JWST/NIRSpec

MSA + Crowded Fields

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Observing Resolved Stellar Populations

with the Micro Shutter Array on the JWST Near Infrared Spectrograph

JWST NIRSpec

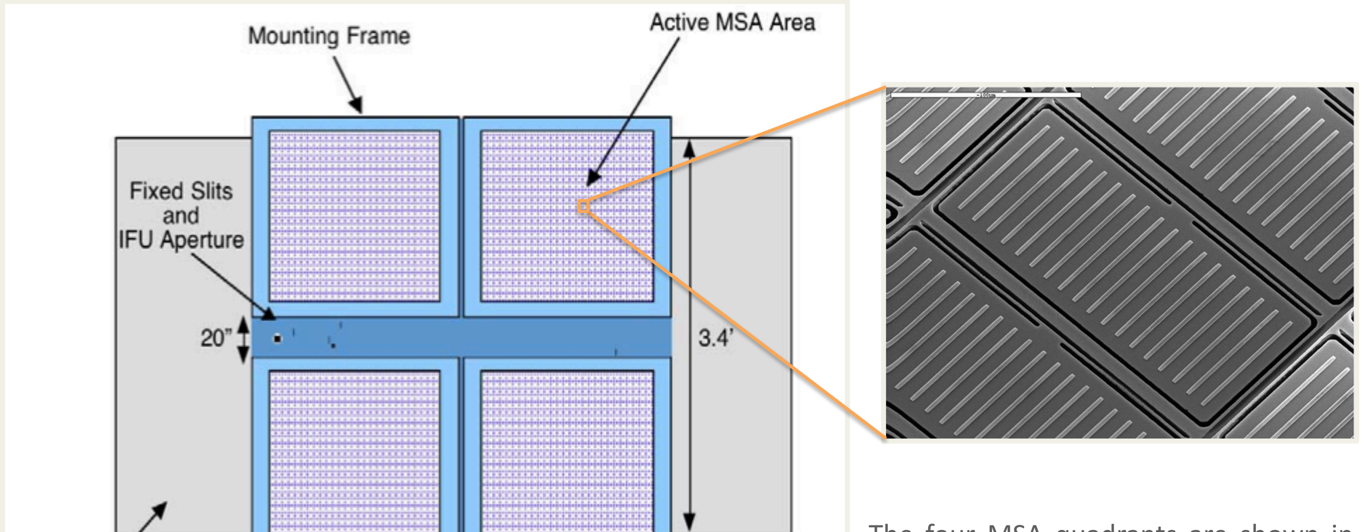
Abstract

The James Webb Space Telescope's (JWST) Near Infrared Spectrograph (NIRSpec) will provide a multi-object spectroscopy mode through the Micro Shutter Array (MSA). Each MSA quadrant is a grid of contiguous shutters that can be configured to form slits on more than 100 astronomical targets simultaneously. The combination of JWST's sensitivity and superb resolution in the infrared and NIRSpec's full wavelength coverage over 0.6 to 5 µm will open new parameter space for studies of galaxies and resolved stellar populations alike.

We describe a NIRSpec MSA observing scenario for obtaining spectroscopy of individual stars in an external galaxy, and investigate the technical challenges posed by this scenario. This use case and several others, including a deep galaxy survey and observations of Galactic H II regions, are guiding development of the NIRSpec user interfaces, including proposal planning and pipeline calibrations.

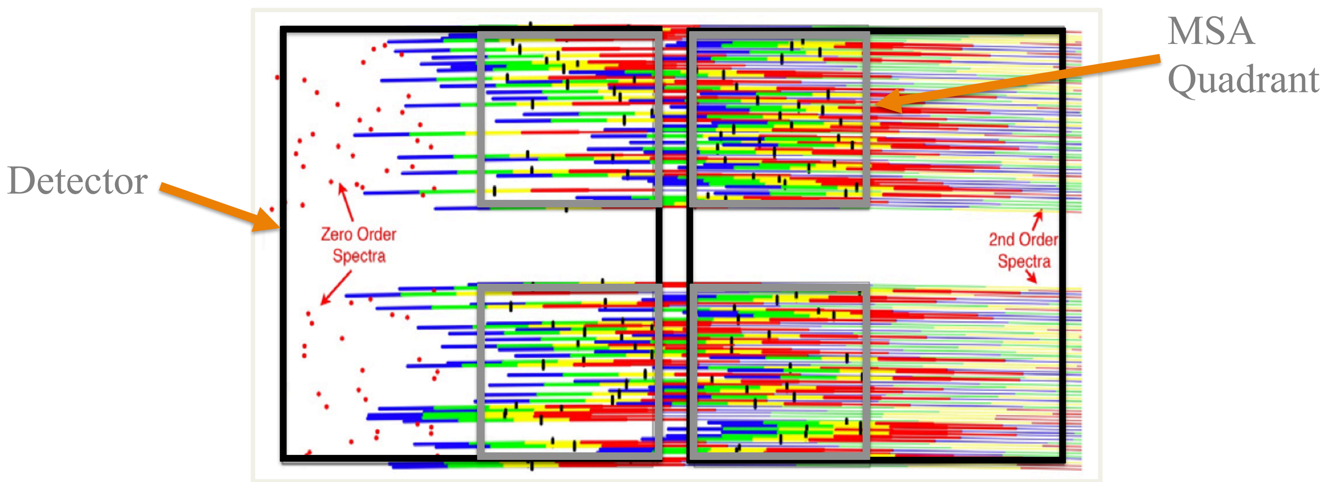
Multi-object Spectroscopy with the NIRSpec MSA

The 4 MSAs on NIRSpec are each comprised of a grid of more than 62000 shutters, configured in 365 rows and 171 columns. Each shutter can be individually commanded open or closed, resulting in an extraordinarily flexible multi-object spectrograph.



The four MSA quadrants are shown in relation to the NIRSpec Detector Array. (left), along with a highly magnified image of the shutters that make up the MSA (right).

NIRSpec's gratings and prism each provide contiguous wavelength coverage from 0.6 to 5 µm at R ~ 100, 1000, and 2700. For the R ~ 1000 and 2700 gratings, only one source can be observed per MSA row. This can be seen in the diagram below, which illustrates the approximate spectral locations on the detector array for a configuration of opened MSA shutters and the R ~ 2700 grating.



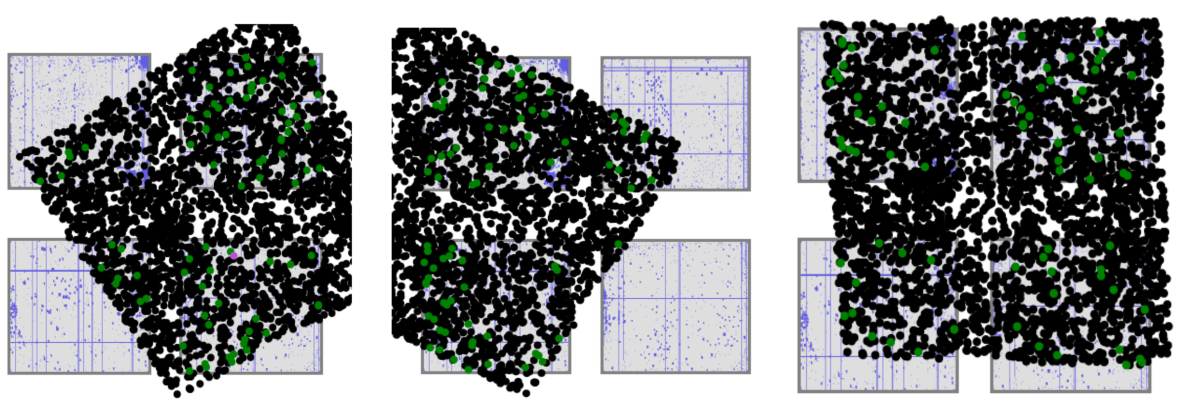
Multiplexing in Crowded Fields

Context

Multi-object spectroscopy is a powerful way to study the dynamics and chemical abundances of stellar systems. The NIRSpec MSA mode will enable observations of crowded and dust-obscured stellar populations in the nearby universe. Below, we explore the effect of observational design choices on the multiplexing achieved in an MSA plan, using a stellar catalog derived from ACS imaging of the inner region of M33's disk. The primary targets are bright red giant branch and asymptotic giant branch stars. The results will be applicable to any field with similar source density (the primary target density is 275 stars arcmin^{-2}). With this source density, approximately 70 primary targets can be observed in one MSA configuration with a 3 shutter slitlet.

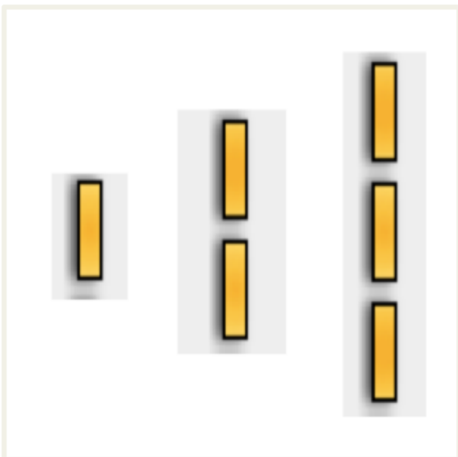
Orientation

The available roll angles for a given date and sky location will be significantly more constrained for JWST than for HST. Fortunately, for crowded fields the orientation has a small effect on the number of observed sources. Even for source catalogs (black circles) with spatial extents well matched to the field of view of the MSA, there is less than a 10% difference in the number of observed sources (green circles) in the 3 orientations shown here.



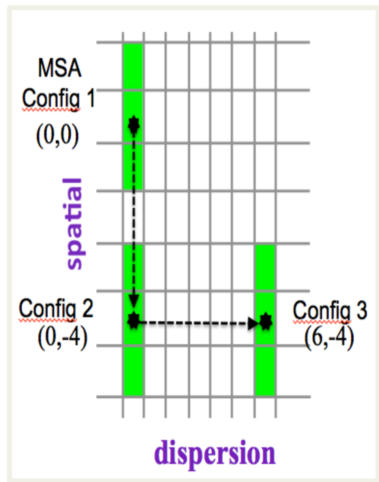
Slitlet Shape

For crowded stellar fields, many primary targets are available in every MSA row and the slitlet shape has a strong impact on the number of targets observed. In this example, the stellar density is high enough that using a one shutter slitlet instead of a three shutter slitlet results in a factor of 3.7 increase in the number of observed primary targets.



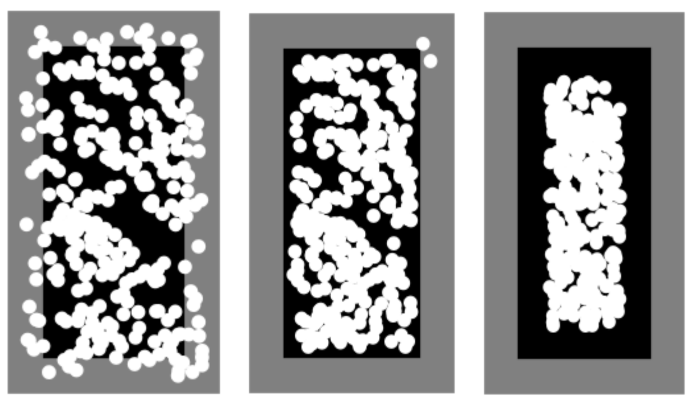
Dithers

Most observations will benefit from performing dithers of at least a few shutters in the spatial or dispersion directions. For small dithers such as these, the number of primary targets observed in all dither positions is decreased by ~20%, because distortion will cause some targets will fall outside the slitlet in one of the dither positions. Large dithers, which are needed to cover the wavelength gap in the detectors, have a significantly larger effect.



Restricting Source Location in the Shutters

If a source is offset from the center of a shutter, the observed flux of the source is reduced. Users can restrict the locations of sources in the shutters to ensure a limited loss of flux. The figure below overplots the position of each observed source in its respective shutter for three different observing plans, with an increasingly large constraint applied on the source location in the shutter. The allowed shutter regions in the middle and right panels correspond to a minimum slit transmission relative to a centered point source of 50% and 90%, resulting in roughly 5% and 10% fewer observed sources compared to the unconstrained case (left-most panel).

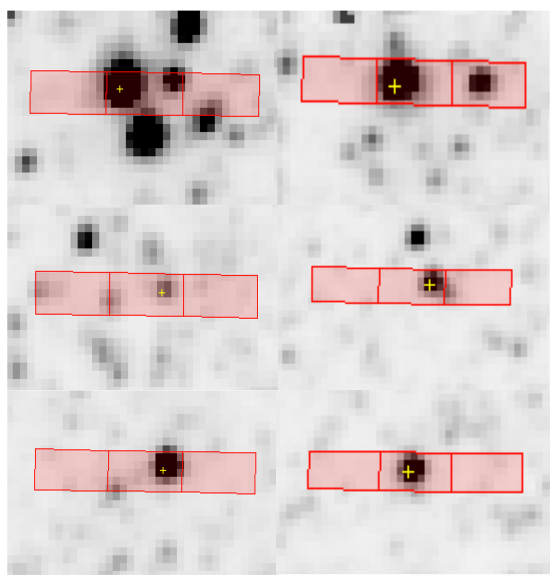


All the sources observed in a single configuration of the MSA, overlaid on a schematic shutter. Three different plans are shown, with increasing constraints on the allowed location of a source in its shutter.

Technical Challenges

Crowded shutters

In dense fields, multiple sources in a single slitlet will be common, as seen to the right. Many of the faint sources visible in the F814W image are below the magnitude limit used for selecting primary targets, but they will adversely affect target or background measurements. Obtaining background shutters with no stellar sources will be challenging in dense fields. **Solution:** Implement a check for contamination within the slitlet during planning, and use the interactive planning tool to open background shutters free of contaminating sources.



Precision Kinematics

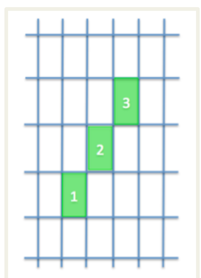
The NIRSpec MSA will be an excellent instrument for obtaining spectra of stars in crowded or highly extincted regions, including globular clusters, the Milky Way bulge, and dwarf galaxies. However, studying velocity distributions in low-mass systems will require extra care in obtaining and reducing the observations, as it will push the limits of the velocity precision achievable with the NIRSpec MSA.

The location of the source in the shutter: The spectra of two sources with the same intrinsic velocity, but located on opposite edges of the shutter, will be shifted by 2 pixels with respect to each other. This results in an offset of 120 km s^{-1} in the measured velocities. Therefore, the location of each source in the shutter must be determined with an accuracy of ~0.1 pixels. One possibility is to obtain and analyze an image taken through the configured MSA after target acquisition. The position of each source in the shutter during the observations must be used by the data reduction pipeline when determining the wavelength solution for each target.

Relative Wavelength Calibration: The requirement on the accuracy of the absolute wavelength calibration is ~15 km s^{-1} for the R~2700 grating. However, the relative wavelength calibration for targets observed with a single target acquisition, and no movement of the grating wheel, will likely be significantly better and could reasonably attain ~3 km s^{-1} precision. For programs that require multiple target acquisitions, observers could force the MPT to observe sources from the first target set in the second, by placing a very high priority on those targets. This would allow an empirical calibration between the wavelength solutions for each target set.

A schematic view of overlapping MSA pointings, with stars in the overlap region observed in the first target set given very high priority in the second.

Increased Centroiding Accuracy on absorption lines can be gained by sub-pixel sampling of the line spread function. This can be achieved naturally by implementing a diagonal slitlet shape, as shown to the right, and observing the source in each shutter of the slitlet.



Do you have an observing scenario that will push the limits of NIRSpec and the planning or data processing systems? Come to a demo of the NIRSpec MSA Planning Tool, find me at coffee, or contact me at kgilbert@stsci.edu to discuss the planning and reduction needs of your observing scenario.