JWST MIRI/MRS Synthetic Cubes (ERS & GTO)

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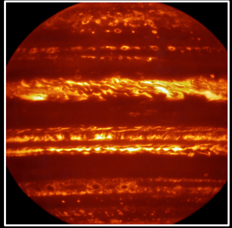
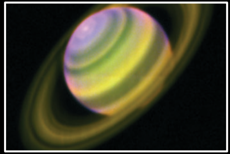
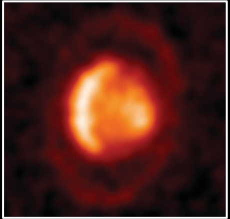
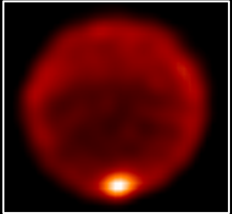
Leigh N. Fletcher

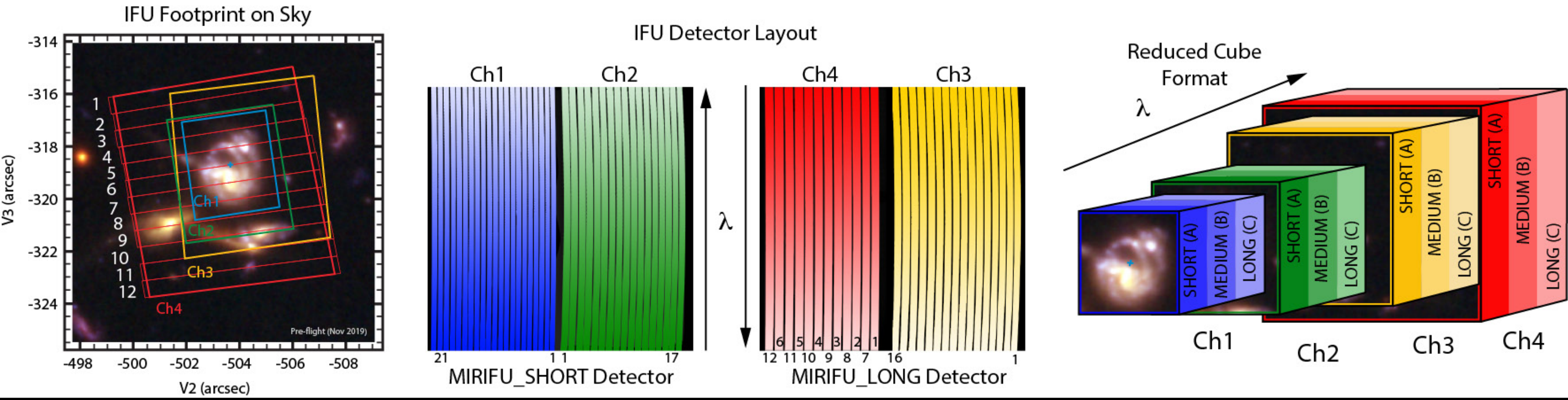
JWST Giant Planet Programme

	**MIRI MRS:** GRS (GTO); S. Pole (ERS); 5-11 µm	**NIRSPEC IFU** GRS (ERS); S. Pole (ERS)	**NIRCAM** Global (ERS)
	**MIRI MRS:** N. Hemisphere map (5-16 µm)	**NIRSPEC IFU** **[Cycle 1]**	**NIRCAM** Context images for system (GTO)
	**MIRI MRS:** Global map (5-28 µm)	**NIRSPEC IFU** **2-5 µm H3+ & comp. (GTO).**	**NIRCAM**
	**MIRI MRS:** Global map (5-28 µm)	**NIRSPEC IFU** **[Cycle 1]**	**NIRCAM**

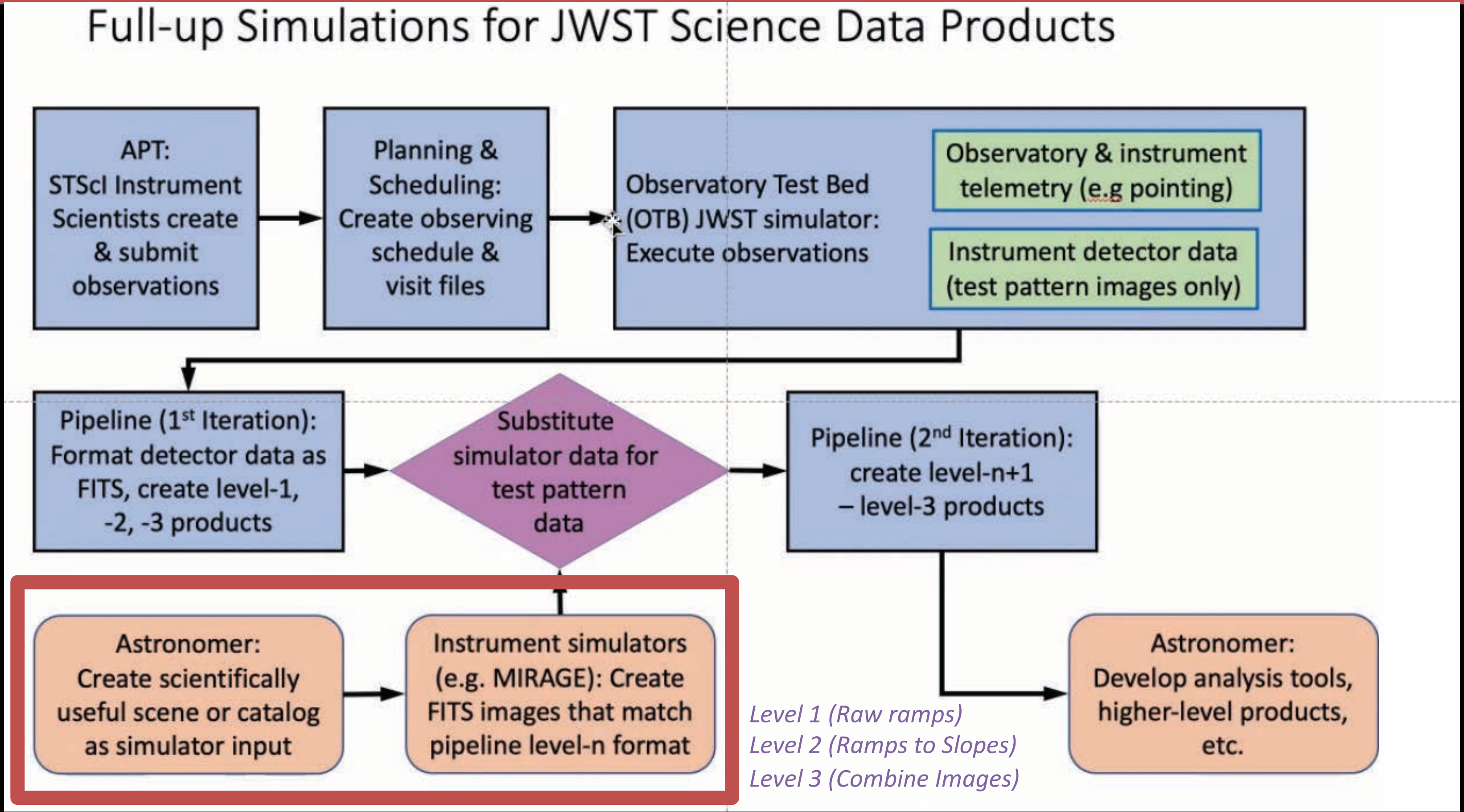
MIRI IFU Observations

- Spaxels = combine imaging & spectroscopy.
  - 3D cube (2 spatial, 1 spectral).
- MIRI MRS IFUs split the field of view into spatial slices:
  - Separate dispersed "long-slit" spectrum.
  - We get a set of 4 sub-bands (4 channels over 2 detectors) for each disperser (SHORT, MEDIUM, LONG) – 3 chunks.

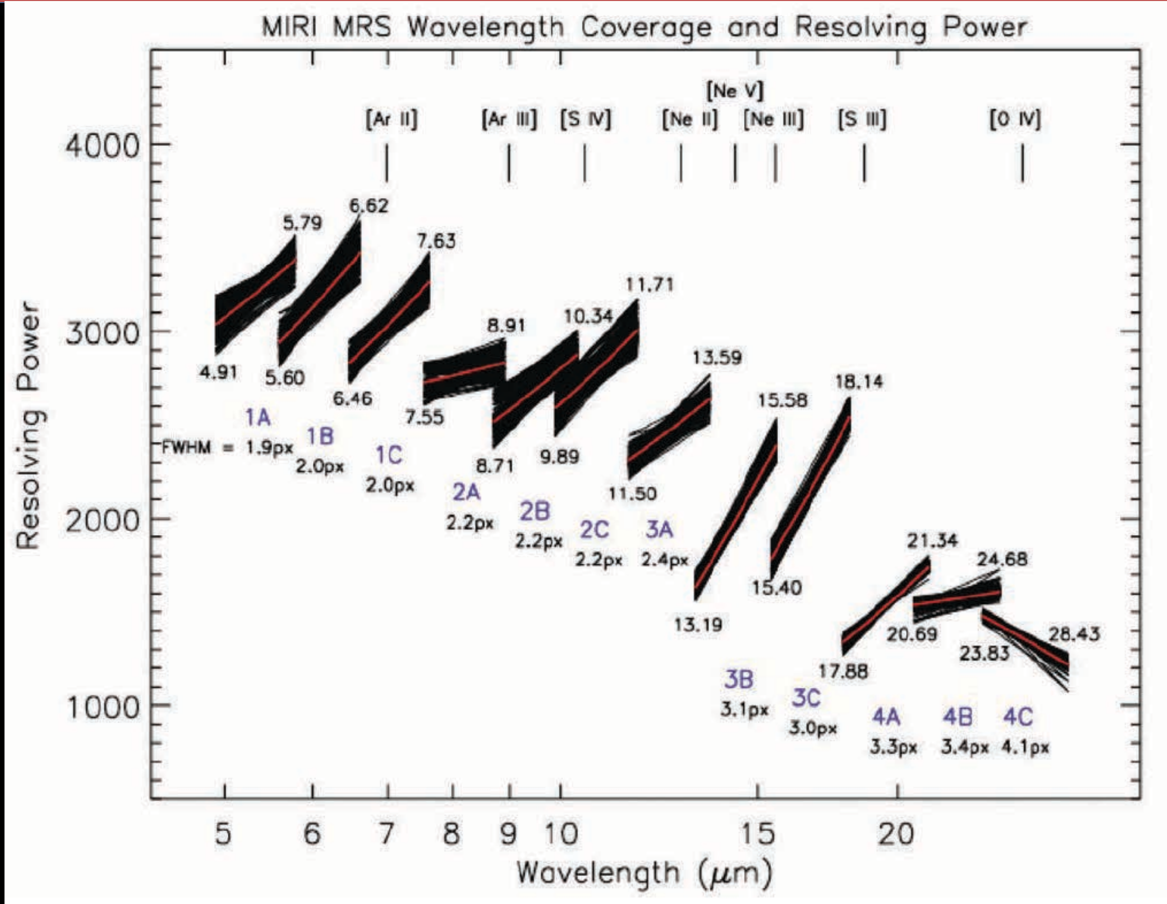
- *2 detectors (SW = channels 1,2, LW= channels 3,4)*
- *4 channels/sub-bands*
- *3 dispersers = (SHORT/MEDIUM/LONG, aka A/B/C)*



Fitting in with OTB

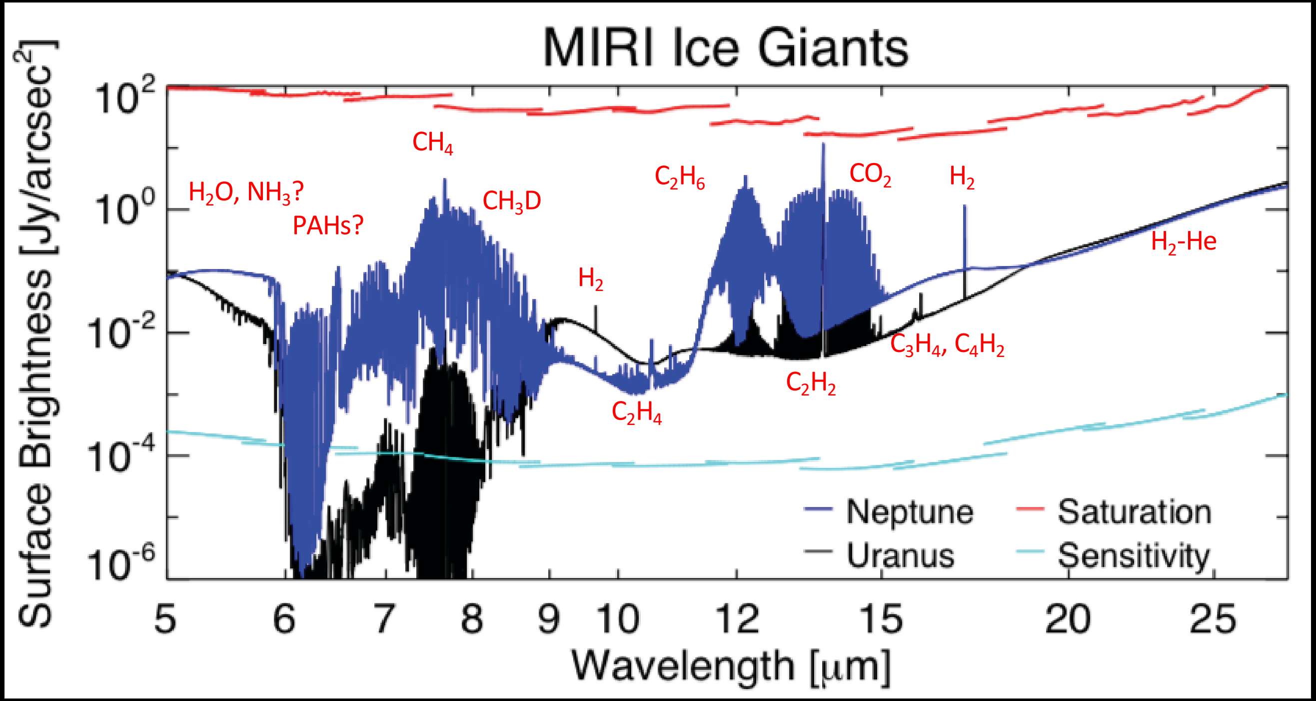


Step 1: NEMESIS Forward Models

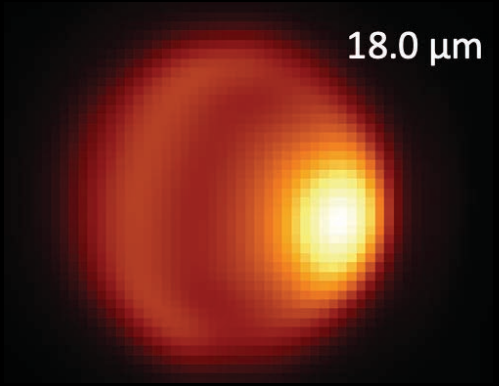


- Each sub-band has unique ν_{min}, ν_{max}, and FWHM.
- We choose minimum dispersion as step-size for k-table.
- K-tables for all gases, 12 separate sets.

Step 1: NEMESIS Forward Models



- Uranus and Neptune single-pixel spectra compared to saturation and MRS sensitivity.
- Cross-checked with ETC.
- Same done for gas giants.
- Extend over whole disc at 0.1”/px.
- Removed PSF (MIRISim does this for us).



Step 2: Preparing NEMESIS Cubes for MIRISim

- MIRISim simulates instrumental effects through MIRI, replicating on-orbit performance.
  - Returns “Level 1B” uncalibrated data as if from the telescope.
- Combine 12 sub-band cubes into one large cube spanning 5-29 μm
  - Interpolate to the finest dispersion (wavelength grid).
  - Adding header info (pixel size, dispersion, v_{min}, units).
  - Units μJy/arcsec^2
- New cube is the “scene”.
  - Background is added automatically by MIRISim (P. Klaasen).
  - MIRISim uses a simple model of the JWST pupil to simulate an idealistic PSF and modifies it according best knowledge for the MRS.

Step 3: Setting up and Running MIRISim

- Jupyter notebooks and conda mirisim environment.

1. SimConfig – parameters for the MRS simulation, informed by APT file.
2. SimulatorConfig – used in default mode.
3. SceneConfig – specifies the scene (i.e., combined fits file).

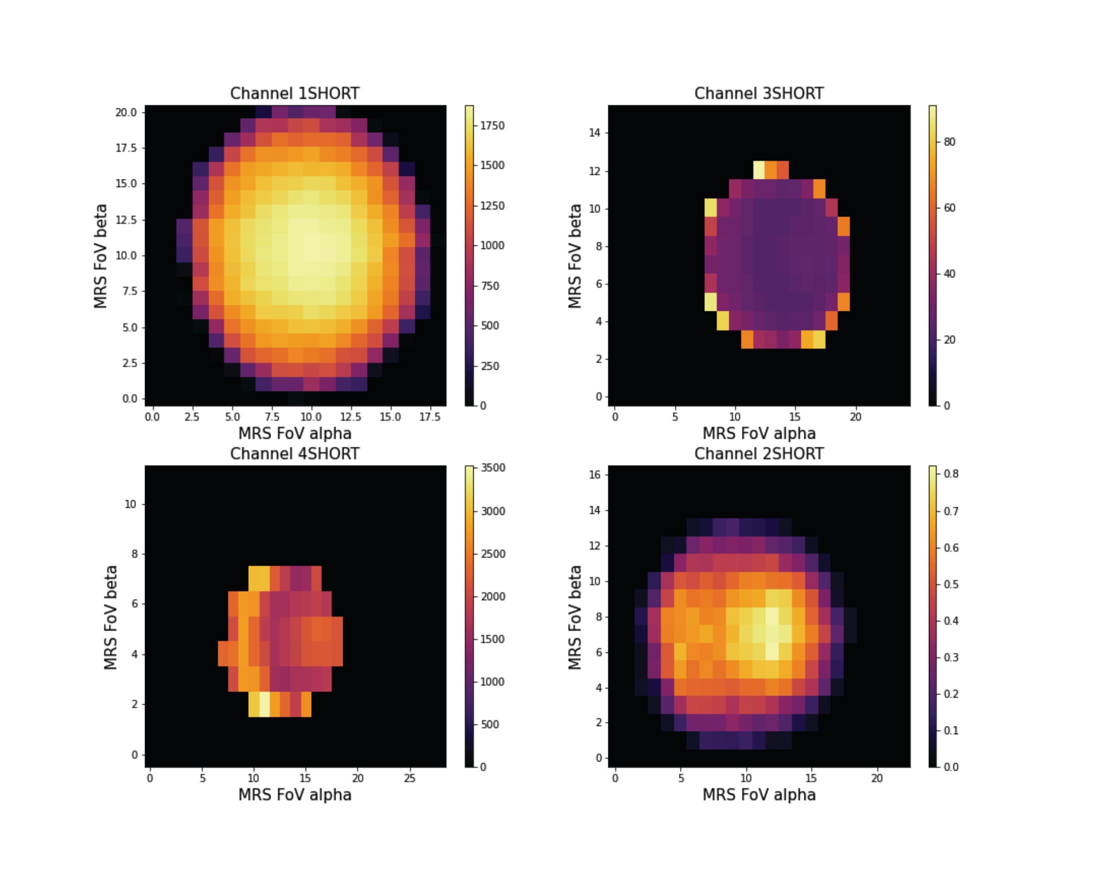
- Notes:
  - No dithering (currently point source only).
  - ConfigPath always uses Channel 1 (smallest FOV used to centre target).
  - Ngroups, integrations and exposures from APT file.

```
name        = UranusMIRI                # Default Simulation

[Scene]
  filename   = uranus_scene             # name of scene file to be used to generate sky cube.

[Observation]
  rel_obsdate = 0                       # relative observation date (0 = launch, 1 = end of 5 yr).

[Pointing_and_Optical_Path]

  [[Primary_Optical_Path]]
    POP        = MRS                    # Component on which to centre, choose from MRS, IMA.
    ConfigPath = MRS_1SHORT             # Configure the optical path (MRS sub-band or Imager mode).

[Integration_and_patterns]

  [[Dither_Patterns]]
    Dither      = False                 # Include Dithering (True/False).
    StartInd    = 1                     # Index of first position in dither pattern (lowest possible = 1).
    NDither     = 4                     # Number of Dither Positions.
    DitherPat   = mrs_recommended_dither.dat          # Name of input dither pattern file.

  [[MRS_configuration]]
    disperser   = SHORT                 # Specify grating position (SHORT, MEDIUM, LONG).
    detector    = BOTH                  # Specify Channel (SW, LW or BOTH).
    Mode        = FAST                  # Detector read-out mode. Options are 'FAST' or 'SLOW'.
    Exposures   = 1                     # Number of Exposures.
    Integrations = 3                    # Number of Integrations (per exposure).
    Frames      = 10                    # Number of frames (or groups) per integration. Note for MIRI NFrames = NGroups.
```

Run 3 times – SHORT, MEDIUM, LONG dispersers

Step 4: Inspecting MIRISim Outputs

- **MIRISim produces three directories for each disperser (SHORT, MEDIUM, LONG):**
  - **skycubes** - 3D representation of the input scene. This cube has not been processed by MIRISim, it is simply a gridded (spatially and spectrally) version of the input scene.



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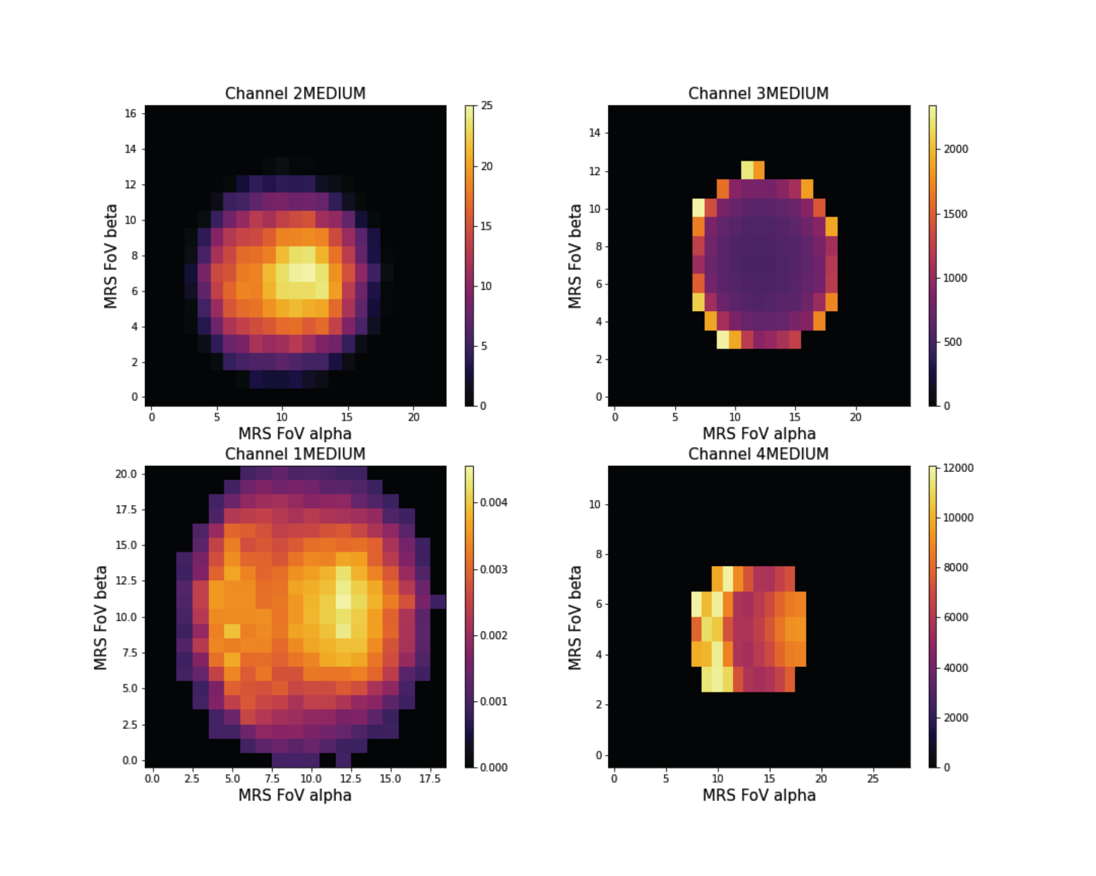

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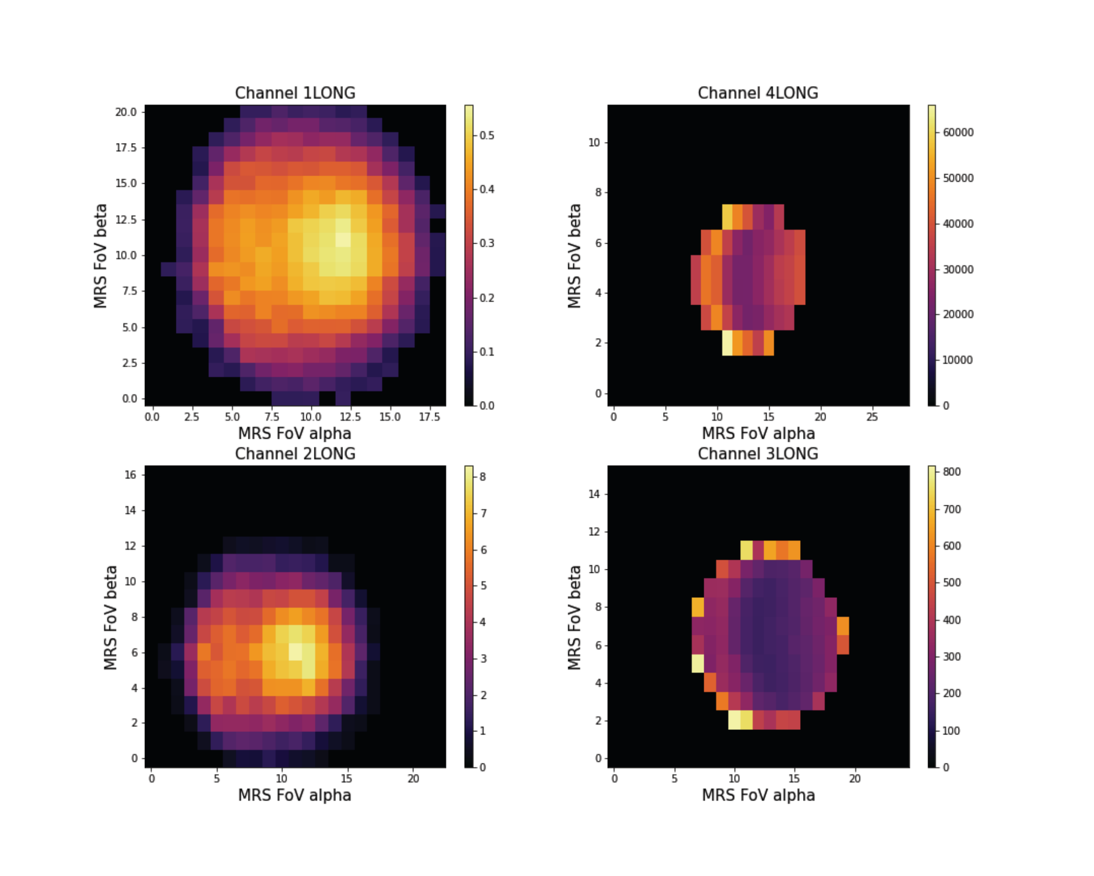
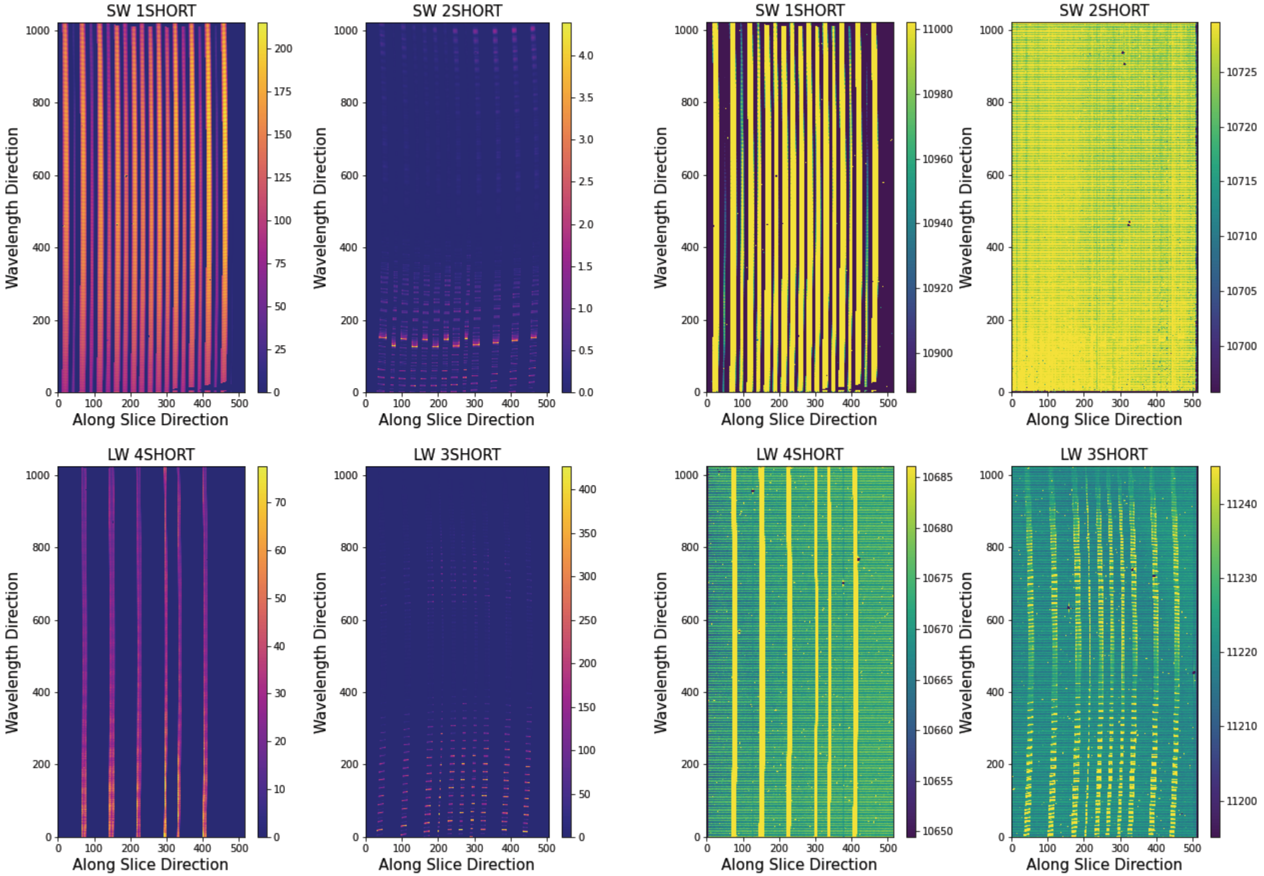


Step 4: Outputs

- **illum_models**
  - FITS images of the illuminations sent to the detector.
  - This should have the same format as the detector image, but without all of the detector effects and noise.
- **det_images**
  - FITS images of the final outputs of MIRISim.
  - These detector images have all of the detector effects and noise incorporated.
  - This is the “Level 1” data.

SHORT



Step 4: Outputs

- **illum_models**
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- **det_images**
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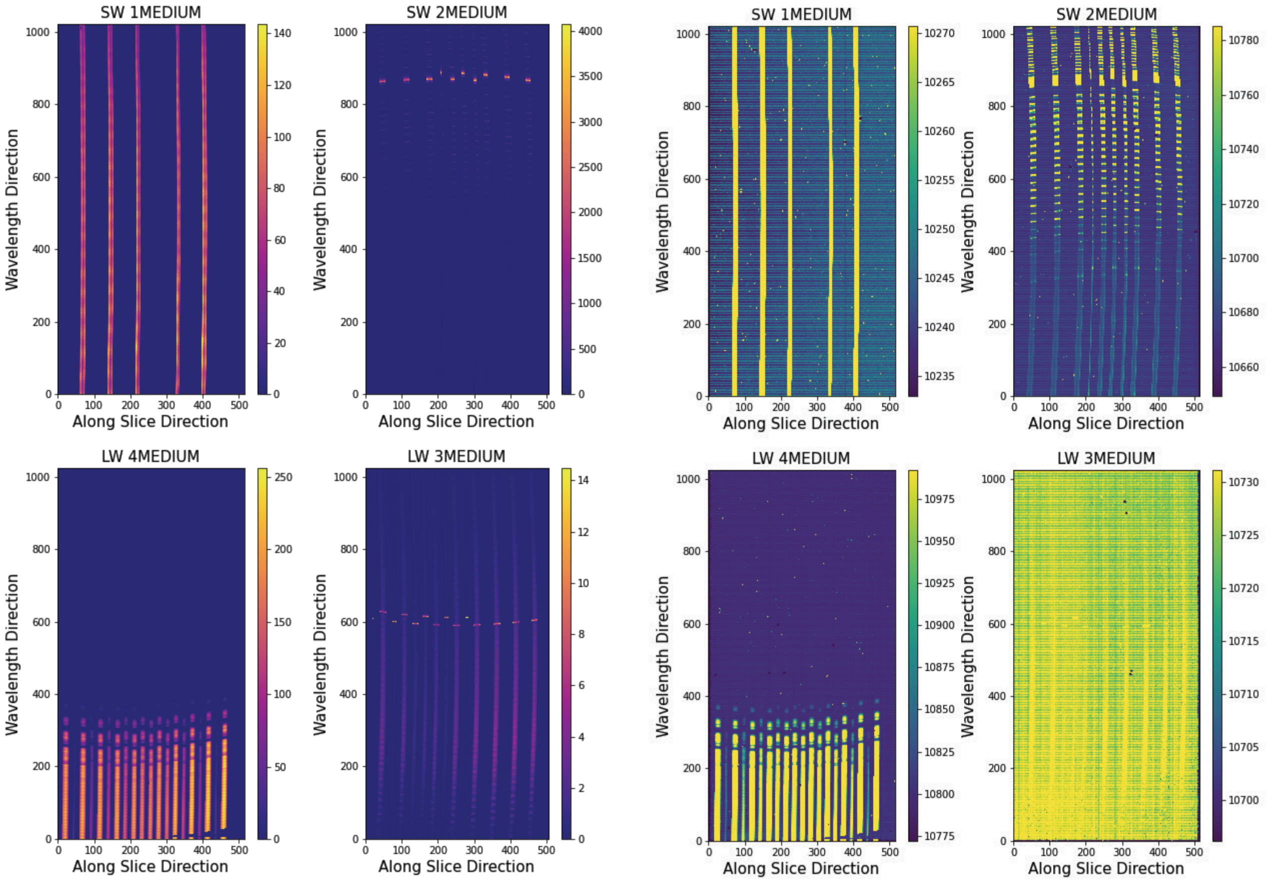
  - These detector images have all of the detector effects and noise incorporated.
  - This is the "Level 1" data.

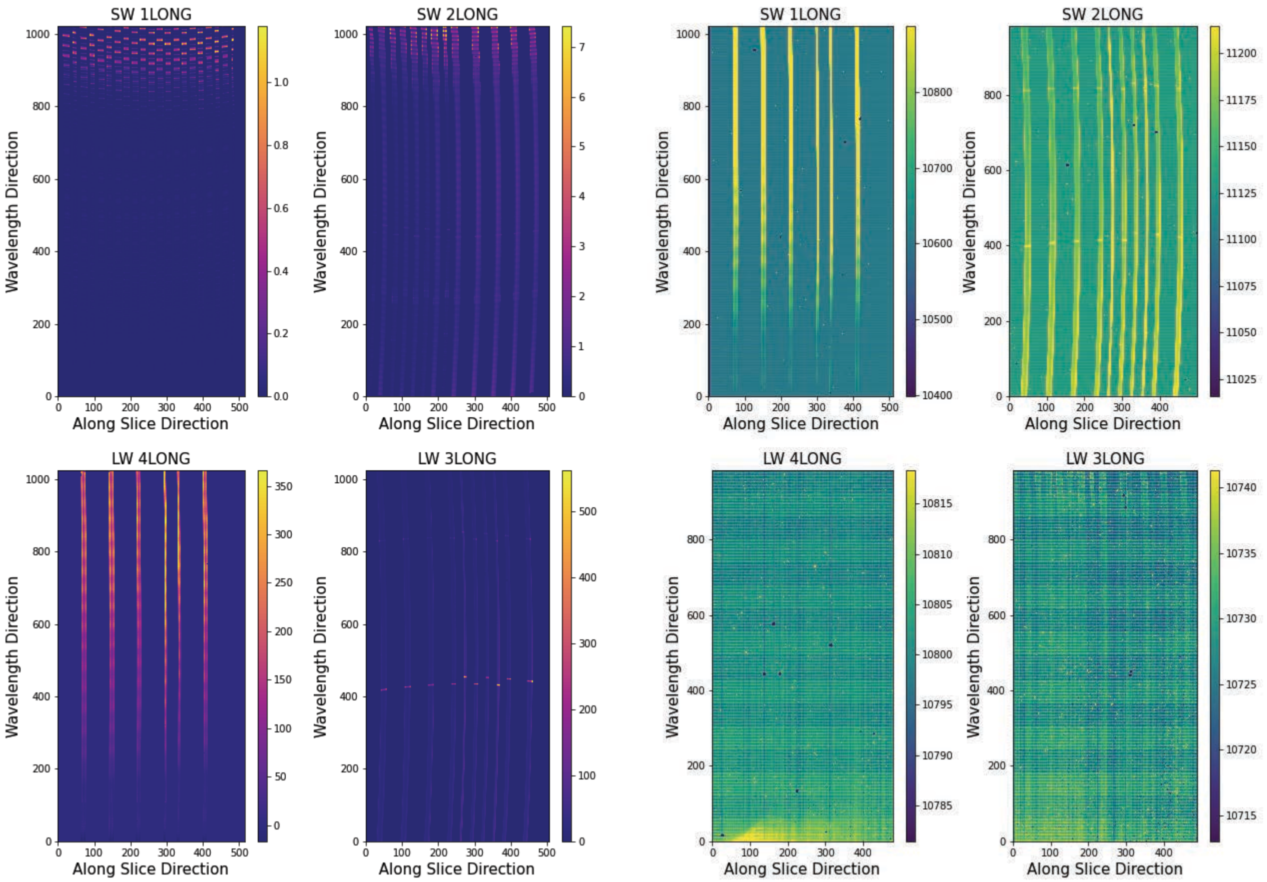
MEDIUM



Step 4: Outputs

- **illum_models**
  - FITS images of the illuminations sent to the detector.
  - This should have the same format as the detector image, but without all of the detector effects and noise.
- **det_images**
  - FITS images of the final outputs of MIRISim.
  - These detector images have all of the detector effects and noise incorporated.
  - This is the “Level 1” data.

LONG



After Step 4: We Have Level-1 Data ("Ramp Images")

- PSF simple model included.
- Corrections for the distortion and wavelength calibrations for each light path.
- Variations of FoV for individual pixels.
- Photon conversion efficiencies.
- Read noise.
- Bad pixel masks.
- Dark currents.
- Gain to convert DN into electrons.
- Cosmic ray effects, detector non-linearity, Poisson noise, detector latency, all applied to illumination ramps.
- NOTE – stray light not included.

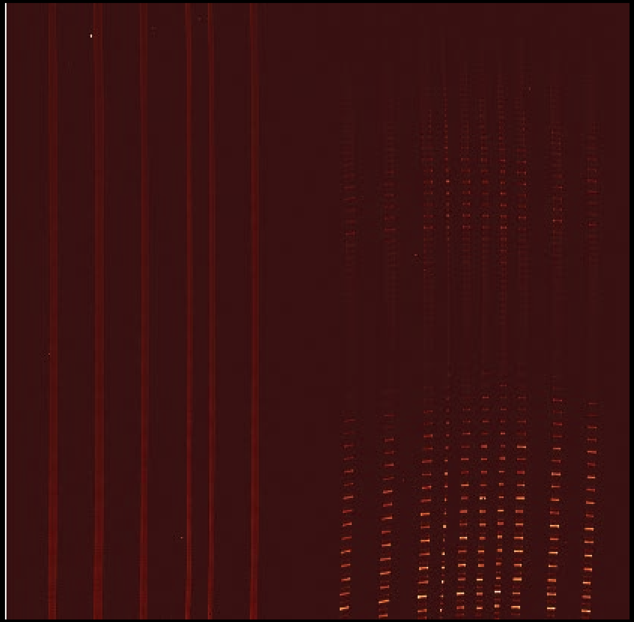
```
YYYYMMDD_HHMMSS_mirisim/
|--- det_images/
|--- illum_models/
|--- mirisim.log
|--- skycubes/          [MRS simulations only]
|--- simulation.ini
|--- scene.ini
`--- simulator.ini
```

Next: JWST Calibration Pipeline

Step 5: Level 2A ("Ramps to Slopes")

```
Detector1Pipeline: Apply all calibration steps to raw JWST
ramps to produce a 2-D slope product. Included steps are:
group_scale, dq_init, saturation, ipc, superbias, refpix, rscd,
lastframe, linearity, dark_current, persistence, jump detection,
ramp_fit, and gain_scale.
```

- The output level 2A files will be saved in the output_dir as: "detimage*_rate.fits" & "detimage*_rateints.fits"
  - One detimage for each detector (SW and LW)

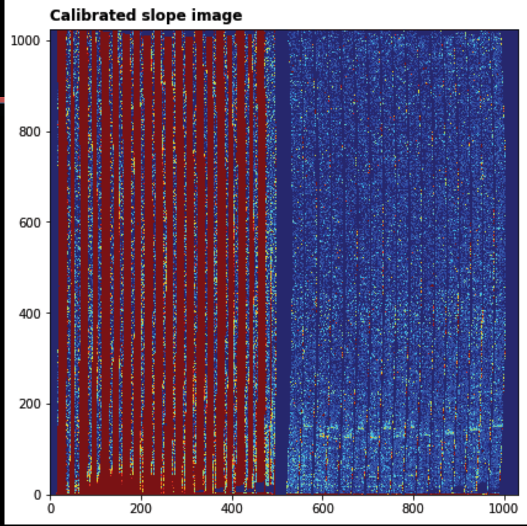


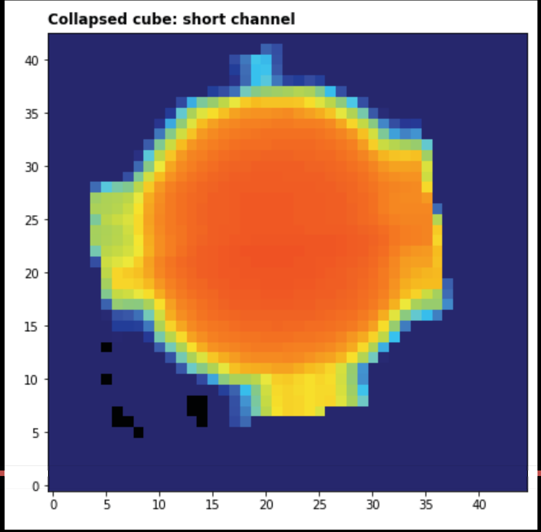
Step 6: Level 2B ("Calibrated Slope Images")

```
Spec2Pipeline: Processes JWST spectroscopic exposures from Level 2a to 2b.
Accepts a single exposure or an association as input.

Included steps are:
assign_wcs, background subtraction, NIRSpec MSA imprint subtraction,
NIRSpec MSA bad shutter flagging, 2-D subwindow extraction, flat field,
source type decision, straylight, fringe, pathloss, barshadow,  photom,
resample_spec, cube_build, and extract_1d.
```

- The level 2B pipeline for the MRS produces three files for each detector (SW, LW):
  - "detimage*_cal.fits" - the calibrated level 2B file from each dither
  - "detimage*_ s3d.fits" - the cube from each dither
  - "detimage*_ x1d.fits" - the 1d spectrum extracted from each dither.



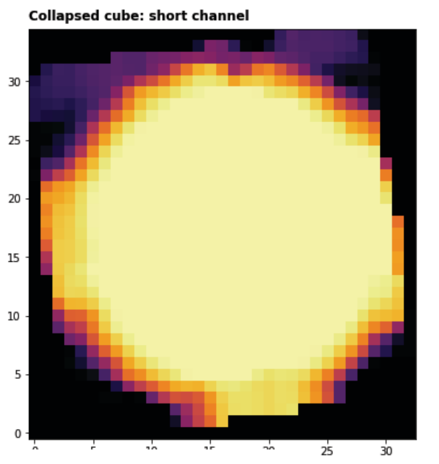


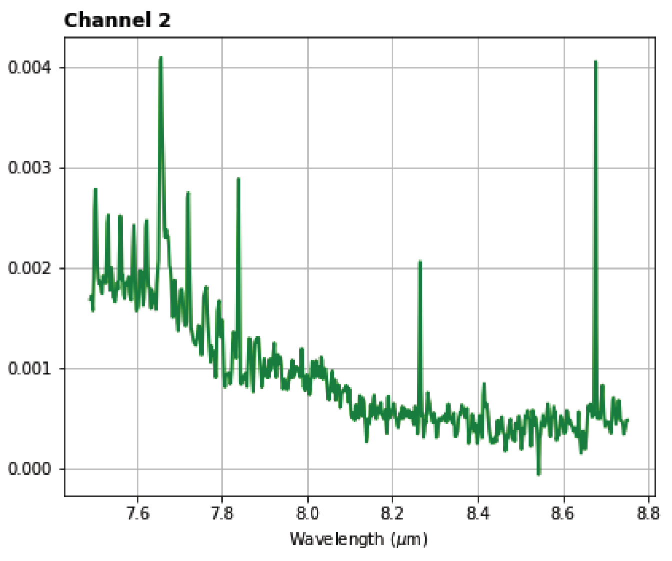
Step 7: Level 3 Pipeline ("Combine Dithers")

```
Spec3Pipeline: Processes JWST spectroscopic exposures from Level 2b to 3.

Included steps are:
assign moving target wcs (assign_mtwcs)
master background subtraction (master_background)
MIRI MRS background matching (mrs_imatch)
outlier detection (outlier_detection)
2-D spectroscopic resampling (resample_spec)
3-D spectroscopic resampling (cube_build)
1-D spectral extraction (extract_1d)
1-D spectral combination (combine_1d)
```

- Combination of dithers and spectral extraction (Spec3Pipeline)
- Produces cube files: 'dither*s3d.fits'
- Produces spec files: 'dither*1d.fits'





After Step 7? Now have calibrated *s3d.fits files

- **Next Steps:**
  - Navigate these reconstructed cubes to assign lat/lon/emission.
  - Check sensitivity/saturation compared to ETC.
  - Perform inversions on spectra to see if we can recover inputs.

1. NEMESIS Forward Models
2. Cubes for MIRISim
3. Run MIRISim
4. Inspect Level 1 Ramp Images
5. Ramps to Slope (2A Detector1Pipeline)
6. Calibrate Slopes (2B Spec2Pipeline)
7. Combine dithers (3 Spec3Pipeline)
8. Navigate Reconstructed Cubes

Where does OTB and WCS fit in?

Level 1 and 2 Processes

Stage 1 and 2 Product Types - Detector-based

	File ProdType	calwebb_ Module	Processing Level	Dimensions: Units	Description
Stage 1	*original*	formatting	1a	4D : DN	Bare-bones raw ramp data, not available in MAST
	uncal	add header	1b	4D : DN	raw ramp data w/ full header
	trapsfilled	detector1 (tso1 is very similar)	2a	N/A	charge traps status
	ramp			4D : DN	Corrected ramp data
	rate			2D : DN/s	Count rate averaged over integrations
	rateints			3D : DN/s	Count rate for each integration. Equals 'rate' when NInts=1.
Stage 2	*bsub*	image2, tso-image2	2b	2D : DN/s	Background subtracted (only if background observation available)
	cal			2D: MJy/sr, MJy	Calibrated data. MJy/sr (image); MJy (tso)
	i2d				Calibrated data, resampled to un-distorted on-sky pixels
	calints			3D: MJy/sr, MJy	Calibrated data for each integration; coronagrphy and tso only
	bsub	spec2, tso-spec2	2b	2D : DN/s	Background subtracted (only if background observation available)
	cal			2D: MJy/sr, MJy	Calibrated data. MJy/sr (image); MJy (tso)
	s2d				Calibrated data, resampled to un-distorted on-sky spaxels
	s3d			3D : MJy/sr, MJy	Calibrated data, MIRI & NIRspec IFUs
	x1d			1D : various	Extracted spectra
	calints			3D : MJy/sr, MJy	Calibrated data for each integration; tso only
	x1dints			1D : various	Extracted spectra for each integration

bold: standard / high-interest science products

italics: non-standard / less useful for science (intermediate pipeline products in some cases)

Level 3 Processing

Stage 3 Product Types - Combined dithers, mosaics, etc.

	File ProdType	calwebb_ Module	Processing Level	Dimensions: Units	Description
Stage 3	**crf**	image3	3	2D : MJy/sr, MJy	CR-flagged calibrated data
	i2d				Calibrated data, resampled to un-distorted on-sky pixels
	cat			n/a	Source catalog
	crf	spec3		2D : MJy/sr, MJy	CR-flagged calibrated data
	s2d				Calibrated data, resampled to un-distorted on-sky spaxels
	s3d			3D : MJy/sr, MJy	Calibrated data, resampled to un-distorted on-sky spaxels (IFUs)
	x1d			1D: various	Extracted spectra
	c1d				Combined extracted spectra
	ami	ami3		N/A	Fringe parameters (per exposure)
	amiavg				Averaged fringe parameters
	aminorm				Normalized fringe parameters
	crfints	coron3		MJy/sr, MJy	3D CR-flagged calibrated data
	psfstack				PSF library images
	psfalighn				Aligned PSF images
	psfsub				PSF subtracted images
	i2d				2D Subtracted images resampled to un-distorted on-sky pixels
	crfints	tso3		3D : MJy/sr, MJy	CR-flagged calibrated data
	phot			N/A	TSO Imaging catalog
	x1dints			various	TSO 1-D extracted spectra
	whtlt			N/A	TSO spectrocsopy white-light catalog
	wfscmb	wfs-image3		2D : MJy/sr, MJy	Combineed Wavefront Control image

bold: standard / high-interest science products