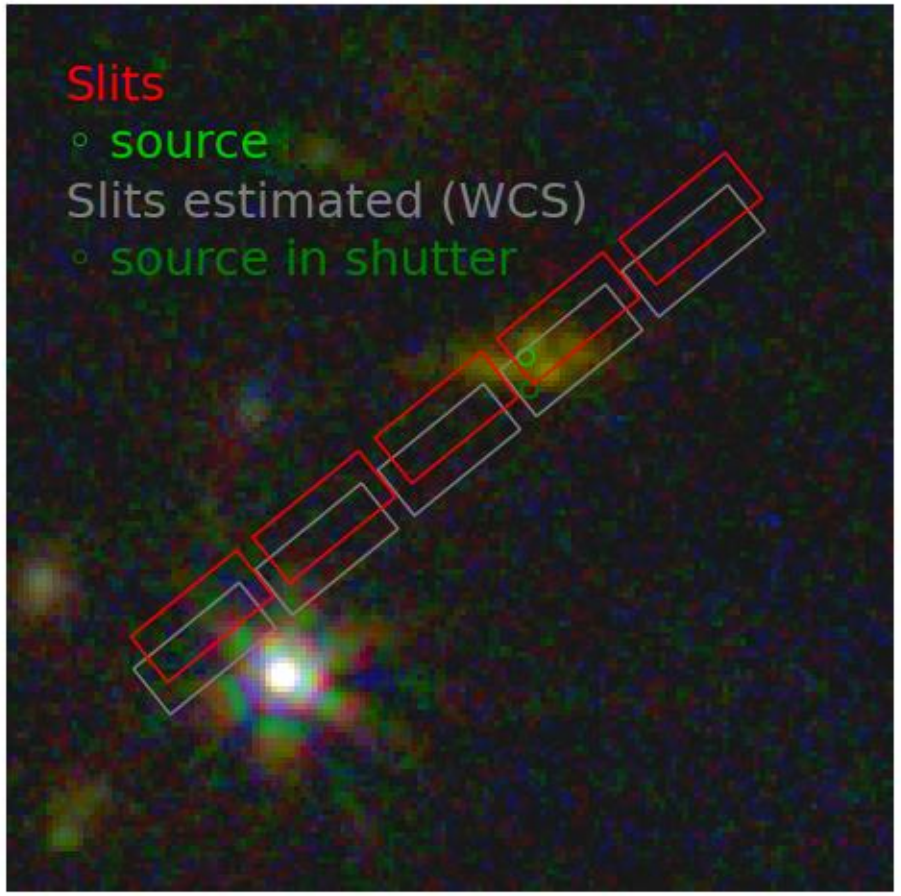

Image Credit: D. Coe
JWebbinar 33 slits-to-sky notebook

Miscellaneous – MOS Known Issues

There can be a few additional issues when working with MOS data that are worth being aware of.

- Spontaneous open/closed shutters
  - While there are a set of known stuck closed and open shutters, occasionally the MSA magnet arm can fail to open shutters that should be or open shutters that shouldn't be opened.
- Flux differences from different length slitlets (i.e., different numbers of shutters)
  - Previously there was a problem with the resampling so that extracted fluxes changed with slitlet length. Fixed as of version 1.16.0 and later.
- Occasional poor extraction box centering for point sources
  - Point source extraction uses expected source positions
  - Poor source astrometry and TA pointing errors can lead to offsets, so only the wings of the source PSF are extracted (and can feature ringing in the spectrum due to resampling effects).