MRS

Calibration Pipeline & Example

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MIRI
European
Consortium

CENTRO DE ASTROBIOLOGÍA

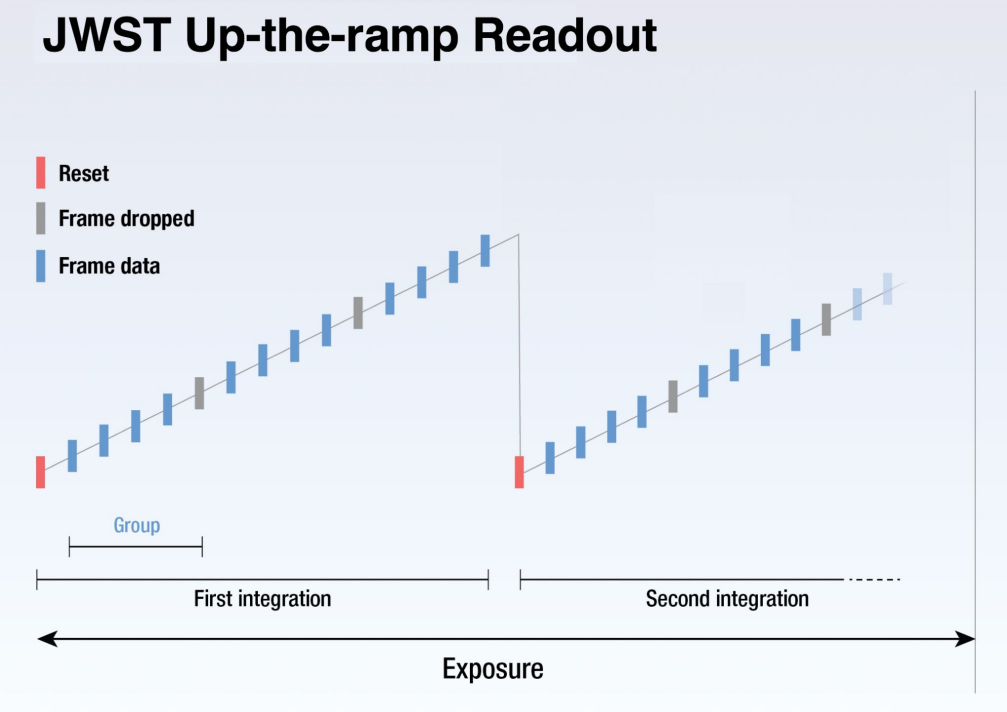
CSIC
Consejo Superior de Investigaciones Científicas

INTA
Instituto Nacional de Técnica Aeroespacial

Outline

1. **Reminders before the MRS calibrations**
   a. Frame, Group, Integration, Exposure
   b. Dithering
2. **JWST MRS IFS of NGC7319:** An AGN in the Stephan's Quintet
3. **Configuration of the NGC7319 MRS observations**
4. **MRS Raw Observations Overview**
5. **JWST MRS calibration pipeline**
   a. Stage 1 (detector level corrections)
   b. stage 2 (observing mode corrections)
   c. stage 3 (3D cubes and 1D spectra)
6. **MRS analysis of NGC7319**

MIRI detectors readout modes: Frame, Group, Integration, Exposure



Non destructive frame reads in a integration (temporal information)

MIRI detector readout modes:

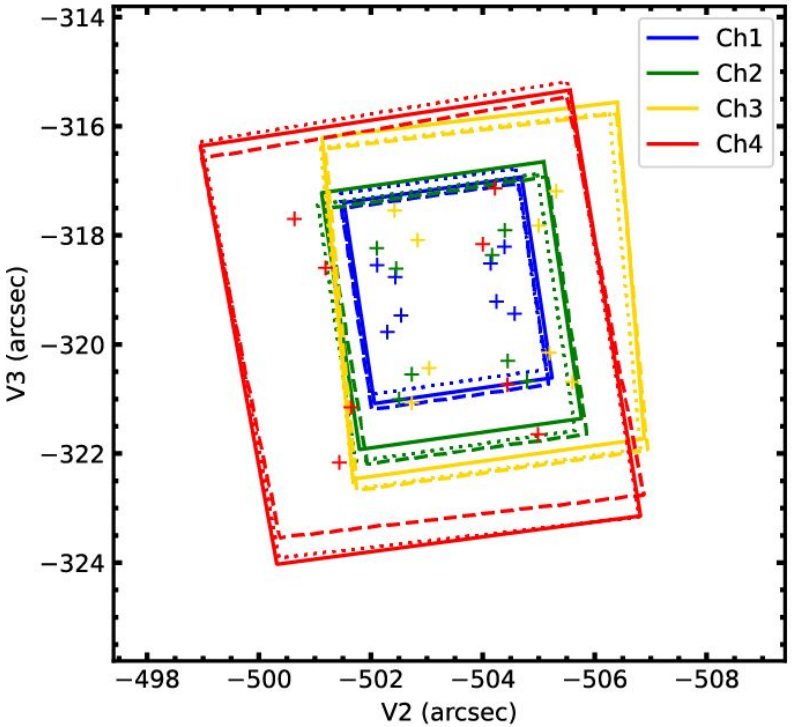
- FASTR1: 1 Group = 1 Frame
- SLOWR1: 1 Group = 9 Frame

$SLOWR1\ (N_{samples} = 9, t_1 = 23.890\ s)$

$FASTR1\ (N_{samples} = 1,\ t_1 = 2.775\ s)$

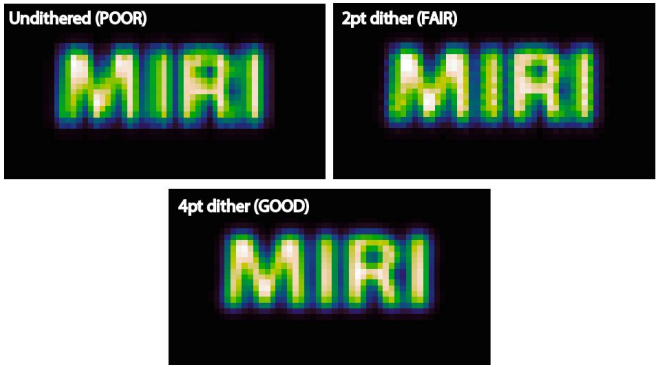
MIRI MRS dithering

Point-source dither patterns for all MRS channels

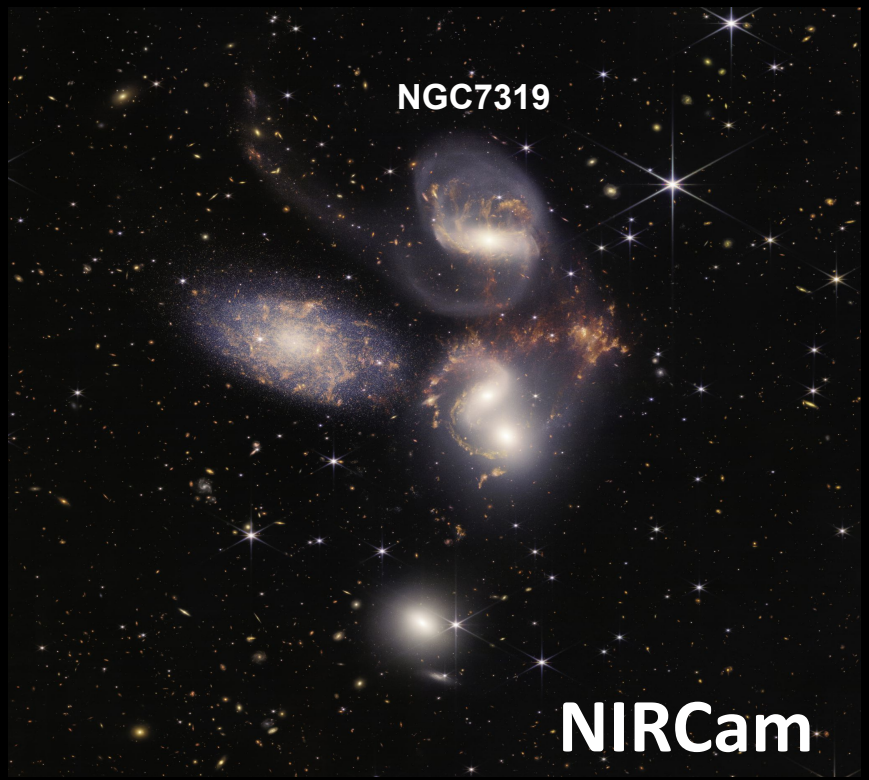


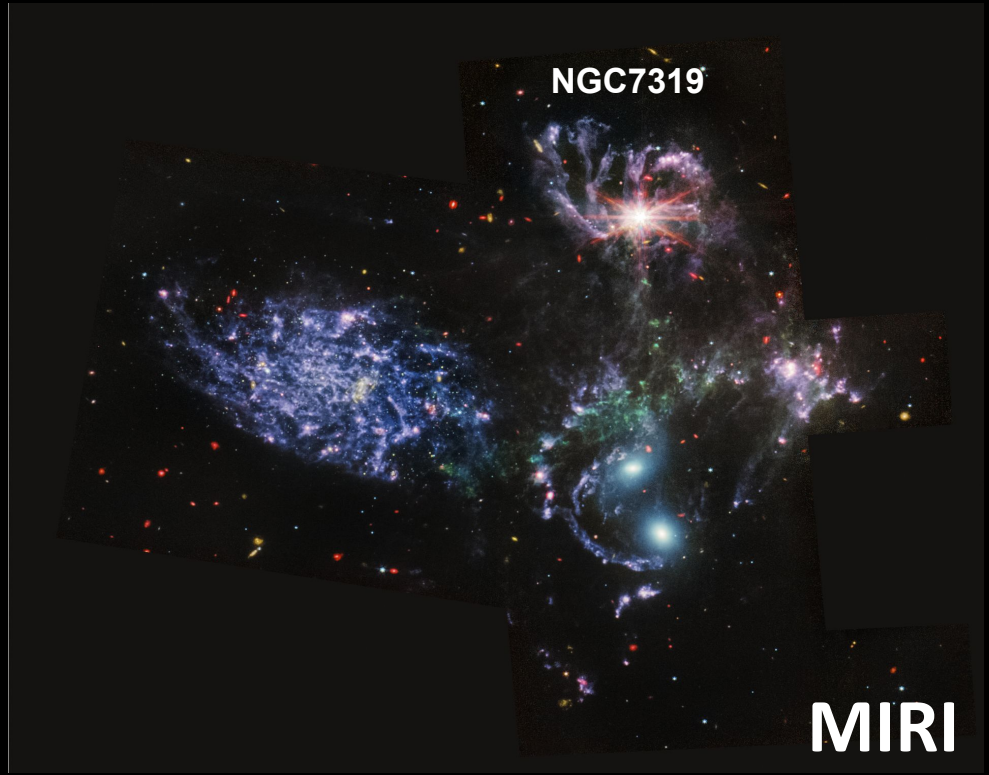
Dithers are mandatory and really useful on JWST observations:

- Have the best spatial and spectral sampling
- Reduce the impact of the detector features and CRs residuals in the final observations
- …

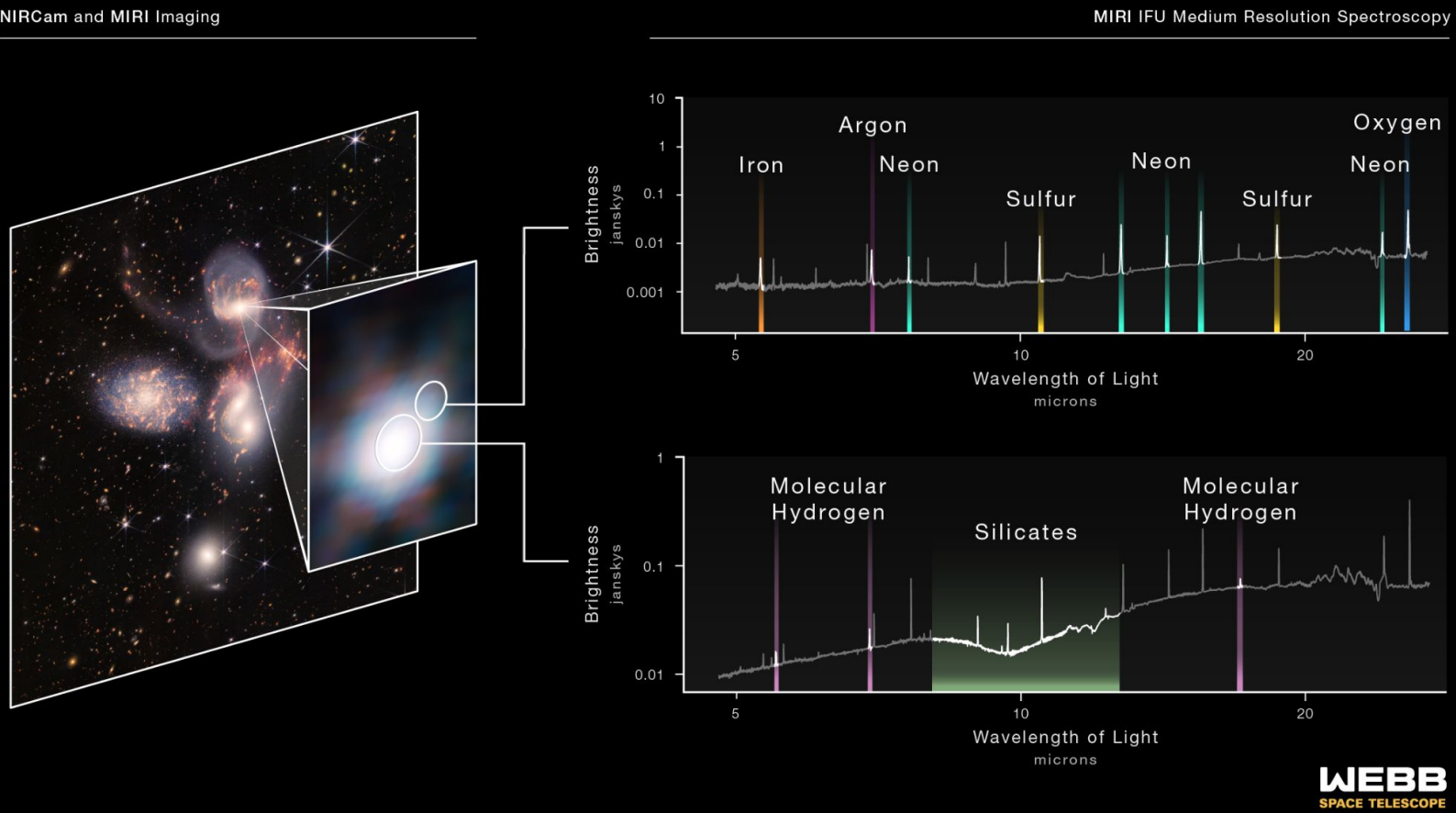


JWST images of the Stephan's Quintet





JWST MRS IFS of NGC7319: An AGN in the Stephan's Quintet



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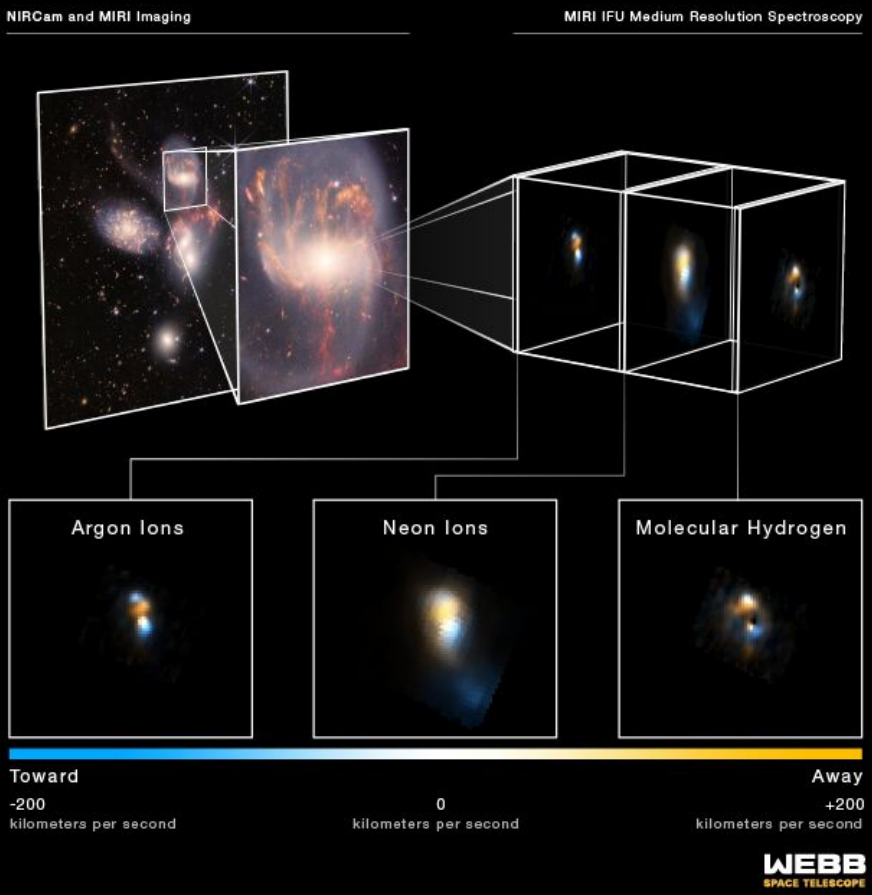
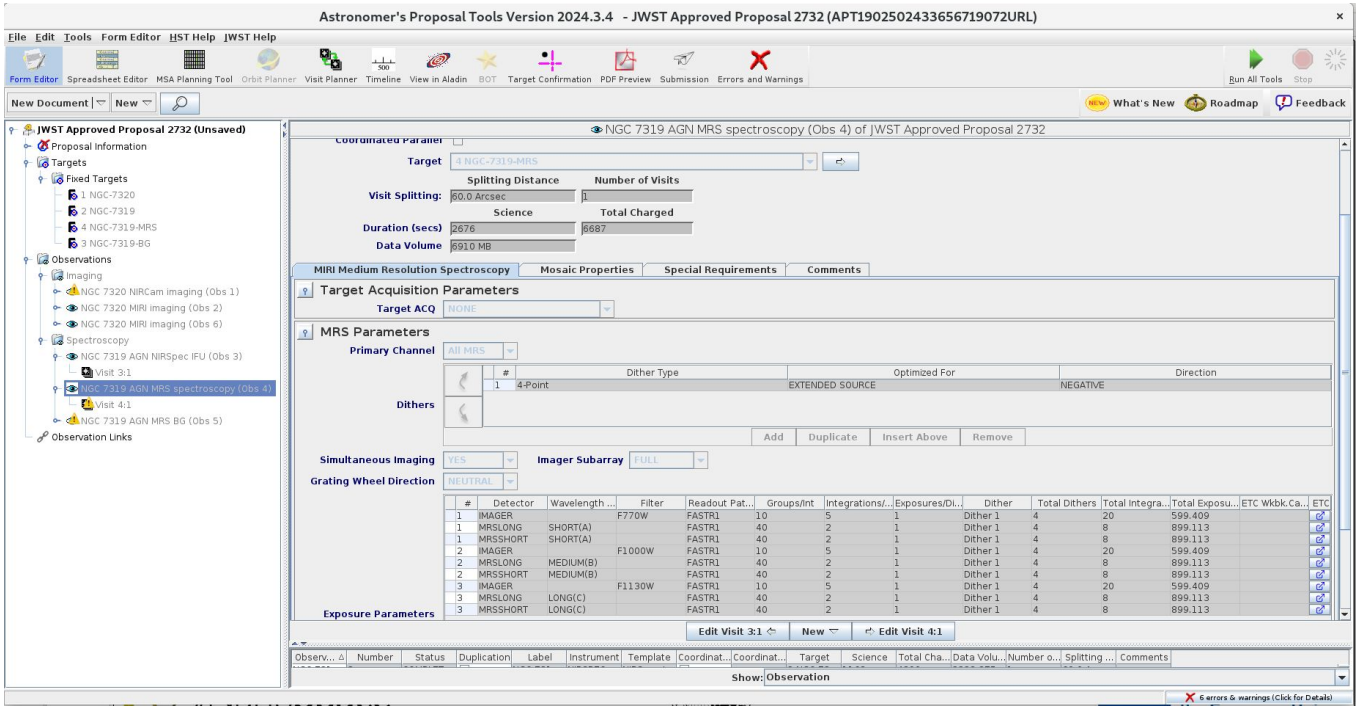


Observational MRS configuration of NGC7319: APT & obs. setup

Which is the configuration of the MRS observations of NGC7319?

1. Open the APT
2. Retrieve program 2732 (File/Retrieve from STScI/Retrieve using program ID/)



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Questions to answer:

- What MRS Channels and Bands have been observed?
- What readout was used for these observations?
- How many groups and integrations?
- What was the dithering strategy?
- What is the total exposure time of each individual MRS band?
- Do these observations include background?
- How many uncal files (raw observations) will I have?

	Science	Back.
Channels		
Bands		
Readout		
Groups		
Integrations		
Dithers		
Texp per band		
Nº uncal files		

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	Science	Back.
Channels	ALL	
Bands	ALL	
Readout	FASTR1	
Groups	40	
Integrations	2	
Dithers	4	
Texp per band	899s	
Nº uncal files	24 (12x4/2)	

Observational MRS configuration of NGC7319: APT & obs. setup

Which is the configuration of the MRS observations of NGC7319?

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	Science	Back.
Channels	ALL	ALL
Bands	ALL	ALL
Readout	FASTR1	FASTR1
Groups	40	40
Integrations	2	2
Dithers	4	2
Texp per band	899s	449s
Nº uncal files	24 (12x4/2)	12 (12x4/2)

MRS Raw Observations Overview (uncal files): shared data

/home/christ/JWST/projects/IFU_MRS/Data/

- Background/ & Source/
  - uncal/
    - Uncalibrated data from NGC7319
  - stage1/
    - Rate detector images
  - stage2/
    - Fully calibrated detector images
  - stage3/
    - Fully calibrated 3D spectral cubes and 1D extracted spectra
- Notebook/
  - JWPipeNB-MIRI-MRS.ipynb
    - Example of a JWST pipeline running code for the MRS
  - Analysis_MRS_1Dspectrum_3Dcubes.ipynb
    - Example to visualize and analyze the 3D spectral cube and 1D extracted spectra
- Plots/
  - Folder to store the plots that you generate in the Analysis_MRS_1Dspectrum_3Dcubes.ipynb

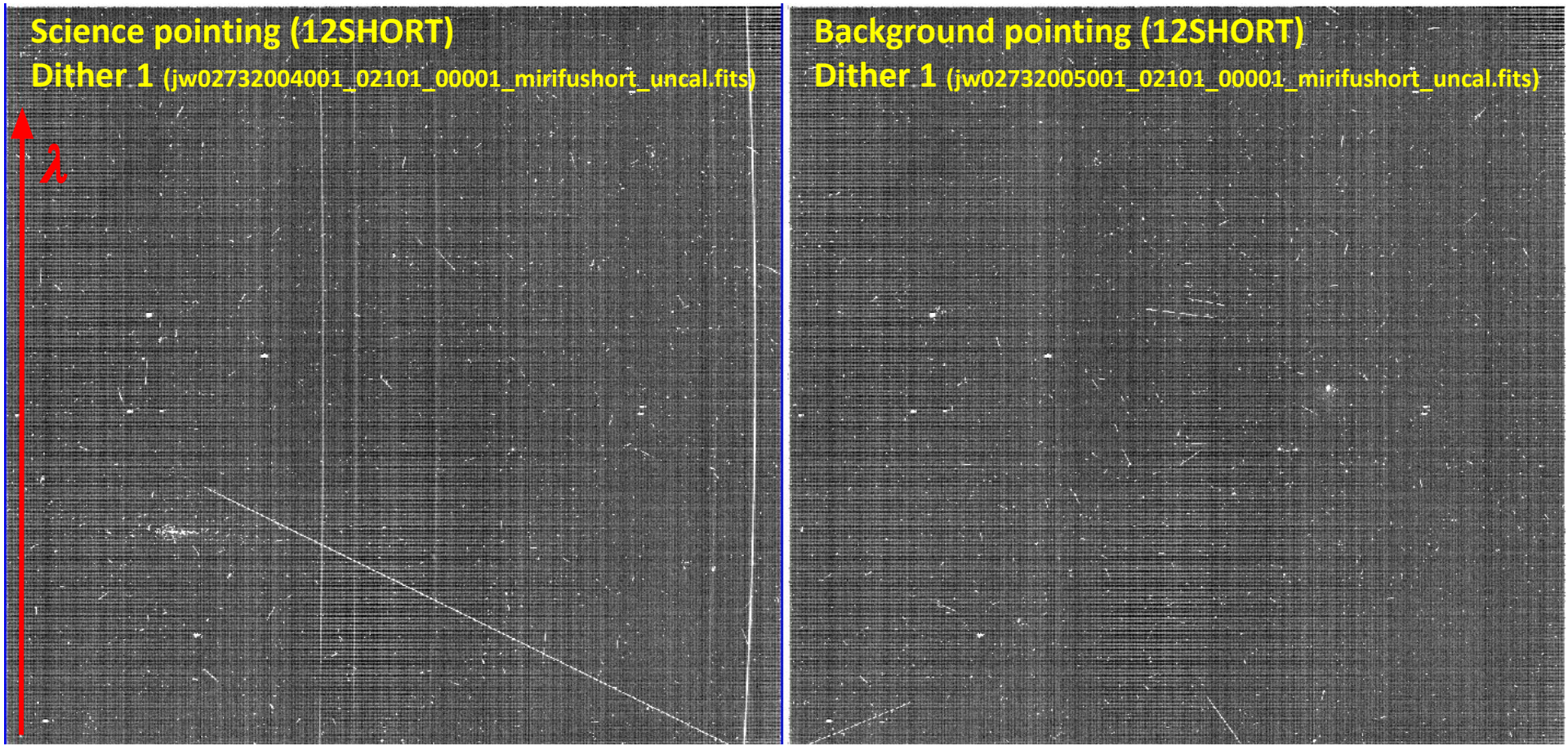
/lustre/JDAP/jdap_data/crds_cache

- Folder with all the JWST reference files needed to run the JWST pipeline

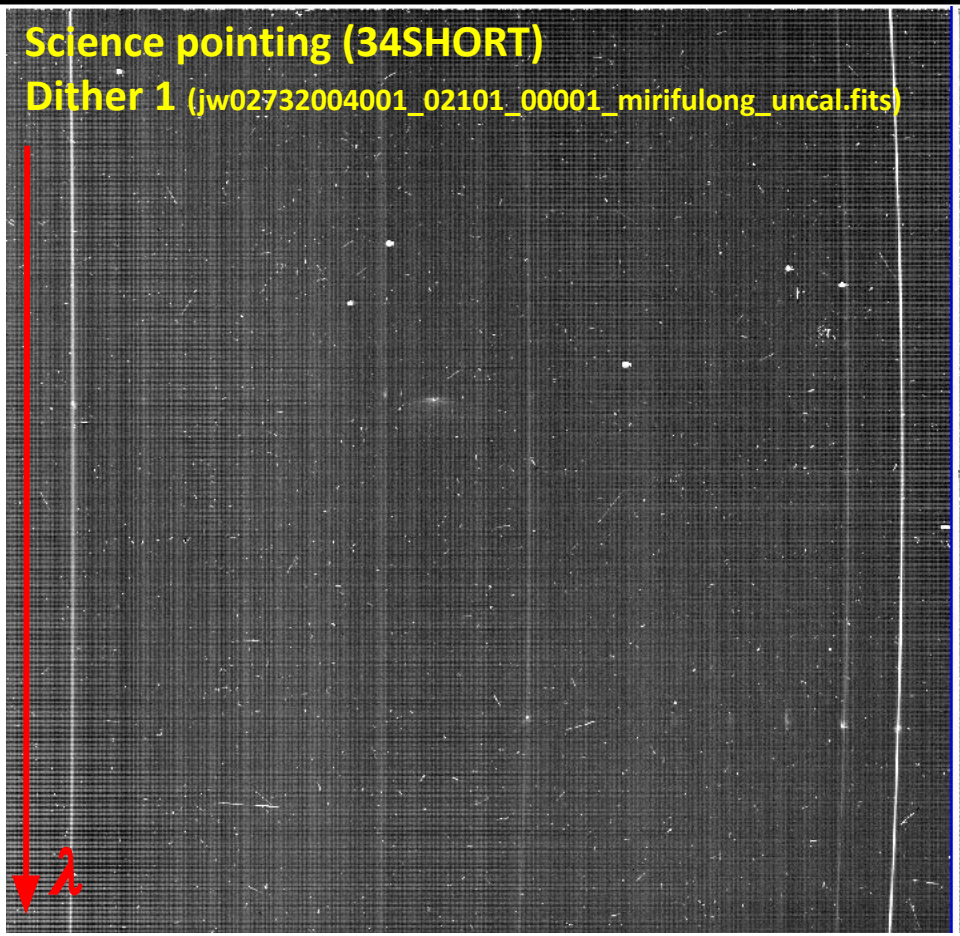
Use ds9 program to perform a first overview of the raw data

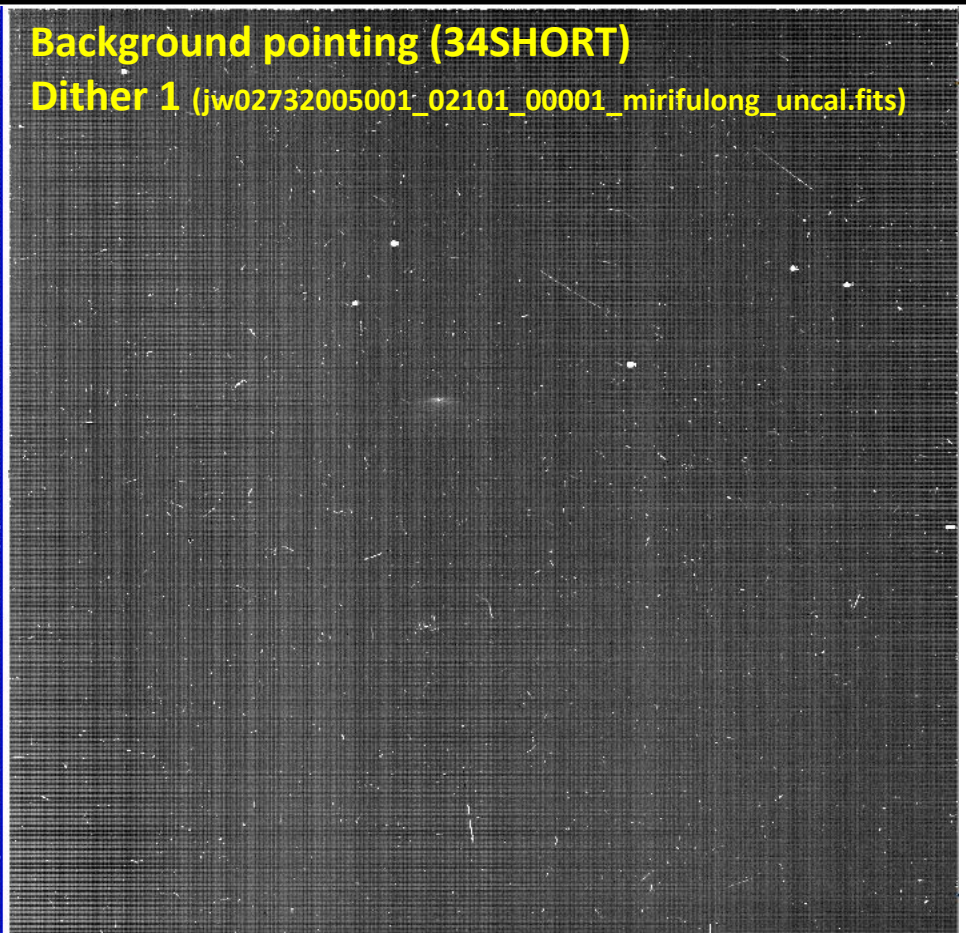
Science obs.: ~/Data/Science/uncal/
Background obs.: ~/Data/Background/uncal/

MRS Raw Observations Overview (uncal files): short detector (ch 12)

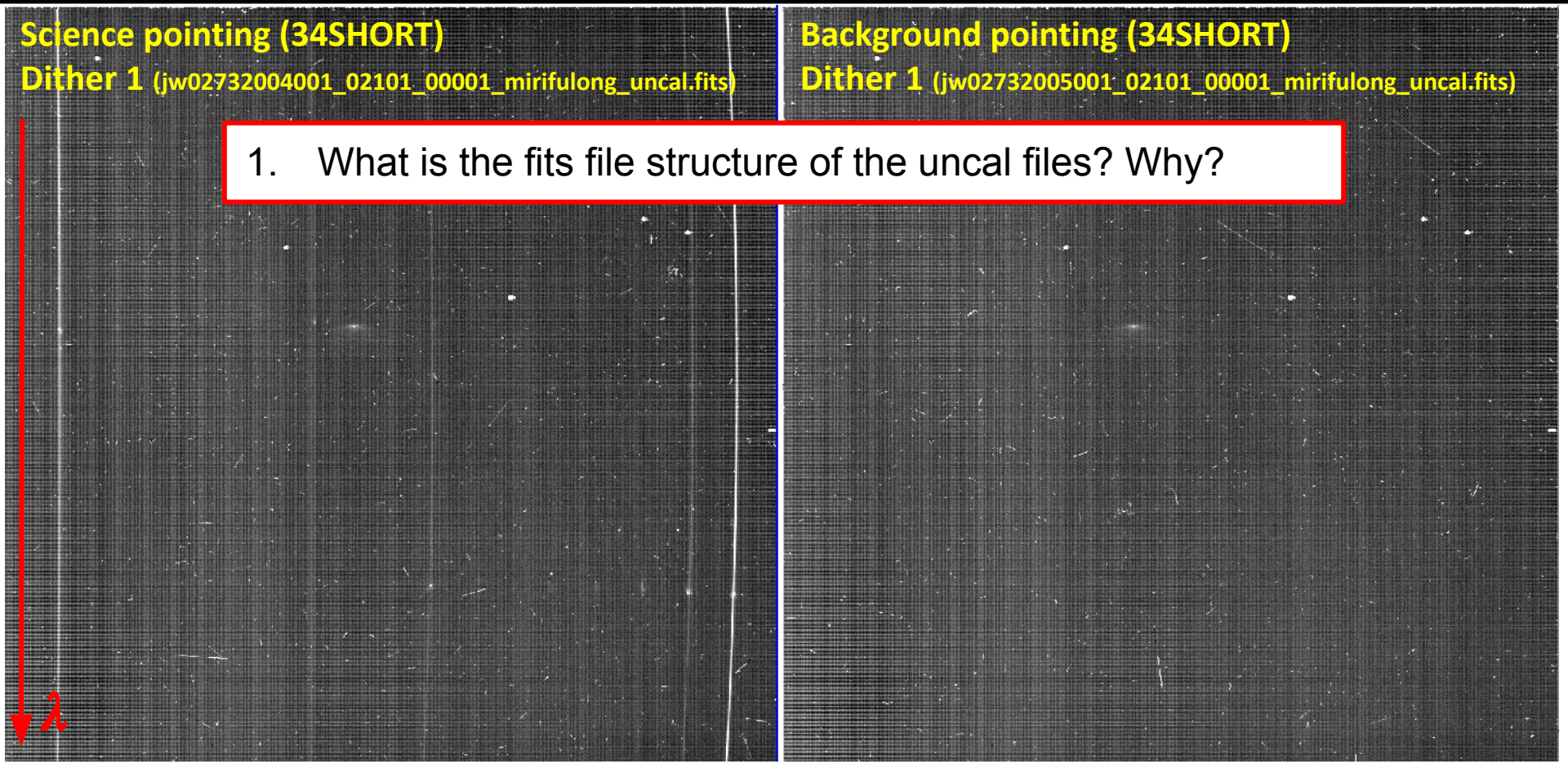


MRS Raw Observations Overview (uncal files): long detector (ch 34)

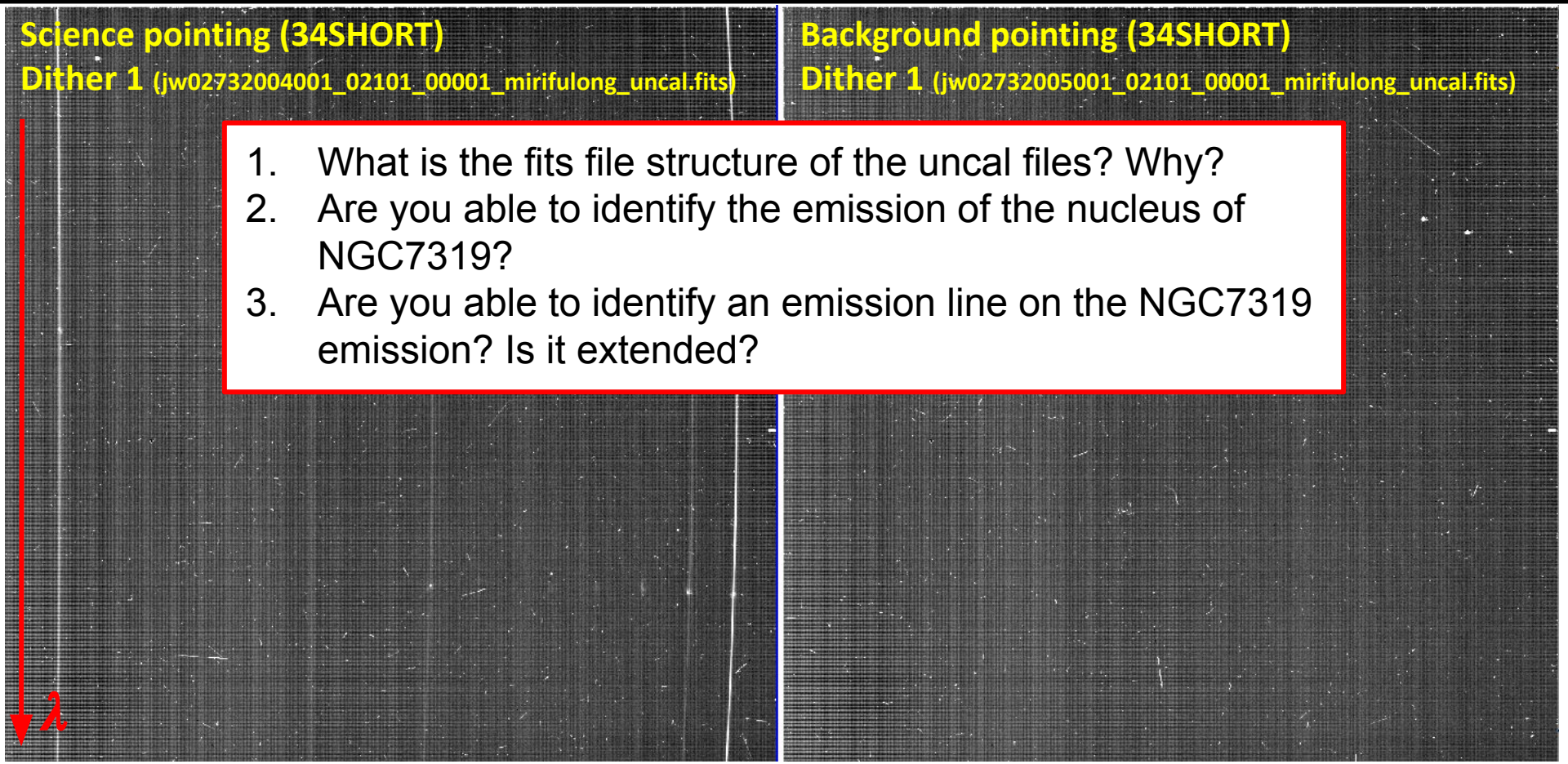




MRS Raw Observations Overview (uncal files): long detector (ch 34)

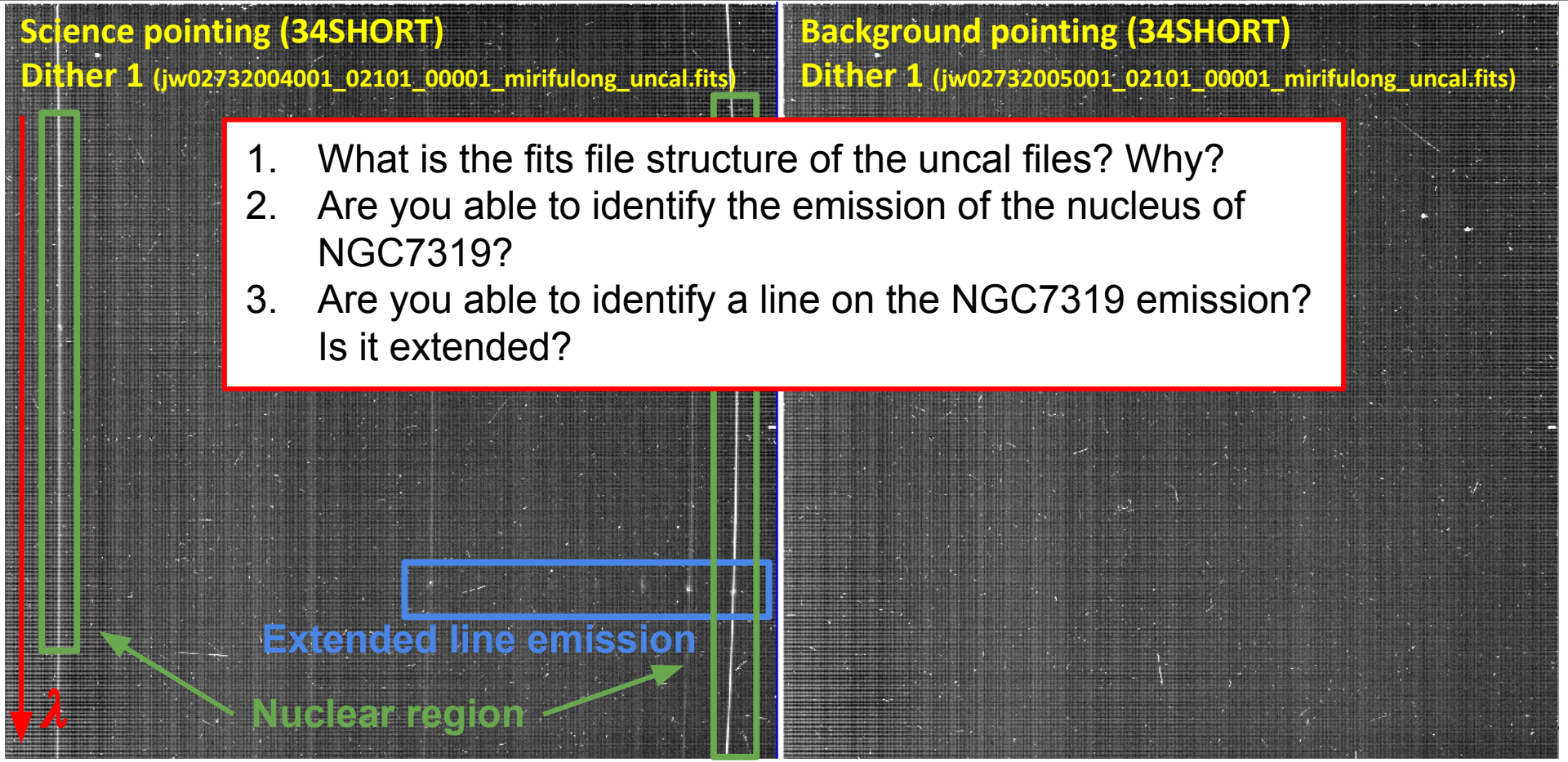


MRS Raw Observations Overview (uncal files): long detector (ch 34)



1. What is the fits file structure of the uncal files? Why?
2. Are you able to identify the emission of the nucleus of NGC7319?
3. Are you able to identify an emission line on the NGC7319 emission? Is it extended?

MRS Raw Observations Overview (uncal files): long detector (ch 34)



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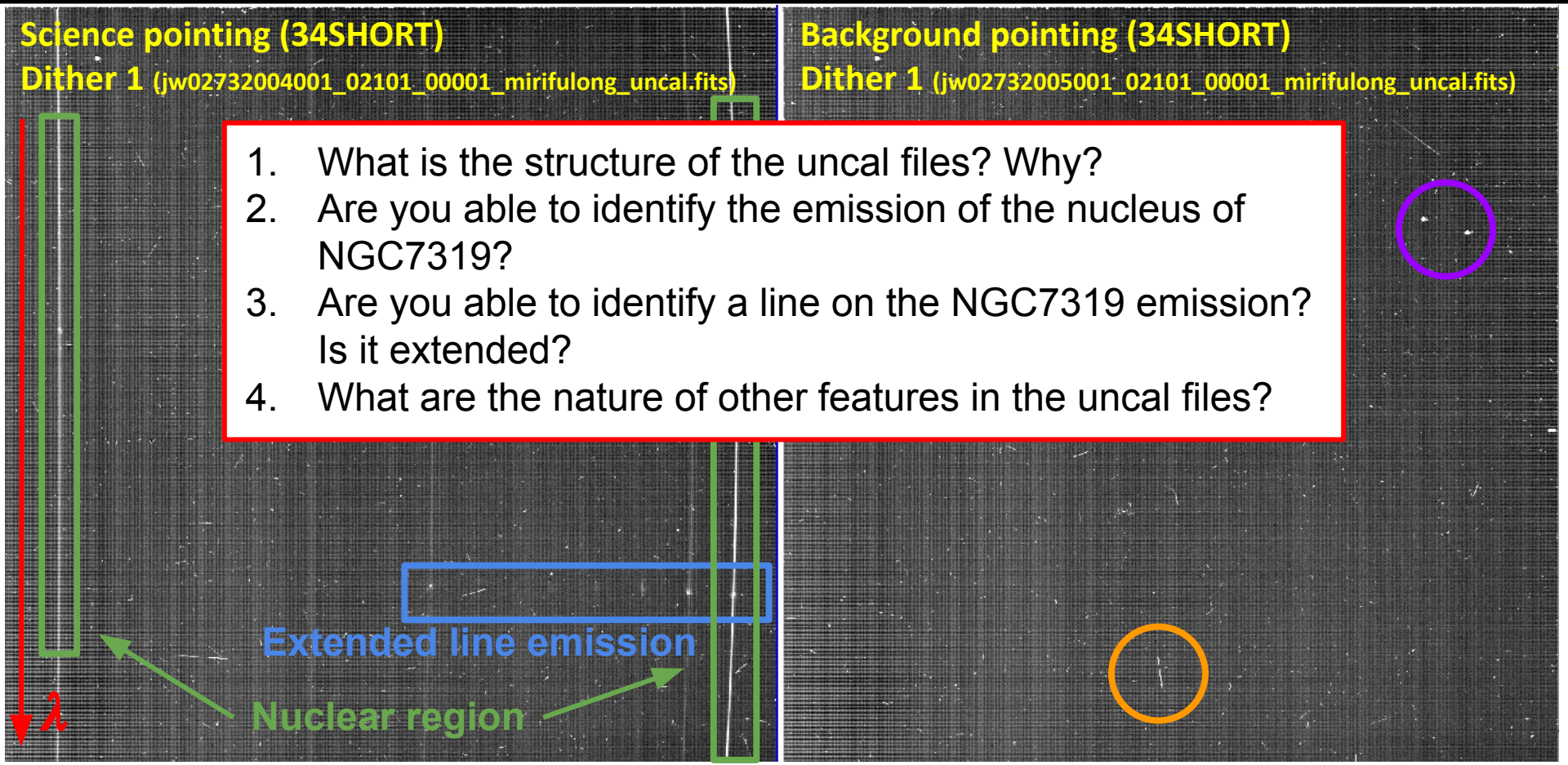

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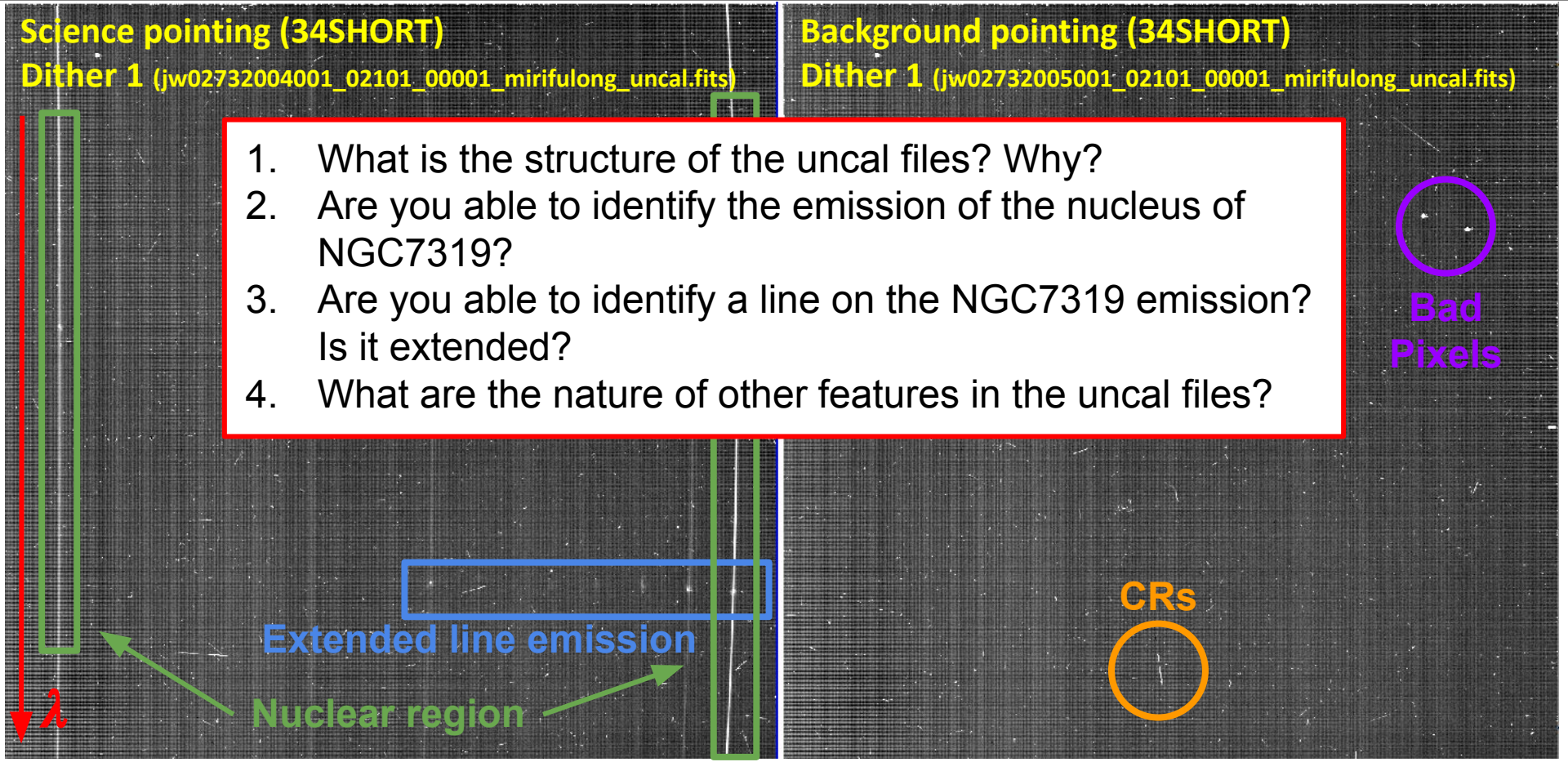
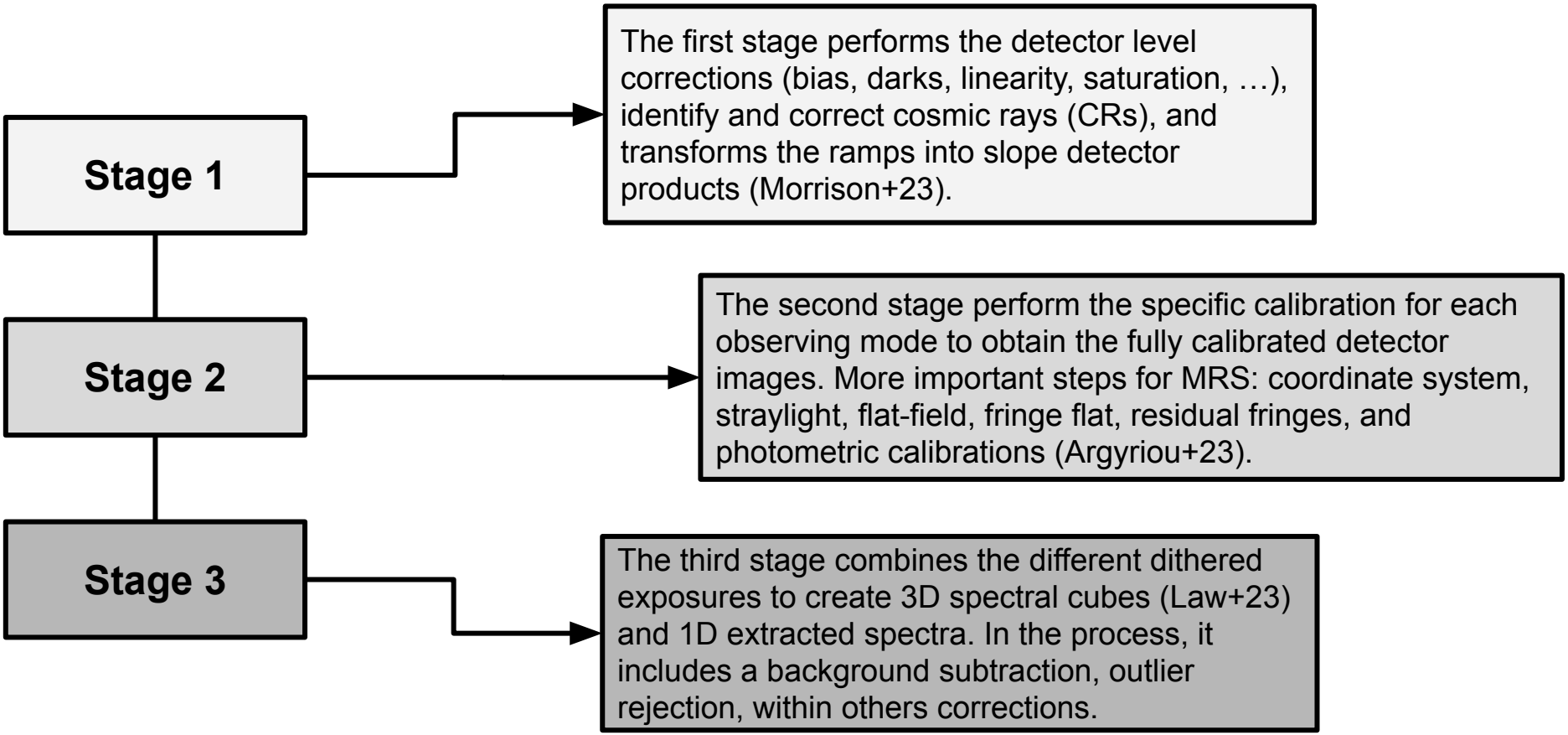


JWST MRS calibration pipeline: overview



Open notebook JWPipeNB-MIRI-MRS.ipynb

1) Set the location of the uncal observations

```
# --------------------------User Mode Directories-----------------------
# If demo_mode = False, look for user data in these paths
if not demo_mode:
    # Set directory paths for processing specific data; these will need
    # to be changed to your local directory setup (below are given as
    # examples)
    user_home_dir = os.path.expanduser('/home/jalvarez/Postdoc_JWST/COSPAR_INDIA_JWST/MRS/Data/')

    # Point to where science observation data are
    # Assumes uncalibrated data in sci_dir/uncal/ and results in stage1,
    # stage2, stage3 directories
    sci_dir = os.path.join(user_home_dir, 'Source/')

    # Point to where background observation data are
    # Assumes uncalibrated data in bg_dir/uncal/ and results in stage1,
    # stage2, stage3 directories
    bg_dir = os.path.join(user_home_dir, 'Background/')
    #bg_dir = '' # If no background observation, use an empty string
```

JWST MRS calibration pipeline: set up the notebooks

2) Select the channels and bands that you would like to calibrate (only two channel and one band to reduce time in the calibration process during the workshop)

```
# Whether or not to process only data from a given band/channel
# Useful if overriding reference files
# Note BOTH must be set in order to work
use_ch='12' # '12' or '34' or ''
use_band='SHORT' # 'SHORT', 'MEDIUM', 'LONG', or ''
```

3) Select the pipeline stages that you would like to run for the science and background data set

```
# Science processing
dodet1=True
dospec2=True
dospec3=True

# Background processing
dodet1bg=True
dospec2bg=True #needed for Master Background subtraction
```

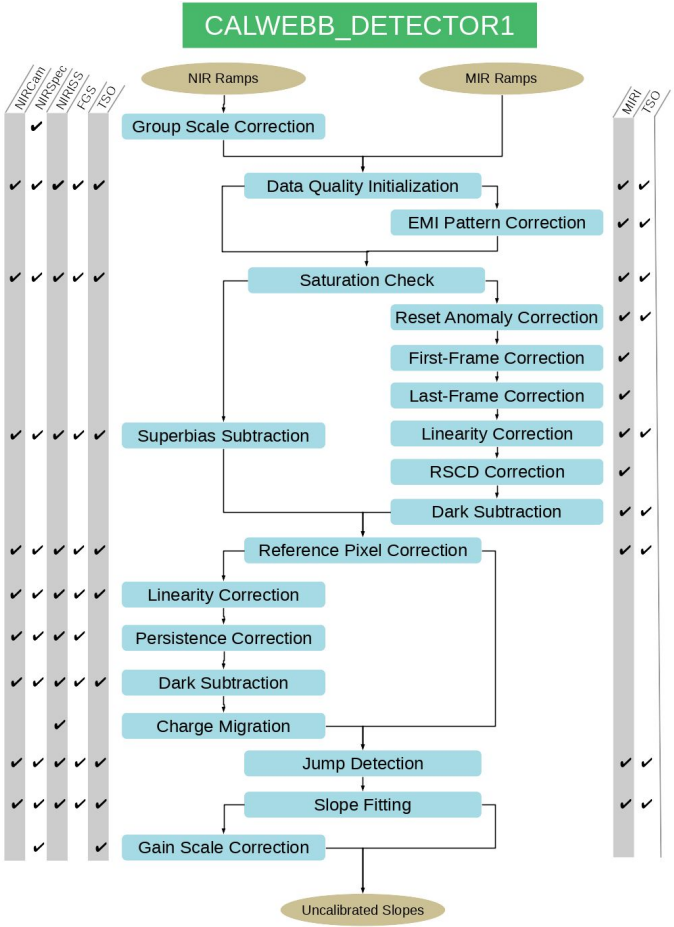
4) Select the background subtraction methodology (explained later on this presentation)

```
# Where should background subtraction using the dedicated backgrounds be done?
# (Note that if using master-background subtraction, backgrounds must be select above to process through spec2)
pixel_bg = False # Pixel-based background subtraction in spec2 (direct pixel subtraction) -Deep background exposures needed to not add noise.
master_bg = True # Master-background subtraction in spec3 (subtract spectrum generated from the backgrounds) -This is the default pipeline setting
```

5) Set up the CRDS

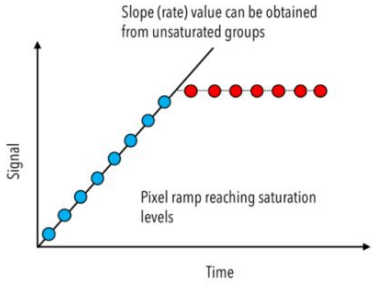
```
# Check whether the local CRDS cache directory has been set.
# If not, set it to the user home directory
if (os.getenv('CRDS_PATH') is None):
    os.environ['CRDS_PATH'] = os.path.join(os.path.expanduser('~'), 'crds')
# Check whether the CRDS server URL has been set.  If not, set it.
if (os.getenv('CRDS_SERVER_URL') is None):
    os.environ['CRDS_SERVER_URL'] = 'https://jwst-crds.stsci.edu'

# Echo CRDS path and context in use
print('CRDS local filepath:', os.environ['CRDS_PATH'])
print('CRDS file server:', os.environ['CRDS_SERVER_URL'])
```

JWST MRS calibration pipeline: stage 1 (detector level corrections)

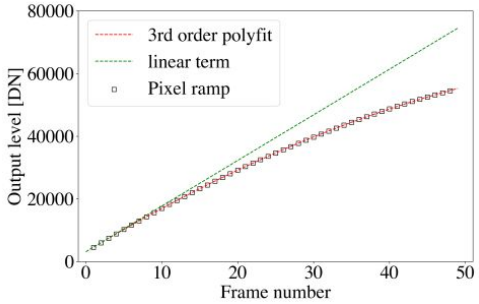


Run Section 5 (Detector1 Pipeline) of the notebook

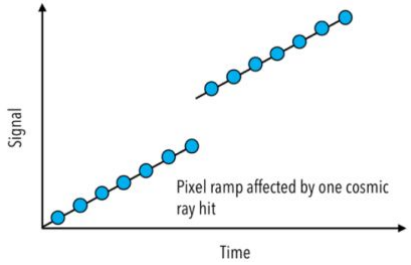
Saturation



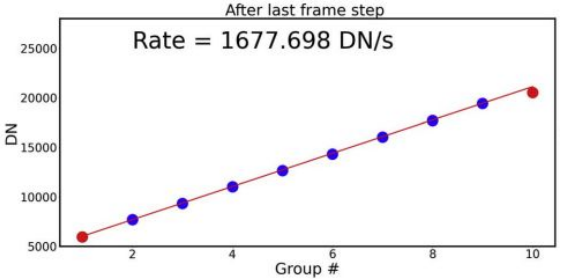
Linearity



CR hit in pixel ramp



Slope fitting (DN to DN/s)

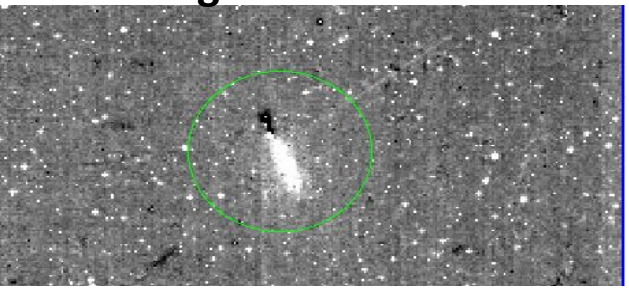


JWST MRS calibration pipeline: Cosmic ray showers corrections

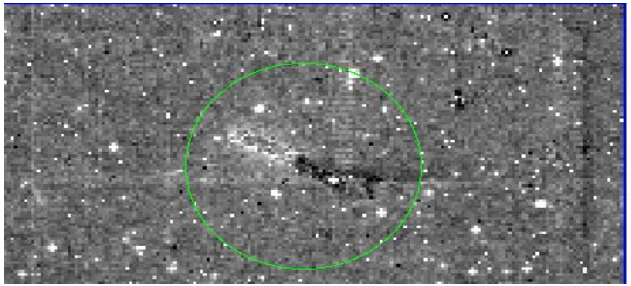
- The Cosmic Rays Showers have a high impact on deep MRS observations and the study of faint sources
- CR showers have a large variety of shapes and intensities in the MIRI detectors
  - This makes really difficult to find a general algorithm that identification and correct all of them
- The MIRI pipeline incorporate two algorithms to detect and correct Cosmic Ray Showers in the Stage 1 & 2.
- First CR shower correction is included in the jump step of the pipeline, and can be turn it on following this:

```
# Toggle detection of cosmic ray showers if desired (on by default)
det1dict['jump']['expand_large_events'] = True
det1dict['jump']['find_showers'] = True
det1dict['jump']['extend_snr_threshold'] = 1.4
```

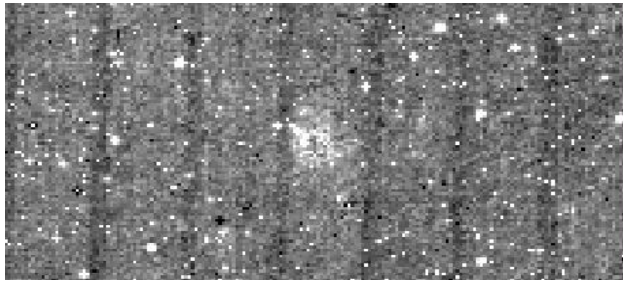
Bright CR shower



Intermediate CR shower



Shallower CR shower

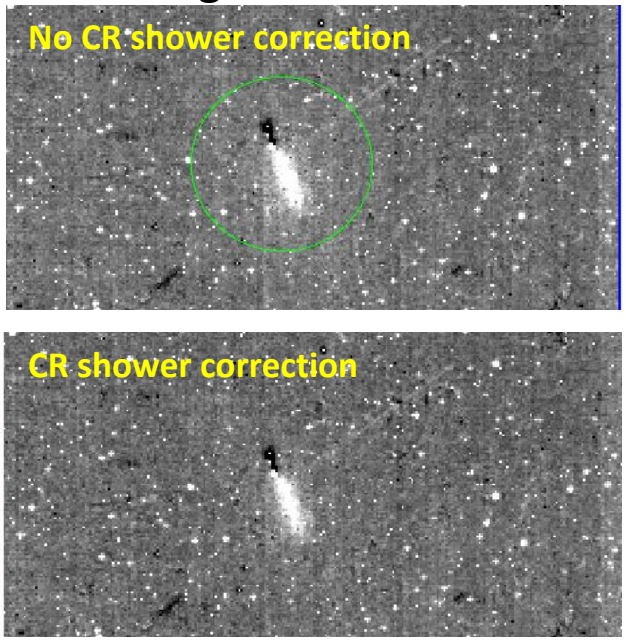


JWST MRS calibration pipeline: Cosmic ray showers corrections

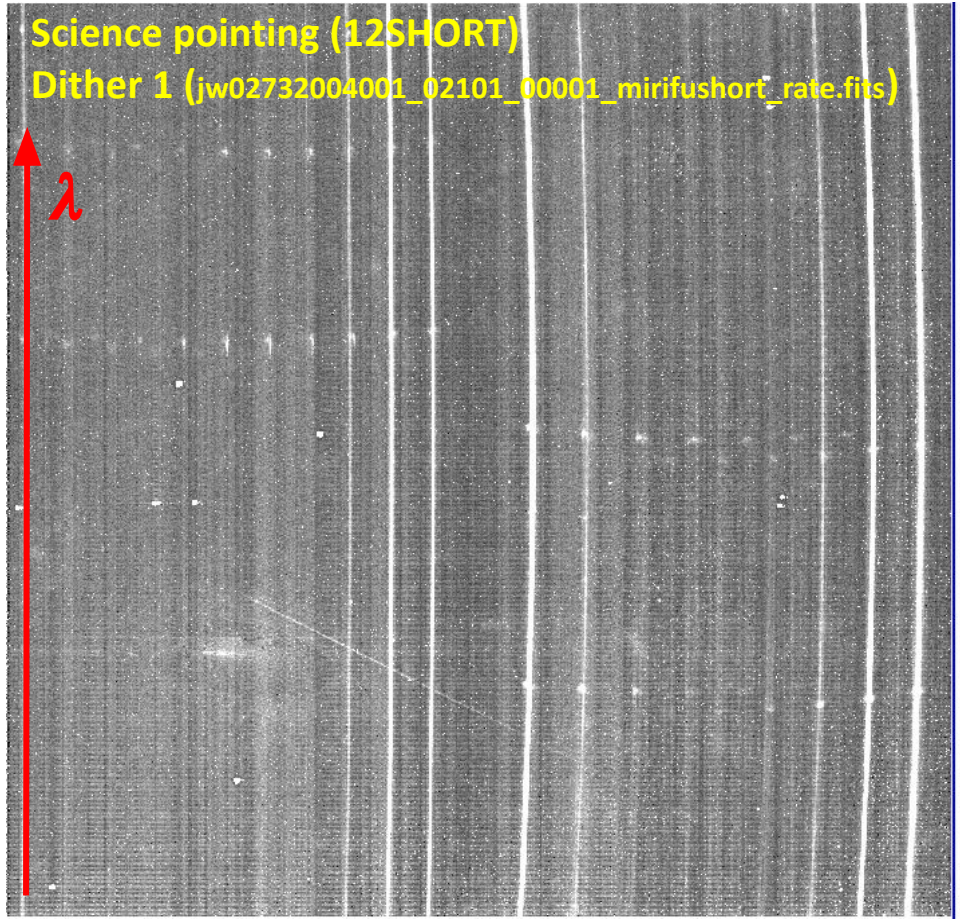
Bright CR shower

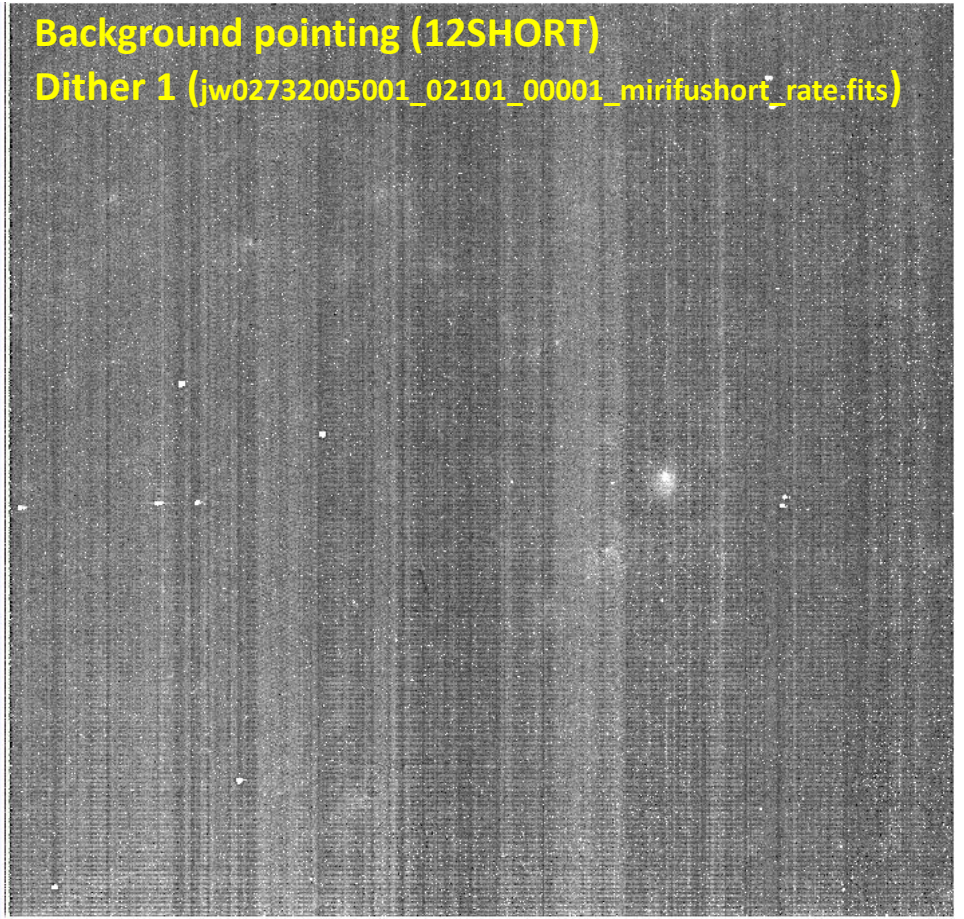
Intermediate CR shower

Shallower CR shower



JWST MRS calibration pipeline: rate images (DN/s)





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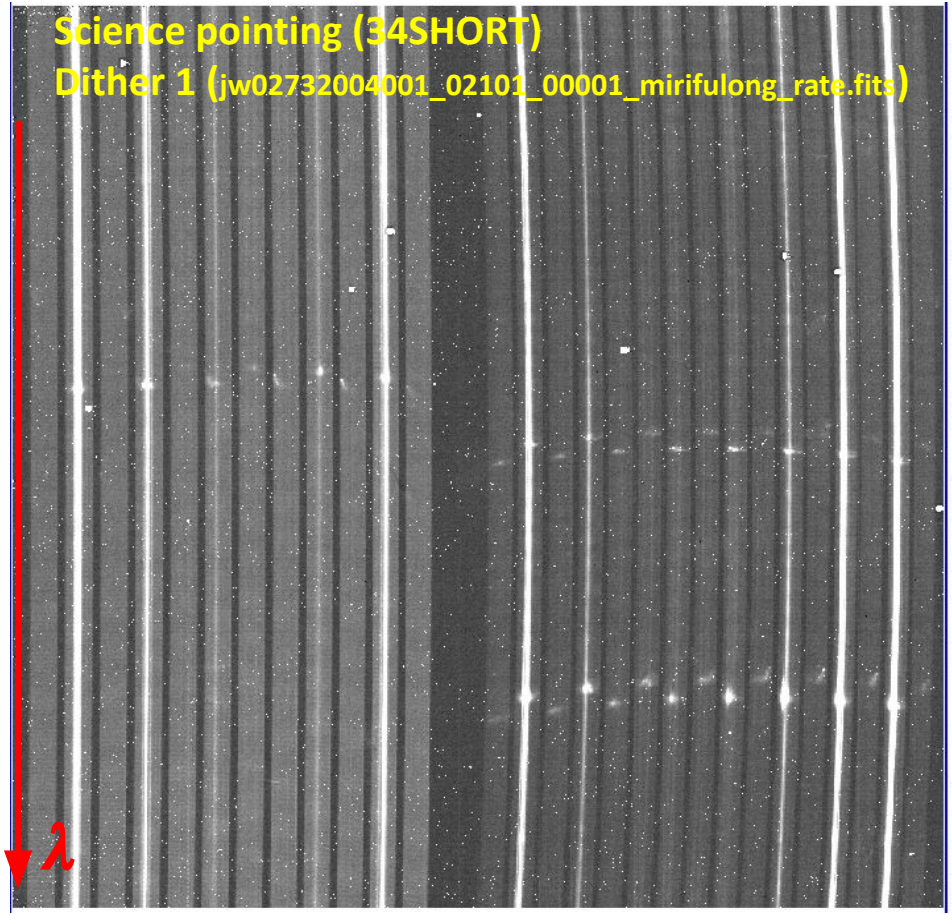

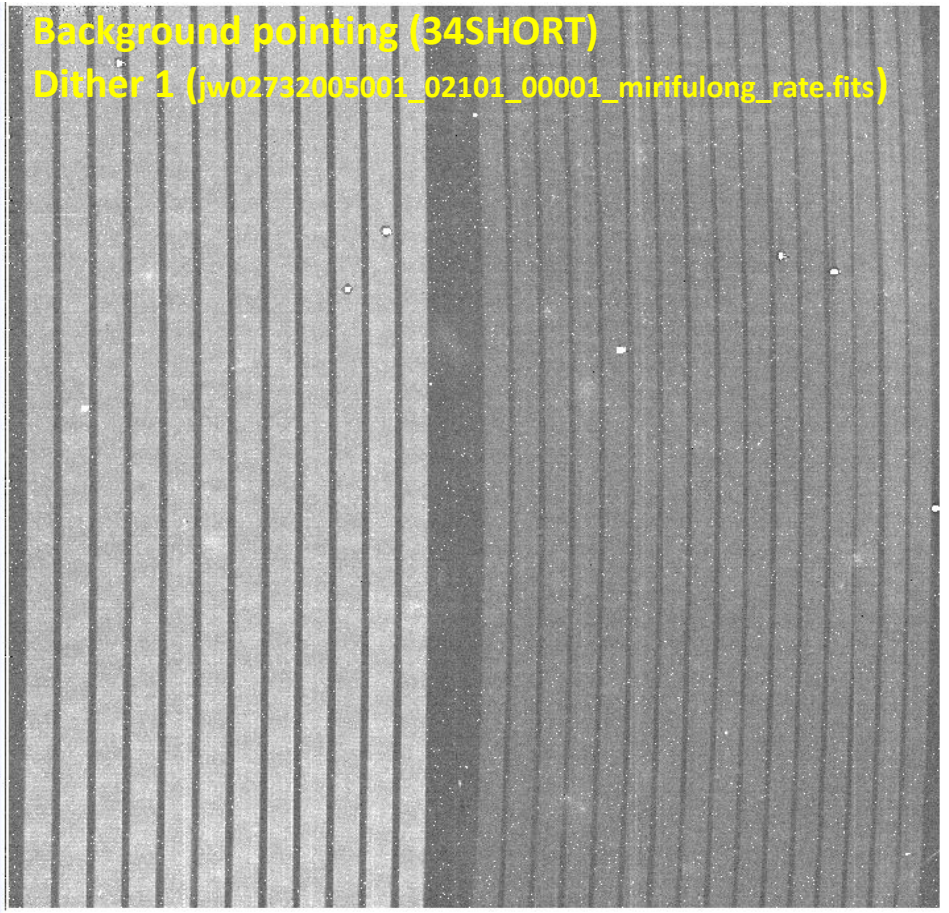

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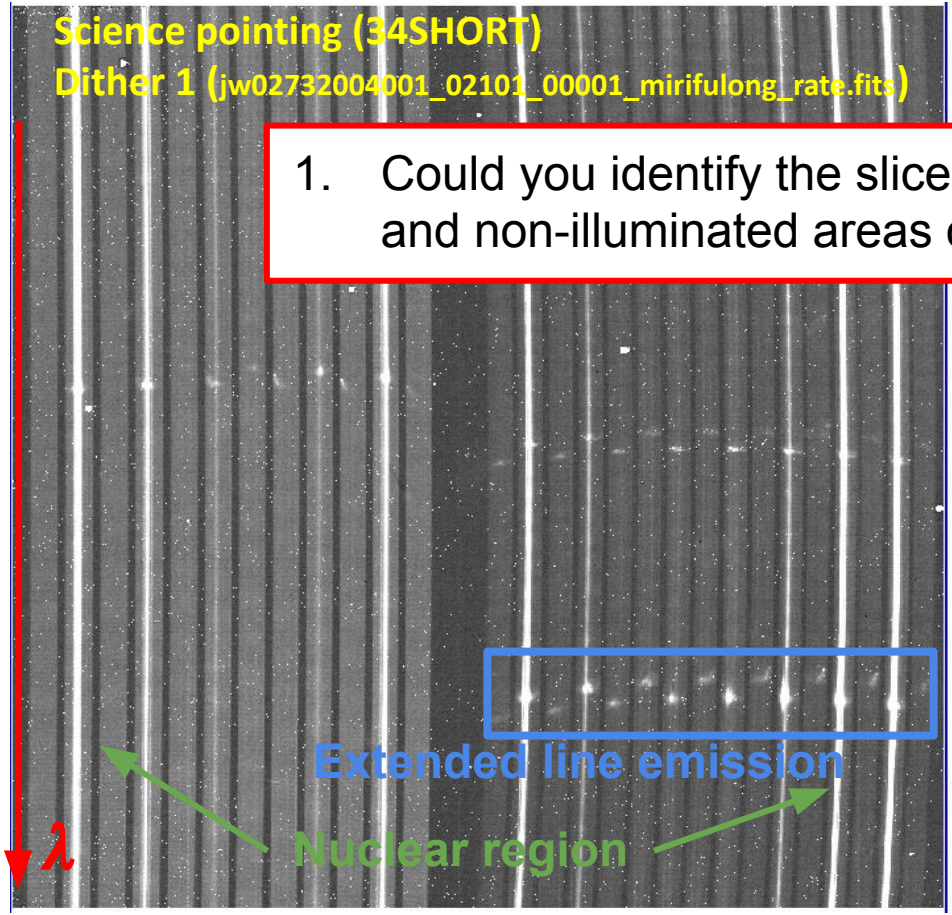
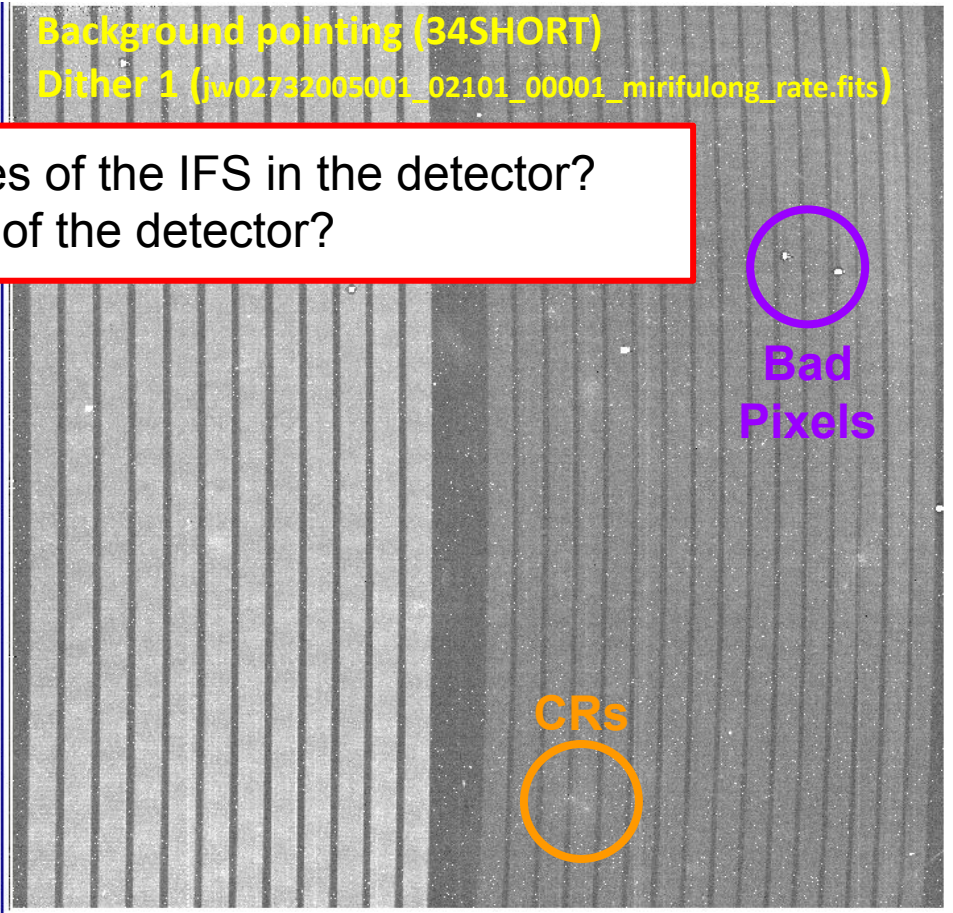
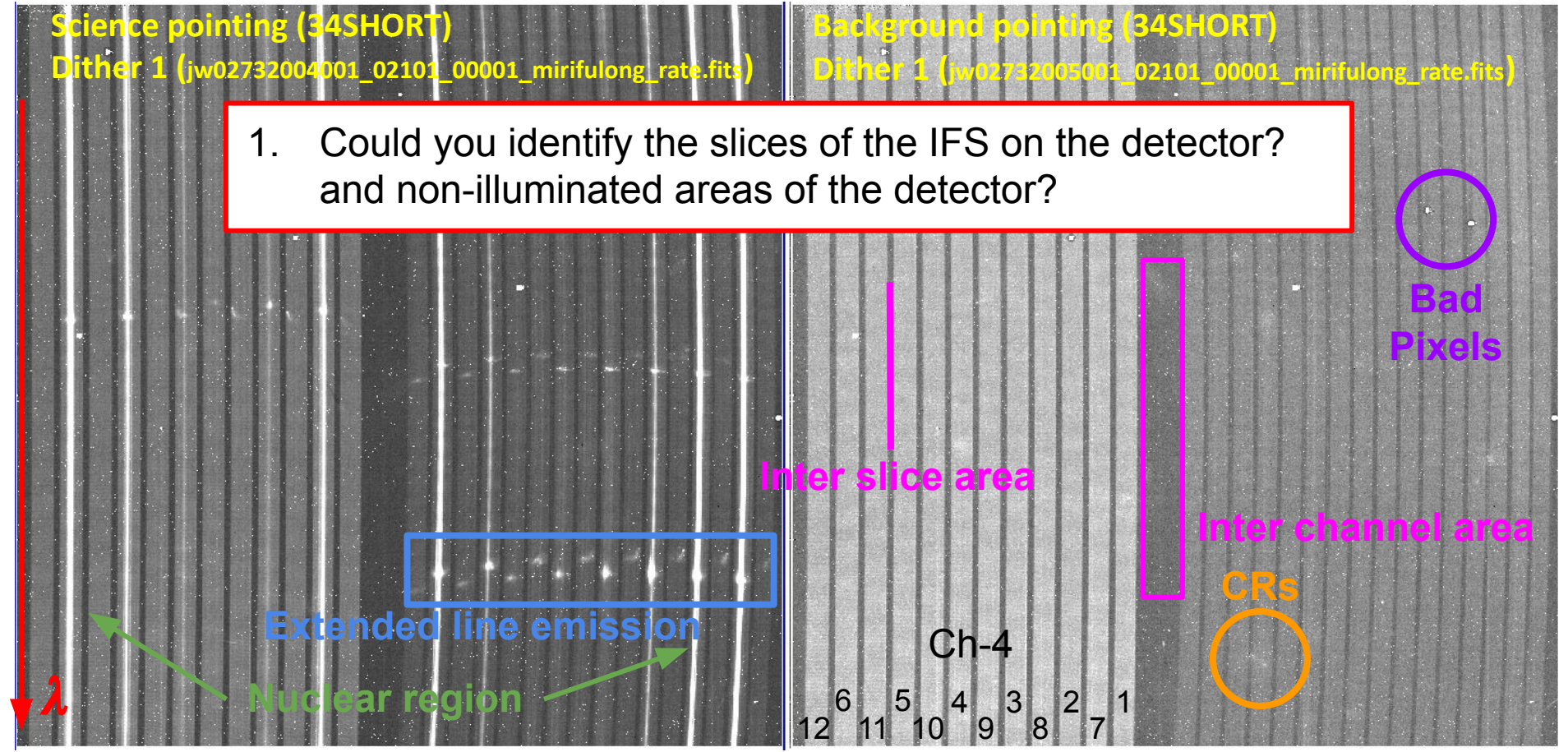




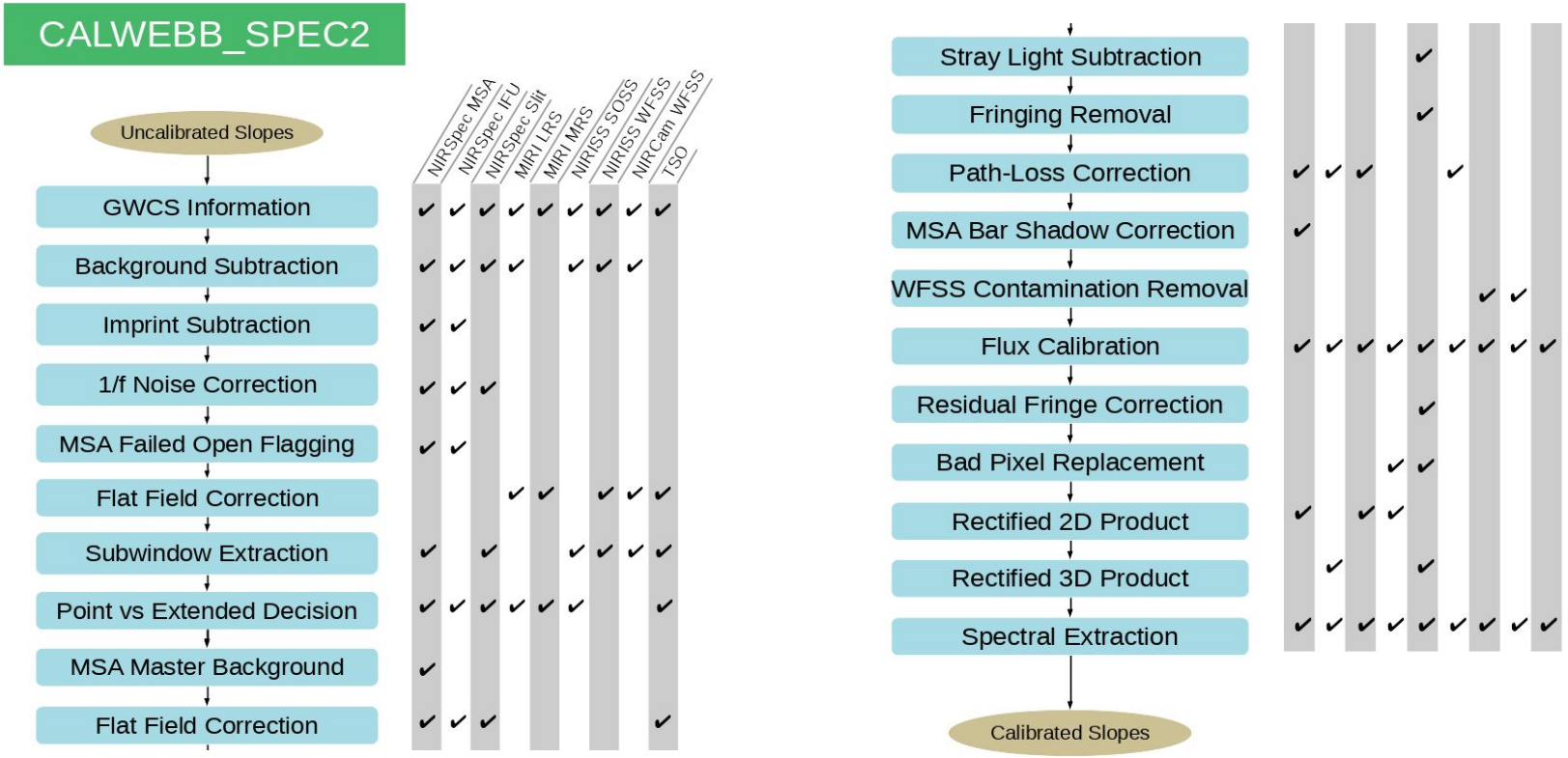
1. Could you identify the slices of the IFS in the detector? and non-illuminated areas of the detector?

JWST MRS calibration pipeline: rate images (DN/s)

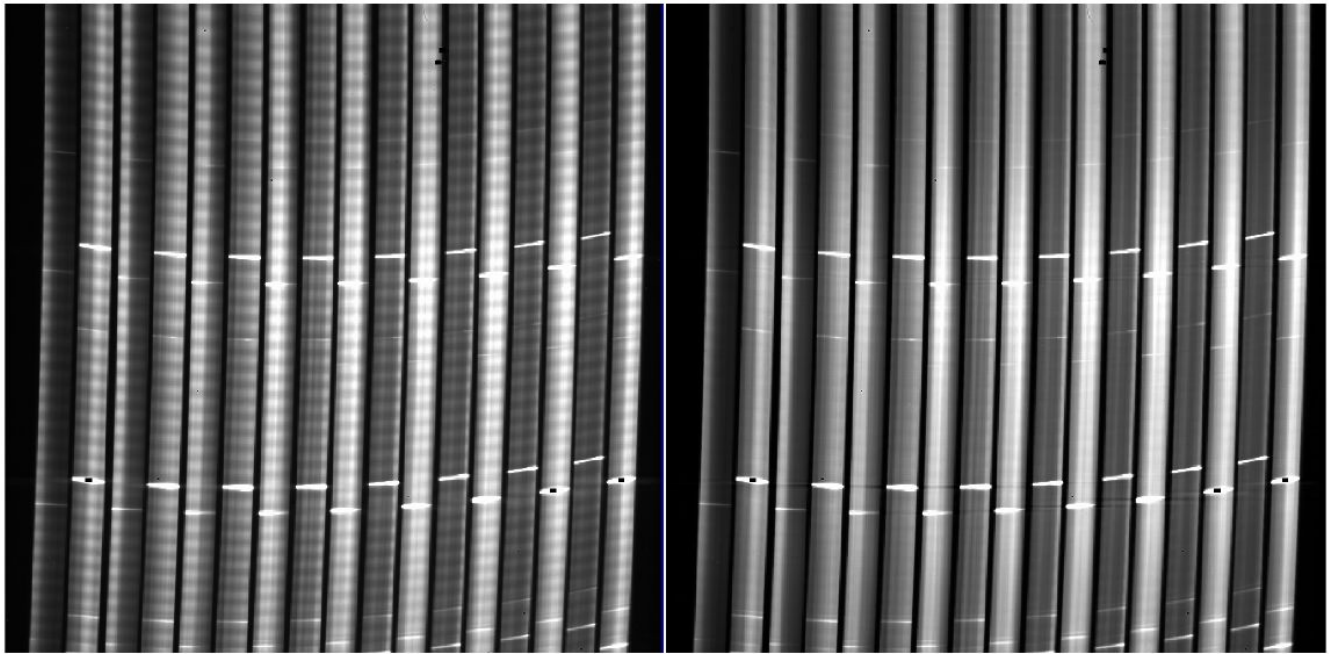


JWST MRS calibration pipeline: stage 2 (observing mode corrections)

Run Section 6 (Spec2 Pipeline) of the notebook

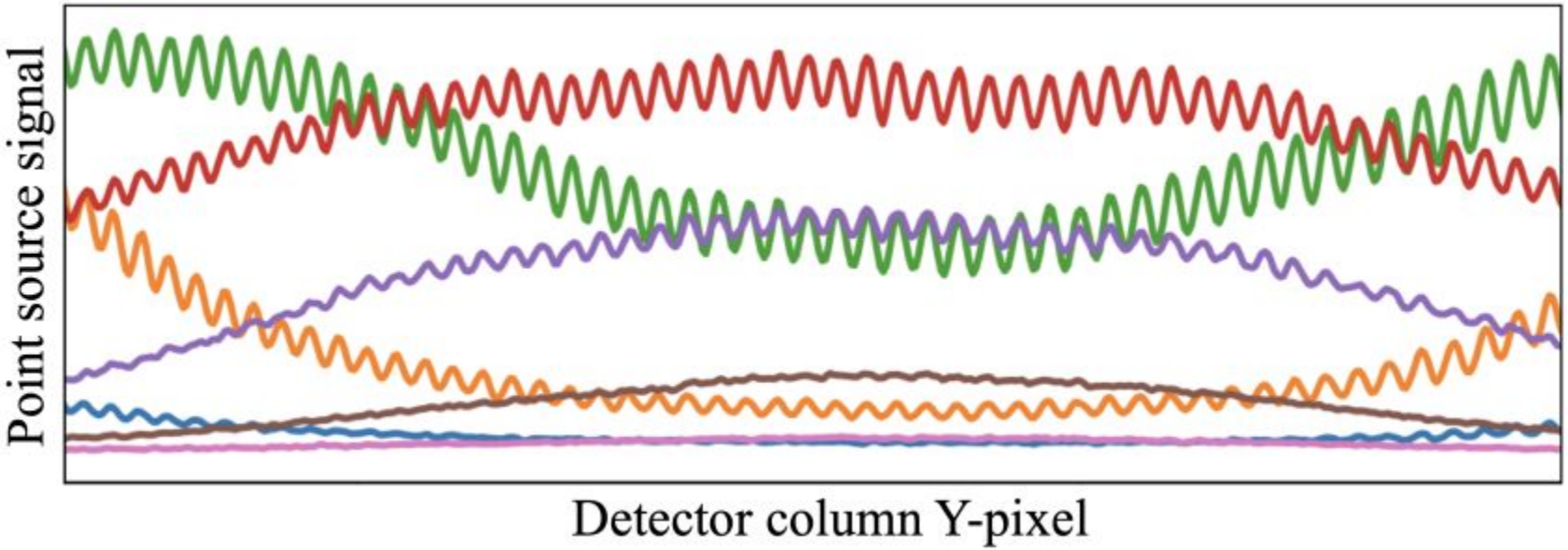


JWST MRS calibration pipeline: fringe correction



- Fringes are generated due to internal detector reflexions that produce interference pattern
- The pattern depend on the detector illumination, and could have an amplitude up to 40%
- Two corrections, fringe flat & residual fringe, reduce the effect to few %

JWST MRS calibration pipeline: fringe correction



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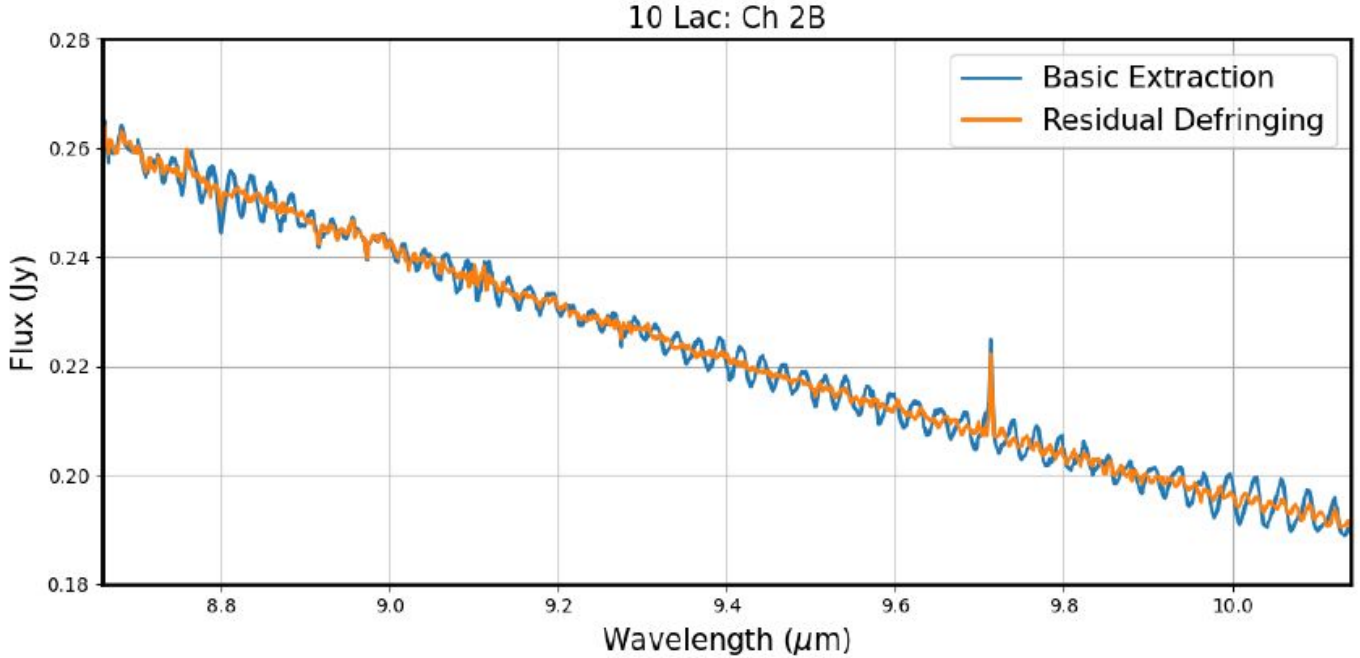

- Fringes are generated due to internal detector reflexions that produce interference pattern
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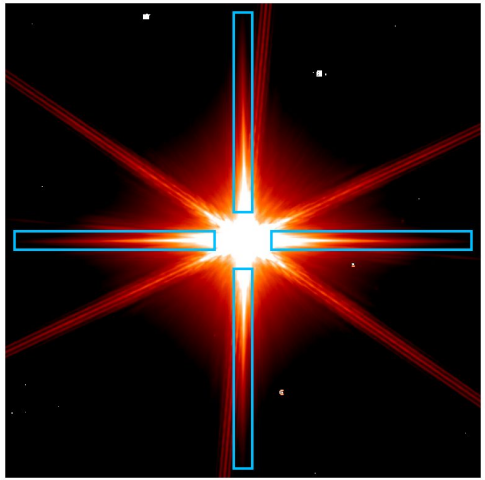
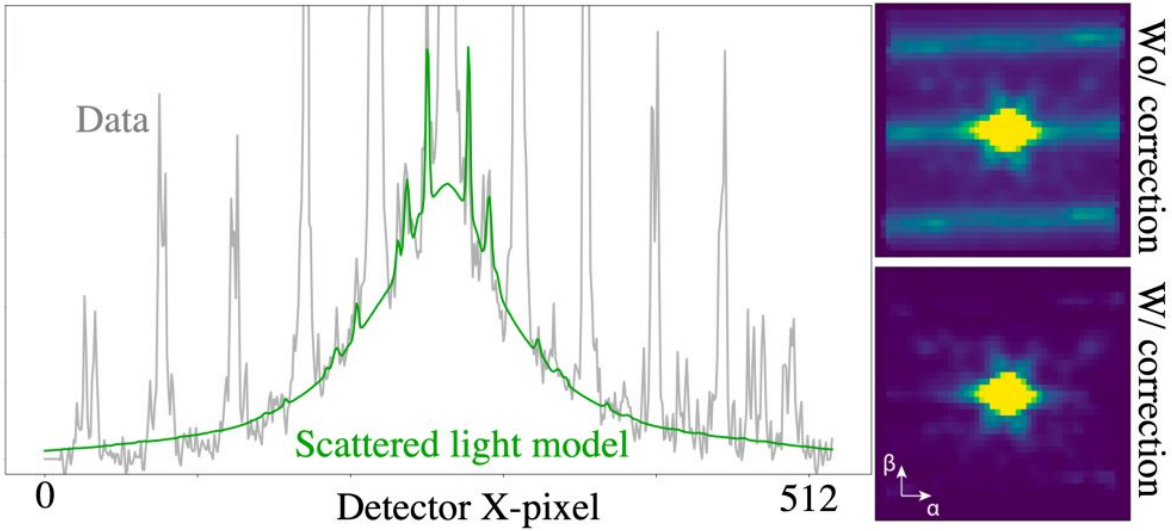
- Two corrections, fringe flat & residual fringe, reduce the effect to few %

JWST MRS calibration pipeline: straylight correction

MIRI Imager

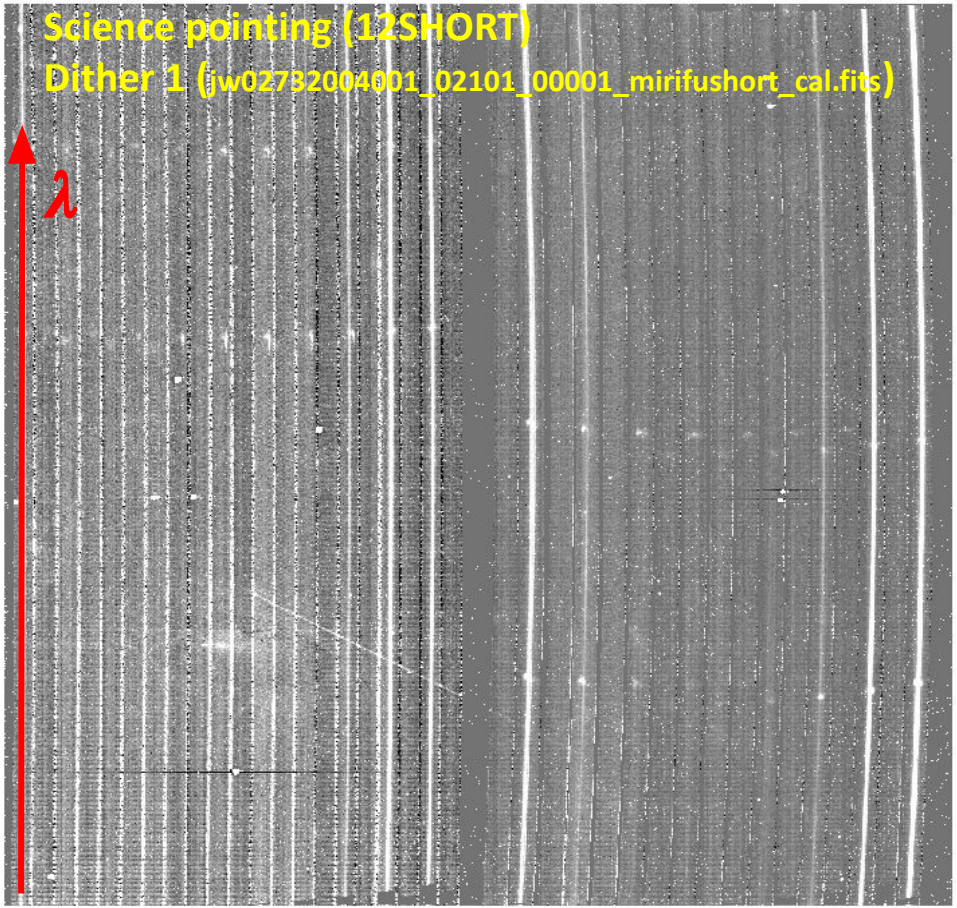


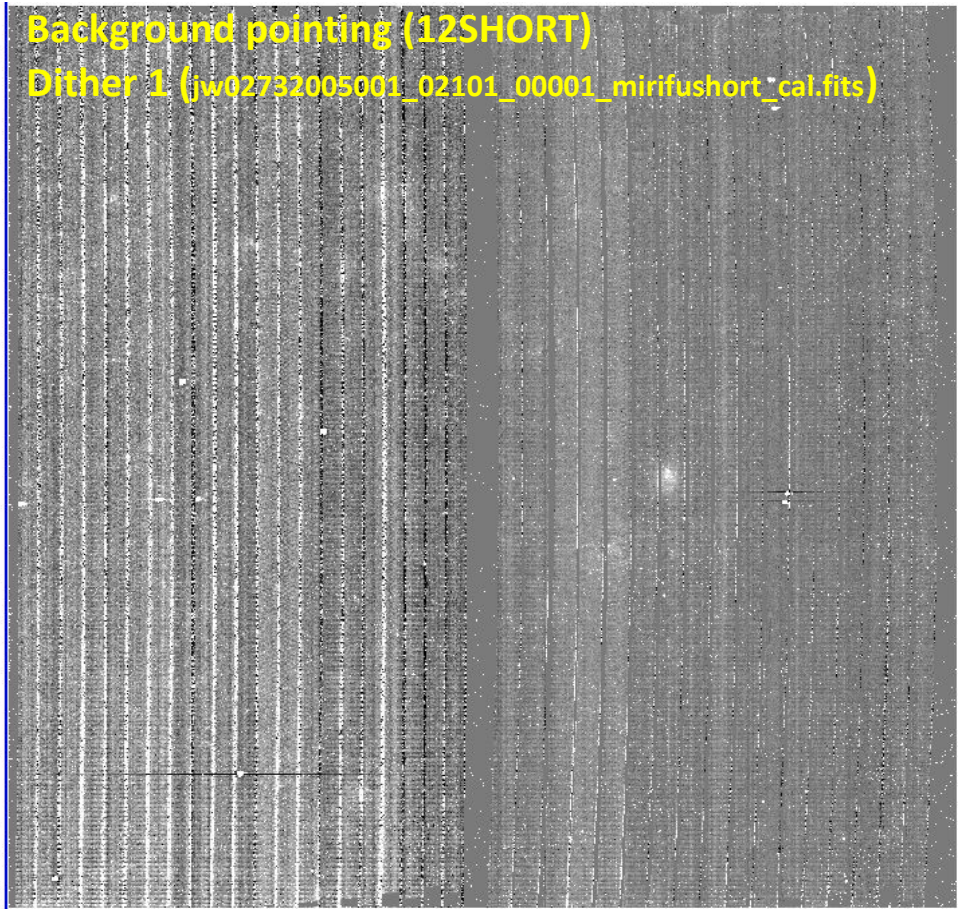
MRS



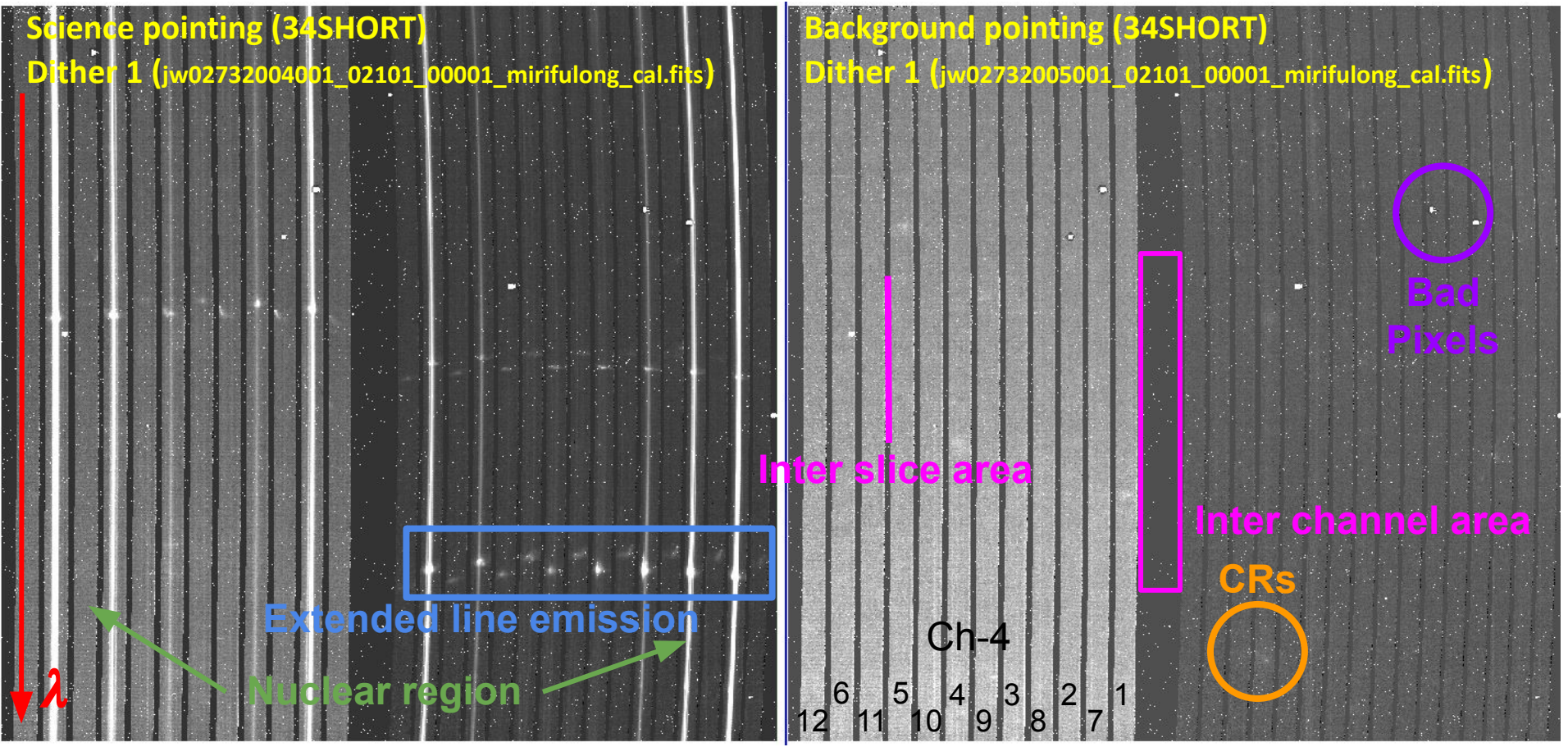
- Internal detector reflection produce a straylight for bright sources (up 20% of a PSF flux)
- Bacon shape on the 3D cube and diffuse emission in the MRS detector (Imager: cruciform)
- Correction is in place for the MRS, and reduce the effect from 20% to 1-2%

JWST MRS calibration pipeline: cal images

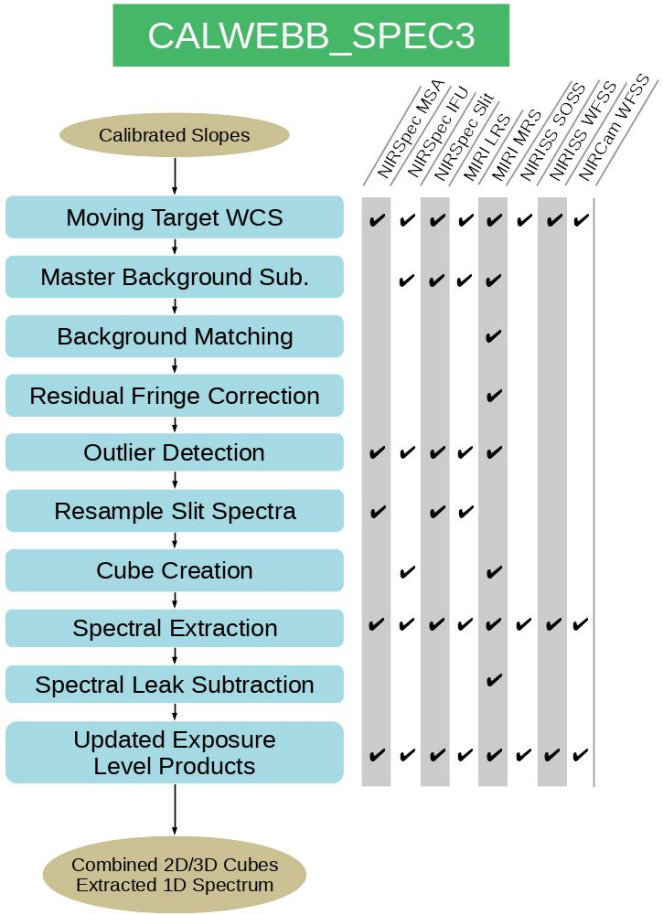




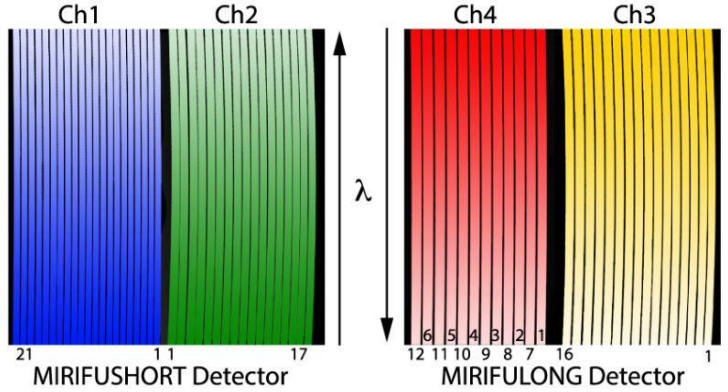
JWST MRS calibration pipeline: cal images



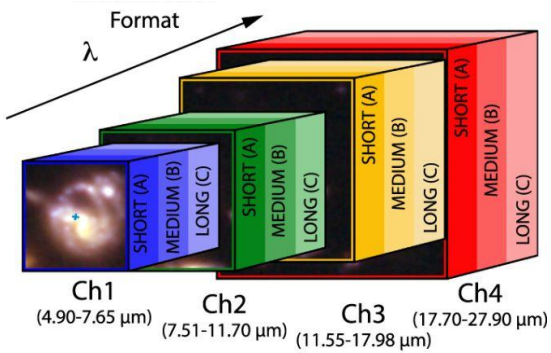
JWST MRS calibration pipeline: stage 3 (3D cubes and 1D spectra)



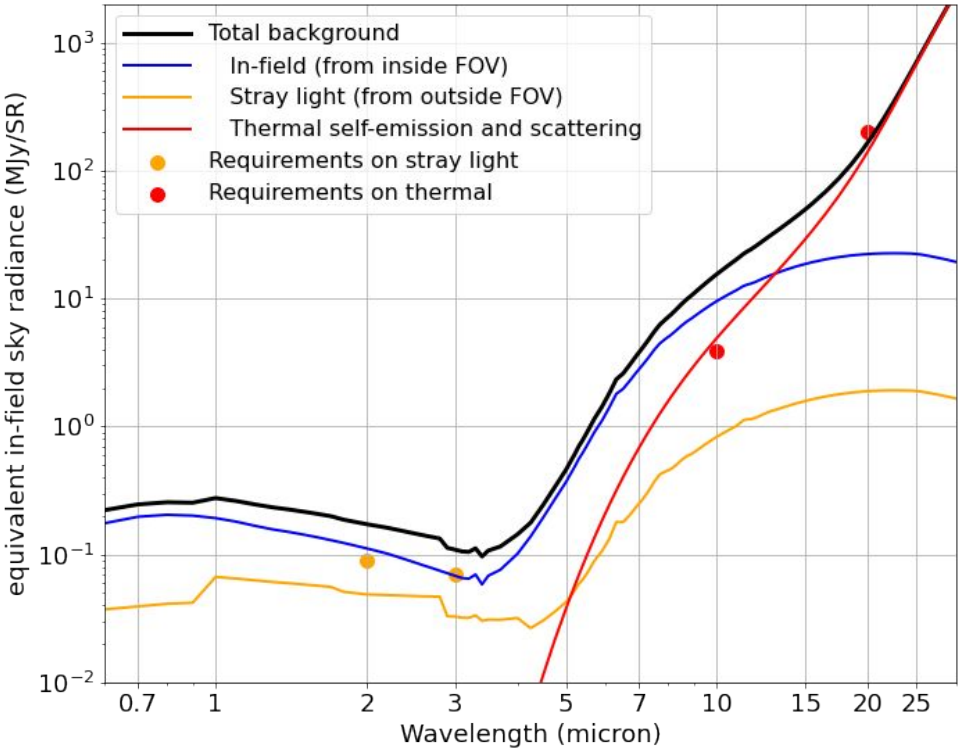
From fully calibrated detector files



to 3D spectral cubes and 1D spectrum



JWST MRS calibration pipeline: Background subtraction



Background emission is important on the MIRI spectral range

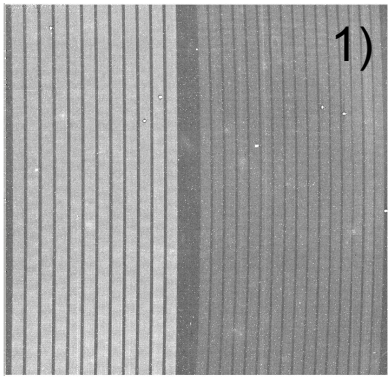
Three different methodologies to correct the background on the MRS:

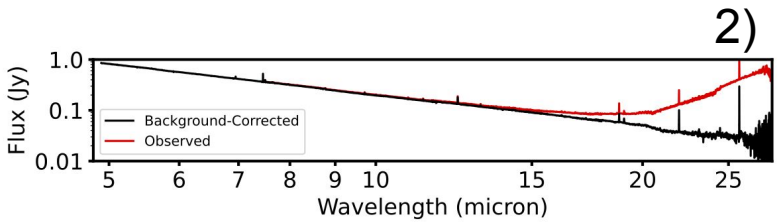
- Pixel-to-pixel detector subtraction
  - Stage 2
- Master background subtraction
  - Stage 3
- Annulus background subtraction
  - Cube based

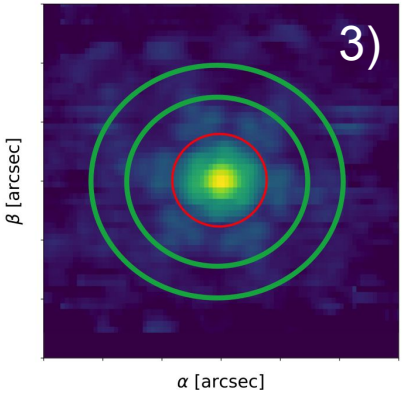
Need dedicated background obs.
No dedicated background obs.

JWST MRS calibration pipeline: Background subtraction

1) **Pixel-to-pixel based subtraction:**
   - Median background exposures, subtract from science data pixel-by-pixel
   - Noisier in general, but help with systematic residuals effects (flatfield errors, darks, …)
2) **Model-based master background subtraction:**
   - Construct 1d background spectrum from background observations
   - Higher SNR, but can suffer from systematics
3) **Annular subtraction**
   - Background estimated from annular region and subtracted, PSF losses included in aperture correction factor.
   - Cannot be applied to extended sources







JWST MRS calibration pipeline: Background subtraction

NGC7319 galaxy is an extended source. Then, we have to perform a background subtraction using the dedicated background observations.

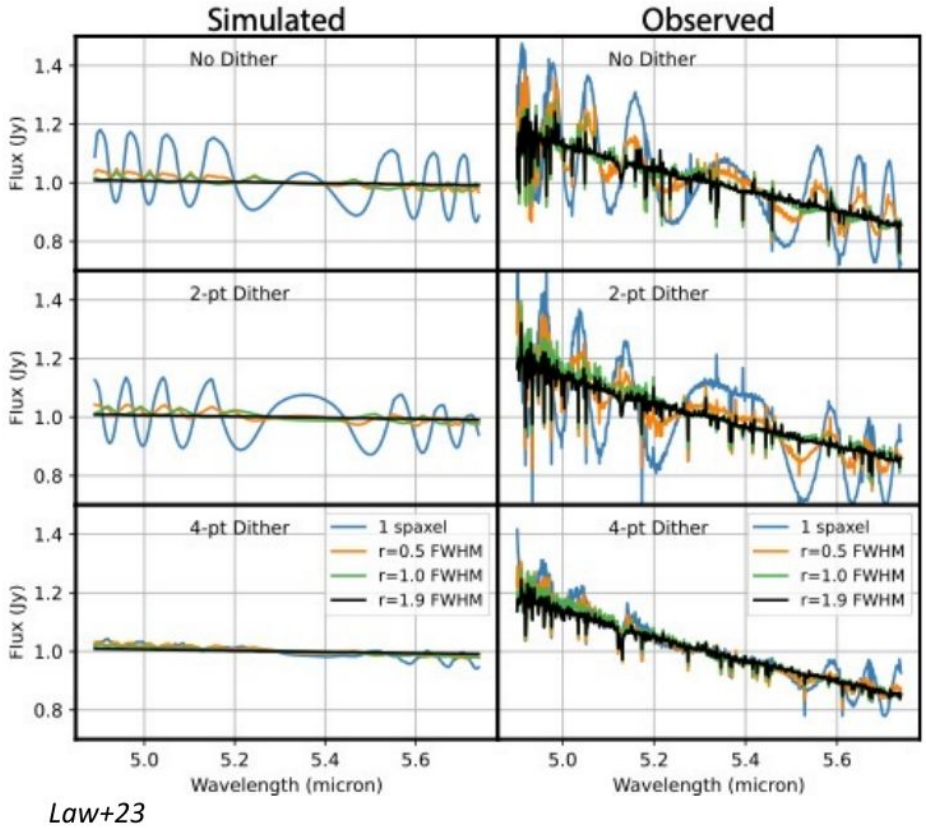
- We will use the model-based master background subtraction from stage 3 of the pipeline
  - Perform a median of the full FoV from the background observations, and generate a 1D background spectrum
  - The 1D extracted background spectrum is used to subtract the background in the science observations

Note that science and background observations need to be associated to generate the final 3D background subtracted spectral cube

➡

Run Section 7 (Spec3 Pipeline) of the notebook

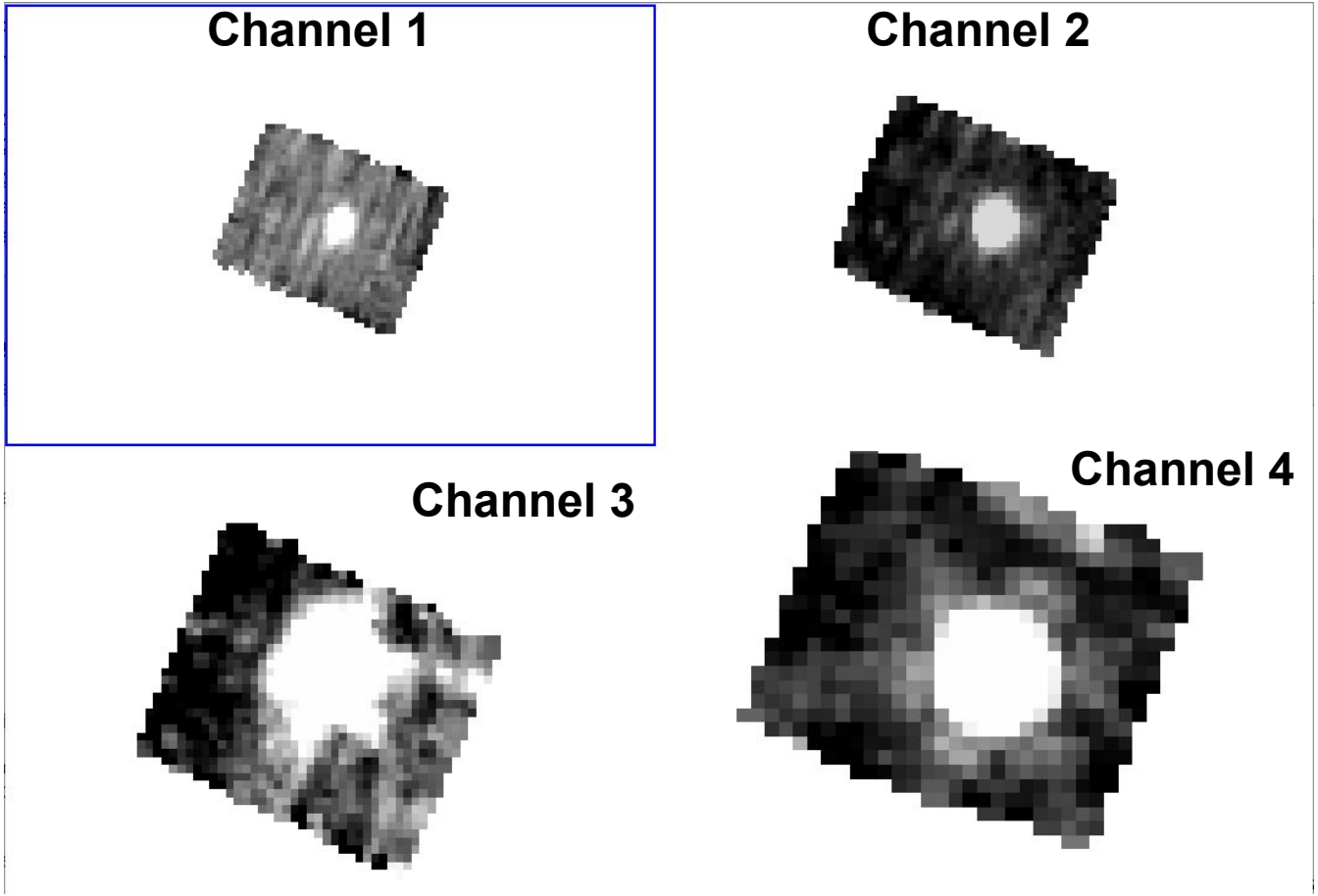
JWST MRS calibration pipeline: PSF sampling in the MRS cubes



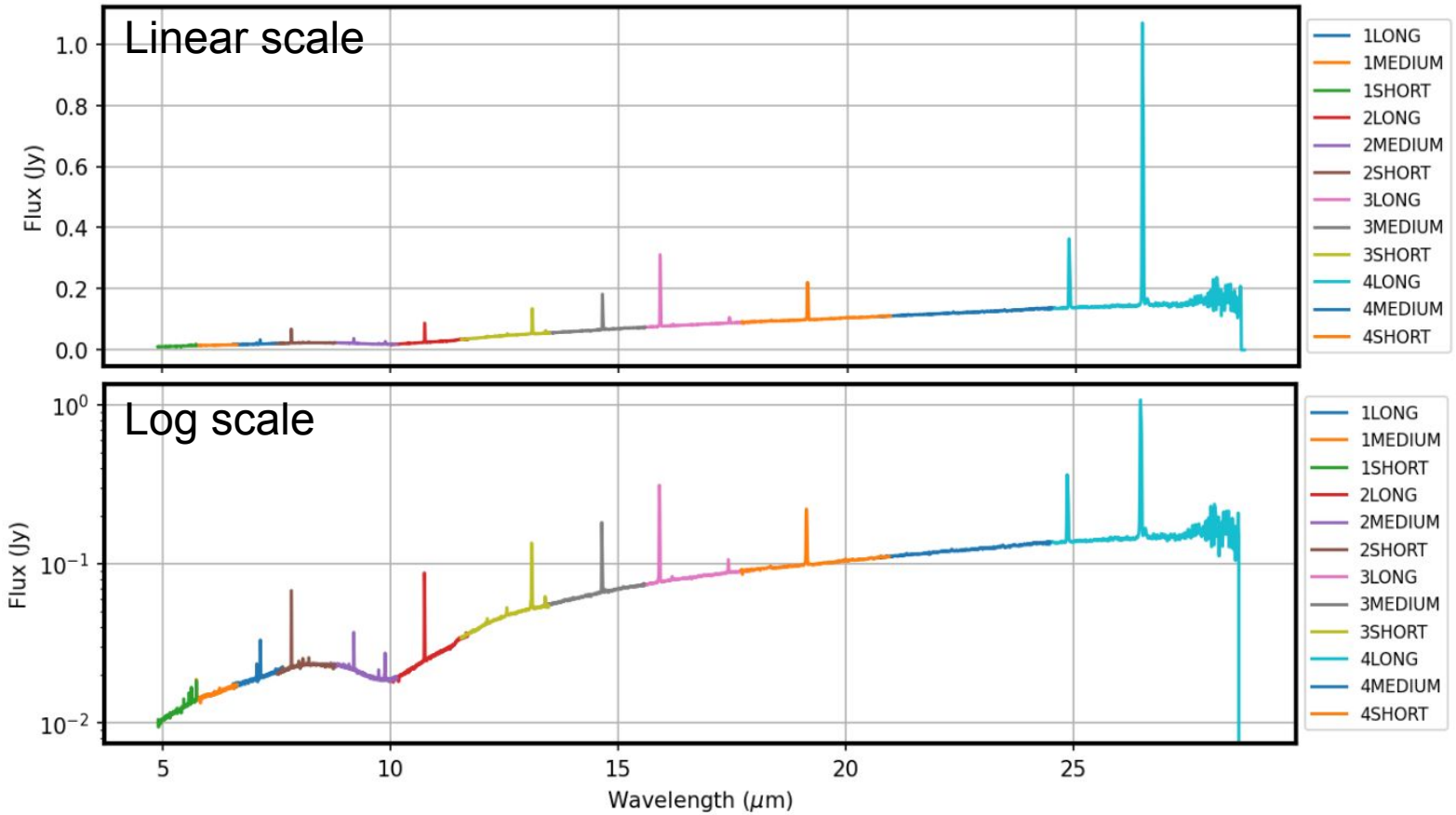
The JWST PSF is undersampled in the bluer MRS channels

- Produce effects on the 1D spectrum for a single pixel extraction
- Dithers help to sample the PSF and reduce the effects
- Aperture subtraction is needed for point like sources in the MRS
  - Aperture sizes larger than the FWHM of the PSF

JWST MRS calibration pipeline: final 3D spectral cubes (ds9 view)

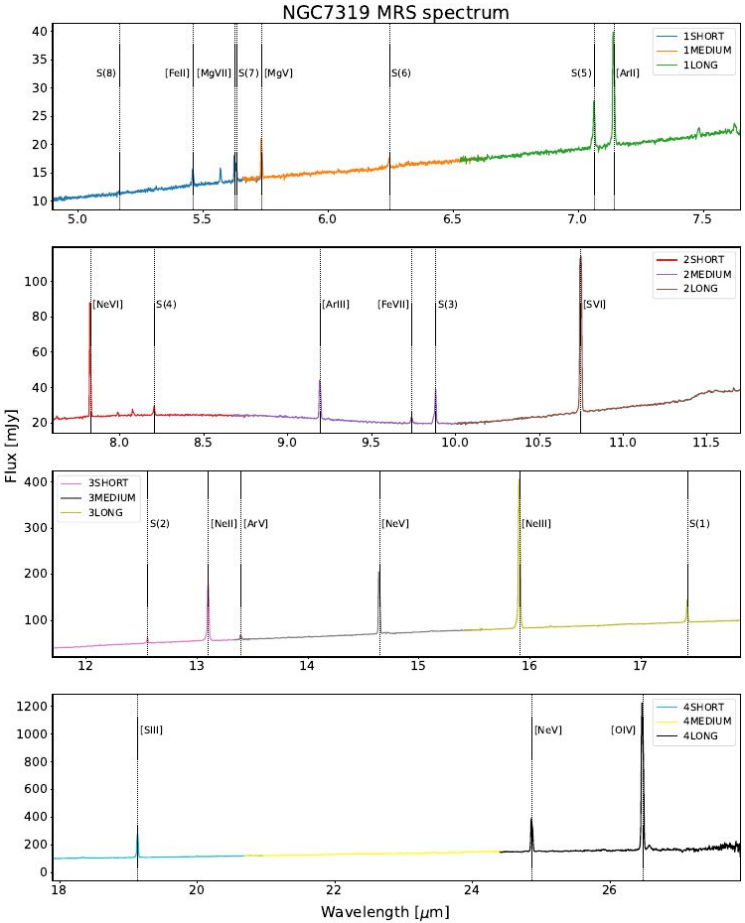


JWST MRS calibration pipeline: final 1D extracted spectra

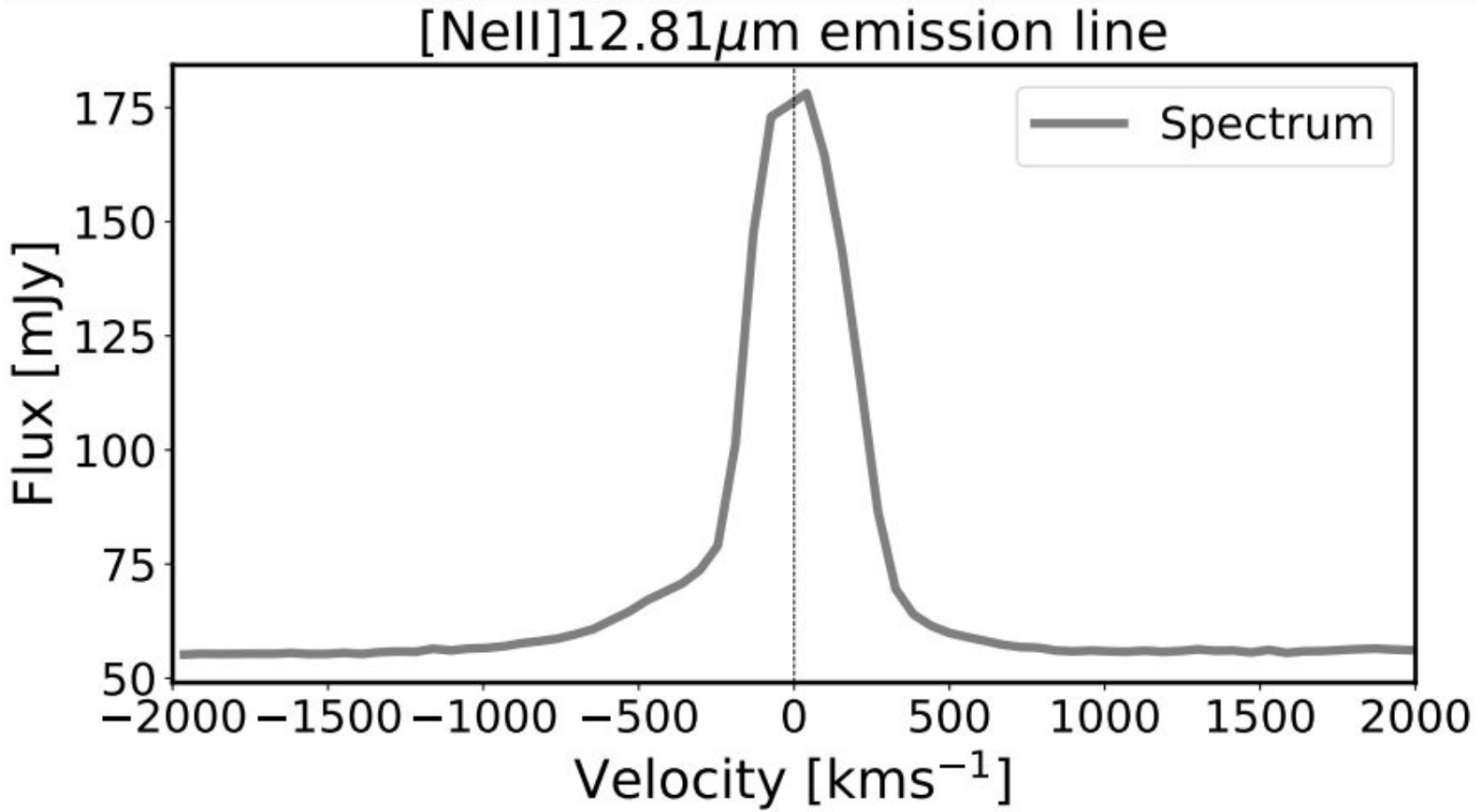


Open and run the notebook
Analysis_MRS_1Dspectrum_3Dcubes.ipynb

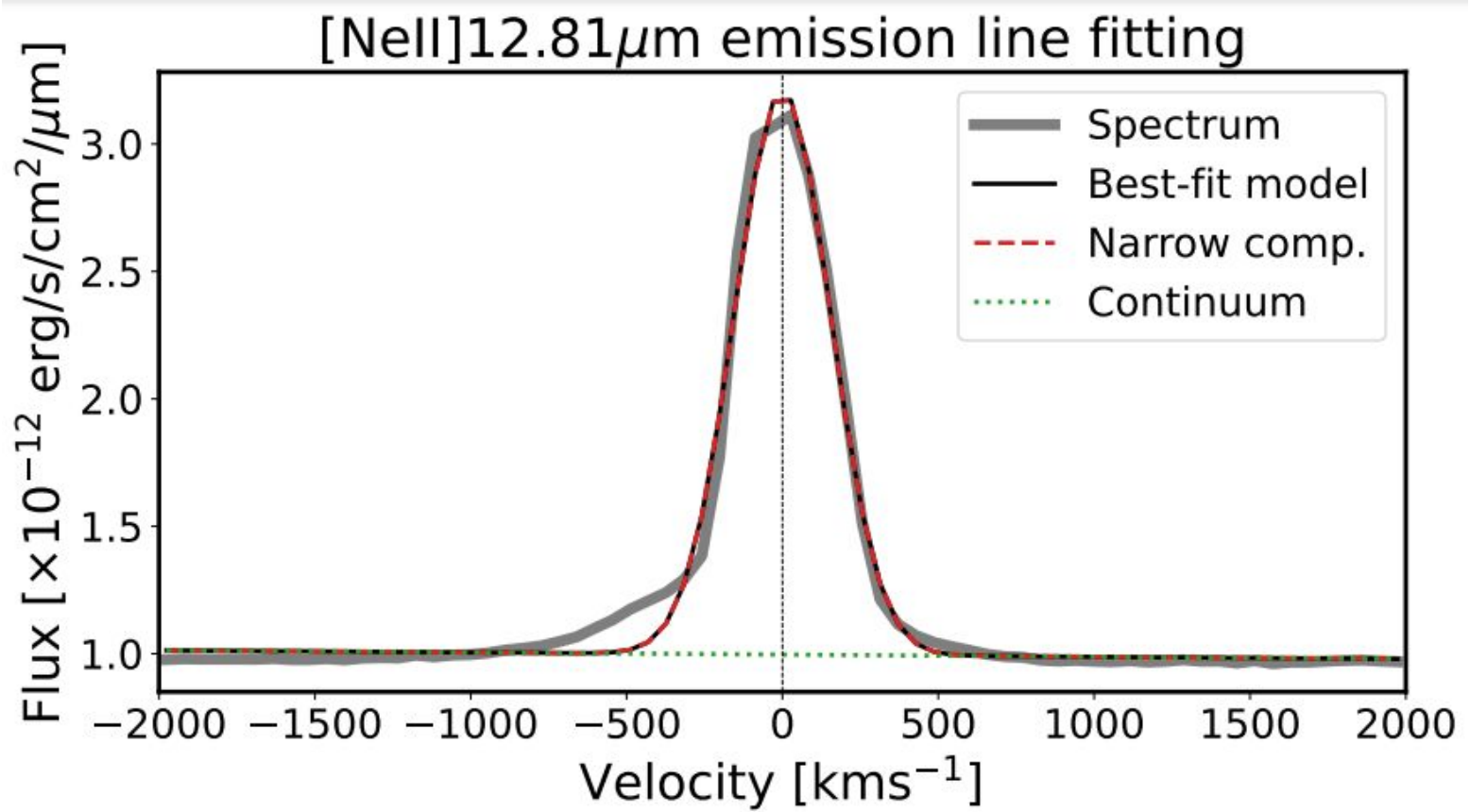
MRS analysis: visualize the full spectrum



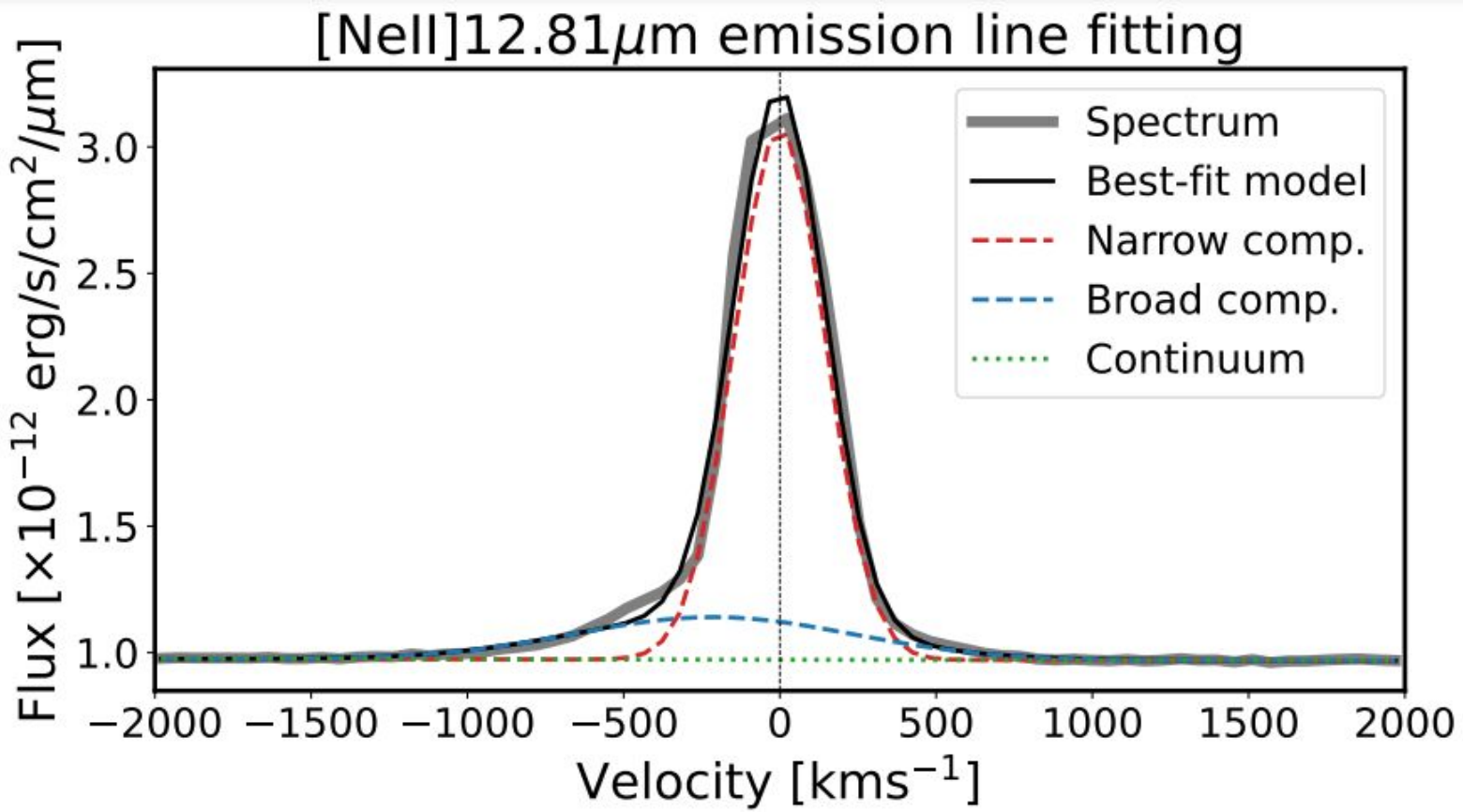
MRS analysis: zoom to an emission line



MRS analysis: Emission line fit to 1 or 2 Gaussian components



MRS analysis: Emission line fit to 1 or 2 Gaussian components



MRS analysis: Line maps