Spectroscopy with JWST/NIRSpec: Calibration & Data Products

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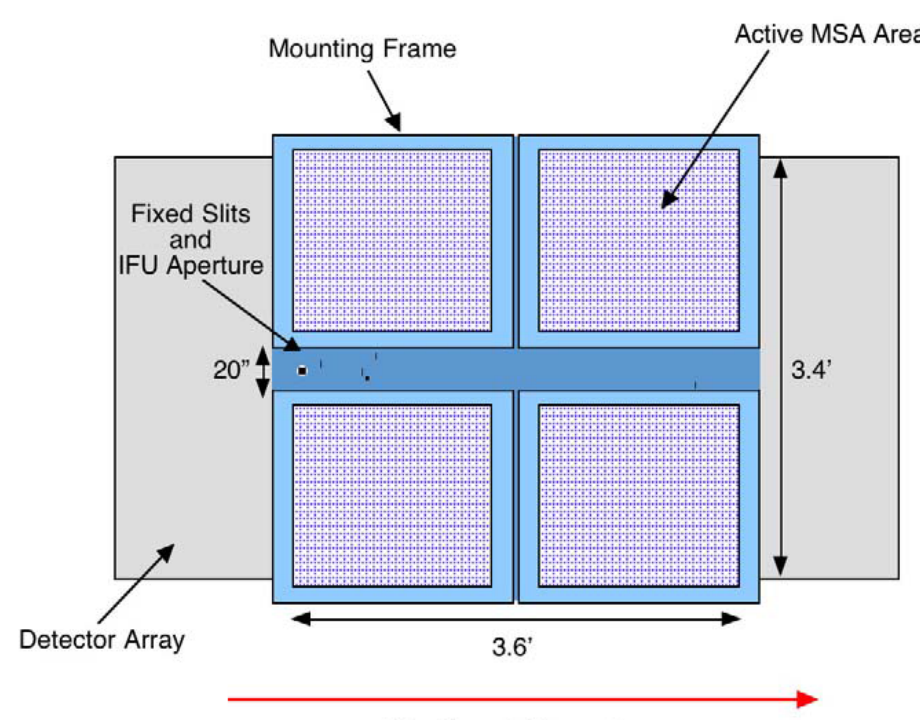
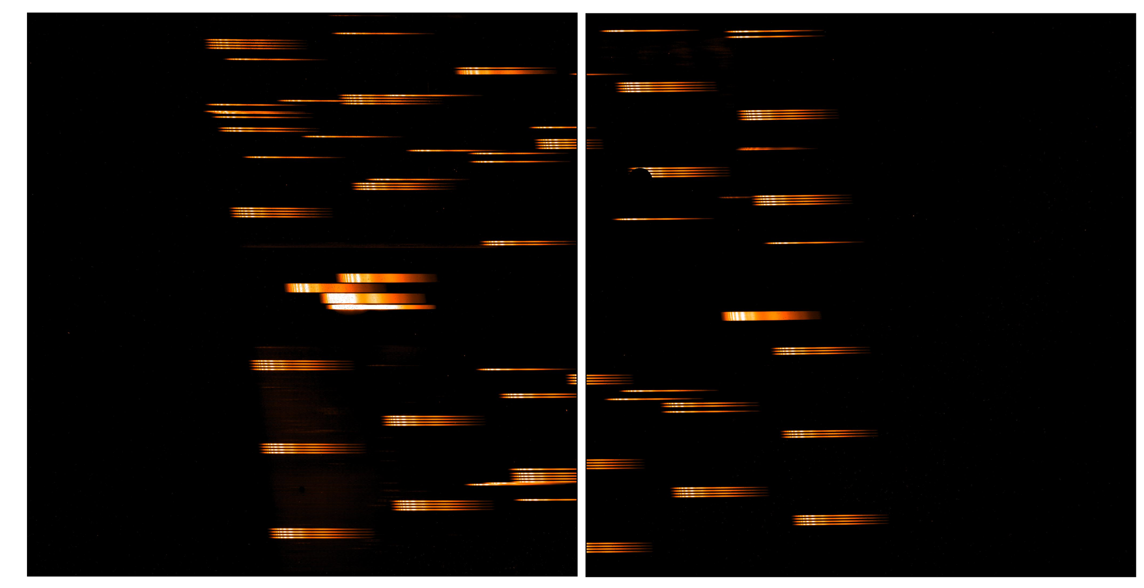
Operated for NASA by AURA

Introduction

The JWST Near-Infrared Spectrograph (NIRSpec) provides three modes of spectroscopic observations: high-contrast spectroscopy with five fixed slit (FS) apertures, spatially resolved spectroscopy with an integral field unit (IFU), and multi-object spectroscopy via the Microshutter Array (MSA). The MSA contains four quadrants each with 365x171 independently operable shutters. An open shutter subtends an area of ~0.2x0.4″ on the sky, and the total field of view spans ~3.6′. NIRSpec contains seven dispersers, including a prism with R~100 and medium-and high-resolution gratings with R~1000/2700, all providing wavelength coverage from 0.7 to 5 μm. These disparate modes, along with the highly configurable nature of the MSA, provide considerable flexibility in observational strategies, but at the same time require considerable complexity on the back-end for calibration and spectral extraction.



Schematic of NIRSpec apertures superimposed on the detector array FOV.

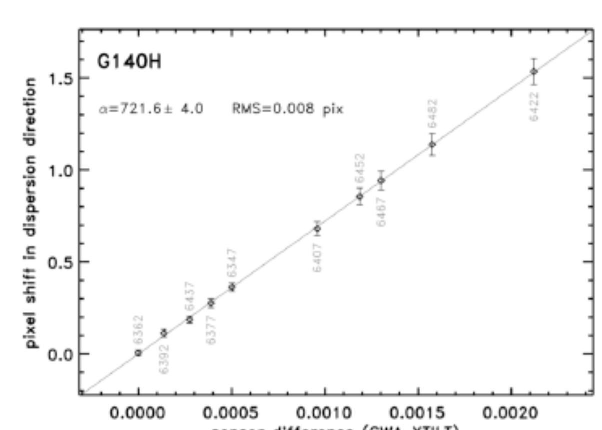


Exposure of an Argon lamp taken with the Prism during ground test. The MSA was configured in "slitlets" with sets of 4 alternating open/closed shutters. Spectra from four of the fixed slits can also be seen in the center/left, and the fifth slit in the center/right.

Calibration pipeline concept

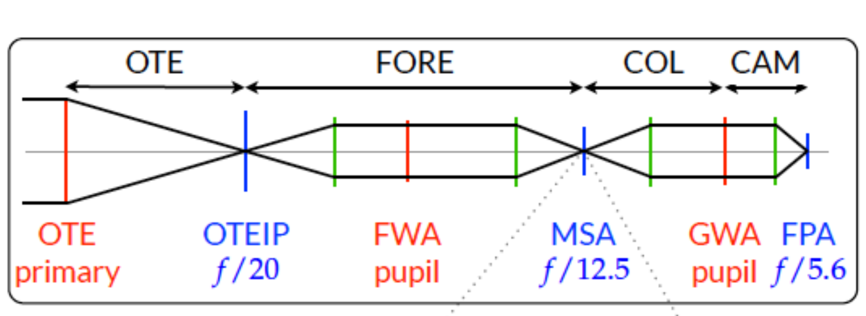
(also see poster by Pavlovsky)

The automated processing pipeline will extract both 1D and 2D spectra from observations taken with the MSA and fixed slits, and 3D spectral cubes from IFU observations. The process is complicated by the fact that spectra from different apertures are imaged in different locations on the detector arrays. Moreover, the positioning of the spectra in the dispersion direction is not strictly repeatable in between moves of the Grating Wheel Assembly (GWA), with shifts of several pixels possible. The shift is correctable to <1/10 pix using telemetry from the GWA position sensors. The pipeline must take this into account in order to derive an accurate wavelength solution.



GWA position sensor voltage vs. spectral shift. Courtesy DeMarchi/ESA.

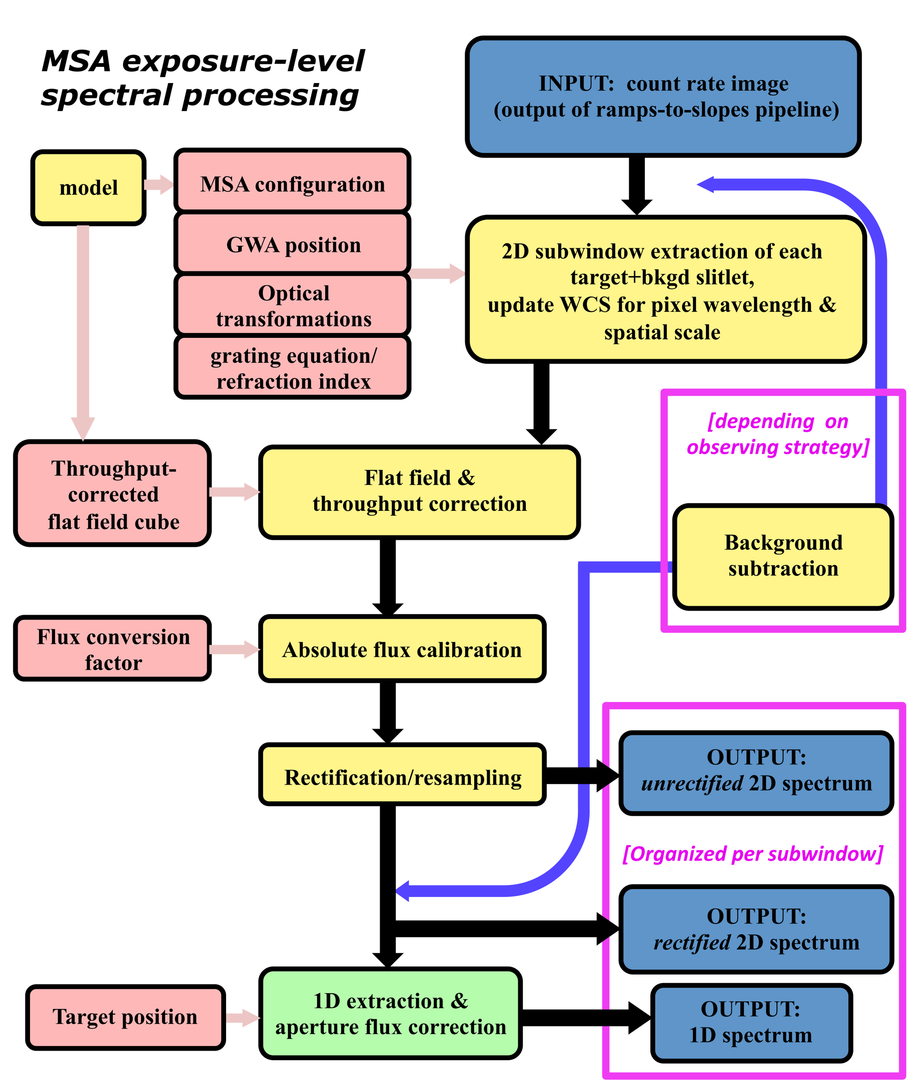
To deal with these effects, we are implementing an extraction algorithm based on a parametric model of the instrument. Developed by the ESA Science Operations Team, the model calculates coordinate transforms between each of the principal optical planes in the instrument, including parametric descriptions of each component (apertures, GWA, detectors, etc.) that are tuned using test data taken during ground testing (and eventually on-orbit; see wavelength calibration at right). The pipeline will use the model to determine the location of a 2D "subwindow" around each spectrum, extract them, and at the same time calculate the wavelength of each pixel in the subwindow.



Principal optical planes treated by the instrument model. Courtesy Giardino/ESA.

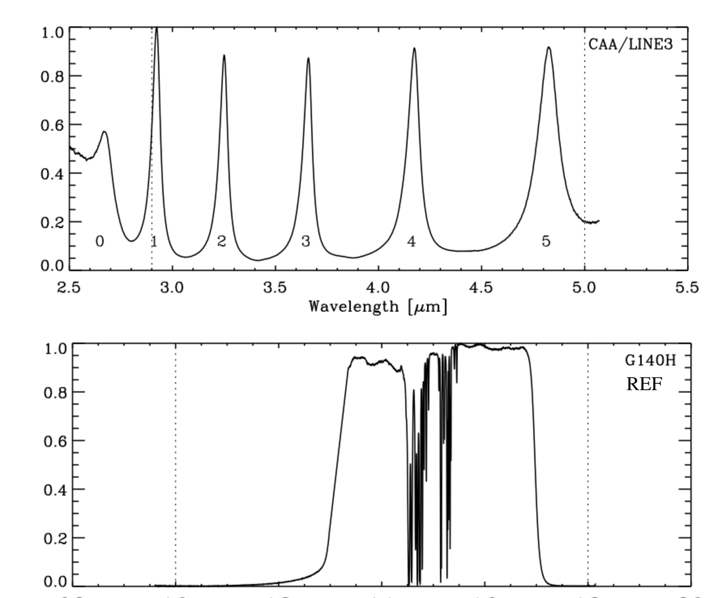
Further processing occurs on each 2D extracted spectrum. The method of background subtraction will depend on observing strategy. In the case of a standard MSA observation with a 2- or 3-shutter slitlet pattern or FS on-slit nodding, separate exposures will be subtracted before the 2D extraction step. Background from dedicated background shutters will have to be extracted separately and resampled into the unrectified science target pixel space before subtraction. To minimize resampling errors, spectral rectification will be done only once when multiple exposures are combined.

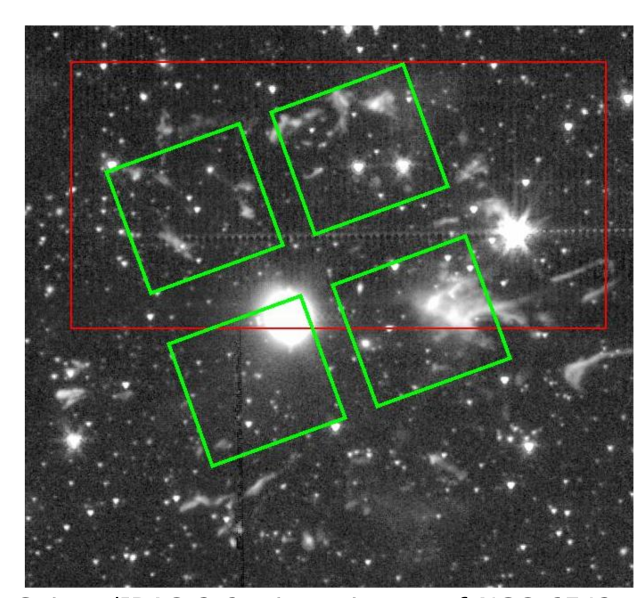
MSA exposure-level spectral processing



Wavelength calibration

NIRSpec contains several flavors of internal line lamps as part of its Calibration Assembly (which also includes flat field continuum lamps). These include "LINE" lamps that use interferometric filters to produce broad emission-like transmission peaks, and an erbium filter "REF" lamp that produces continuum plus a stable set of absorption lines in a narrow range of wavelengths.

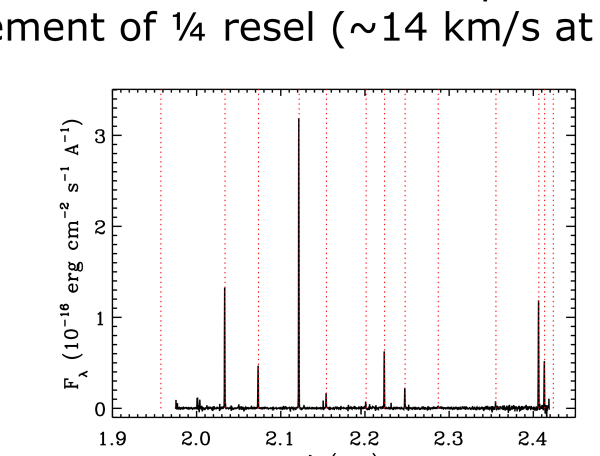




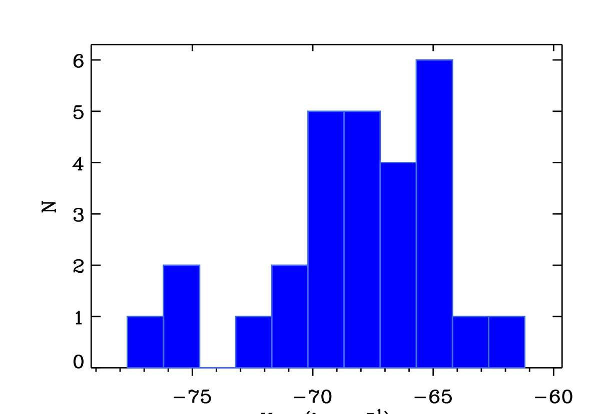
Spitzer/IRAC 3.6 micron image of NGC 6543; MSA FOV in green, MOSFIRE FOV in red.

Observations of celestial targets, preferably spectrally unresolved emission line sources, will be done on-orbit for a full verification of the dispersion and zero point. An excellent target for NIRSpec is the planetary nebula NGC 6543 ("Cat's Eye"). This object is located in JWST's Continuous Viewing Zone (CVZ) and hence is ideal for scheduling flexibility. It has an extended halo of faint emission line knots whose spatial extent is well-matched to the MSA FOV, and individual knots can also be used for calibration of the IFU.

We recently obtained ground-based *H* and *K* band spectroscopy of a sample of 32 knots using MOSFIRE on Keck, with time granted through NASA for mission support activities. The data were needed to constrain the emission line fluxes and measure any large dispersions in the knot radial velocities. Surprisingly, we see emission solely from H_2 lines probably tracing slow shocks in material ejected from the progenitor; shock models will be needed to predict line fluxes at other wavelengths in the NIRSpec range. The measured RV errors and dispersion are within our calibration accuracy requirement of ¼ resel (~14 km/s at R=2700).

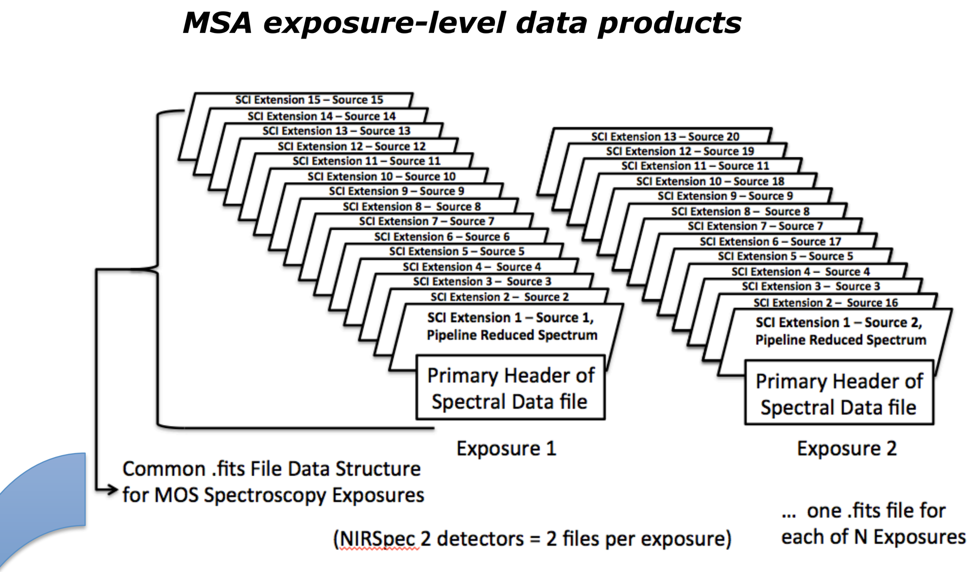


MOSFIRE spectrum of one NGC 6543 halo knot; red lines mark the known wavelengths of H_2 transitions.

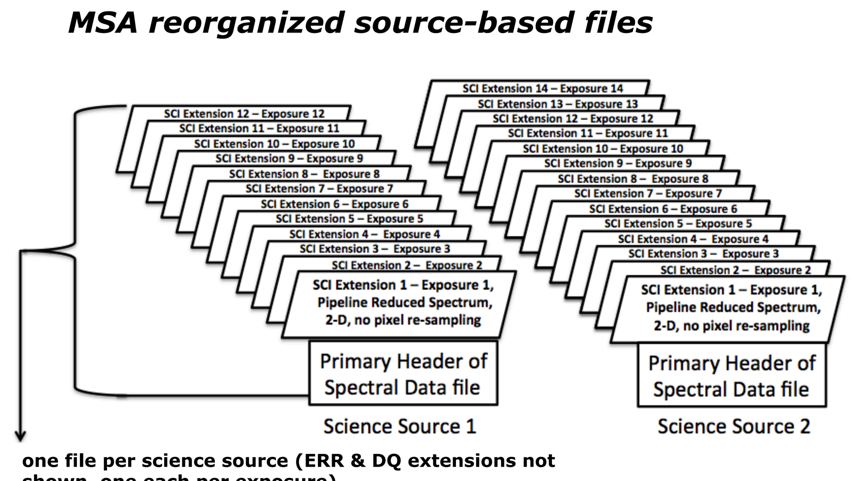


Distribution of RV for all observed halo knots.

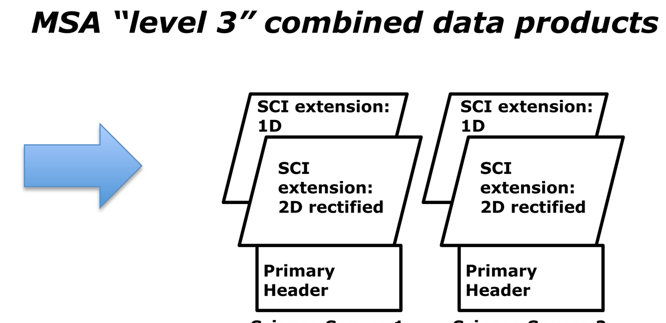
MSA exposure-level data products



MSA reorganized source-based files



MSA "level 3" combined data products



Data products & format

FS: The primary exposure-level product will be a 2D unrectified spectrum for each slit aperture used in the observation; browse-quality 2D rectified and 1D spectra will also be provided for quick-look purposes. The final "level 3" product will include the 1D & 2D spectra produced from combination of multiple exposures (such as at different slit-nod positions). Uncombined integration-level products will be provided for bright object observations with the 1.6″ square aperture (i.e., exoplanet transit observations).

MSA: Exposure-level data products will be packaged as a single fits file per configuration, with extensions containing each 2D source spectrum (see schematic at left). Before multi-exposure combination, the data will be reformatted to a source-based structure. The final combined products will include one file per source, with data from multiple gratings stitched together.

IFU: The primary product will be a 3D data cube with rectified spatial (RA, DEC) and dispersion axes. We expect to make a single cube out of mapped/mosaicked pointings, and also combine data taken with multiple gratings.

We have just begun to scope out functionality of analysis tools that will allow interactive visualization of the spectra and related data such as NIRCam pre-imaging mosaics, and carry out various analysis tasks such as spectral line measurements, redshift determinations, template fitting, etc. using both the intermediate and final data products - see poster by *Kassin*.