

JWST Pipeline & Data Products

Karl D. Gordon
JWST Calibration WG Lead
Space Telescope Sci. Inst.
Baltimore, MD, USA

Stage 1: Ramps-to-Slopes

```
graph TD; S1[Stage 1: Ramps-to-Slopes] --> S2[Stage 2: Calibrated Slopes]; S2 --> S3[Stage 3: Ensemble Processing]; S3 --> A[Archive];
```

Stage 2: Calibrated Slopes

Stage 3: Ensemble Processing

Archive

18 May 2017
STScI

Outline

- Pipeline Philosophy
- User Experience
- High level pipeline structure
- How the pipeline is decided and built
- Baseline and Optimal versions
- Pipeline Availability
- Data Products

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

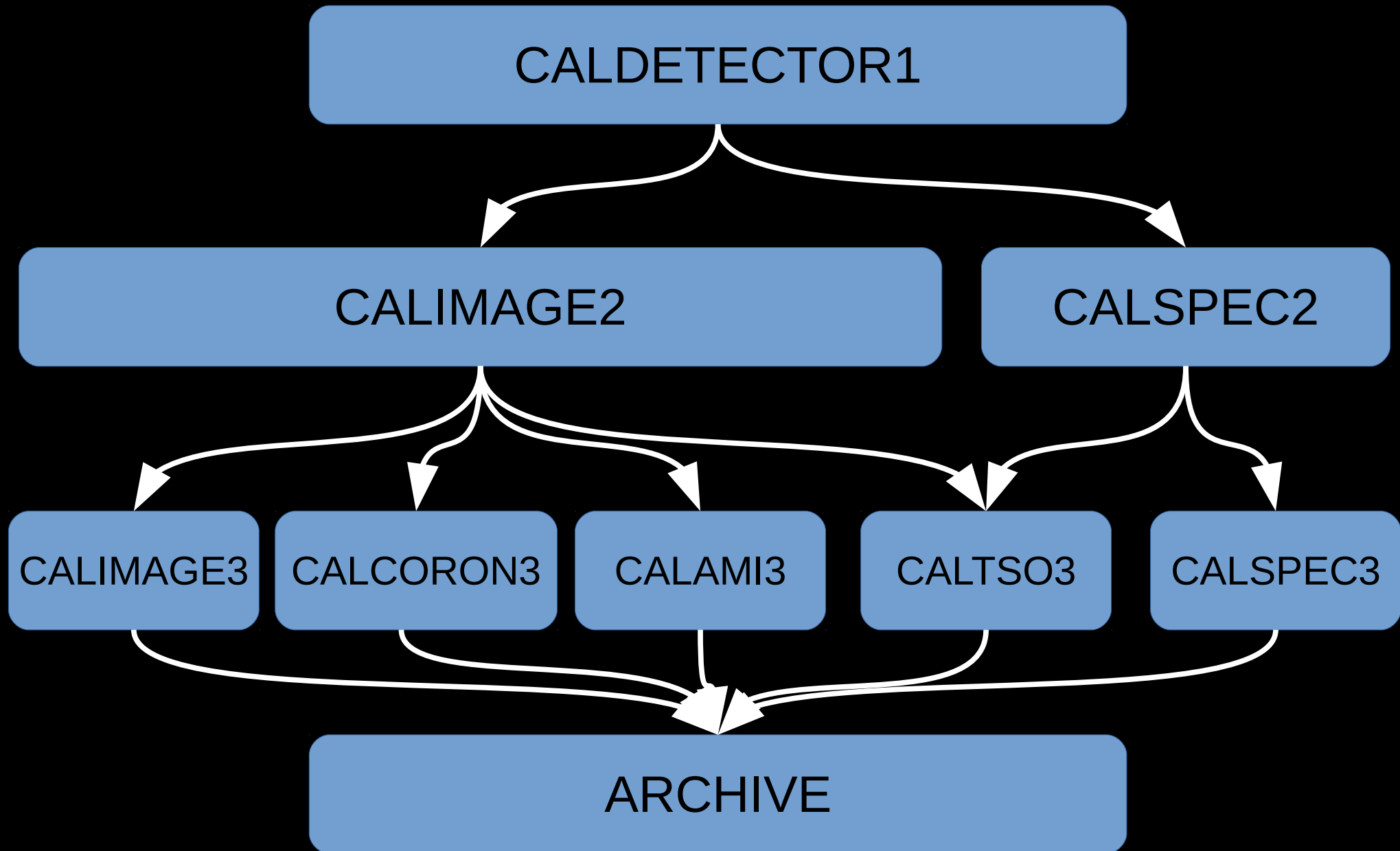
User Experience

- 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

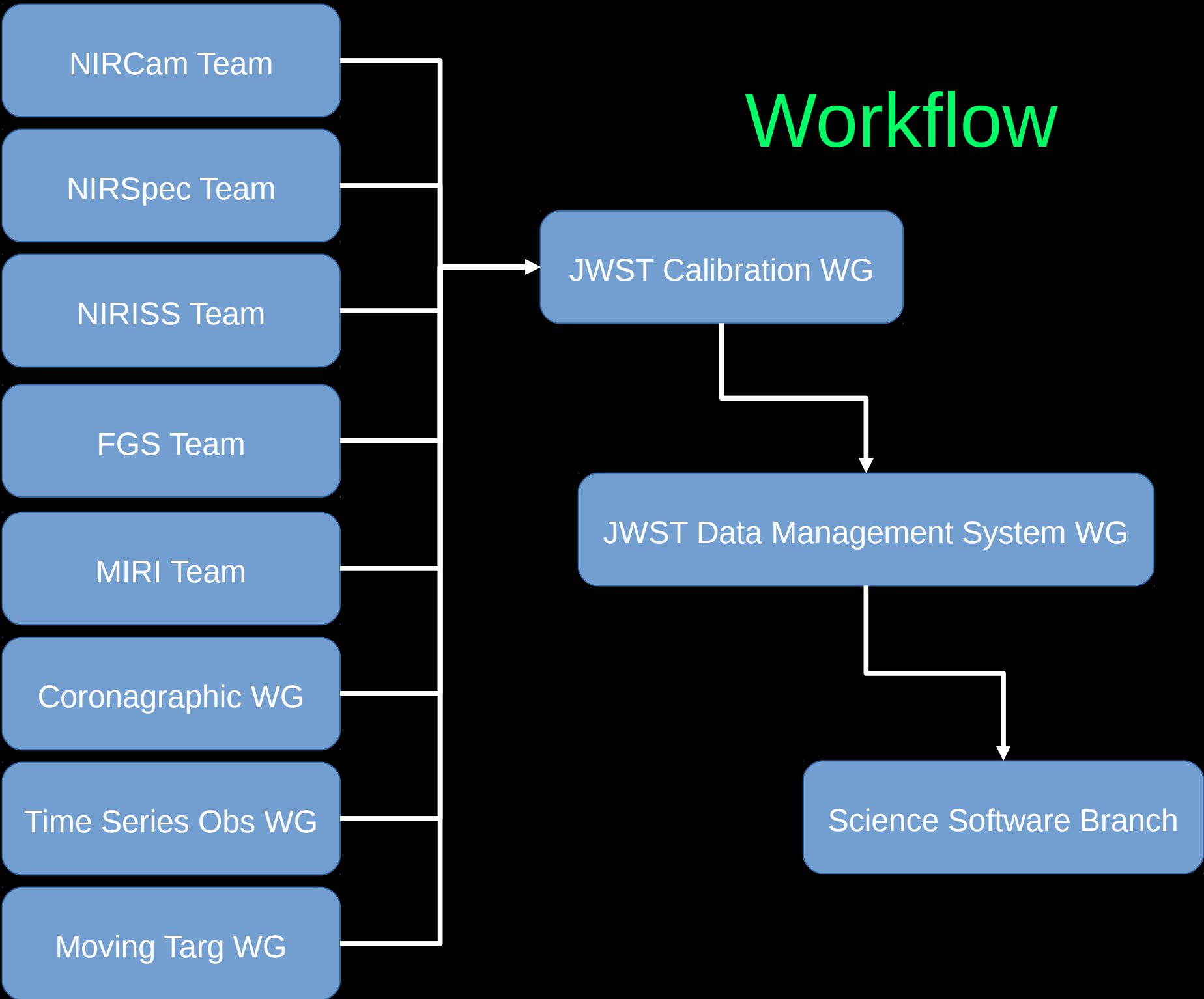
Pipeline versus Data Analysis Tools

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

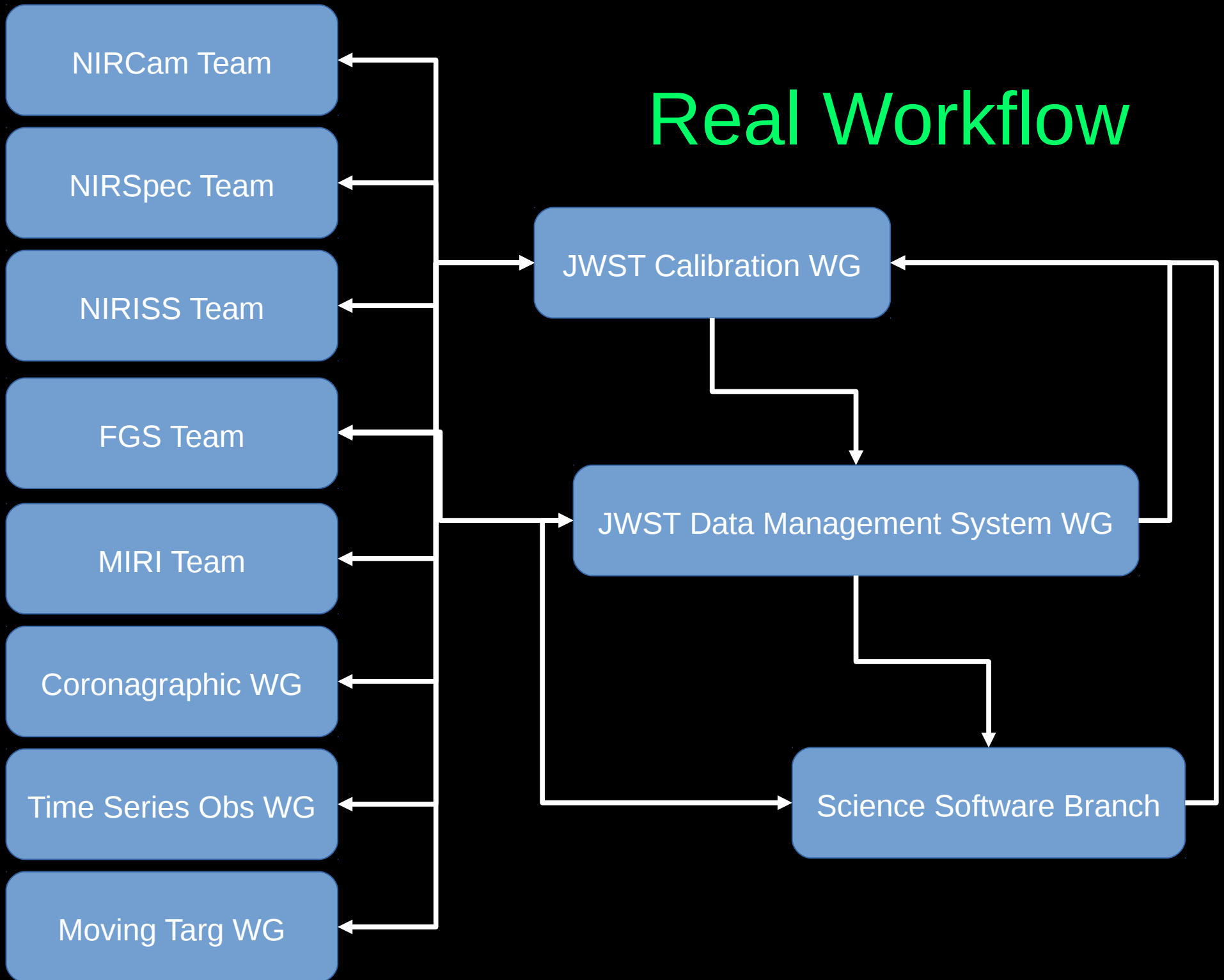
Overall Pipeline Architecture



Workflow



Real Workflow



Development Plan

- **Baseline Pipeline**

- All instruments and all modes
- Provides good science
- Meets requirements
- Algorithms defined – implementation in progress
- Implementation done by Dec 31, 2017
 - Final testing to happen in early 2018

- **Optimal 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

Potential Optimal Algorithms

- In development
- A few examples
- Upgrade for slope fitting
 - Weighted linear least squares to Generalized Least Squares
- “Optimal” Spectral Extraction
 - Use knowledge of spatial profile
 - Flag outliers and improve S/N of extracted spectra
- MIR self-calibration
 - Correct for small drift in MIR detectors using dithered data

Pipeline Availability

- Written in python (uses astropy)
- Freely available
- Configurable
- Users can rerun all or part of the pipeline
- Users can replace specific modules
- Hosted on github
- Part of astroconda
- Official release early 2018
 - Will include high level and detailed code documentation

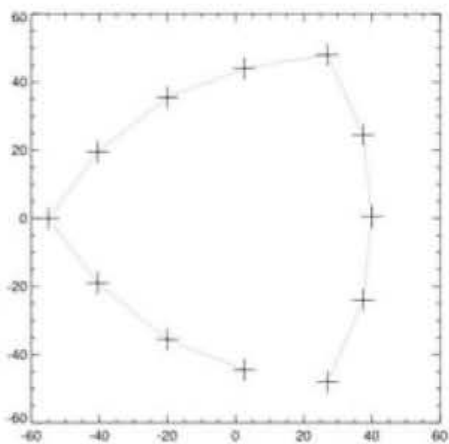
Data Products

- Raw data
- Intermediate stage data
- Final data
 - Best quality from an automated pipeline
 - “browse-quality” data in Spitzer terminology
 - Flux, wavelength, and position calibrated
 - Baseline and Optimal versions very similar
 - Optimal have improved quality
- Any user can rerun the pipeline offline
 - Changed parameters to specific steps
 - Replace a step with a user written version

Imaging Data Products

- Mosaic of all images with the same filter
 - In sky coordinates (e.g., ra, dec)
- Catalog of sources
 - automated generation
- Integration level
 - All images fully corrected with flagging of CRs, etc.
 - In detector & sky(rectified) coordinates

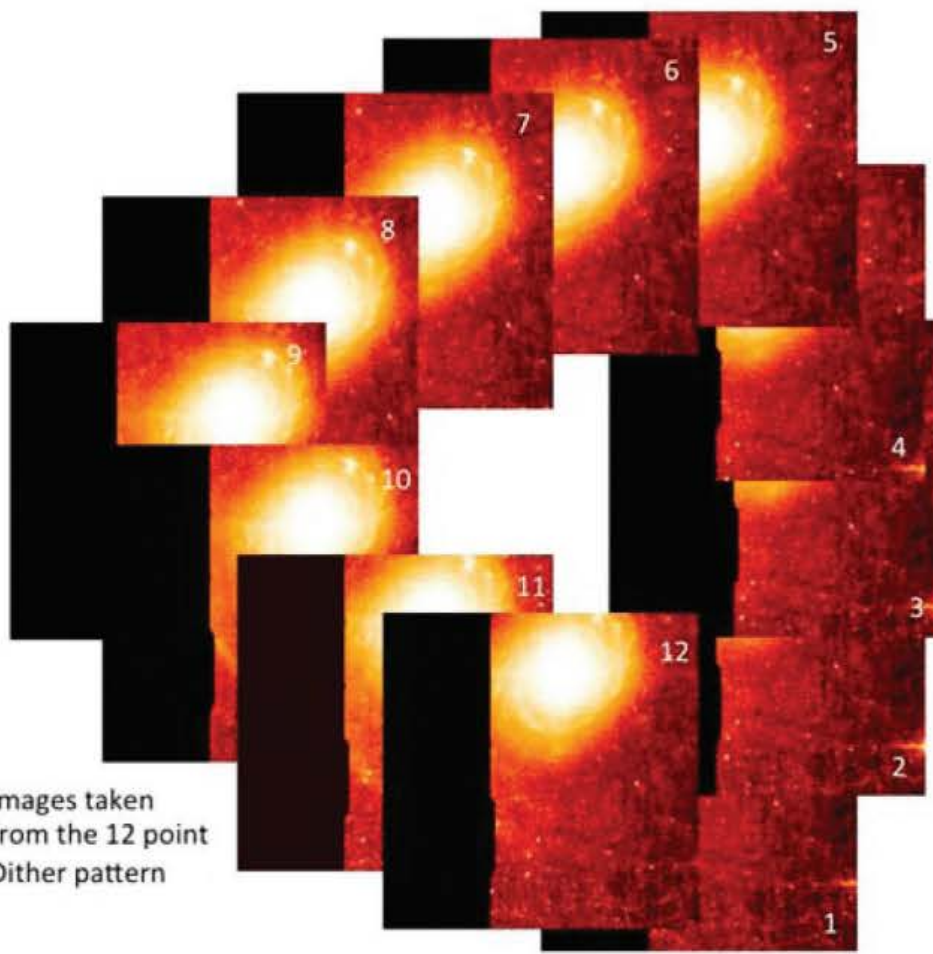
Imaging Data Products: Example



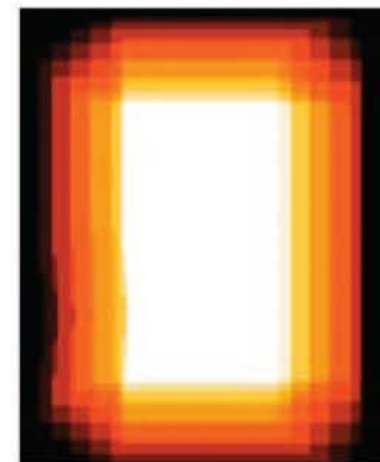
Reuleaux 12 point Dither pattern



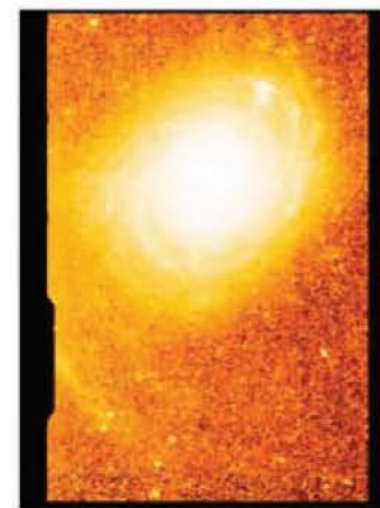
The MIRIM footprint



Images taken from the 12 point Dither pattern



Mosaic coverage map

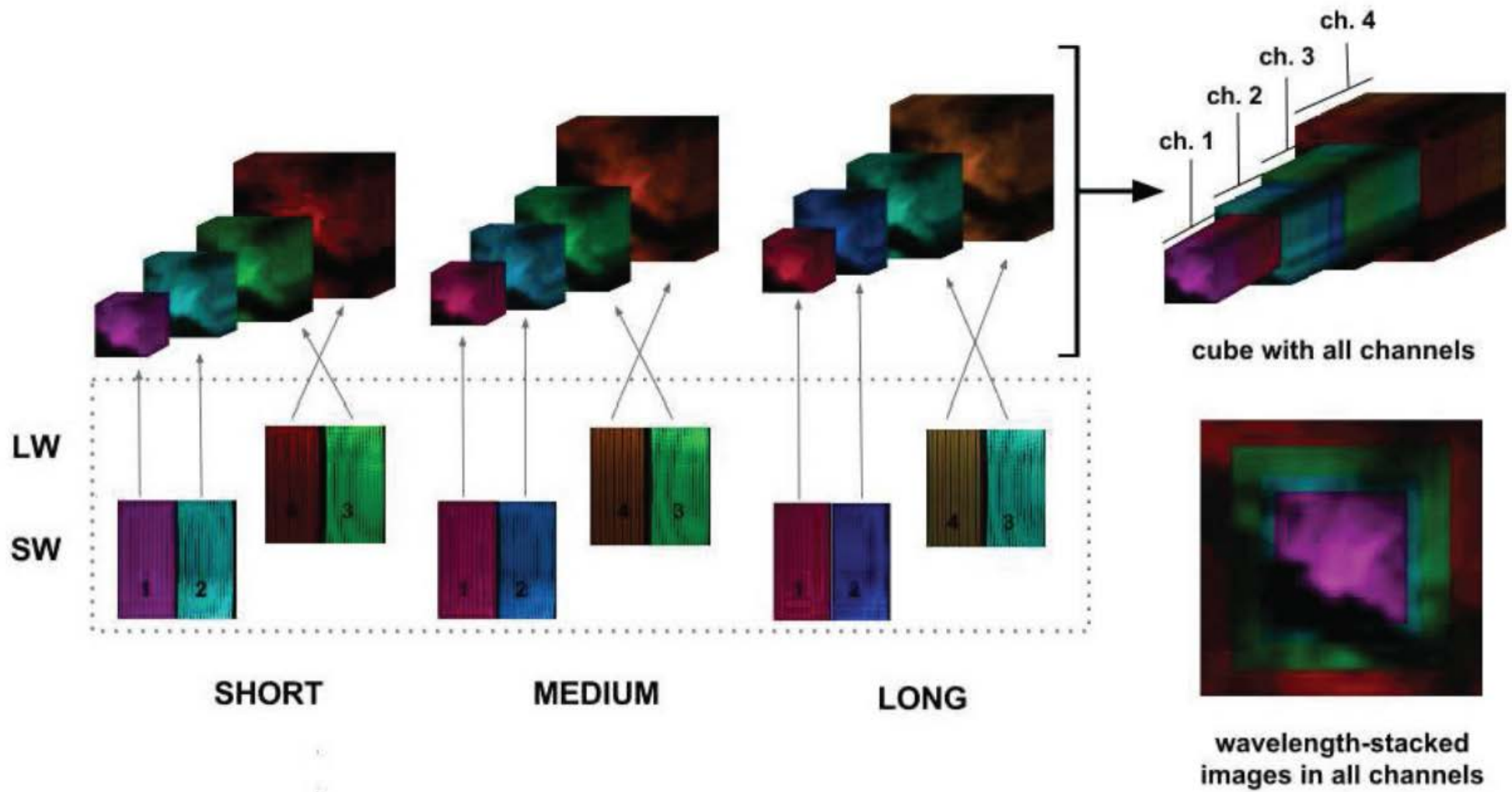


Resulting mosaicked image

Spectroscopic Data Products

- Slit & Slitless: 2D spectral image
 - along-slit and wavelength
 - Includes MOS targets (each processed separately)
- IFU: 3D spectral cube
 - ra, dec, and wavelength
- Extracted spectrum for the target source
 - will be able to advise pipeline if source is point/extended via APT
- Integration level
 - All images fully corrected with flagging of CRs, etc.
 - In detector & sky(rectified) coordinates
 - 3D cubes or 2D images depending on observation type

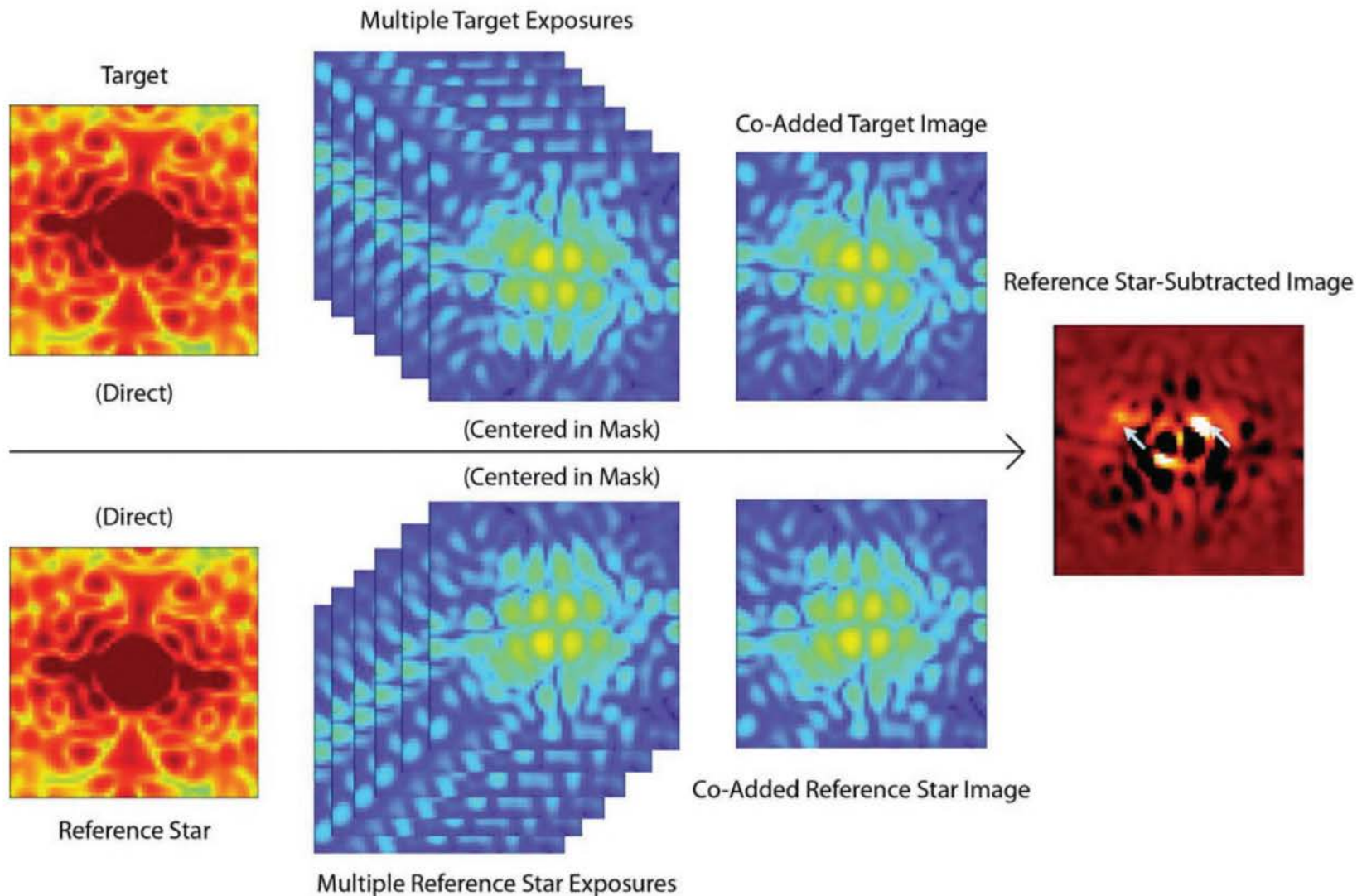
Spectroscopic Data Products: IFU Example



Coronagraphic Data Products

- Coadded images
 - In detector coordinates
 - After PSF subtraction
- Integration level
 - All images fully calibrated with flagging of CRs, etc.
 - In detector & sky(rectified) coordinates

Coronagraphic Data Products: MIRI 4QPM Example



Aperture Masking Interferometry Data Products

- Fringe parameters
 - Closure phases and amplitudes
- Reconstructed images

Time Series Observation Data Products

- Photometry
 - Aperture photometry per integration
- Spectroscopy
 - Extracted spectrum per integration
 - White-light photometry per integration
- Integration level
 - Image or spectral image as appropriate
 - fully corrected with flagging of CRs, etc.
 - In detector & sky(rectified) coordinates

Interested?

- Talk to me or any of the many members of the JWST Cal WG
 - Instrument team members both at STScI and external
- Really motivated
 - Join the JWST Calibration WG
 - Email kgordon@stsci.edu
 - details including discussions are on a set of confluence(wiki) pages
 - Can provide an account so you can view them and comment (full version control)

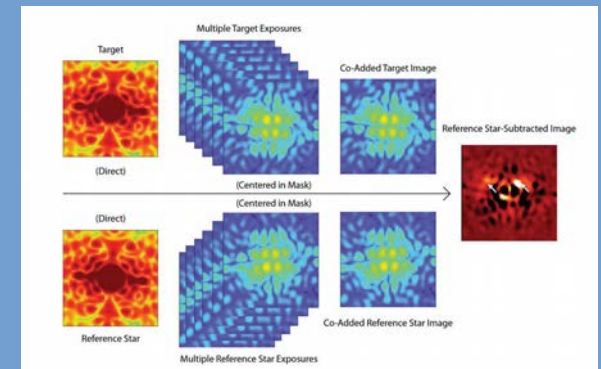
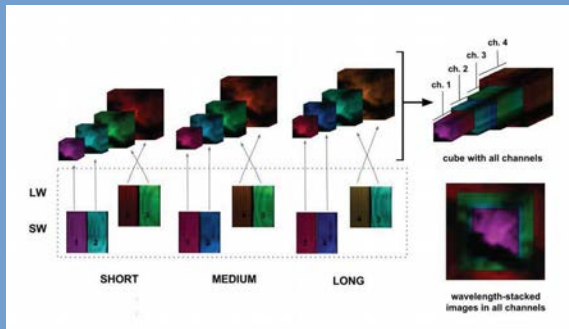
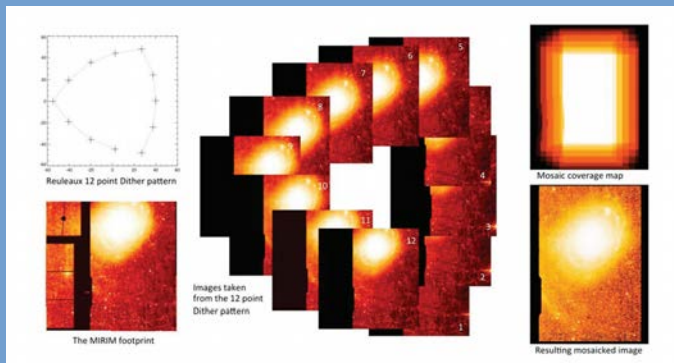
Stage 1: Ramps-to-Slopes

Stage 2: Calibrated Slopes

Stage 3: Ensemble Processing

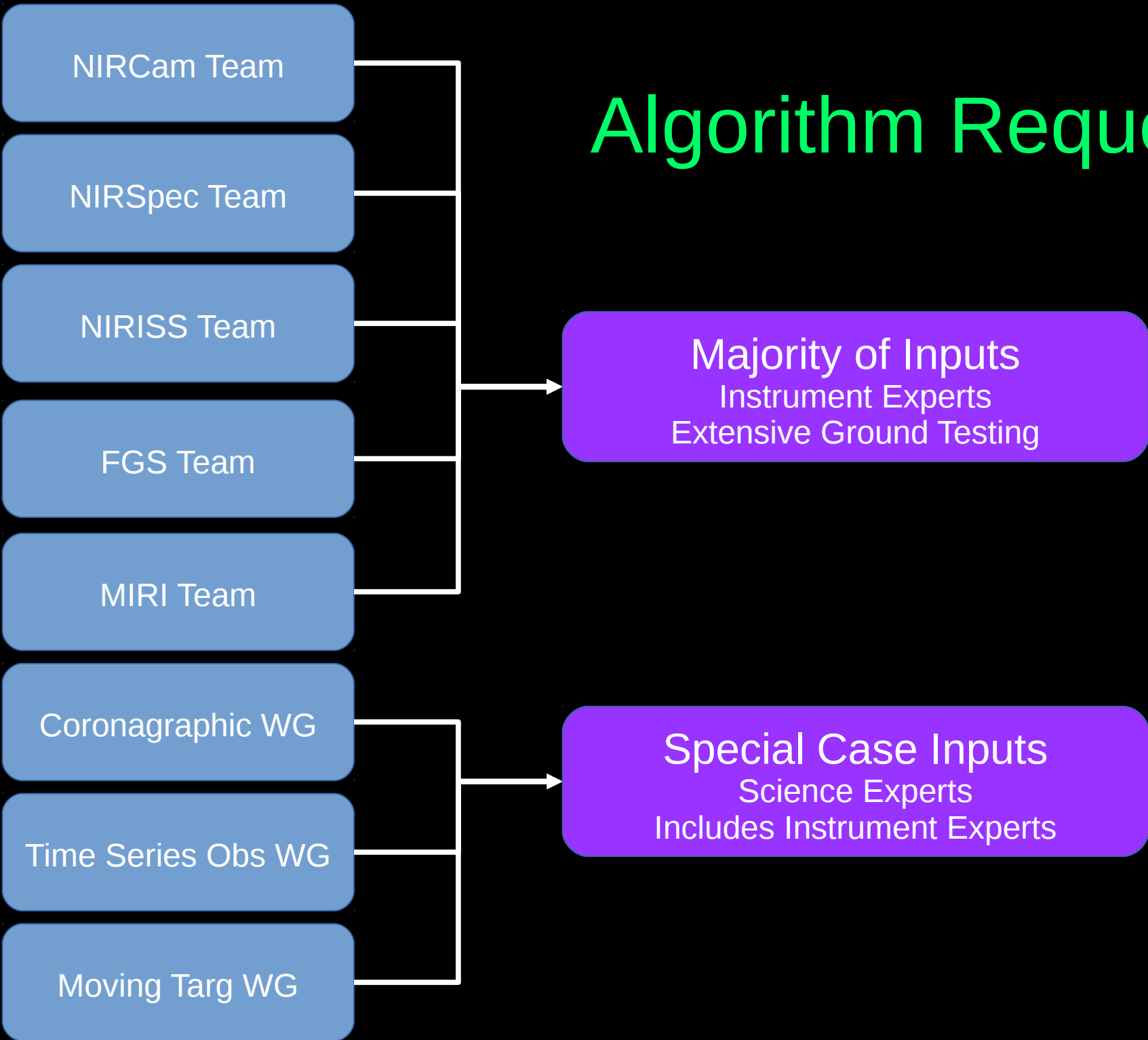
JWST Pipeline
& Data Products

Archive



Backup Slides

Algorithm Requests



NIRCam Team

NIRSpec Team

NIRISS Team

FGS Team

MIRI Team

Coronagraphic WG

Time Series Obs WG

Moving Targ WG

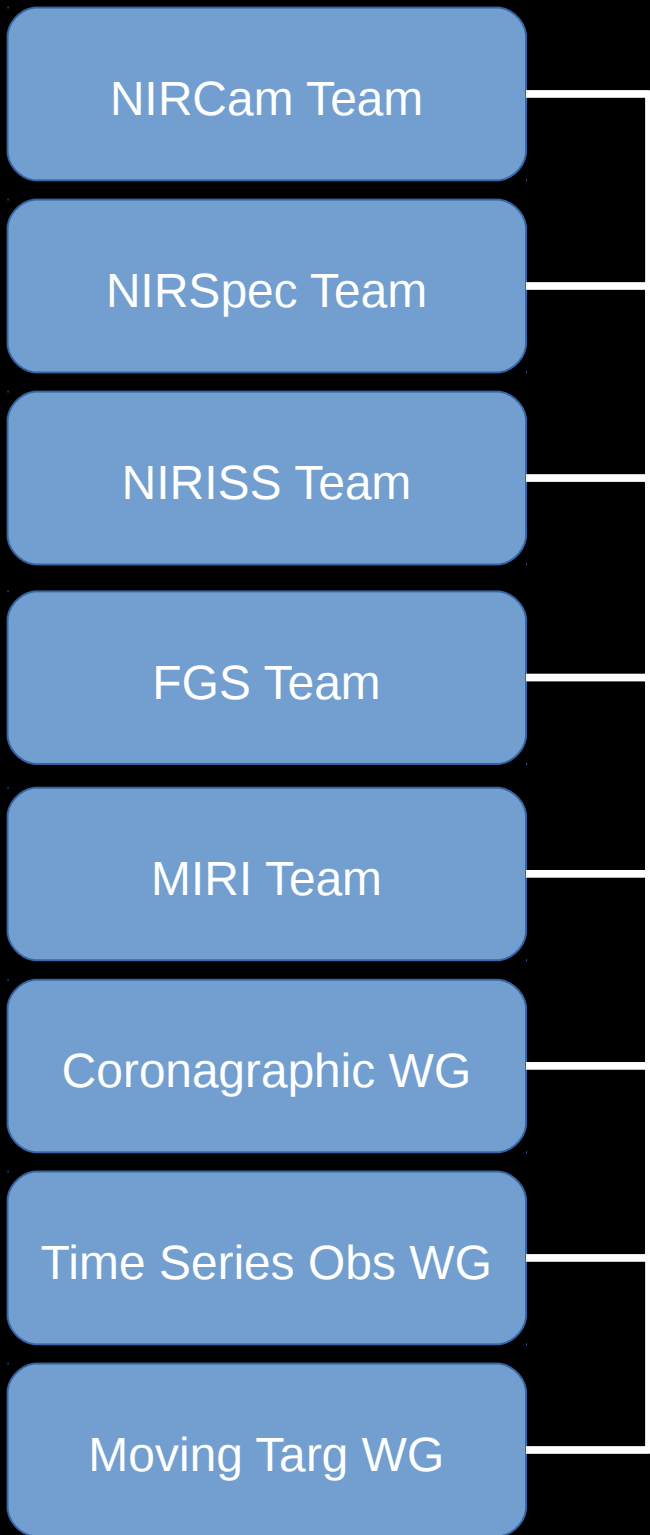
Majority of Inputs

Instrument Experts
Extensive Ground Testing

Special Case Inputs

Science Experts
Includes Instrument Experts

Decisions



JWST Calibration WG

Composed of STScI and external members

Critical Review of Inputs

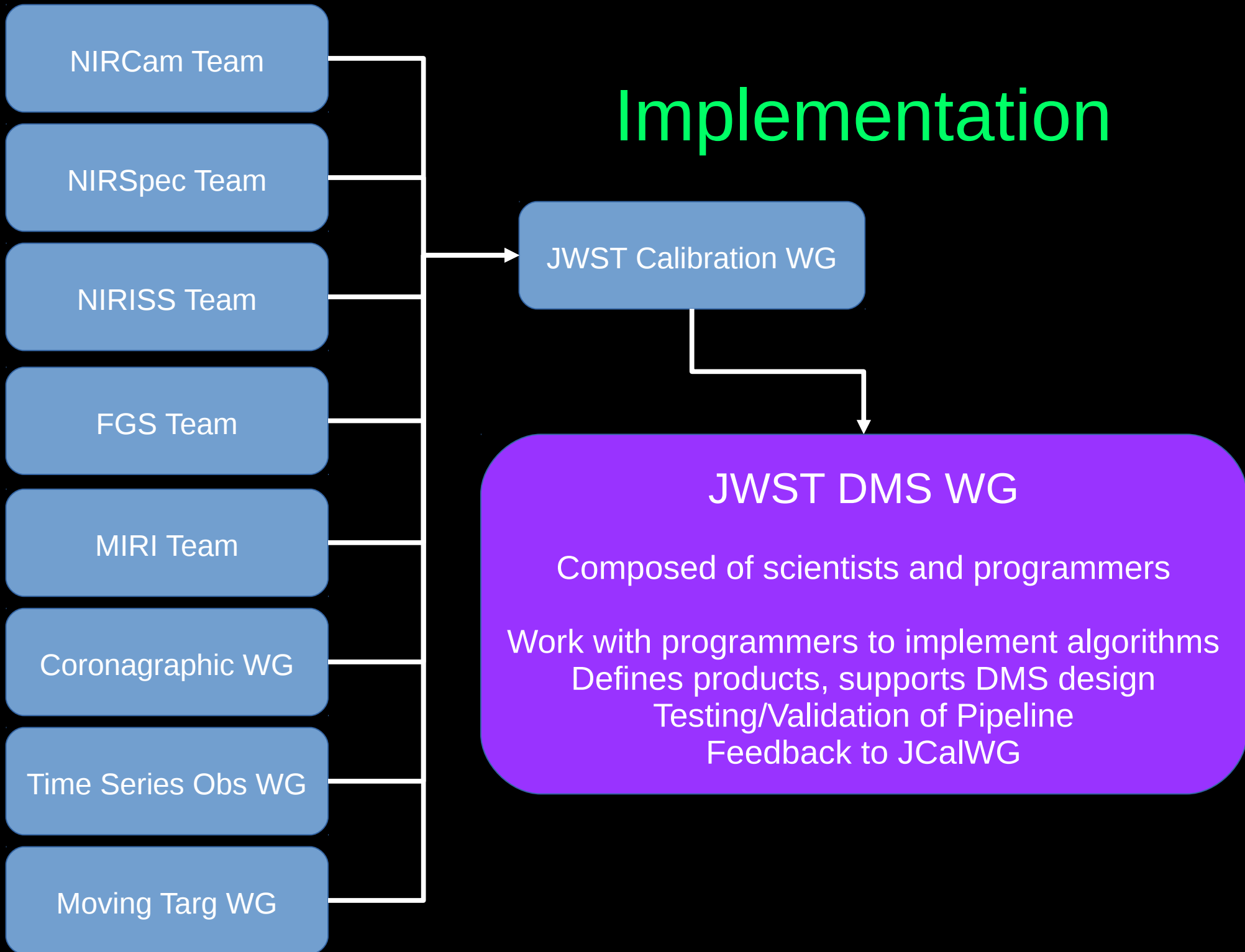
Identify Common Steps

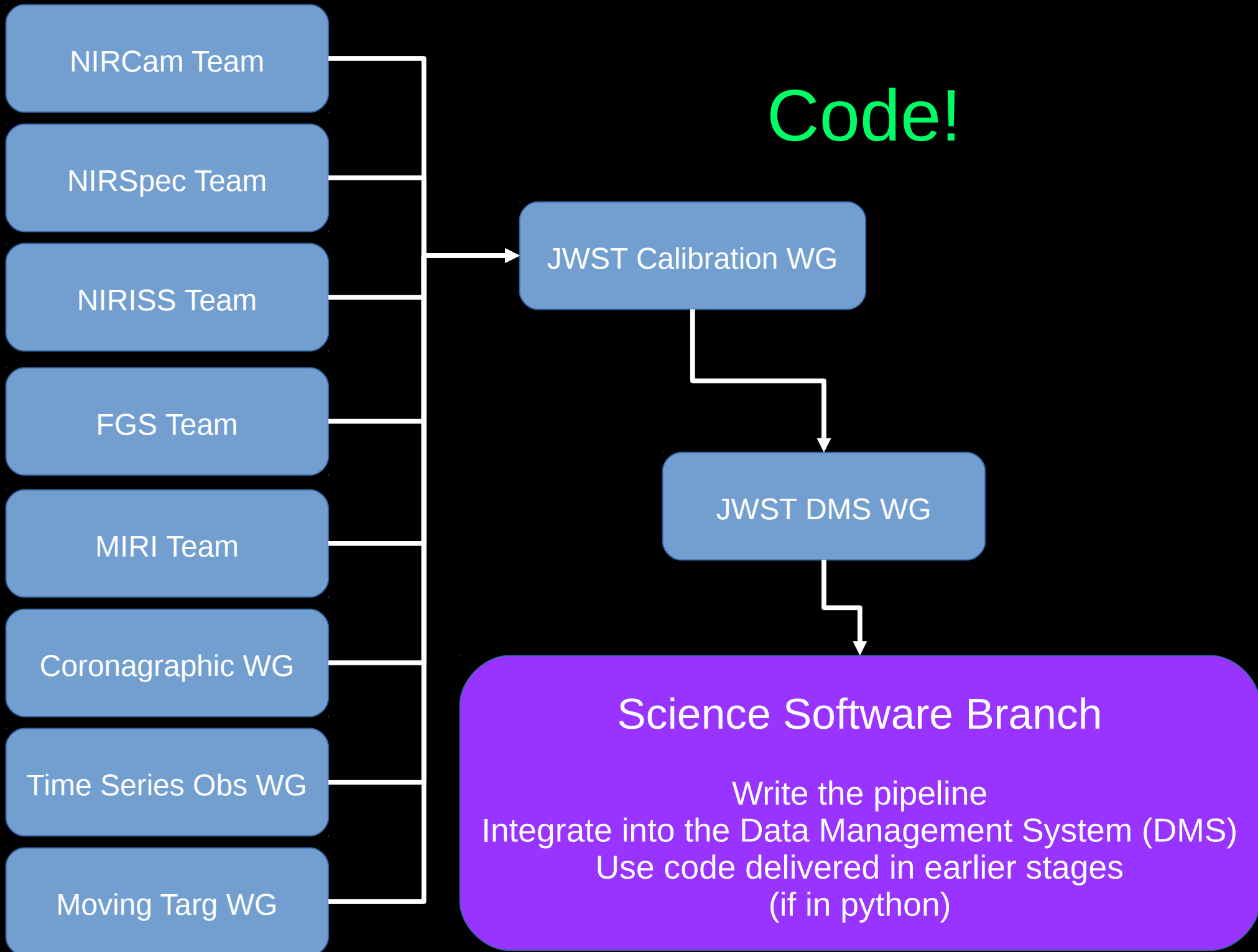
Encourage cross pollination of ideas

Encourage cross instrument development

Decide on the algorithms for development
(resource constrained)

Implementation





Baseline Implementation

- Most of the baseline is implemented
 - Build 7.0 (Coding finished by Dec 31, 2016)
 - Testing in the 1st three months of 2017
 - Pipeline stages 1 & 2 basically complete
 - Stage 3 for imaging and AMI complete
 - Partial completion of stage 3 for other modes
- Complete baseline
 - Build 7.1 (Coding finished by Dec 31, 2017)
 - Completing stage 3 of pipeline
 - Spectroscopy, Coronography, and TSO

Stage 1



Stage 2



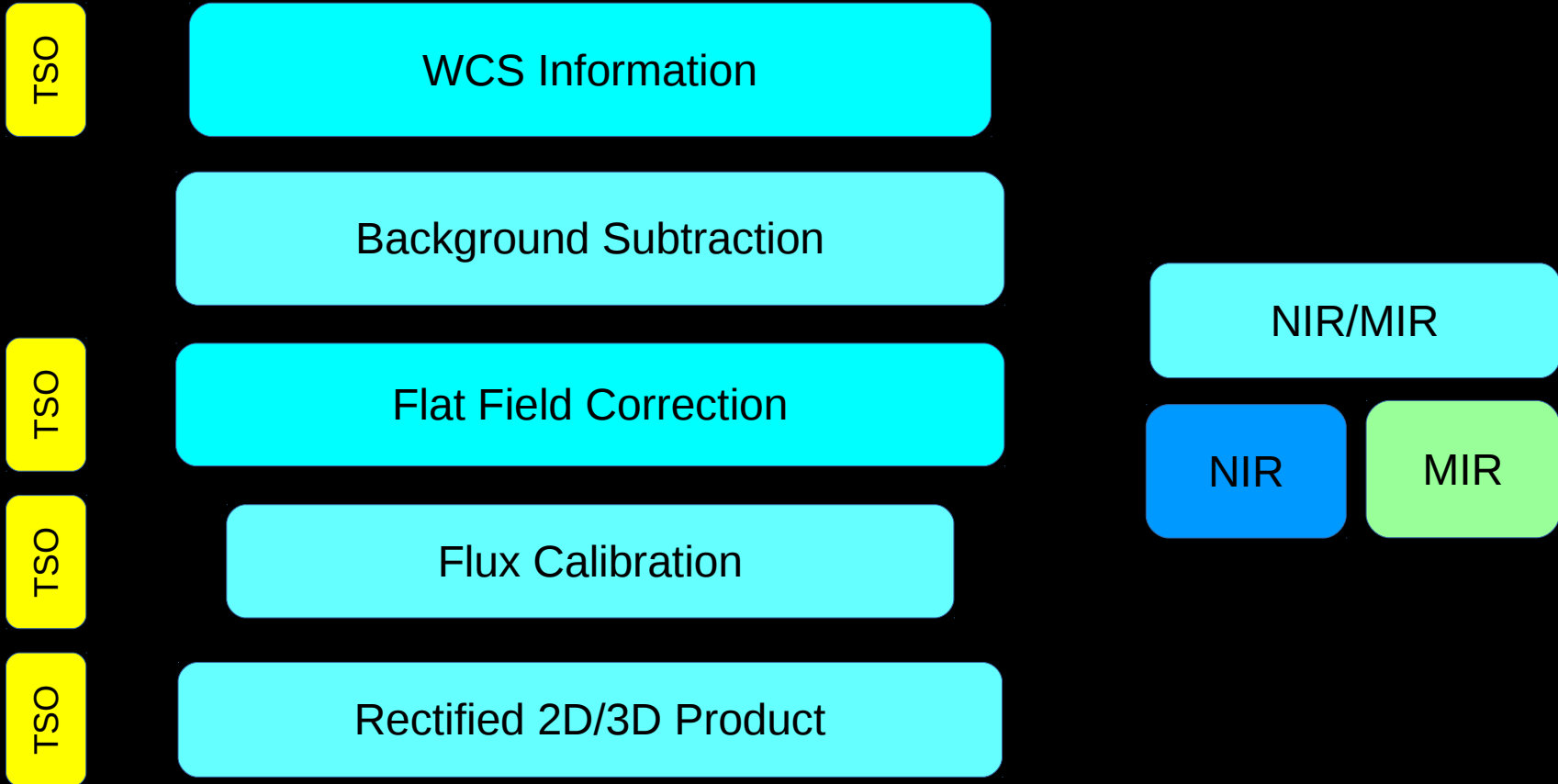
Stage 3



CALDETECTOR1



CALIMAGE2



CALSPEC2

Background Subtraction

Imprint Subtraction

NIRSpec MSA & IFU

MSA Failed Open Flagging

NIRSpec MSA & IFU

TSO

WCS Information

Subwindow Extraction

NIRSpec MSA/Fixed Slit
NIRCam/NIRISS WFSS
NIRIS SOSS

TSO

Flat Field Correction

Stray Light Subtraction

MIRI MRS

Fringing Removal

MIRI MRS

Path-Loss Correction

TSO

Flux Calibration

NIR/MIR

TSO

Rectified 2D/3D Product

NIR

MIR

CALIMAGE3

Refine Relative WCS

Background Matching

Outlier Detection

Image Combination

Create Exp Level Products

Source Catalog

NIR/MIR

NIR

MIR

CALCORON3

Assemble Reference PSFs

Align Reference PSFs

Reference PSF Sutraction

Outlier Detection

Image Combination

Create Exp Level Products

NIR/MIR

NIR

MIR

CALAMI3

Assemble Reference PSFs

Calculate Fringe Parameters

Final Fringe Parameters

NIR/MIR

NIR

MIR

CALSPEC3

Master Background Subtraction

Background Matching

Point vs Extended Decision

Residual Fringe Correction

Outlier Detection

Cube Creation

Create Exp Level Products

Spectral Extraction

Spectral Leak Subtraction

NIRSpec & MIRI

MIRI MRS

NIR/MIR

NIR

MIR

MIRI MRS

CALTSO3

Outlier Detection

Create Exp Level Products

Extract Photometry

Extract Spectroscopy

White-Light Photometry

Imaging

Spectroscopy

CALDETECTOR1

Step	Baseline	Build	Optimal	Build	NIRCam	NIRSpec	NIRISS	FGS	MIRI	TSO
Input	Raw ramps for all integrations									
Data Quality Initialization	DECIDED Details	5/6	VANILLA		X	X	X	X	X	X
Saturation Check	DECIDED Details	7	VANILLA		X	X	X	X	X	X
IPC Deconvolution	NOT USED		IN PROGRESS Details	5/6	X	X	X	X	X	
Error Initialization	DECIDED Details		IN PROGRESS Details	7.1+	X	X	X	X	X	
MIR Linearity Correction	DECIDED Details	7	IN PROGRESS Details	7.1+					X	X
MIR RSCD Correction	DECIDED Details	7	VANILLA						X	X
MIR Last-Frame Correction	DECIDED Details	7	IN PROGRESS Details	7.1+					X	X
MIR Dark Subtraction	DECIDED Details	5	VANILLA						X	X
NIR Superbias Subtraction	DECIDED Details	5/6	VANILLA		X	X	X	X		X
Reference Pixel Correction	DECIDED Details	6	VANILLA		X	X	X	X	X	X
NIR Linearity Correction	DECIDED Details	7	IN PROGRESS Details	7.1+	X	X	X	X		X
Persistence Correction	DECIDED Details	7	IN PROGRESS Details	7.1	X	X	X	X	X	
NIR Dark Subtraction	DECIDED Details	5	VANILLA		X	X	X	X	X	X
Jump Detection	DECIDED Details	7	IN PROGRESS Details	7.1+	X	X	X	X	X	X
Slope Fitting	DECIDED Details	5/6	IN PROGRESS Details	7.1+	X	X	X	X	X	X
Output	Uncalibrated slope images for each integration and exposure. Optional: Corrected ramp images.									

CALIMAGE2

Step	Vanilla	Build	Optimal	Build	NIRCam	NIRISS	FGS	MIRI	NIRSpec	All TA
Input	Uncalibrated slope images for all integrations and exposures									
GWCS Information	DECIDED Details	5	VANILLA		X	X	X	X	X	X
Background Subtraction	DECIDED Details	7			X	X		X	X	
Telescope Emission Subtraction	NOT DONE		IN PROGRESS Details	7.1				X		
Flat Field Correction	DECIDED Details	5	VANILLA		X	X	X	X	X	X
Flux Calibration	DECIDED Details	5	VANILLA		X	X	X	X		
Rectify 2D Image	DECIDED Details	5/6	VANILLA		X	X	X	X	X	X
Output	Calibrated slope images for all integrations and exposures									

CALSPEC2

					NIRCam	NIRSpec			NIRISS		MIRI		
Step	Baseline	Build	Optimal	Build	Slitless	MSA	IFU	Fixed Slit	SOSS	WFSS	LRS	MRS	TSO
Input	Uncalibrated slope images for all integrations and exposures												
Background Subtraction	DECIDED Details	6/7	VANILLA		X	X	X	X	X	X	X		
Imprint Subtraction	DECIDED Details	6	IN PROGRESS Details	7.1		X	X						
MSA Failed Open Flagging	DECIDED Details	6	VANILLA			X	X						
WCS Information	DECIDED Details	6/7	VANILLA		X	X	X	X	X	X	X	X	X
Subwindow Extraction	DECIDED Details	6/7	VANILLA		X	X		X	X	X			
Flat Field Correction	DECIDED Details	5/6	IN PROGRESS Details	7.1	X	X	X	X	X	X	X	X	X
Stray Light Subtraction	DECIDED Details	5/7	VANILLA								X	X	
Fringing Removal	DECIDED Details	5	VANILLA									X	
Path-Loss Correction	DECIDED Details	7	VANILLA			X	X	X	X		X		
Flux Calibration	DECIDED Details	5/6	VANILLA		X	X	X	X	X	X	X	X	X
Recified 2D/3D Product	DECIDED Details	7	VANILLA		X	X	X	X	X	X	X	X	X
Output	Calibrated slope images for all integrations and exposures												

CALIMAGE3

Step	Baseline	Build	Optimal	Build	NIRCam	NIRISS	FGS	MIRI
Input	Calibrated slope images for all integrations and exposures (reordered by source)							
Refine Relative WCS	DECIDED Details	6	VANILLA		X	X	X	X
Background Matching	DECIDED Details	6	VANILLA		X	X	X	X
Outlier Detection	DECIDED Details	6	VANILLA		X	X	X	X
Image Combination	DECIDED Details	6	VANILLA		X	X	X	X
Self Calibration	NOT USED		IN PROGRESS Details	7.1				X
Create Exp Level Products	DECIDED Details	6	VANILLA		X	X	X	X
Source Catalog	DECIDED Details	6	VANILLA		X	X	X	X
Output	Coadded image(s) (e.g., mosaic). Catalog of sources. Updated exposure level products.							

CALCORON3

Step	Baseline	Build	Optimal	Build	NIRCam	MIRI
Input	Calibrated slope images for all integrations and exposures (reordered by source)					
Assemble Ref PSFs	DECIDED Details	7	IN PROGRESS Details	7.1	X	X
Align Ref PSFs	DECIDED Details	7	VANILLA		X	X
Background Matching	NOT DONE		IN PROGRESS Details	7.1		X
Ref PSF Subtraction	DECIDED Details	4	VANILLA		X	X
Outlier Detection	DECIDED Details	6	VANILLA		X	X
Image Combination	DECIDED Details	6	VANILLA		X	X
Create Exp Level Products	DECIDED Details	6	VANILLA		X	X
Ancillary Science Products	NOT DONE		IN PROGRESS Details	7.1	X	X
Output	Coadded image(s). Updated exposure level products.					

CALAMI3

Step	Baseline	Build	Optimal	Build	NIRISS
Input	Calibrated slope images for all integrations and exposures (reordered by source)				
Assemble Ref PSFs	DECIDED Details	7	VANILLA		X
Calc. Fringe Params	DECIDED Details	7	VANILLA		X
Final Fringe Params	DECIDED Details	7	VANILLA		X
Image Reconstruction	NOT DONE		IN PROGRESS Details	7.1	X
Output	Fringe parameters. Reconstructed Image.				

CALSPEC3

Step	Baseline	Build	Optimal	Build	NIRSpec	NIRISS	NIRCam	MIRI LRS	MIRI MRS
Input	Calibrated slope images for all integrations and exposures (reordered by source)								
Master Background Sub.	DECIDED Details	7	VANILLA		X			X	X
Background Matching	DECIDED Details	7	VANILLA					X	X
Point vs Extended Decision	DECIDED Details	7	VANILLA		X	X	X	X	X
Residual Fringe Corr.	DECIDED Details	7	VANILLA						X
Outlier Detection	DECIDED Details	7	VANILLA		X	X	X	X	X
Cube Creation	DECIDED Details	6/7	VANILLA		X	X	X	X	X
Self Calibration	NOT DONE		IN PROGRESS Details	7.1				X	X
Create Exp Level Products	DECIDED Details	6	VANILLA		X	X	X	X	X
Spectral Extraction	DECIDED Details	6	IN PROGRESS Details	7.1	X	X	X	X	X
Spectral Leak Sub.	DECIDED Details	7	VANILLA						X
Output	Coadded spectral cube. Extracted 1D spectrum. Updated exposure level products.								

CALTSO3

Step	Vanilla	Build	Optimal	Imaging			Spectroscopy			
				Build	NIRCam	MIRI	NIRCam	NIRISS	NIRSpec	MIRI
Input	Calibrated slope images for all integrations and exposures (reordered by source)									
Outlier Detection	DECIDED Details	7	VANILLA		X	X	X	X	X	X
TSO Background Subtraction	NOT USED		IN PROGRESS Details	7.1+			X	X	X	X
Create Exp Level Products	DECIDED Details	7	VANILLA		X	X	X	X	X	X
Extract Photometry	DECIDED Details	7	IN PROGRESS Details		X	X				
Extract 1D Spectrum	DECIDED Details	6	IN PROGRESS Details	7.1+			X	X	X	X
White-Light Photometry	DECIDED Details	7	VANILLA				X	X	X	X
Output	Photometry and 1D spectroscopy for each integration and exposure. Updated exposure level products.									