JWST Pipeline Overview

Jwebbinar
AAS

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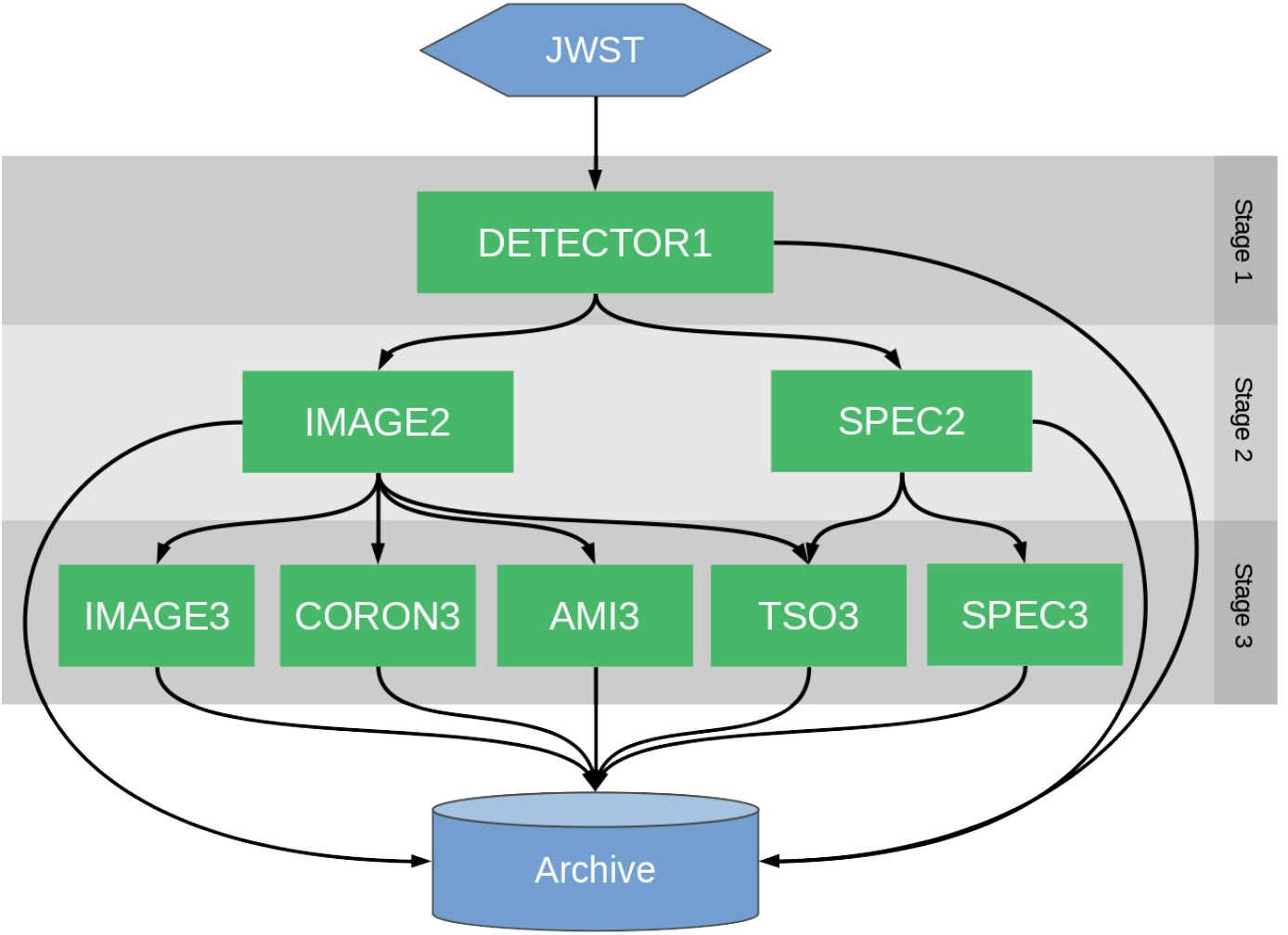


Team Effort

JWST Calibration Working Group

Current Lead:
Anton Koekemoer

Past Leads:
Christine Chen
Karl Gordon

Instrument / Branch (Team)	Primary STScI representatives in CalWG meetings	Other STScI (on email list, not specifically required to join every meeting)	IDT / external representatives (on email list, welcome to join in meetings), to add any new members please contact @Anton Koekemoer
NIRCam (STScI) NIRCam (IDT)	@Armin Rest @Bryan Hilbert	@Alicia Canipe * @Brian Brooks * @John Stansberry * @Julien Girard @Martha Boyer @Massimo Robberto @Matteo Correnti * @Nikolay Nikolov	@Marcia Rieke @Douglas Kelly @Everett Schlawin @Jarron Leisenring @Jonathan Fraine @Karl Misselt
NIRISS (STScI) NIRISS (IDT)	@Kevin Volk @Swara Ravindranath	@Anand Sivaramakrishnan @André Martel @Deepashri Thatte @Joseph Filippazzo @Nestor Espinoza * @Paul Goudfrooij * @Stephanie La Massa	@Loic Albert Jason Rowe
NIRSpec (STScI) NIRSpec (ESA)	@Cheryl Pavlovsky @James Muzerolle	@Elena Sabbi @Emily Wislowski @Graham Kanarek @Leonardo Ubeda @Tony Keyes	@Pierre Ferruit @Catarina Alves de Oliveira @Giovanna Giardino @Nora Luetzgendorf @Stephan Birkmann @Tim Rawle @Torsten Boeker
MIRI (STScI) MIRI (IDT)	@Misty Cracraft * @Karl Gordon *	@Beth Sargent @Bryan Holler * @David Law @Dean Hines * @Greg Sloan * @Macarena Garcia Marin @Mattia Libralato @Sarah Kendrew *	@George Rieke @Jane Morrison @Kate Su @Michael Ressler @Patrice Bouchet @Alistair Glasse @Alvaro Labiano @Bart Vandenbussche @Christophe Cossou @Jeroen Bouwman @Martin Topinka @Pamela Klaassen @Patrick Kavanagh @Silvia Scheithauer @Vincent Geers
FGS / Telescopes	@Sherie Holfeltz @Ed Nelan	@Pierre Chayer @Randal Telfer	
MESA	@Michael Regan @Rosa Diaz	@Douglas Long @Eddie Bergeron @Van Dixon	
Science Instrument Calibration Software Branch support:			
SCSB	@Nadia Dencheva @Howard Bushouse	@Jonathan Eisenhamer @James Davies @Larry Bradley @David Grumm @Warren Hack	

Current JWST Calibration Working Group Members

Learning from Past Efforts

- Previous Missions
  - Hubble, Spitzer, Herschel, etc.
  - Ground-based observatories/instruments
    - Especially important for integral field spectroscopy (IFU), coronagraphy, and multi-object spectroscopy (MOS)
- What to do
- What not to do

Pipeline Philosophy

- Algorithms based on community best
  - Input from instrument teams and mode specific expert teams
  - Overall goal is best justified algorithms
- Use same code for different instruments
  - Where possible
  - Easier to maintain
  - Takes advantage of strengths of all teams
- Provide pipeline directly to community

Development Plan

- Baseline Pipeline
  - All instruments and all modes
  - Provides good science
  - Meets requirements
  - Algorithms defined – implementation in progress
  - Pipeline at Launch
- Enhanced Pipeline
  - Best possible reductions
  - Highest quality science data
  - This is the final goal (launch + many years)
  - Start work after baseline pipeline done and continue for the mission lifetime and beyond
    - Will need to prioritize effort

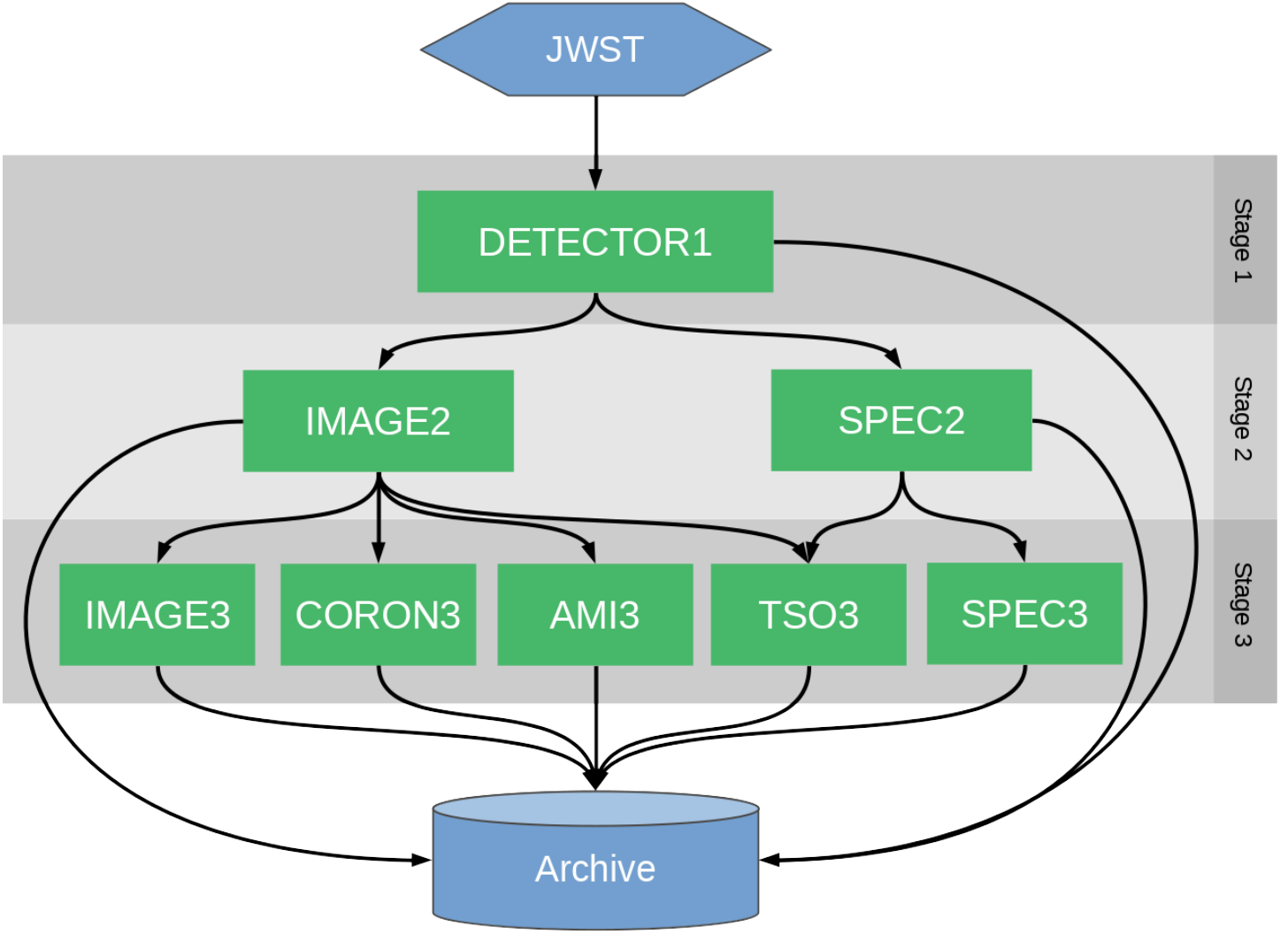
User Experience

- Pipeline automatically run on all data
- Default parameters for all pipeline steps
- Pipeline products produced and archived
  - Final as well as raw and intermediate products
- User can download and run pipeline locally
  - Change defaults
  - Add customized reduction steps
  - Pipeline may require internet connection for telemetry and reference file queries

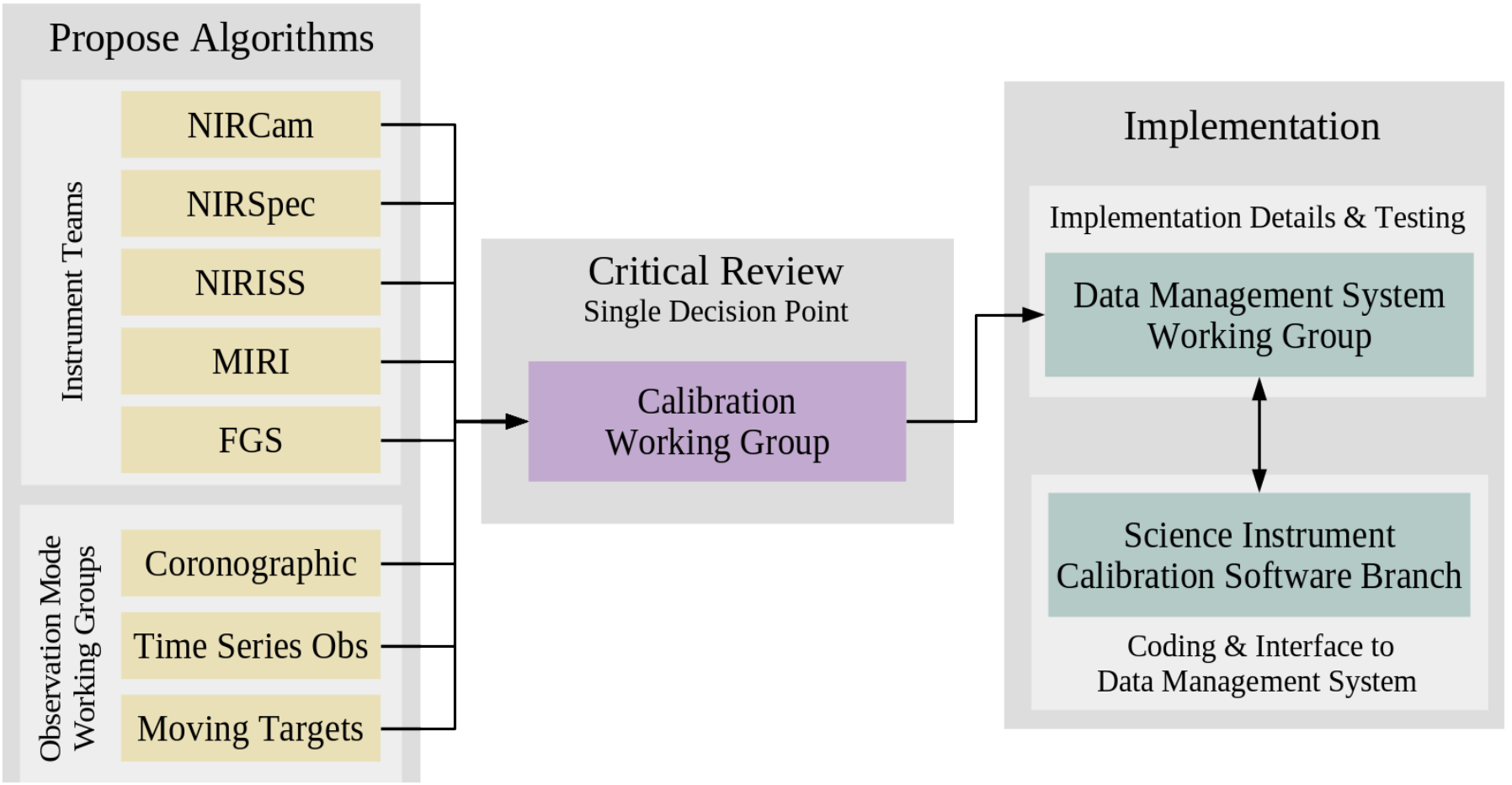
Pipeline versus Data Analysis Tools

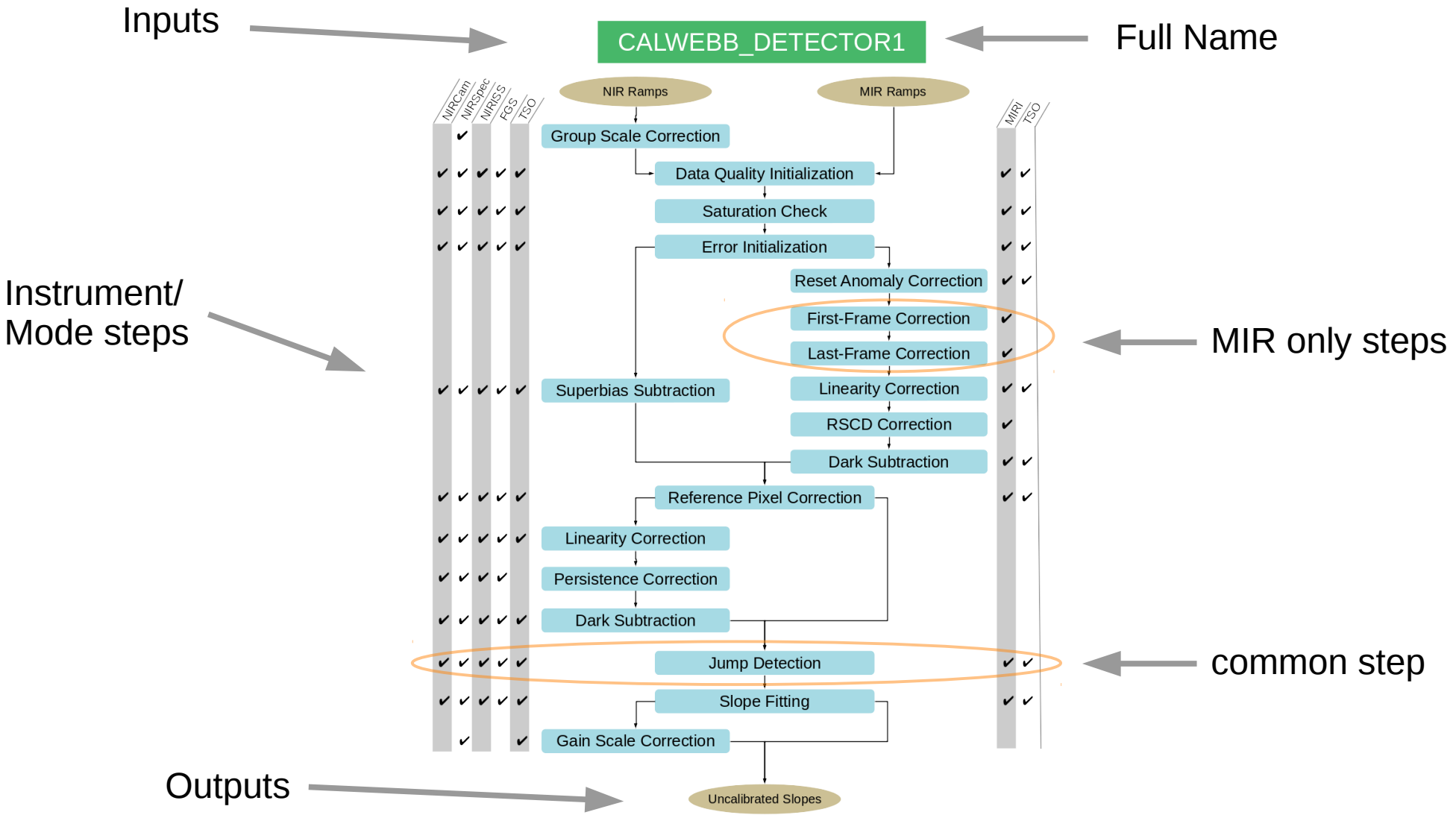
- Pipeline
  - Automatically runs on all data
  - Requires no human interaction
- Data Analysis Tools
  - Requires science decisions – human interaction
  - Usually based on pipeline products
- Overlaps
  - For example, parts of the pipeline can be re-run interactively with non-default options

Overview


JWST
DETECTOR1
IMAGE2
SPEC2
IMAGE3
CORON3
AMI3
TSO3
SPEC3
Archive
Stage 1
Stage 2
Stage 3

Algorithms Decisions

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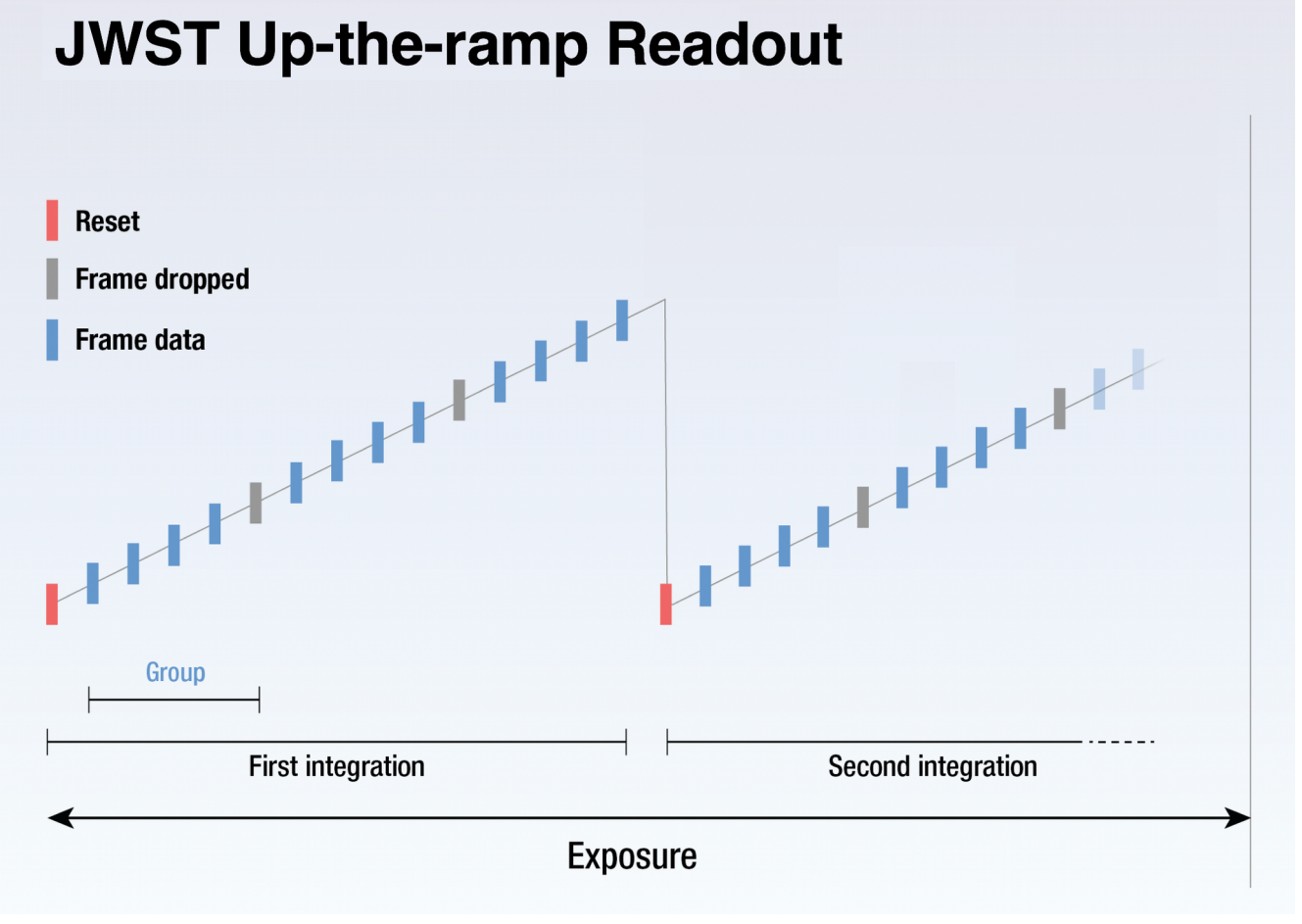
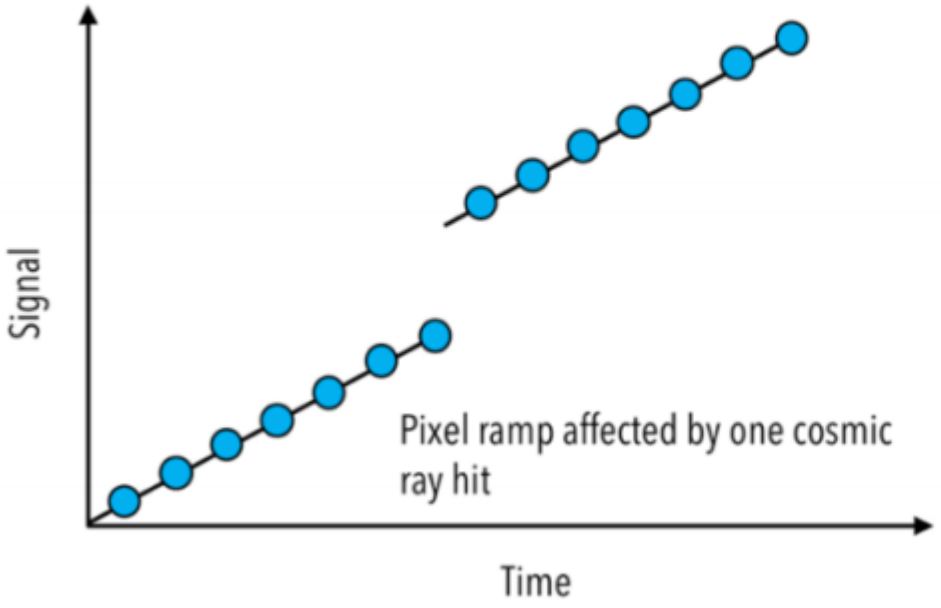
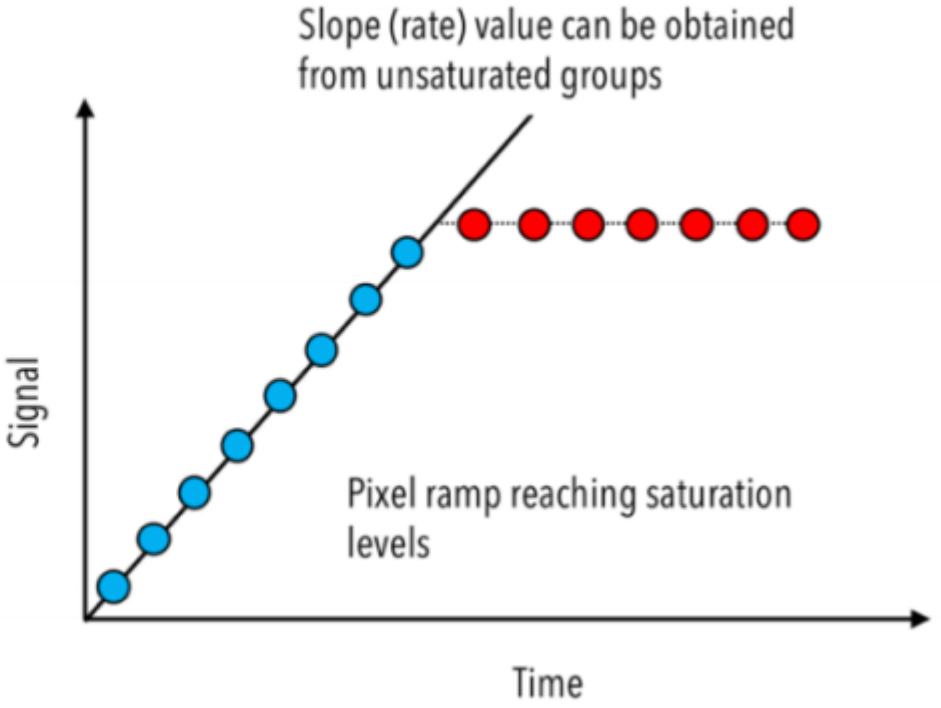
Full Name
Instrument/
Mode steps
MIR only steps
common step
Outputs
NIRCam
NIRSpec
NIRISS
FGS
TSO
MIRI
TSO
NIR Ramps
MIR Ramps
Group Scale Correction
Data Quality Initialization
Saturation Check
Error Initialization
Reset Anomaly Correction
First-Frame Correction
Last-Frame Correction
Superbias Subtraction
Linearity Correction
RSCD Correction
Dark Subtraction
Reference Pixel Correction
Linearity Correction
Persistence Correction
Dark Subtraction
Jump Detection
Slope Fitting
Gain Scale Correction
Uncalibrated Slopes

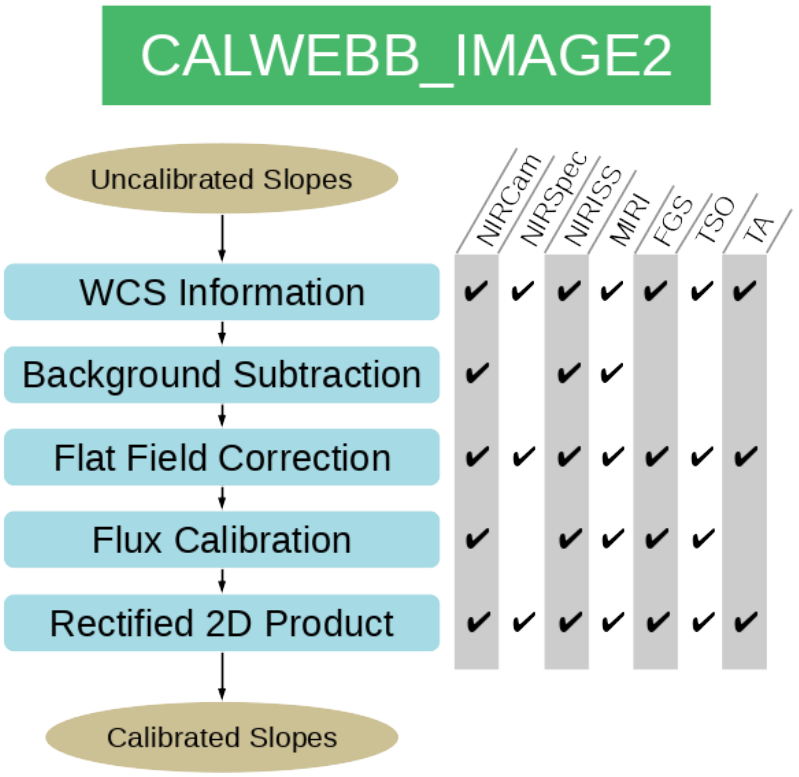
JWST Measurement = Ramp → Slope

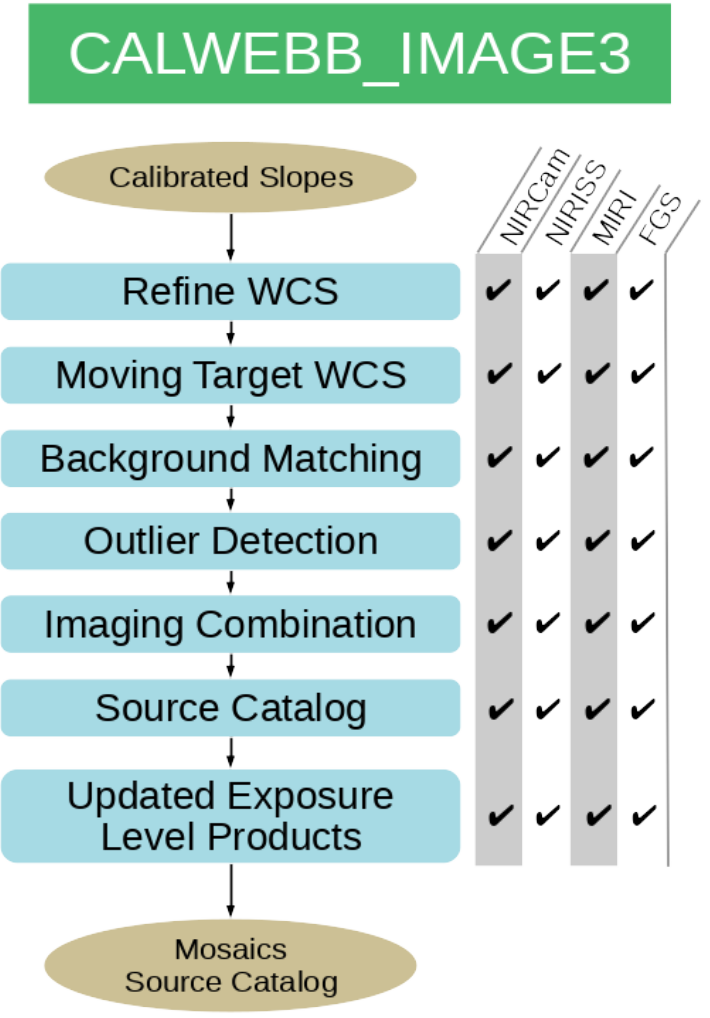


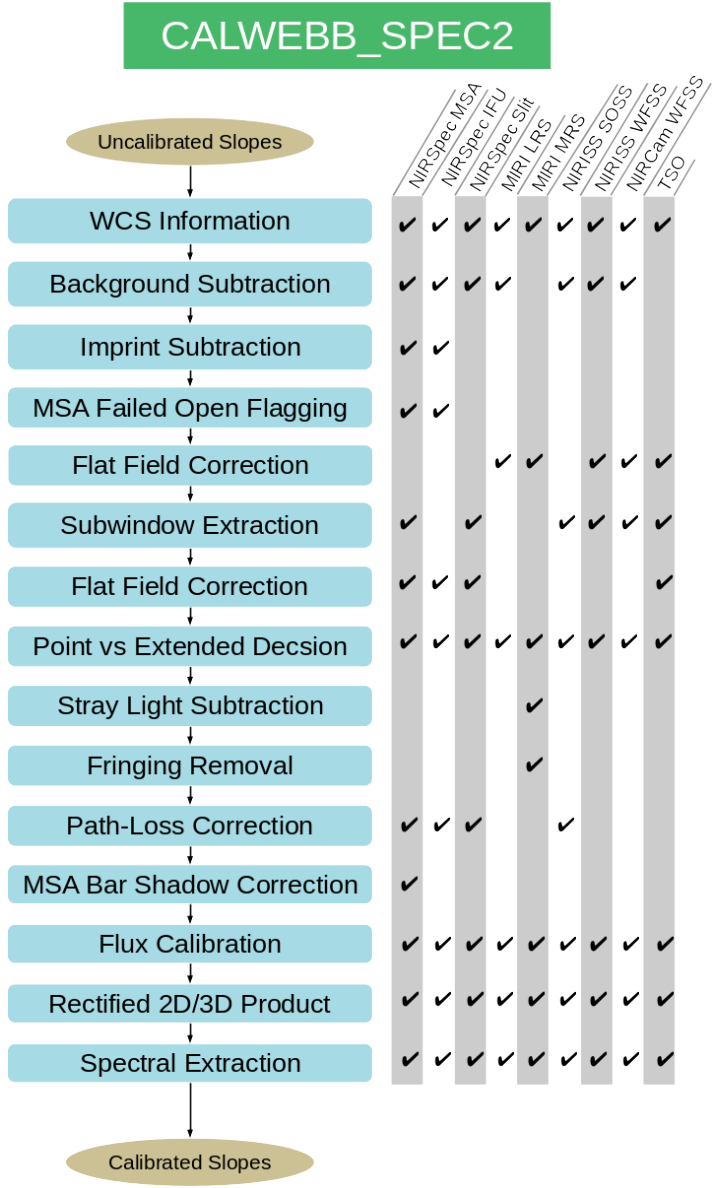
Ramp Jumps and Saturation






CALWEBB_IMAGE2
Uncalibrated Slopes
WCS Information
Background Subtraction
Flat Field Correction
Flux Calibration
Rectified 2D Product
Calibrated Slopes
NIRCam
NIRSpec
NIRISS
MIRI
FGS
TSO
TA


CALWEBB_IMAGE3
Calibrated Slopes
Refine WCS
Moving Target WCS
Background Matching
Outlier Detection
Imaging Combination
Source Catalog
Updated Exposure Level Products
Mosaics Source Catalog
NIRCam
NIRISS
MIRI
FGS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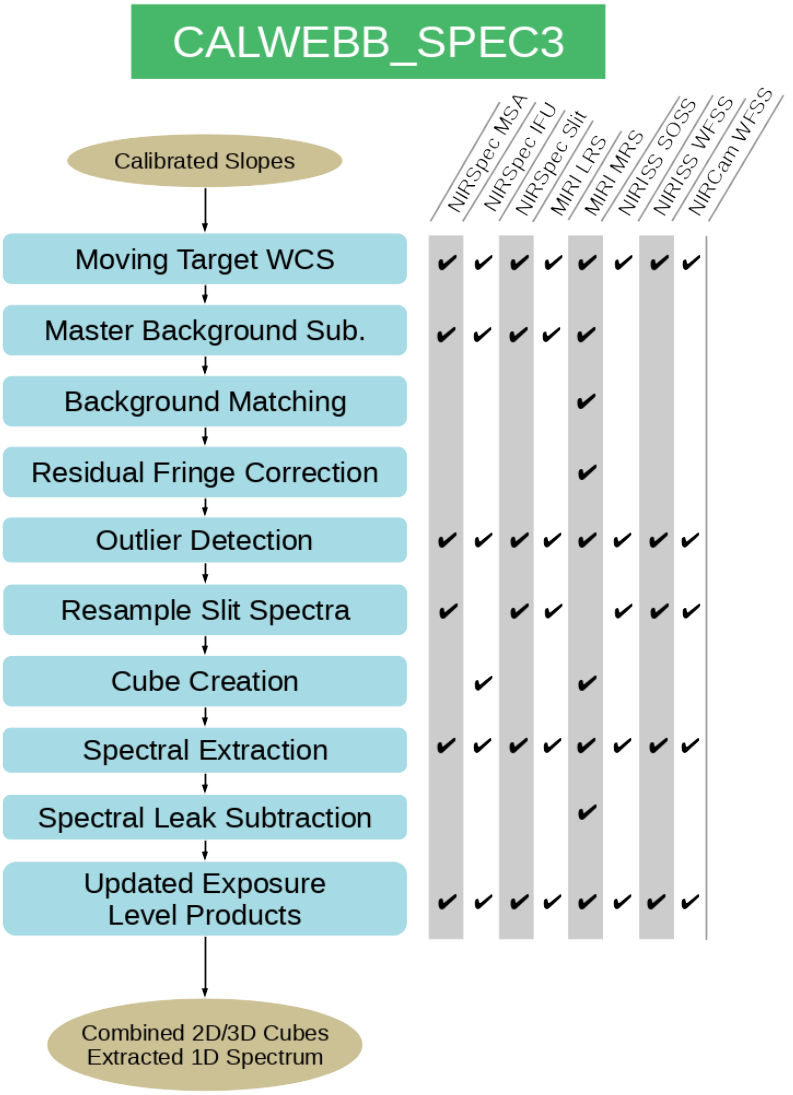
NIRSpec MSA
NIRSpec IFU
NIRSpec Slit
MIRI LRS
MIRI MRS
NIRISS SOSS
NIRISS WFSS
NIRCam WFSS
TSO
Uncalibrated Slopes
WCS Information
Background Subtraction
Imprint Subtraction
MSA Failed Open Flagging
Flat Field Correction
Subwindow Extraction
Flat Field Correction
Point vs Extended Decsion
Stray Light Subtraction
Fringing Removal
Path-Loss Correction
MSA Bar Shadow Correction
Flux Calibration
Rectified 2D/3D Product
Spectral Extraction
Calibrated Slopes


CALWEBB_SPEC3
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MIRI LRS
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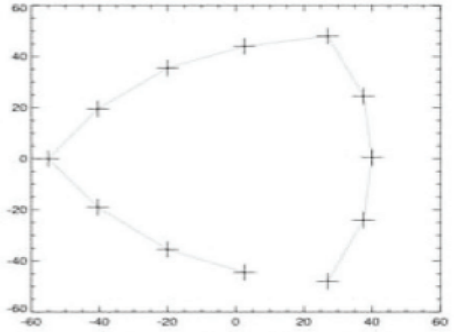
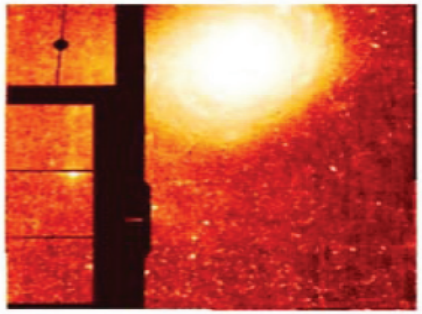
NIRISS SOSS
NIRISS WFSS
NIRCam WFSS
Calibrated Slopes
Moving Target WCS
Master Background Sub.
Background Matching
Residual Fringe Correction
Outlier Detection
Resample Slit Spectra
Cube Creation
Spectral Extraction
Spectral Leak Subtraction
Updated Exposure Level Products
Combined 2D/3D Cubes Extracted 1D Spectrum

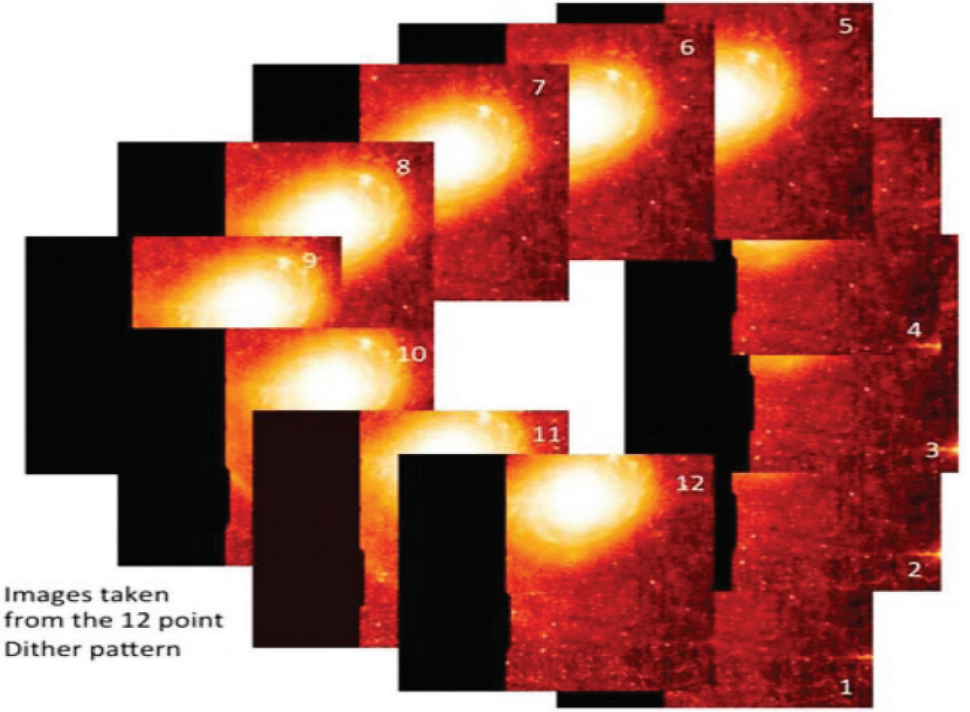
Imaging Data Products: Example



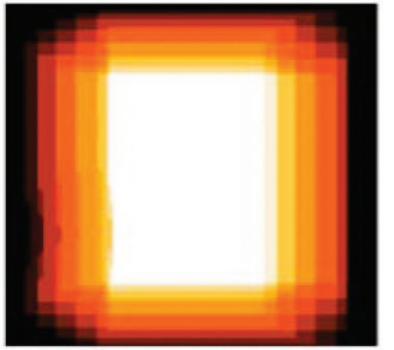
Reuleaux 12 point Dither pattern



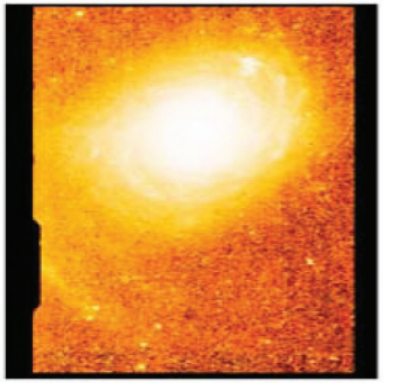
The MIRIM footprint



Images taken from the 12 point Dither pattern



Mosaic coverage map



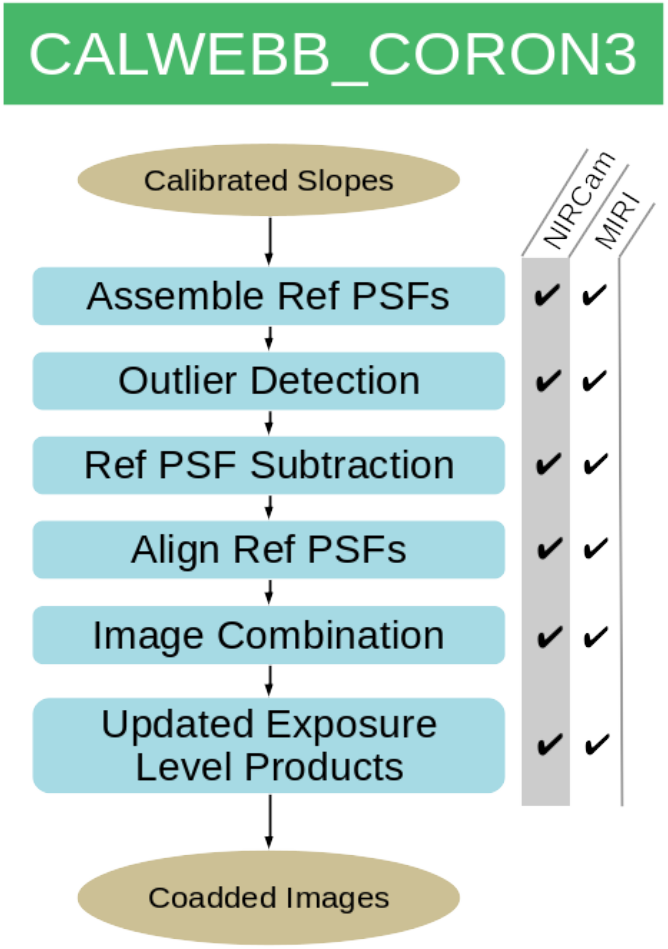
Resulting mosaicked image

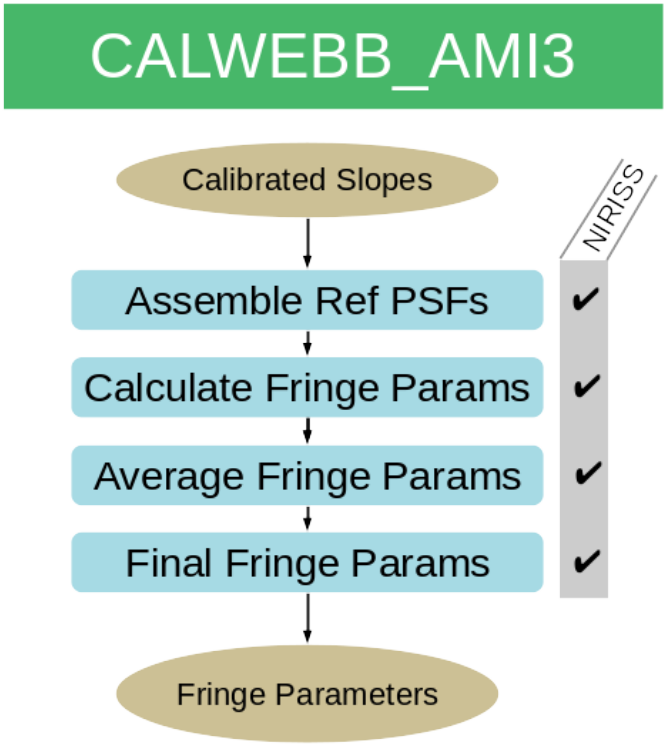
Gordon et al. (2015, PASP, 127, 696) – MIRI PASP paper X

More Information

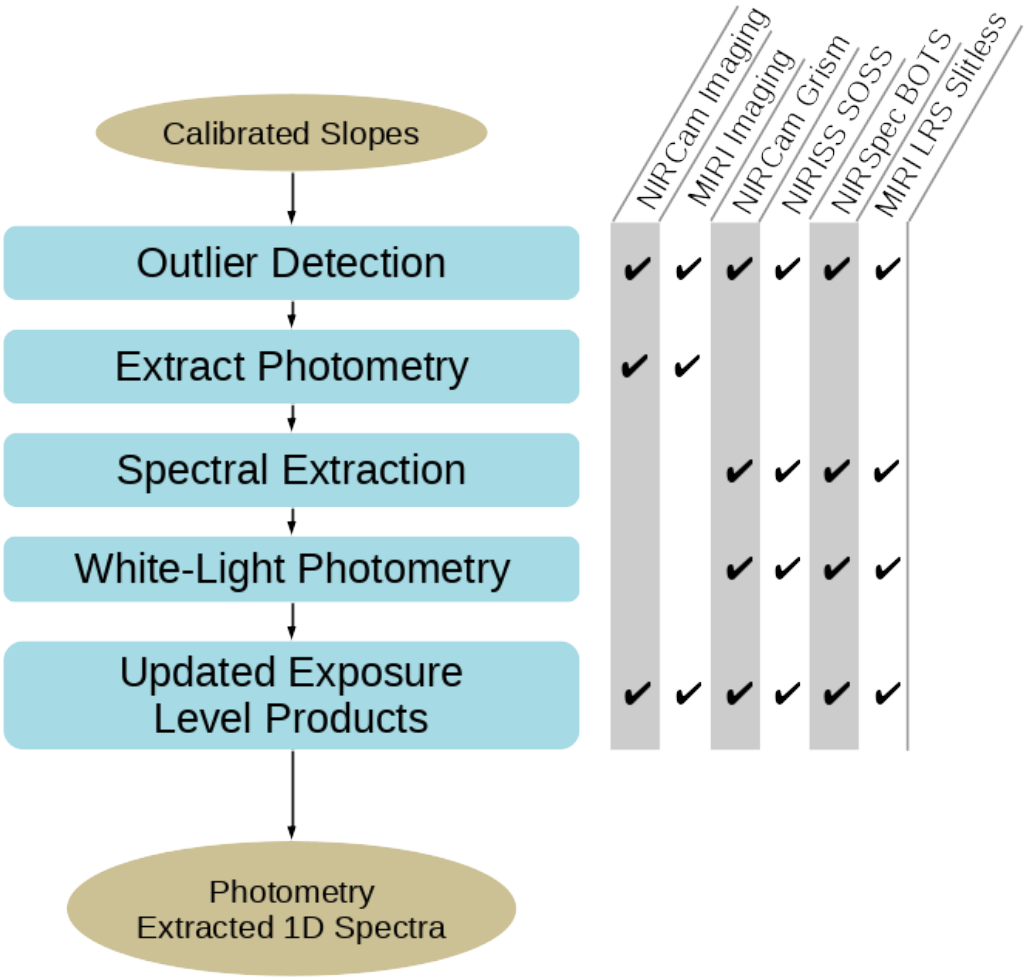
- Algorithm details
  - https://jwst-docs.stsci.edu/jwst-data-reduction-pipeline/algorithm-documentation
- Code focused documentation
  - https://jwst-pipeline.readthedocs.io/en/latest/index.html

Backup Slides

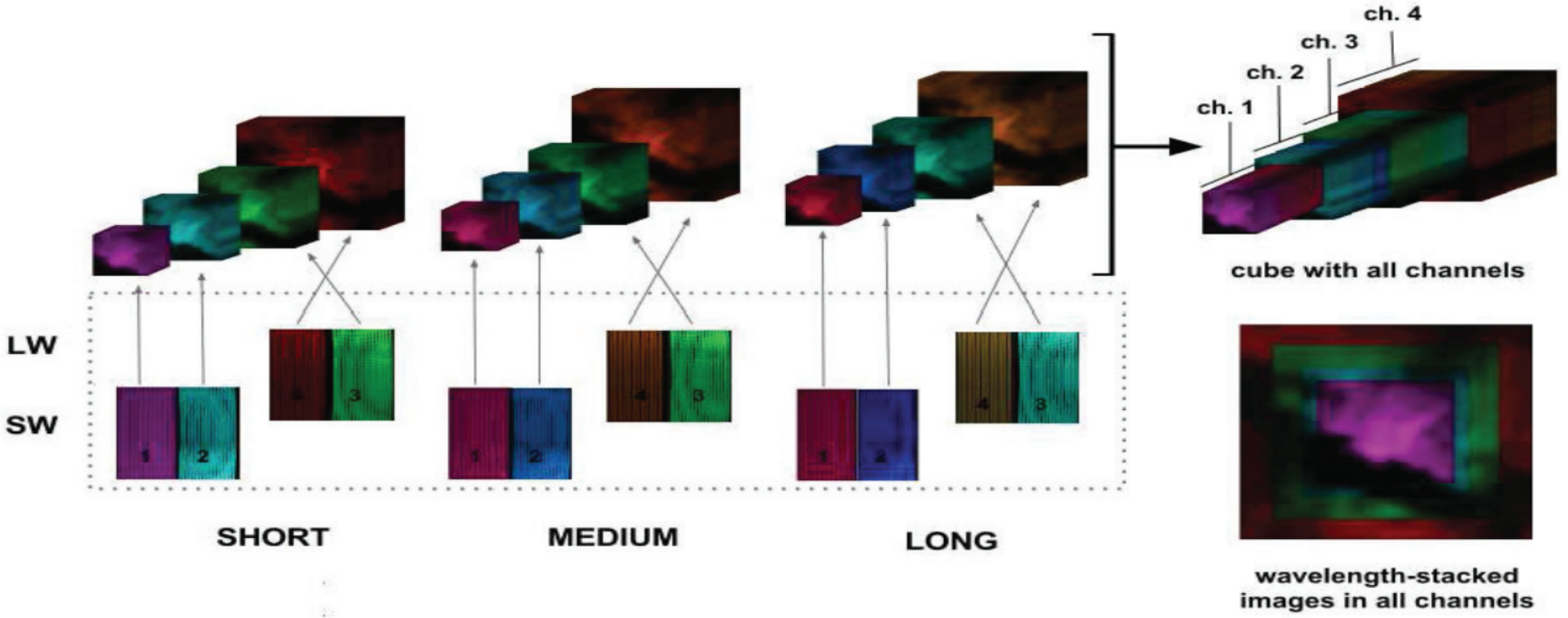

CALWEBB_CORON3
Calibrated Slopes
Assemble Ref PSFs
Outlier Detection
Ref PSF Subtraction
Align Ref PSFs
Image Combination
Updated Exposure Level Products
Coadded Images
NIRCam
MIRI
✔ ✔
✔ ✔
✔ ✔
✔ ✔
✔ ✔


CALWEBB_AMI3
Calibrated Slopes
Assemble Ref PSFs
Calculate Fringe Params
Average Fringe Params
Final Fringe Params
Fringe Parameters
NIRISS
✔
✔
✔
✔

CALWEBB_TSO3

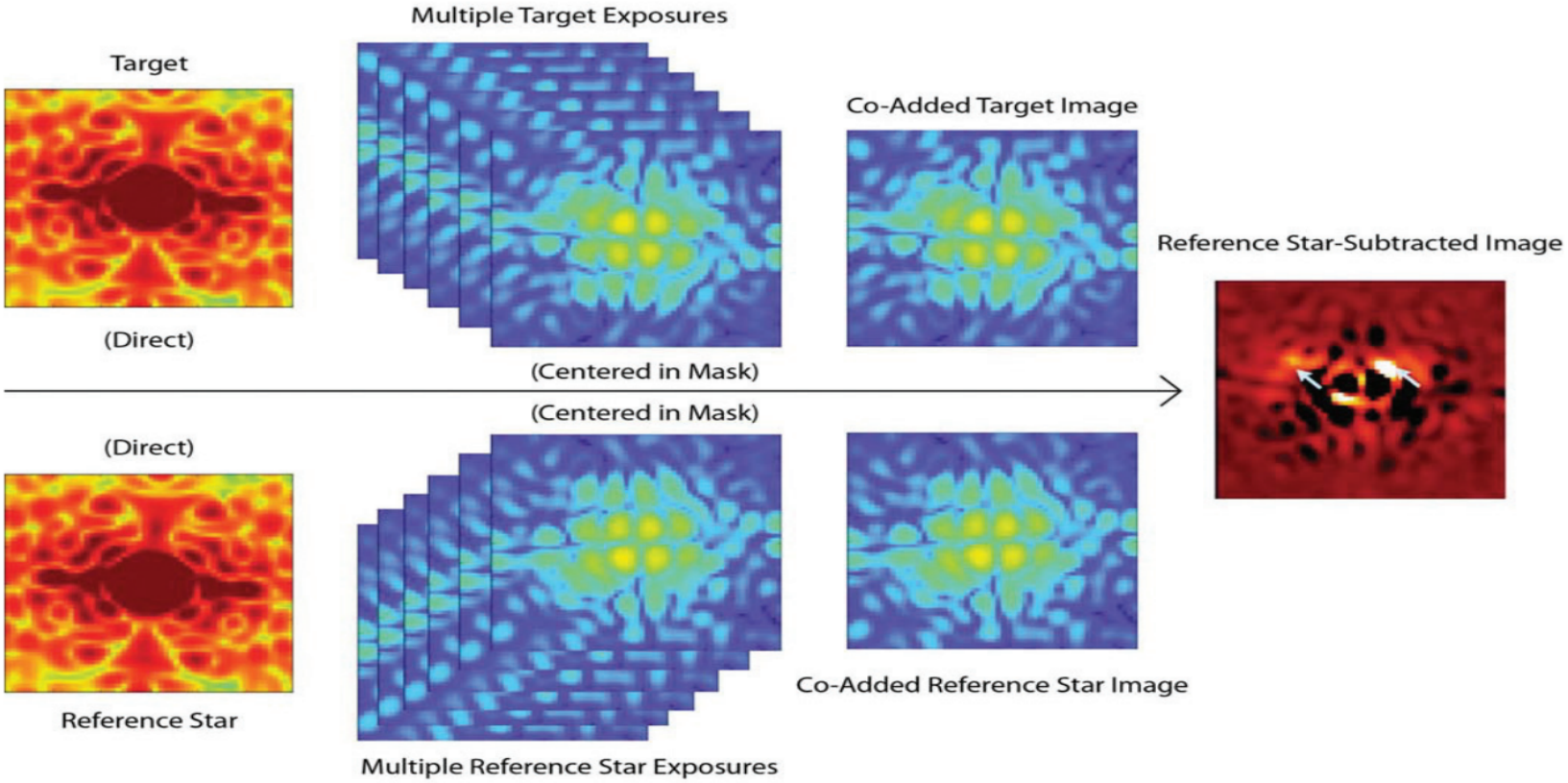


Spectroscopic Data Products: IFU Example



Gordon et al. (2015, PASP, 127, 696) – MIRI PASP paper X

Coronagraphic Data Products: MIRI 4QPM Example



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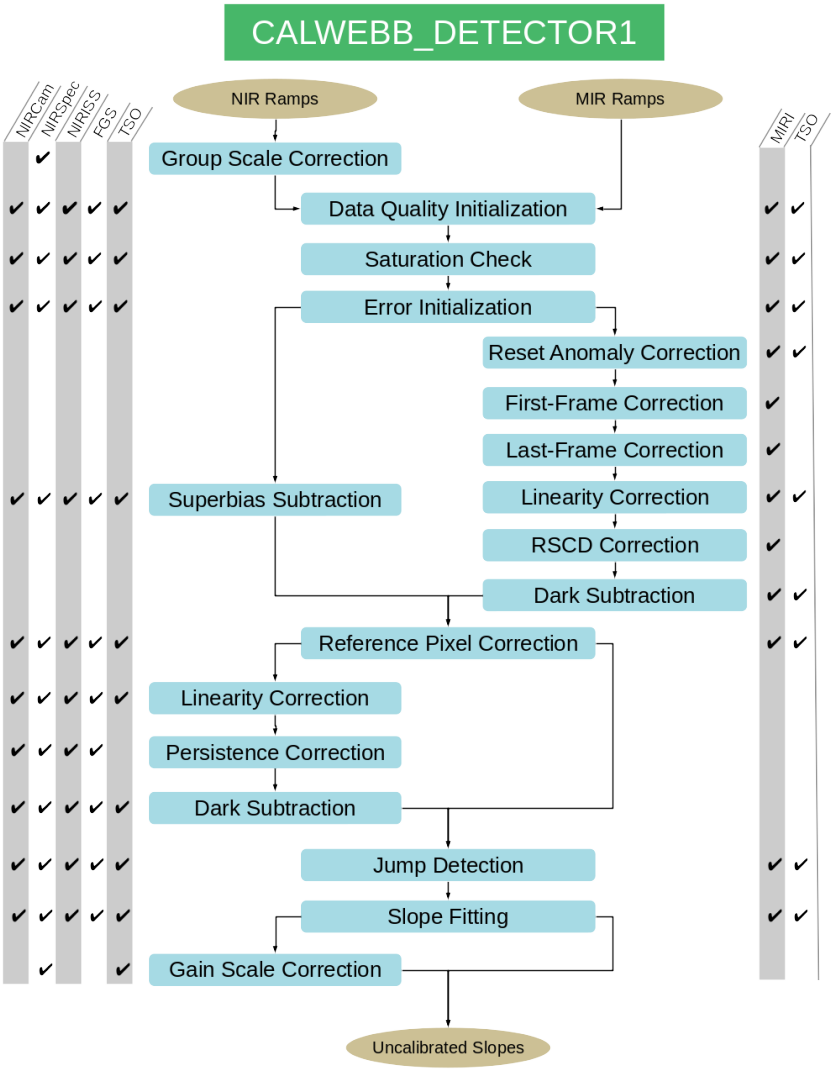
CALWEBB_DETECTOR1
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NIRSpec
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FGS
TSO
MIRI
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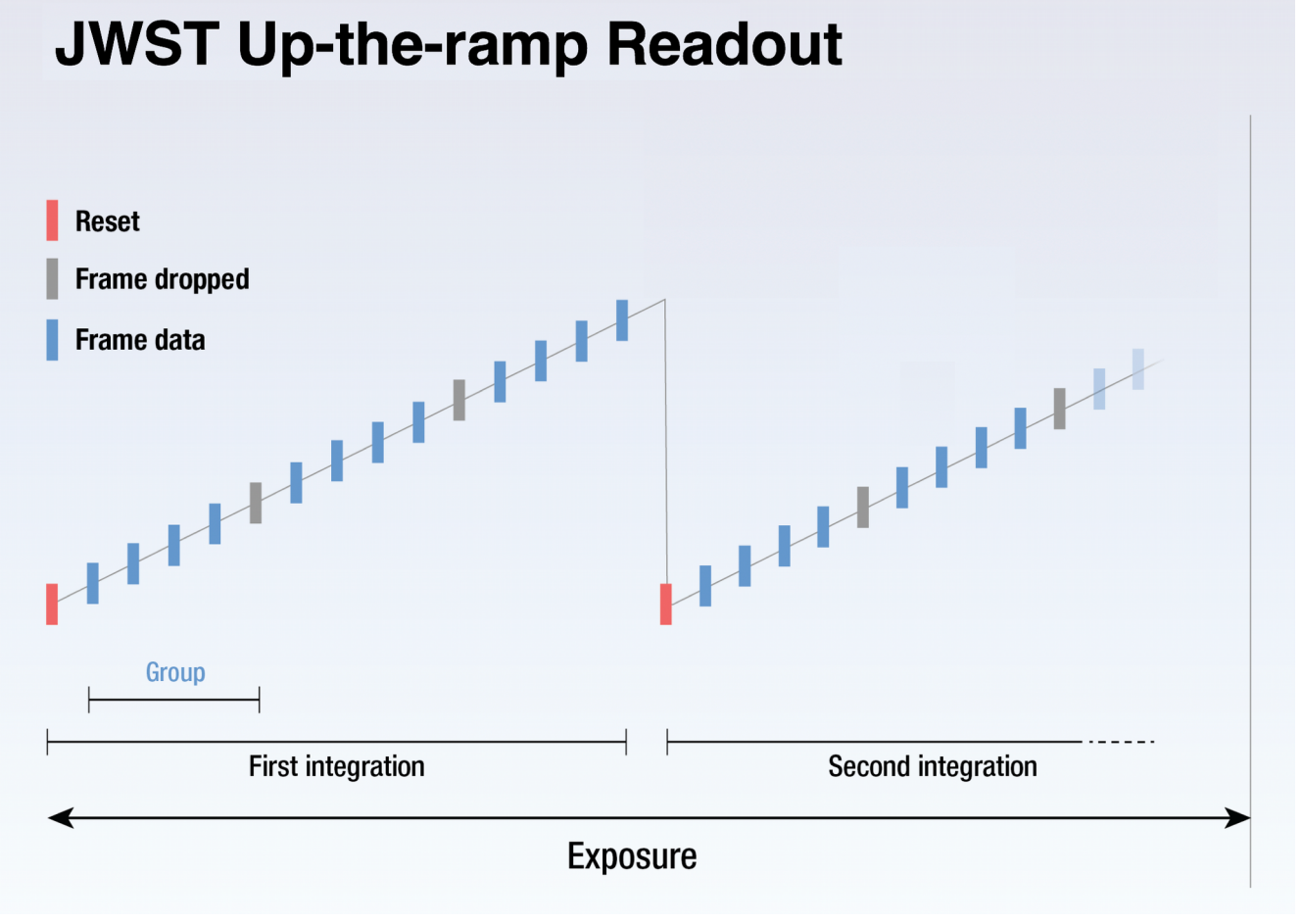
Group Scale Correction
Data Quality Initialization
Saturation Check
Error Initialization
Reset Anomaly Correction
First-Frame Correction
Last-Frame Correction
Linearity Correction
RSCD Correction
Dark Subtraction
Superbias Subtraction
Reference Pixel Correction
Linearity Correction
Persistence Correction
Dark Subtraction
Jump Detection
Slope Fitting
Gain Scale Correction
Uncalibrated Slopes

Detector1

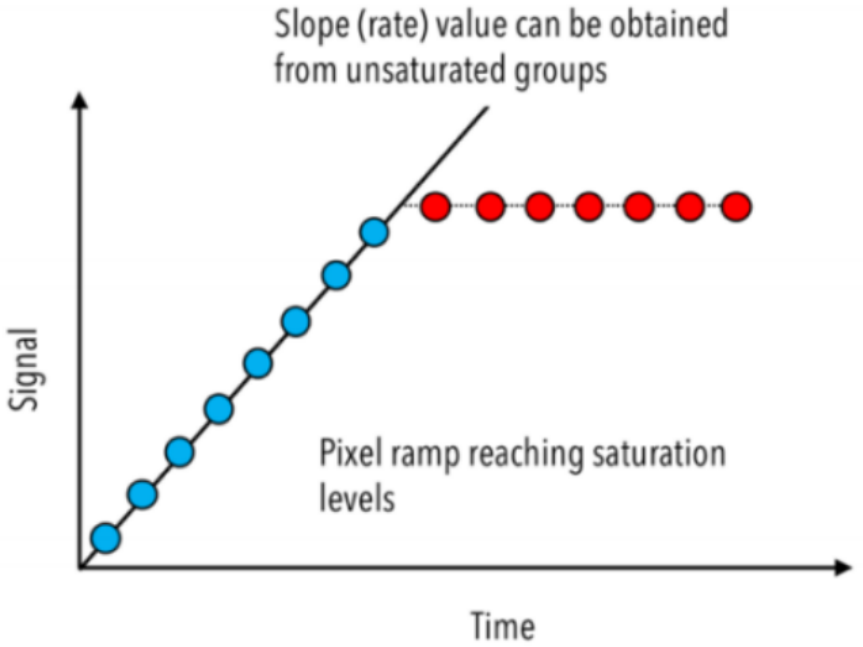
- Many instrumental level effects corrected or accounted for
- A number different between the NIR and MIR detectors
  - Different materials and technologies
- Will only discuss a few Detector1 steps

JWST Measurement = Ramp → Slope



Detector1: Saturation

- Saturation above some Signal (DN) Value
- Groups flagged and not used in slope fit



Detector1: Reference Pixel Correction

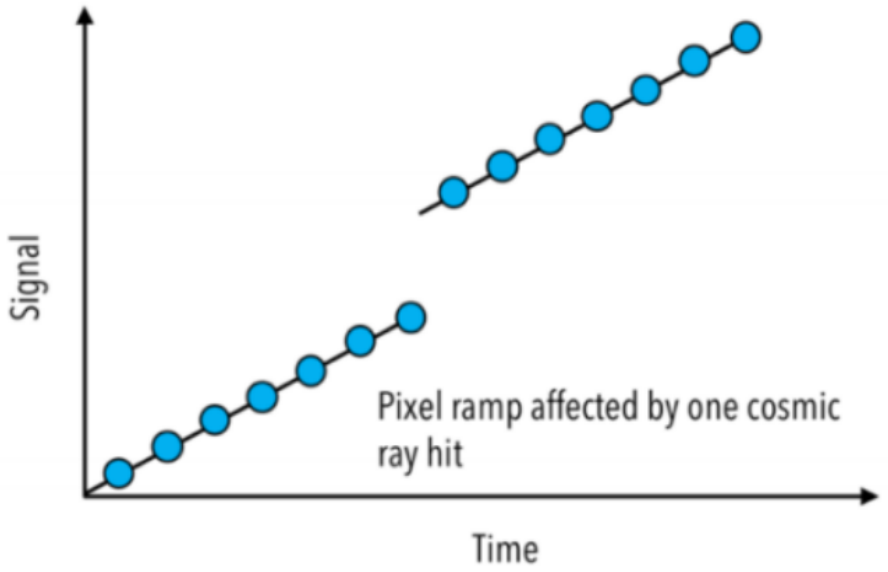
- Subtract an average of “reference” pixels
- Reference pixels are non-photon seeing pixels that track variations in the electronic baselines
- Generally located at the edges of the arrays

Detector1: Linearity Correction

- Linearize the ramps based on appropriate reference file
- Non-linearities well characterized by sum of low order polynomials

Detector1: Detect Jumps

- Cosmic rays inject step functions to ramps
- Jumps flagged and not used in slope fit



Detector1: Calculate Slope

- Basic JWST data is ramps
- Basic measurement is a slope → DN/sec
  - Average of ramps between ramp jumps (when present)
- Weighted linear fit
  - Weights based on read and photon noise
- Uncertainty on slope from read and photon noise
  - Total, read, and photon uncertainty terms calculated

CALWEBB_IMAGE2

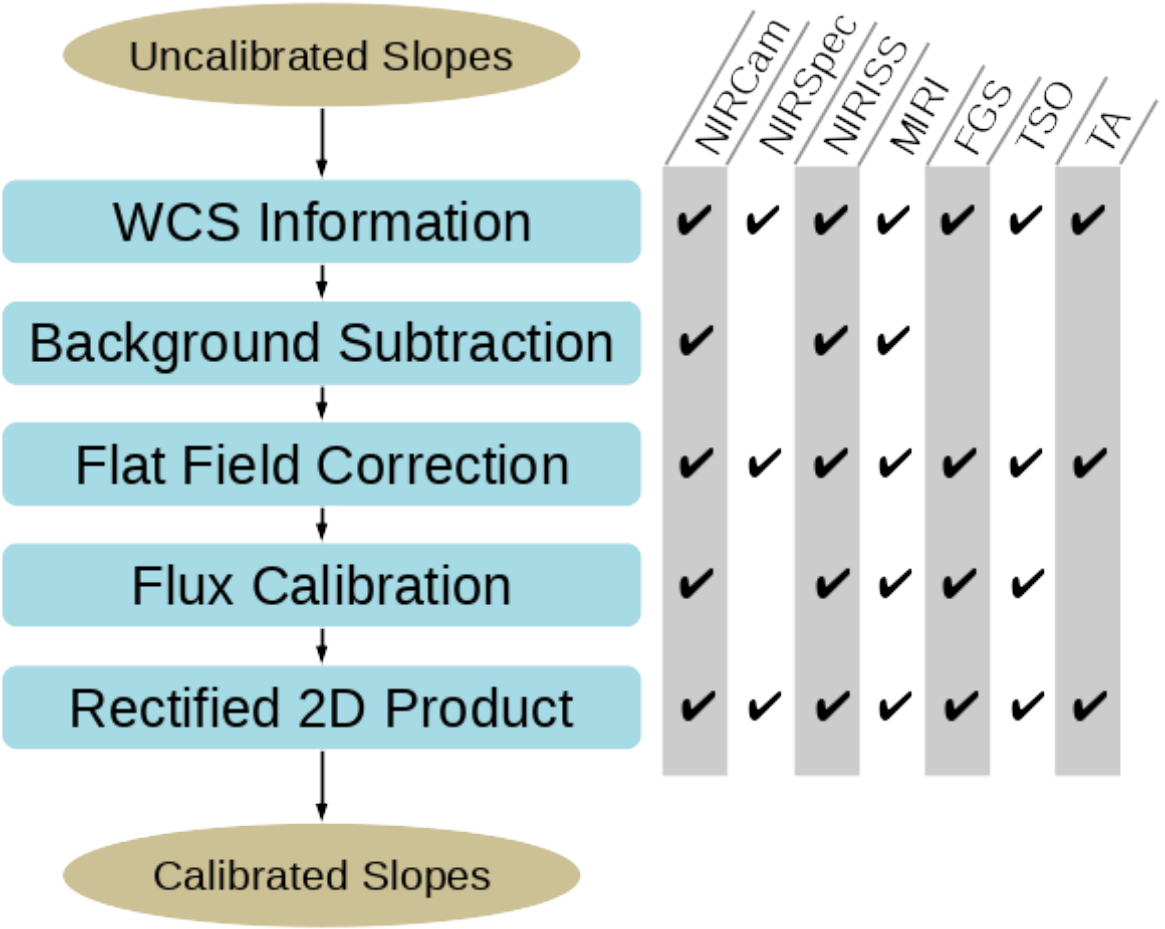


Image2: GWCS Information

- Add Generalized Word Coordinate System (GWGS) information to the data
- FITS WCS information & distortion information
- Determined from Observatory telemetry

Image2: Background Subtraction

- Subtract any dedicated background images taken in the same filter
- If there are multiple bkg images, combine them with sigma clipping before subtraction

Image2: Flat Field Correction

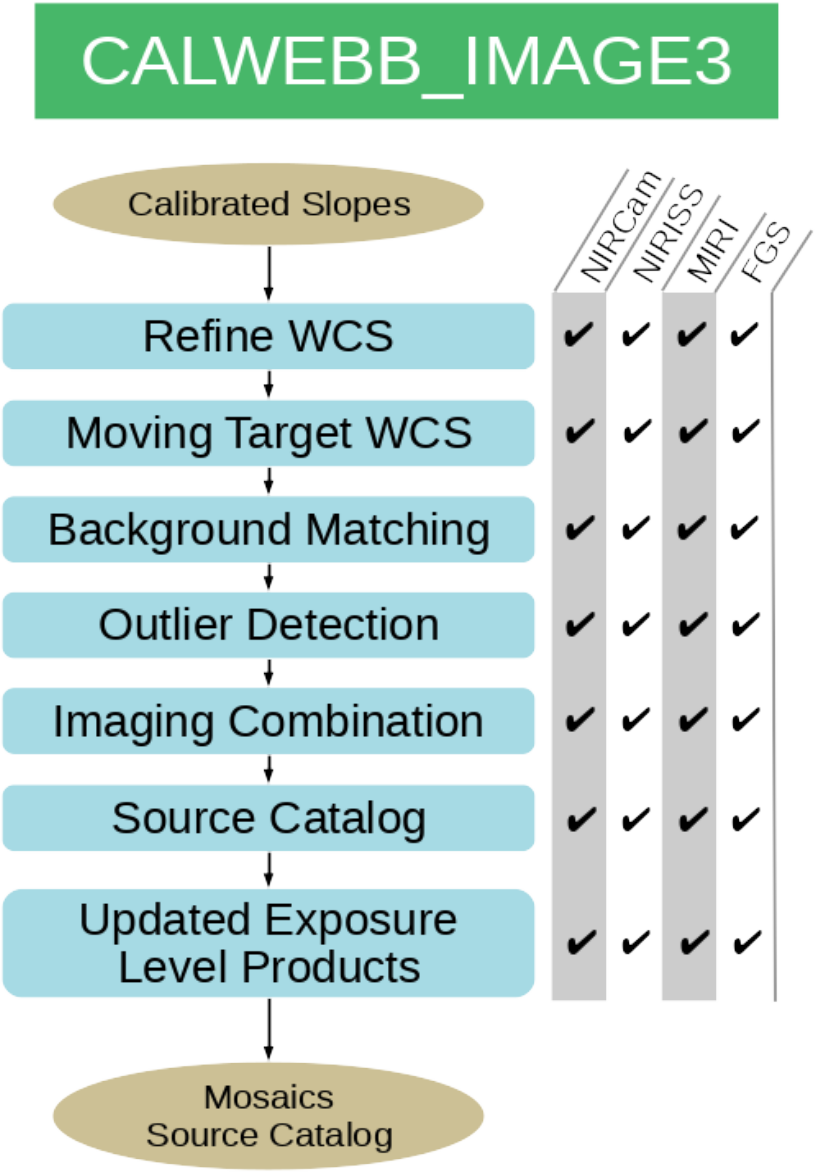
- Correct for variations in responsivity, illumination, and pixel sizes
  - Note: this transforms the basic unit to surface brightness per average sized pixel
- Divide by the appropriate flat field given as a reference file
  - Mask in flat field removes non-active regions
- Add flat field uncertainty term to the associated unc information
  - Given as part of the flat field reference file provided

Image2: Flux Calibration

- Multiply image by the appropriate calibration factor
  - Provided by reference file
- Calibrated units are MJy/sr
  - Supports both point and extended source science
- All error terms updated for unit change

Image2: Rectify 2D Product

- Archive product only
  - Not for use latter in the pipeline
- Apply the distortion solution creating an image that does not have distortion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NIRCam
NIRISS
MIRI
FGS
✔

Image3: Refine GWCS

- Use the location of point sources to refine GWCS
- Relative GWCS through sources in overlap regions
- Absolute GWCS through comparing sources with existing catalogs
  - E.g., Gaia and other astrometric catalogs

Image3: Moving Targets GWCS

- For moving targets, add GWCS information that tracks the moving target
- Allows use of this GWCS to stack on the moving target

Image3: Background Matching

- Equalize the background using overlapping regions between images
- Delta background values are added to the image info/headers for use in latter steps

Image3: Outlier Detection

- Detect outliers using overlapping regions
- Outliers found when n-sigma from the average
  - Includes term to account for interpolation errors for spatially undersampled data
- Outliers flagged and not used

Image3: Imaging Combination

- Combine images into a single coadded mosaic
- Use GWCS information & applies delta backgrounds
  - Standard mosaicking algorithm (aka drizzle with pixfrac=1)
  - Weights are read noise uncertainty term (avoids biases)
- Uncertainty mosaics created
  - Standard error propagation
  - Total, photon, read noise, flat field terms

Image3: Source Catalog

- Catalog of point and compact sources
- Using standard aperture photometry algorithms
- Aperture and corrected to infinite aperture flux densities in Jy

Image3: Updated Exp Level Products

- Updated versions created
- Refined GWCS, delta backgrounds, and outlier flags