The NIRSpec Data Calibration Pipeline

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Based in Baltimore, MD - STScI is presently the main science center for the Hubble Space Telescope, future science and operations center for JWST
JWST Data Management

Level 0 - Communication from spacecraft
Level 1 - Conversion to raw .fits files
Level 2 - removing telescope/instrument effects, Calibrating data
Level 3 - Combining dithers and associated data
Level 4 - Creating catalogs, extracting spectra, classification

“Calibration”
“Processing”
“Reduction”
The Purpose of Data Processing

Perfectly Calibrated data is what would have been received if an ideal JWST with ideal instruments and ideal detectors had observed the chosen field in the chosen observing mode. Goal - Remove all Instrument and telescope effects from data!

Using calibrated data, it is possible to:
- Determine the flux incident on each pixel, along with its uncertainty (relative and absolute flux determinations limited by different effects)
- Determine the relative locations and wavelengths of each pixel to very high accuracy (limited by knowledge of the geometric distortions in the telescope + instruments)
- Determine the absolute locations of the observed field to high accuracy (limited by absolute Guide Star / instrument accuracies)
- Do Science!
STScI Calibration Pipeline
Philosophy & Archive

Proposer

Calibrated data
Delivered within
5 days

Raw data
Delivered within
3 hours

NASA

STScI - Data Management System
- .fits file structure,
engineering data,
Calibration Pipeline
Reduction, best data
reduction possible

STScI Data Archive

JWST

Archive User

1.5 years

Calibrated data delivered within 5 days.
Raw data delivered within 3 hours.
Calibrated data reduction possible.

1.5 years to Archive User.
Data Calibration - Lessons Learned from the Hubble Space Telescope

Many instruments with similar “modes” - NICMOS imaging, WFC3 IR… STIS / COS Spectroscopy

ALL HST pipelines are instrument-specific, not ‘mode’ specific

A LOT of redundancy - same processing steps, have to change things in multiple different places if better processing methods are found

JWST Goal - Avoid a lot of redundancy, whenever possible
NIRSpec Raw Data Format

An exposure is made up of a sequence of frames (or groups):

Instead of just an image, get a 3-D datacube, with many exposures - one every 10.6 (or 42) seconds

“Ramps”

= 1 .fits file exposure
Common Instrument Detector Processing Steps

- NIRSpec, NIRCam and FGS/TFI all have the same kind of detectors
- Initial processing steps to remove detector effects may be identical
- 3D Datacubes to calibrated 2D images of e- per second
NIRSpec Data Pipeline Processing

Detector Processing Steps - raw .fits files to calibrated e- per second images

Fixed-Slit Data Reduction
IFU Data Reduction
MSA Data Reduction

Processed - Science Ready! - NIRSpec Spectra

(Similar to MIRI Reduction?)
NIRSpec MSA Data Reduction Flow Chart

**Input:** Dark and bias subtracted, linearized, CR cleaned Flux Image (output from CALWebb)

- Data Combine
- Background Subtract

- "P-Flat" Reference Image
- Full Flat Field Flux Reference

- Pixel-to-Pixel Flat Correction
- Throughput Correction including L-flat, blaze function transmission of optics & "default" chromatic slit loss (pixel-to-pixel flat TBD)

- Individual Slit Extracted 2-D Spectra
- Initial wavelength and spatial cal (Instrument model)

- Throughput Correction
- Final wavelength calibration and rectification, spatial distortion rectification (re-sampled pixel grid)

- Photometric Calibration (header keyword)

**Output:** Calibrated 2-D and 1-D Spectra of each MSA shutter

- I-D Spectral Extraction (optimal/collapse, TBD)
- 1-D Spectral Combine

- Aperture Flux (alpha) Correction
- Absolute Flux Calibration

- GW Telemetry
- Geometric Distortion Map

- Grating Equation

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*NIRSpec*
Calibration of NIRSpec Data

For efficiency, we plan to use a NIRSpec throughput and flat field model, rather than telescope images to correct for instrument illumination effects.

Spectra for one MSA quadrant - Each MSA shutter has an associated throughput model spectrum
Simulated MSA Data

1st Order (Primary data)  R=1000 Spectra

~100+ Targets observed simultaneously + background shutters!
Calibration of NIRSpec Data

- Red = Science Target
- Green = Background

Must remove background flux from science targets. How do we know which shutter has which target in it? & Which is Background? (done in the Planning Tool - info. propagated to the pipeline reduction)
Calibration of NIRSpec Data

Best Order of Processing steps may depend on data acquisition strategy!

Proper Background Subtraction - Here??

Or Here??
Calibration of NIRSpec Data

NIRSpec Spectra are curved, tilted, flared and irregularly sampled in the detector pixels.

Want spectra on a regular pixel grid in spatial and wavelength dimensions.
Calibration of NIRSpec Data

- PSF varies with wavelength - NIRSpec varies by a factor of 5
- Imperfectly centered target results in larger slit losses, which can vary by a lot in wavelength
- Point source versus Galaxy spatial profile?
Data Challenges for NIRSpec

- Flat Field / Throughput - “Model” approach versus Observed Flat
- Proper background flux subtraction?
- Spectral character (tilted, curved spectra)
- Target Centering / Aperture Flux Losses
- Target Profile Shape
- Processing many data files, dithers?

OPEN QUESTION - How much of the data processing can be automated to remove these effects to provide the most useful NIRSpec data product to the user and in the archive?
Goal is Absolute Astronomical Flux Calibration of NIRSpec Spectra to 10% Accuracy!

This will of course be tricky! & it won’t be possible for faint targets in all modes
Calibration pipeline will be continually improved - particularly MSA reduction for previous issues - we won’t “stop” at 10%
NIRSpec Pipeline Processing - Where we’re at…

- Presently clarifying the data processing steps and their order, methods to propagate information to the pipeline.
- Cross reference processing steps with other JWST instrument teams (particularly for detector processing).
- High-level requirements are being written - requirements review in September (very “high level”).
- After ground tests, ESA NIRSpec team will deliver data processing algorithms and calibration reference files to STScI - we will all work together to optimize the pipeline reduction.
- Plan - Tests of NIRSpec pipeline calibration reductions before launch - using NIRSpec ground test data and/or simulated spectra.
NIRSpec Team @ STScI!

9 Members (+ ~1 New hire in Fall)
Largest team for JWST at STScI
Future - ~10(?) ESA Employees will work on NIRSpec at STScI!

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Thanks for your attention!

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