Step-by-Step ETC Guide for NIRISS WFSS and Parallel NIRCam Imaging of Galaxies in Lensing Clusters

Example Science Program #33 ETC Guide

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

Introduction

> *Main article: NIRISS Wide Field Slitless Spectroscopy, JWST ETC 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 "Using NIRISS WFSS and NIRCam Imaging to Observe Galaxies Within Lensing Clusters" Example Science Program, we focus on selecting exposure parameters for NIRISS WFSS as the prime observing mode. Direct images are taken before and after each set of dithered grism exposures for the NIRISS WFSS mode.

We start by defining a scene of sources relevant to this science case. We show how to run ETC calculations to achieve the desired SNR for both the direct imaging and grism observations. 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., number 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 "#33: NIRISS WFSS with NIRCam Parallel Imaging of Galaxies in Lensing Clusters" 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 Sources and Scene in the ETC

Main articles: JWST ETC Scenes and Sources Page Overview

Define sources for the "Multiple Galaxies" scene

Main articles: JWST ETC Defining a New Source, JWST ETC Source Spectral Energy Distribution

We first set up a scene with multiple galaxies with a range of magnitudes and SED types. We define the following sources in ETC:

- **Galaxy m_{AB}= 26**: a point source galaxy with a flat continuum in F_ν, normalized to **m_{AB} = 26** in the NIRISS /Imaging ***F200W*** filter;
- **Galaxy m_{AB}=28:** a point source galaxy with a flat continuum in F_ν, normalized to **m_{AB} = 28** in the NIRISS /Imaging ***F200W*** filter;
- **Emission Line Galaxy**: a point source emission line only galaxy with no continuum and not renormalized, where emission line wavelengths, widths, and intensities are specified in the Lines tab in the Source Editor as:
  - center = 1.15 µm, width = 1,000 km/s, strength = 8e−18
  - center = 1.5 µm, width = 1,000 km/s, strength = 8e−18
  - center = 2 µm, width = 1,000 km/s, strength = 8e−18
- **Starburst Galaxy:** an extended (Sersic profile (Effective Radius), semi-major axis = 0.3" and semi-minor axis = 0.15") starburst galaxy (using the SED of NGC 3690 from the extragalactic spectral templates available in the ETC) at z = 2, normalized to **m_{AB} = 25** in the NIRISS/Imaging ***F200W*** filter.

Assign sources to "Multiple Galaxies" scene

Main articles: JWST ETC Defining a Scene

After assigning these sources to one ETC scene, by highlighting them one-by-one and clicking the "Add Source" button in the "Select a Scene" tab, and renaming the scene "Multiple Galaxies", we applied the following offsets to the sources within the scene:

- **Galaxy m_{AB}=26**: X offset = 0.7", Y offset = -0.5";
- **Galaxy m_{AB}=28**: X offset = 1", Y offset = -1.5";
- **Emission Line Galaxy**: X offset = 0, Y offset = 0.5";
- **Starburst Galaxy**: X offset = -1.5", Y offset = 1.5", Orientation = 30°.

Note that since the first three galaxies are point sources, orientation need not be specified in the "Offset" tab. The position of the sources in the scene can be viewed in the lower left "Scene Sketch" pane. By checking the checkbox in the "Plot" column in the "Select a Source" pane, the SEDs of the selected sources can be overplotted and easily compared (note: it may be helpful to limit the wavelength axis to the range relevant to the NIRISS WFSS mode, i.e., 0.8 - 2.2 μm).

Run ETC calculation for direct imaging

Main article: JWST ETC Calculations Page Overview, JWST ETC Creating a New Calculation, JWST ETC Imaging Aperture Photometry Strategy
See also: NIRISS Imaging, JWST ETC Backgrounds, JWST ETC Outputs Overview, JWST ETC Batch Expansion

Select NIRISS Imaging Calculation

A direct image is taken before and after each set of dithered grism exposures in NIRISS WFSS mode. This program uses both the GR150R and GR150C grisms, which disperses the light in orthogonal directions. There are therefore four direct image exposures per filter. The ***F115W***, ***F150W***, and ***F200W*** filters are used in this program.

Our goal is to detect **Galaxy m_{AB} = 28** at a SNR ~10 among the four coadded images in each of the filters, so we run ETC calculations for NIRISS/Imaging for the three filters above to determine the exposure parameters we need to achieve this SNR.

Since the JWST background is position dependent, fully specifying background parameters are important for the most accurate SNR calculation. We therefore entered the coordinates of one of the HST Frontier Fields (04:16:09.40 -24:04:04.00) in the "Backgrounds" tab, and selected "Medium" for "Background configuration," which corresponds to the 50th percentile of the sky background.

Select Instrument Parameters

Calculation #1 represents our initial calculation to assess the SNR with (mostly) default parameters, as follows:

- "Instrument Setup" tab - we kept the default filter specification of ***F200W***.
- "Detector Setup" tab -
    - subarray is set to ***Full*** (only full frame readout is supported for NIRISS imaging);
    - we chose the NIS ***Readout Pattern*** (where four frames are averaged in a group, making this ***Readout Pattern*** the preferred option for longer exposures);
    - number of "groups per integration" is kept at the default value of 10 and the number of "integrations per exposure" is kept at the default value of 1 (for NIRISS imaging and WFSS modes, it is recommended to maximize the number of groups per integration (up to a limit of 25 for the NIS ***Readout Pattern*** to mitigate cosmic ray hits) to provide better sampling up-the-ramp);

    - number of exposures ("Exposures per specification") is set to 4 since four direct images will be taken within each filter.
- "Strategy" tab -
    - We selected the "centered on source" option for "Aperture location," choosing "**Galaxy m_{AB} = 28**" from the drop-down menu, so that the SNR is calculated for this source.
    - "Aperture radius" was kept to the default value of 0.1".
    - "Sky annulus" inner and radius values were kept at their default values of 0.22" and 0.4", respectively.

Run ETC Calculation

Running the calculation with these parameters gives a SNR of 10.8, as reported in the upper left "Calculations" pane and the bottom right "Reports" pane.

To calculate the SNR in the other filters, we selected "Copy Calculation" in the "Edit" pull-down menu. We copied this calculation twice, and updated the filters in the "Instrument Setup" tab for the new calculations to ***F115W*** and ***F150W*** (Calculations #2 and #3, respectively). Running these new calculations on the updated filters shows the SNR is under 9 for both filters.

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

The SNR in the ***F150W*** filter is the median value, so we wanted to determine the number of groups needed to achieve a SNR ~10 in this filter. To efficiently run this calculation for a range of groups, where only the number of groups is varied, we used Batch Expansion. Calculations #4 through #8 shows the results of this exercise, where we updated the start value of number of groups in Batch Expansion to 11 and kept the step size and number of iterations at their default values of 1 and 5, respectively.

We see that with number of groups ≥ 13 (Calculations #6 through #8), we achieve a SNR > 10. Since this program is a coordinated parallel program with NIRCam imaging, there is a balancing act when choosing exposure times. The exposure times for the coordinated mode (including overheads) can not exceed the exposure time of the prime observing mode. However, minimizing dead time, when the coordinated mode is not observing, is also important. From experimentation in APT, we find that choosing 13 groups for NIRISS WFSS direct imaging allows us to achieve our SNR goals while making efficient use of simultaneous NIRCam imaging observations (see the Step-by-Step APT Guide for the corresponding NIRCam specifications). In general, determining optimal exposure parameters may involve some iteration between ETC and APT.

To determine the SNR for the other filters, we copied the calculations where the number of groups equals 13 (Calculation #6) twice, and updated the filters to ***F115W*** and ***F200W*** (Calculations #9 and #10, respectively). By selecting the check-box next to the calculations corresponding to these exposure specifications (number of "groups per integration" = 13, number of "integrations per exposure" = 1, number of "exposures per specification = 4) for the various filters (Calculations #6, #9, and #10), we can compare the predicted SNR through these calculations in the "Plots" pane.

Examine Signal-to-Noise Ratio for Parallel NIRCam Imaging Observations

NIRcam imaging observations are taken of a nearby field during the NIRISS WFSS exposures. As discussed in more detail in the Step-by-Step APT Guide, there is a set of NIRCam exposures in the short wavelength channel and long wavelength channel for each set of NIRISS WFSS Direct Image → GR150 → Direct Image exposures. The longest NIRCam imaging exposure sequence is observed in parallel with the set of dithered NIRISS GR150 exposures.

In Calculations #23-24, we show NIRCam Imaging exposures for one of these sets of parallel observations to the dithered GR150 exposures for illustrative purposes. Our set up is as follows:

- "Backgrounds" tab - the position is set to the same position as the prime field, with the medium background level chosen;
- "Instrument Setup" tab - the ***Filter*** is set to ***F090W*** for NIRCam short wavelength imaging (Calculation #23) and to ***F277W*** for NIRCam long wavelength imaging (Calculation #24);
- "Detector Setup" tab -
  - subarray is set to ***Full*** since we are observing faint galaxies and are not concerned about saturation;
  - the readout pattern is set to ***DEEP8*** to obtain the highest quality data for a faint field;
  - "Exposures per specification" is set to 8 to mimic an 8-step dither pattern, "Groups per integration" is set to 5 since experimentation with APT shows that this exposure time best matches the time available during the parallel WFSS GR150 observation, and "Integrations per exposure" is left to 1;
- "Strategy" tab -
  - We selected the "centered on source" option for "Aperture location," choosing "**Galaxy m_{AB} = 26**" from the drop-down menu, so that the SNR is calculated for this source.
  - "Aperture radius" was kept to the default value of 0.1", though see NIRCam Imaging Sensitivity for suggested aperture sizes for the short wavelength and long wavelength channels for point sources.
  - "Sky annulus" inner and radius values were kept at their default values of 0.22" and 0.4", respectively.

From this exercise, we see that if a galaxy with m_{AB} = 26 is in the field, it would be detected with a SNR of ~67 in the ***F090W*** filter (Calculation #23) and with a SNR of ~105 in the ***F227W*** filter (Calculation #24) when using these exposure parameters.

Run ETC calculation for WFSS

Main article: JWST ETC Aperture Spectral Extraction Strategy

Select NIRISS WFSS Calculation

This program uses an 8-step dither pattern for each filter (see NIRISS WFSS Recommended Strategies for a discussion about the trade-offs between dither size and number of dither steps). Our goal is to obtain a SNR ~ 3 per pixel in the emission lines from the Emission Line Galaxy from the coadded dithered WFSS exposures.

We initiated a NIRISS/WFSS calculation and updated the background tab as above for the direct imaging calculations (i.e., the coordinates were set to 04:16:09.40 -24:04:04.00 and we selected "Medium" for "Background configuration").

Select Instrument Parameters

Calculation #11 represents our initial calculation to assess the SNR with (mostly) default parameters, as follows:

- "Instrument Setup" tab -
  - Grism is set to ***GR150R***;
  - we kept the default filter specification of ***F115W***.
- "Detector Setup" tab -
  - subarray is set to "Full" (only full frame readout is supported for the NIRISS WFSS mode);
  - we chose the NIS ***Readout Pattern*** (preferred for long observations);
  - number of "groups per integration" is kept at the default value of 10 and the number of "integrations per exposure" is kept at the default value of 1;
  - number of exposures ("Exposures per specification") is set to 8 since the program uses an 8-point dither pattern.
- "Strategy" tab -
  - We selected the "centered on source" option for "Aperture location," choosing "**Emission Line Galaxy**" from the drop-down menu, so that the SNR is calculated for this source.
  - "Wavelength of interest" was set to the wavelength of the emission line, i.e., 1.15 µm.
  - "Aperture half-height" was kept to the default value of 0.15".
  - "Sky sample region" inner and radius values were kept at their default values of 0.2" and 0.5", respectively.

Run ETC Calculation

With these parameters, we find SNR of ~2.4, which is too low.

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

Similar to the direct imaging calculation, we used batch expansion to repeat the calculation, increasing only the number of groups, using a starting value of 16, 9 iterations, and a step size of 1 (Calculations #12 - #20). It is recommended to limit NGroups to 25 with the NIRISS NIS ***Readout Pattern*** to mitigate the impact of cosmic ray hits which can result in discarded frames.

We find that with number of groups ≥ 16 (Calculation #12), the SNR exceeds 3. Similar to the experimentation we did to match up parallel NIRCam Imaging exposures with NIRISS WFSS direct imaging exposures in APT, we strike a balance between maximizing NIRCam exposure time within the exposure time window allowed by the prime NIRISS WFSS exposures. We find that for 23 groups, we make the most efficient use of a simultaneous NIRCam observation while achieving a WFSS SNR of 3.6 (Calculation #19).

To determine the SNR in filters ***F150W*** and ***F200W*** for this exposure specification, we copied Calculation 19 twice, updated the filters to ***F150W*** and ***F200W*** (Calculations #21 and #22, respectively), and set the wavelength of interest in the "Strategy" tab to the wavelengths of the emission lines (i.e., 1.5 μm and 2 μm). We find a SNR ~5 through both filters with this exposure set-up.

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.