Step-by-Step ETC Guide for NIRISS SOSS Time-Series Observations of HAT-P-1

Example Science Program #31 ETC Guide

A walk through of the JWST ETC for the NIRISS SOSS Example Science Program is provided, demonstrating how to select exposure parameters for this observing program.

Exposure Time Calculator

Main article: NIRISS Single Object Slitless Spectroscopy, JWST Exposure Time Calculator Overview
See also: Video Tutorials

The JWST Exposure Time Calculator performs signal-to-noise (SNR) calculations for the JWST observing modes. Sources of interest are defined by the user and assigned to scenes which are used by the ETC to run calculations for the requested observing mode.

For the "NIRISS SOSS Time-Series Observations of HAT-P-1" Example Science Program, we focus on selecting exposure parameters to detect the exoplanet transit at the desired signal-to-noise ratio (SNR). An accompanying ETC workbook on which this tutorial is based can be downloaded as a sample workbook from the ETC user interface.

The optimal exposure specifications (e.g., numbers of groups and integrations) are the input needed for the Astronomer's Proposal Tool (APT) observation template, which is used to specify an observing program and submit proposals.

The ETC workbook associated with this Example Science Program is called "#31: NIRISS SOSS Time-Series Observations of HAT-P-1 and can be selected from the **Get a Copy of an Example Science Program** dropdown on the ETC **Workbooks** page. The nomenclature and reported SNR values in this article are based on ETC v. 1.4. There may be subtle differences if using a different version of ETC.

Define Source and Scene in the ETC

Main article: JWST ETC Scenes and Sources Overview
See also: JWST ETC Defining a New Source, JWST ETC Defining a New Scene, JWST ETC Source Spectral Energy Distribution

Define source for "HAT-P-1" Scene

We first defined a source in ETC that emulates the HAT-P-1 system. After selecting the source, we opened the Sources and Scenes tab and then updated the default source parameters in the "Source Editor" pane as follows:

- "ID" tab - we updated "Source Identity Information" to "HAT-P-1"
- "Continuum" tab - we selected the "Phoenix Stellar Models" in the Continuum pull-down menu, and chose a star with spectral type G0V.
- "Renorm" tab - we chose the "normalize in bandpass" option, renormalizing the source to a Vega magnitude of K = 8.858 in the Johnson filter.
- "Lines" tab - we left this tab empty since we do not add any emission or absorption lines to the spectrum.
- "Shape" tab - we kept the default option of point source .
- "Offset" tab - we left this tab empty so the source will be at the center of the scene.

Assign source to "HAT-P-1" Scene

We highlighted "Scene 1" in the "Select a Scene" pane and then renamed the "Scene Identity Information" entry in the "ID" tab of the "Source Editor" to "HAT-P-1". Since we updated the default source which was assigned to the default scene, we did not need to define a new ETC scene.

Select NIRISS SOSS Calculation

Main article: JWST ETC Creating a New Calculation
See also: JWST Time-Series Observations, NIRISS-Specific Time Series Observations, Noise Sources for Time-Series Observations

After selecting "SOSS" from the NIRISS pull-down menu in the "Calculation" tab (Calculation #1), we specified the background parameters. Since the JWST Background is position dependent, fully specifying background parameters are important. We entered the coordinates for HAT-P-1 (22:57:46.84 +38:40:30.33) in the "Background" tab, and selected "Medium" for "Background configuration," which corresponds to the 50th percentile of the sky background.

Select Instrument Parameters

Main Article: *NIRISS SOSS Recommended Strategies*
See Also: NIRISS Detector Subarrays, *NIRISS Detector Readout Patterns*, *Understanding Exposure Times*

We specify JWST exposures by number of groups and number of integrations. We want to observe a balanced number of groups per integration to maximize both temporal resolution and spectral precision. Previous experience has led the community to sample up the ramp until we reach half the saturation limit. In the context of number of groups for JWST, we will derive the number of groups corresponding to the onset of saturation ($NGroups_{sat}$) from the Exposure Time Calculator, and choose the number of groups per integration to be $NGroups_{sat}/2$ (rounding up). We will then choose the number of integrations that fully covers the full transit window.

Calculation 1 represents our initial calculation to determine $NGroups_{sat}$, where we set the following parameters:

- "Instrument Setup" tab - there is only one option in the pull-down menu in the "Instrument Setup" tab, which is the ***GR700XD*** (cross-dispersed) grism.
- "Detector Setup" tab -
    - subarray is set to ***SUBSTRIP256***, since this subarray covers a larger portion of the detector than ***SUBSTRIP96***, providing more pixels with which to estimate the background; due to the brightness of the source, a subarray is required to avoid saturation;
    - we chose the ***NISRAPID***readout pattern (where there is 1 frame per group); this is the only permitted readout pattern when using a subarray in the SOSS observing mode.
    - number of "Groups per integration" was set to 2, the minimum value permitted by the ETC, and the number of "Integrations per exposure" and number of "Exposures per specification" were kept at the default values of 1.
- "Strategy" tab - we kept the order for spectral extraction at its default value of 1 and left the wavelength of interest to its default value of 1.575 µm.

After selecting the "calculate" button to perform the calculation with these parameters, we see that the observation does not suffer from saturation, i.e., there is a green checkmark next to Calculation 1 in the "Calculations" tab and no warnings or errors are reported in the "Reports" pane. This pane also reports that the number of groups prior to saturation ($NGroups_{sat}$ - 1) as 4. The reported SNR per pixel is ~290.

Adjust Exposure Parameters to Obtain Desired Signal-to-Noise Ratio

Main Articles: *JWST ETC Batch Expansions*, *JWST ETC Reports*

As noted above, the Reports pane tells us that the onset of saturation thus occurs at $NGroups_{sat}$ = 5. Our optimal number of groups ($NGroups_{sat}/2$, rounding up) is 3. We create a calculation with this number of groups, and find that the exposure time is 22.0s, for a SNR per pixel of ~413 (Calculation #2). To fully cover the transit window of 9.352 hours (33667.199 s), we thus need 1530 integrations.

Interpreting SNR results

Main article: JWST ETC Residual Flat Field Errors

To estimate the SNR for the desired exposure setup that covers the transit window, we use the Poissonian approximation: we multiply the SNR results above for Number of Groups = 3 and Number of Integrations = 1 by the square root of the increase in exposure time. In NISRAPID mode, there is 1 frame per group, so the exposure time for 1530 integrations increases by a factor of 1530, and the SNR increases by √1530. The SNR for the full transit window is thus 413 × √1530 ≈ 16000.

Because we are making a relative measurement, we are comparing the "before/after" window with the window during the transit. The accuracy of the transit depth is defined as $SNR_{transit} = SNR_{total} / \sqrt{2} = 16000 / \sqrt{2} \approx 11300$. This result implies a relative precision on the transit depth of 1/11300 = 89 ppm. Because the spectroscopic features are nominally between 100–250ppm, we want to increase the precision on the time series by binning pixels.

We will bin the spectrum by 10 pixels, which increases the temporal precision by √10, which results in a precision of 28 ppm. This precision is high enough to measure the average exoplanetary atmosphere beyond the 3σ level.

Note that the ETC includes an error term for residual flat field errors which affects long exposures. For exposures longer than ~10,000s, ETC calculations have a "noise floor" above which an increase in exposure time no longer results in an increase in SNR that scales with the square root of the exposure time. Since we are making relative measurements on the same pixels for exoplanet transit spectroscopy, our precision is not affected by the "noise floor" imposed by the residual flat field errors. Thus, using the Poissonian approximation above provides a better estimate of the SNR using the ETC reported results for 1530 integrations 3 groups.

Target acquisition

Main articles: NIRISS Target Acquisition, JWST ETC NIRISS Target Acquisition

A target acquisition (TA) must be performed when using a SOSS subarray so that the target is precisely positioned on the detector. A signal-to-noise ratio (SNR) ≥ 30 is recommended to achieve a successful TA, which achieves a centroid accuracy of ≤ 0.15 pixel. Increasing the SNR to 100 improves the centroiding accuracy up to ≤ 0.05 pixel. If the TA fails, the observation will not be performed. Only one integration and one exposure is allowed for a TA. The acquisition mode is either SOSSFAINT (for objects between 6.1 < M < 14.5, Vega mag) or SOSSBRIGHT (for objects between 3 < M < 6.1, Vega mag).

Calculation #3, where we selected "Target Acquisition" under the NIRISS pull-down menu, shows our initial calculation to determine which parameters to specify for TA:

- "Backgrounds" tab - we entered the coordinates for HAT-P-1 (22:57:46.84 +38:40:30.33) and selected "Medium" for "Background configuration";

- "Instrument Setup" tab - we kept the default selection of "SOSS or AMI Faint" for "Acq Mode" since the target is fainter than M > 6.1 (Vega);
- "Detector Setup" tab - there are no options for the "Subarray", "Integrations" and "Exposures" parameters other than the default values. We left the number of groups to the starting value of 3 and the "Readout Pattern" to ***NISRAPID***;
- "Strategy" - the only permissible option for target acquisition is "Aperture centered on source", which for our case is the science target HAT-P-1.

We see that with this set up, we achieve a SNR ~120, which ensures the TA will succeed.

With the exposure parameters now determined for this program, we can populate the observation template in APT. See the Step-by-Step APT guide to complete the proposal preparation for this example science program.