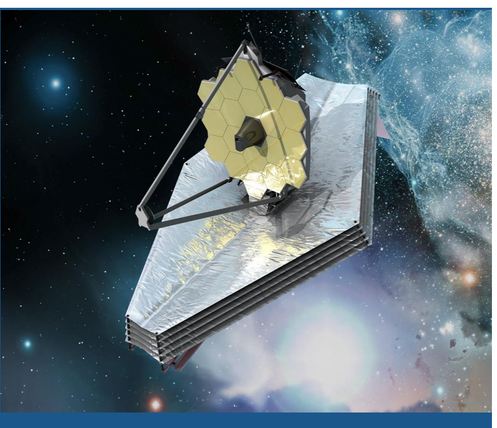
Pointing Requirements and Acquisition Procedures for JWST/NIRSpec Observations

Abstract

The JWST Near-Infrared Spectrograph (NIRSpec) includes a variety of science modes including the Micro-Shutter Assembly (MSA) that will be used for simultaneous observations of 100 or more targets for multi-object spectroscopy (MOS), an Integral Field Unit (IFU), and several fixed slits (FS). Pointing requirements and target acquisition procedures for NIRSpec will vary depending on both the scientific requirements and the mode used for a particular observation. We review the target acquisition algorithms available for each template, and discuss the practical details of planning observations of various kinds. Standard target acquisition using the MSA will be discussed, as will the acquisition of objects into the large S1600A1 aperture which will be used for bright object time series (BOTS) observations. We will also review the circumstances under which no acquisition is needed.



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Introduction to NIRSpec Target Acquisition

Following a slew of the JWST spacecraft, NIRSpec can execute target acquisition (TA) corrections that remove any inaccuracies in the initial (blind) pointing for the guide star and science target coordinate positions. The purpose of these NIRSpec TA procedures is to fine-tune the JWST pointing to place a given target very accurately into one of the fixed slits, the IFU, or to precisely align targets within the grid of MSA shutters.

At present two autonomous methods have been designed for NIRSpec target acquisition, which are available for use with specific observing templates (see Table 1): standard TA (TACQ) using the MSA, and the bright object TA (BOTA) through the wide FS aperture. A third option called "verify only" is available after blind-pointing with some templates; this checks the pointing without executing a full target acquisition sequence.

Table 1: Available NIRSpec TA Methods as function of NIRSpec Observing Mode

Target Acquisition Option*	NIRSpec Observing Modes or Methods				
	MOS	IFU	FS	BOTS	Moving Targets
NIRSpec Standard TA (TACQ)	✓	✓	✓		
NIRSpec VERIFY_ONLY	✓	✓			✓
NIRSpec Bright Object TA (BOTA)				✓	

* Two additional options are planned for use with any template, but are not presently implemented: TA=NONE will allow science observation at the initial blind-pointing without an additional acquisition or verification image. Wide Aperture Target Acquisition (WATA) will center the science target or a nearby offset target in the wide FS aperture followed by a small slew to place the science target in one of the available defined apertures. Both TA=NONE and WATA are planned for APT 25.4 (November 2017) release.

Standard TA (TACQ)

The NIRSpec standard target acquisition method (called TACQ) will be used for most NIRSpec science including all observations performed with the Micro-Shutter Assembly (MSA). For the best pointing performance, astrometry relating the positions of science targets and candidate reference stars with a relative accuracy of 5 mas is preferred. Reference star magnitude limits for observing combinations implemented in TACQ are highlighted in orange in Table 2.

The TACQ algorithm uses sets of 5–20 reference stars observed through the MSA to precisely position and align the science targets within their planned micro–shutters. The NIRSpec TA process (Figure 1) observes the reference stars through the MSA in one exposure, then offsets the telescope by an average ½ shutter pitch in x and y and takes another exposure to mitigate the effects of the micro-shutter grid. Centroids are calculated on-board the JWST spacecraft for each observed star in both exposures. An algorithm is used to calculate the best slew and orient correction to precisely align the science sources in their planned MSA shutters.

The NIRSpec TA procedure imposes strict requirements on the relative astrometry between the reference stars and the science targets. The post-TA uncertainty in science source positioning depends on the input astrometric catalog accuracy A_{Ast} and the number of stars or point-like sources available to use as TA reference, Nstars.

5 mas planning catalog accuracy with Nstars > 5 will yield an estimated science target placement accuracy of 20 mas (1/10th of a MSA shutter width) or better (Figure 2). TACQ acquisitions with fewer than Nstars = 5 will not be supported because of the high potential for very poor accuracy that can result in science targets not placed in their correct MSA shutters. These accuracy numbers assume S/N > 20 is reached on all reference stars in the TA images.

The standard TA procedure should yield a final total pointing accuracy of less than 20 milli-arcseconds (mas) allowing a given NIRSpec target with accurately known coordinates can be placed in a given preselected 200 mas-wide MSA shutter, the fixed-slits (FS), or IFU apertures.

TACQ is presently fully functional in APT for only the MOS template. Support for use of TACQ with FS and IFU templates will be implemented in APT 25.1 (June 2017)

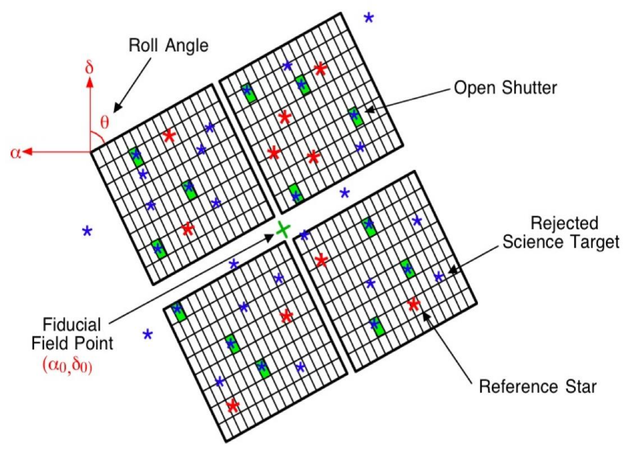

Figure 1: Schematic view of the MSA layout, with target acquisition reference stars shown in red, and science targets (blue) shown in their open MSA shutters (green). Some science targets are not observed because they lie in the same row as other sources (spectral overlap) or because their flux is attenuated by the MSA support grid. The target acquisition process acquires exposures and carefully measures the reference stars to correct the pointing to the best science position.

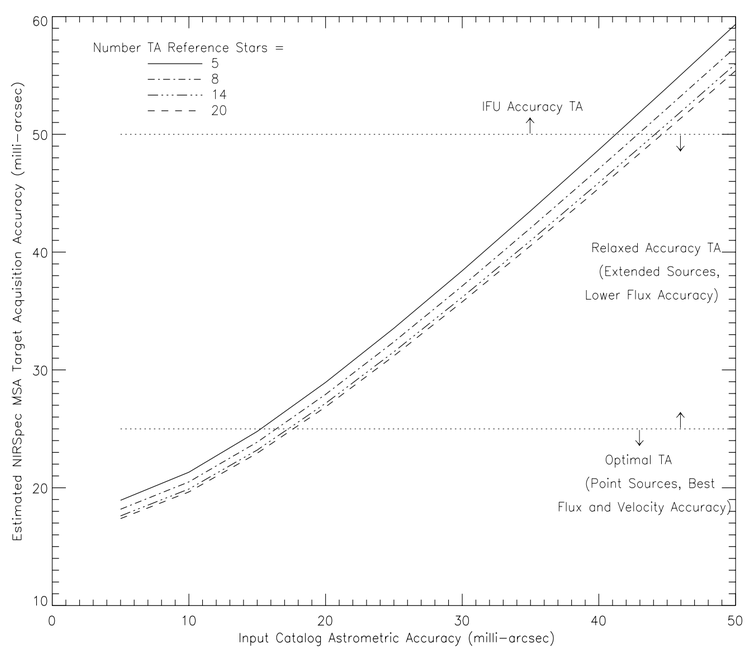

Figure 2: The estimated accuracy of NIRSpec MSA TA as a function of input catalog accuracy. Multiple curves are presented for 5-20 reference stars available for the planning process. Optimal TA planning can be achieved using input catalog astrometric accuracy of <15mas, relaxed accuracy (up to 50mas) can be obtained using poorer coordinate accuracy.

Bright Object TA (BOTA)

The NIRSpec bright object target acquisition (BOTA) is the default method used to acquire most targets for high S/N spectrophotometric observations of Bright Object Time-Series (BOTS) targets, which will be obtained with the 1.6”x1.6” square S1600A1 aperture, including exoplanet transits in the brightness range 11.5 < AB < 18.1 (detailed magnitude limits for observing combinations implemented in BOTA are highlighted in green in Table 2). Target coordinate accuracy of 100 mas will be required.

The BOTA process observes the science target after blind-pointing into the S1600A1 aperture. The target centroid is determined and a centering slew correction is calculated to precisely center the target in the square aperture. The BOTA procedure should yield a final pointing accuracy of less than 20 mas.

Verify_Only

The NIRSpec VERIFY_ONLY method relies only on guide star acquisition performed by the FGS to derive a telescope pointing. This method is suitable for placing extended objects in the field for IFU observations and when using the MSA for moving target observations or as a long slit. The pointing accuracy of this method is limited by the available guide stars and the quality of the desired science target coordinates in the guide star frame, and could be as good as 100 mas. VERIFY_ONLY always obtains a verification image of the target field.

Wide Aperture TA (WATA)

This method will be available with all modes and templates; and will be the acquisition method of choice for single point-source targets that have no specific orientation requirement. Required target coordinate accuracy will be the same as for BOTA (100 mas) and WATA should yield final pointing accuracy of less than 20 mas. This method is not yet implemented, but is planned for inclusion in APT 25.4 (Nov 2017).

TA=NONE

This method will be available with all modes and templates. No target acquisition procedure is performed following the initial telescope blind pointing to targeted coordinates. Pointing accuracy is the same as for VERIFY_ONLY, however, unlike VERIFY-ONLY, no verifying image of the pointing field is obtained. This method is not yet implemented, but is planned for inclusion in APT 25.4 (Nov 2017).

Table 2: Flight Detector MIRROR AB Magnitude Limits for 3-group Image Saturation and 1-group S/N=20 (from Table 2 of C. Alves de Oliveira and P. Ferruit, 2017, ESA-JWST-SCI-NRS-RP-2017-001). The readout/filter combinations highlighted in orange are those implemented in Standard TA. BOTA readout/filter combinations are highlighted in green.

Readout Mode Subarray	Frame Time (sec)	F110W S/N=20	F110W Saturation	F140X S/N=20	F140X Saturation	CLEAR S/N=20	CLEAR Saturation
NRSRAPID SUB32 (32x32)	0.01452	14.8	11.5	15.9	12.6	16.7	13.3
NRS SUB32 (32x32)	0.05808	17.0	13.0	18.1	14.1	18.9	14.8
NRSRAPID SUB2048 (2048x32)	0.90156	19.3	16.0	20.4	17.0	21.2	17.8
NRS SUB2048 (2048x32)	3.6062	21.5	17.5	22.6	18.5	23.4	19.3
NRSRAPID FULL FRAME	10.737	22.0	18.7	23.0	19.7	23.8	20.5
NRS FULL FRAME	42.947	24.1	20.2	25.0	21.2	25.6	22.0