NIRSpec MOS - Deep Extragalactic Survey ETC Guide

This is a JWST NIRSpec MOS deep extragalactic survey use case. The ETC step-by-step instructions are provided in detail here.

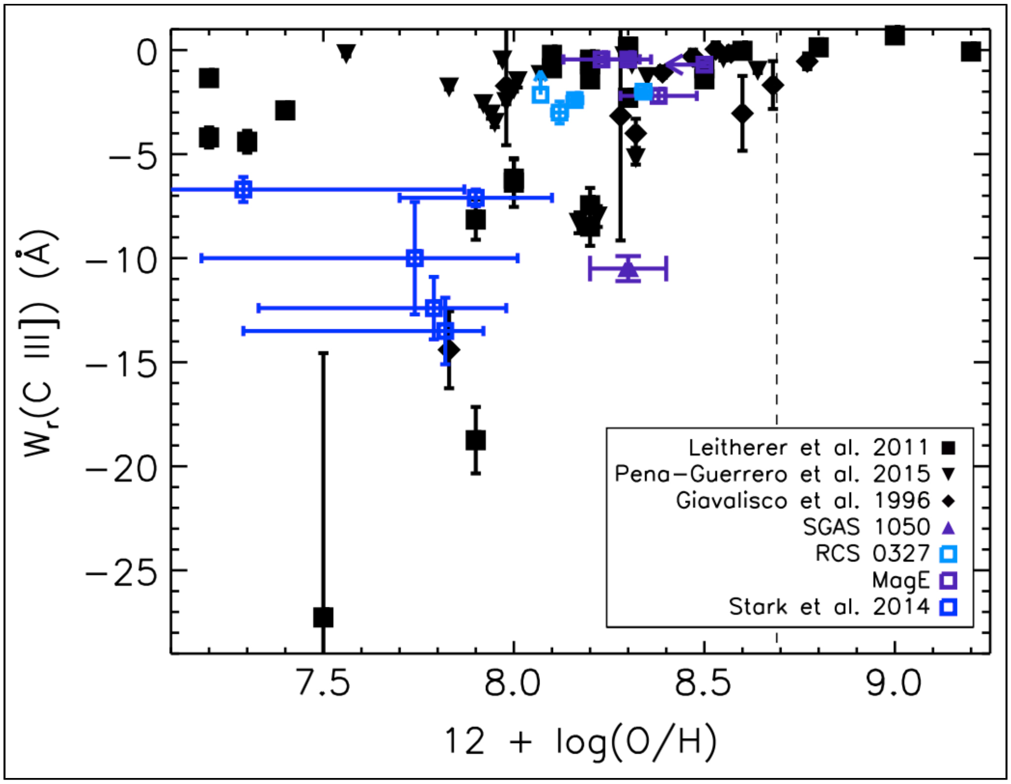
Exposure Time Calculations

As discussed in the Science Goals section, we will observe [CIII], CIII] at 1907 and 1909 Å for galaxies at $5 < z < 6$, in addition to Hα 6563 and other optical emission lines such as [OII], [OIII] and Hβ for galaxies at $2 < z < 6$ (but we only plan for Hα). [CIII], CIII] lands in disperser/filter G140M/F100LP, and the optical emission lines span all three grating/filter combinations that we are using (G140M/F100LP, G235M/F170LP, G395M/F290LP). [CIII], CIII] is much fainter than Hα or any of the other optical lines of interest. Therefore, observing [CIII], CIII] requires longer integrations in G140M/F100LP . Consequently, we present two exposure time calculations below: one for [CIII], CIII] in G140M/F100LP and one for Hα in G235M/F170LP and G395M/F290LP. We are basing our rest-frame line integration times on Hα, even though we will detect other optical emission lines, because Hα is the most relevant line for our science case.

Estimating expected fluxes of the emission lines of interest

We estimate the expected flux of [CIII], CIII], using equivalent width measurements in the literature, along with a WFC3 IR F140W magnitude of 26 AB, representative of the brightest $5 < z < 6$ galaxies in our catalog.

Figure 1. Equivalent width as a function of metallicity



The rest-frame equivalent width is shown as a function of metallicity for galaxies at a range of redshifts. At low metallicities, galaxies have a range of equivalent widths, whereas at high metallicities, the CIII] is weak. We wish to measure this relation for a large sample of galaxies at very high redshift ($5 < z < 6$). From Rigby et al., 2015.

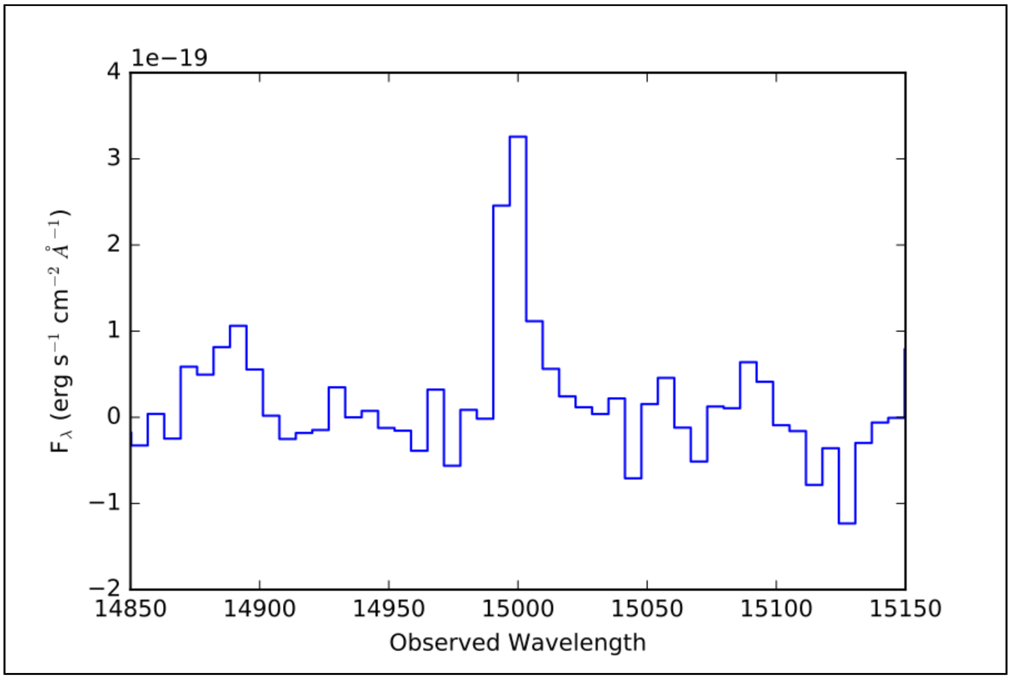
To obtain a typical equivalent width, we look to Figure 1 which is from Rigby et al. 2015. From this figure, we infer that an equivalent width of 10 Å is typical of galaxies with the low metallicities that we may expect at these redshifts. Given these numbers, we estimate that we must reach a flux of 1.5×10^{-18} ergs s^{-1} cm^{-2} (assuming a redshift of $z = 5.5$). Additionally, we wish to measure star-formation rates down to 1 solar mass per year which corresponds to an Hα flux of 3.8×10^{-18} ergs s^{-1} cm^{-2} at a redshift of 6.

Estimating S/N for a continuum-subtracted line

We need to perform continuum subtraction to obtain flux measurements from our emission lines. Therefore, we need to perform an exposure time calculation for a continuum-subtracted line. To do so, we use a combination of JWST ETC calculations and our own custom model, which is provided as an Python notebook in the next section.

The JWST ETC returns S/N per pixel for the entire spectrum of an input source. Our simple model translates this to a S/N integrated over a continuum-subtracted emission line. The model consists of a Monte-Carlo simulation where we add differing amounts of noise to a model galaxy spectrum. We then mock observe the line of interest for each Monte-Carlo realization and determine its S/N. Figure 2 shows an example simulated 1D spectrum from our study.

Figure 2. A simulated 1D spectrum with the same resolution and dispersion as NIRSpec's G140M grating is shown.



This model has a line flux of 3.8 × 10^{-18} ergs s^{-1} cm^{-2} Å^{-1}, and a continuum magnitude of 27 AB, and a continuum S/N of 0.15/pixel. With a Monte Carlo simulation, we determine that the S/N on the line is 7. By trial and error, we conclude that somewhat lower continuum S/N of 0.12/pixel will yield a 5 sigma measurement of the same modeled line.

For [CIII], CIII], we ran the model for an input spectrum with a continuum magnitude of 26 in WFC3/F160W and a line flux of 1.5 10^{-18} ergs s^{-1} cm^{-2}. The lines were assumed to be Gaussian having a width that is the same size as the spectral resolution element. We wish to determine the continuum S/N necessary to obtain a line S/N of 5. By iterating on the continuum S/N in the model, we find that a value of 1.25 per pixel is required.

For Hα, we ran the model for an input spectrum with a continuum magnitude of 27 in WFC3/F160W (typical of the highest redshift sources in our catalog) and a line flux of 3.8 10^{-18} ergs s^{-1} cm^{-2}. Again, the line is assumed to be a Gaussian having a width that is the same as the spectral resolution element. By iterating on the continuum S/N, we find that a value of 0.12 per pixel is required to measure Hα with a S/N of 5 in the line.

Model to estimate S/N for a continuum-subtracted line

The details of our simple model to estimate S/N for a continuum-subtracted emission line are as follows.

The model is available as a Python notebook. First, we start by creating a noise-free model spectrum (line + continuum). Then, we choose a root-mean-square (RMS) for the error spectrum, that will yield a fixed continuum S/N. For each model spectrum we:

- Monte Carlo 5000 noise spectra with the same RMS,
- add these spectra to the noise-free model,
- mock observe the resulting spectra, and
- calculate the RMS of the mock observations of the line and convert it into a S/N by dividing the input flux by this rms.

This results in a S/N measurement for a line, given the S/N on the continuum. We then iterate to determine the continuum S/N that will yield a line S/N of 5. In this model, it is assumed that noise does not vary with wavelength in the vicinity of the line. This is because the lines are faint enough that the Poisson noise from the source is negligible. Note that for [CIII], CIII], both lines in the doublet are simulated, but are blended. For Hα only a single line is simulated.

For [CIII], CIII] and Hα we want a S/N of 5 in the line. This requires a S/N of 1.25 per pixel in G140M/F100LP for a source with 26th magnitude in WFC3 IR F140W, and a S/N of 0.12 per pixel in G235M/F170LP and G395M/F290LP for a source with 27th magnitude (AB). We now use the JWST/ETC to calculate the number of groups, integrations, and exposures required to meet these goals.

Calculating the number of groups, integrations, & exposures

In the ETC we choose the NIRSpec MSA "mode."

For [CIII], CIII], we create our scene as follows. We specify a flat continuum that is normalized to be 26 mag (AB) in the HST WFC3/IR F140W filter. We specify an extended source which is a 2D Gaussian with semi-major and semi-minor axes of 0.17 arcseconds. This corresponds to 1 kpc at a redshift of z = 5.5, a typical size for galaxies at this redshift (Curtis-Lake et al. 2016.) We assume the source is centered in the slit. We select a "wavelength of Interest" in the "strategy" tab of 1.25 μm, which is near the observed wavelength of [CIII], CIII] at a redshift of z = 5.5.

We selected the G140M/F100LP grating/filter combination to cover the [CIII], CIII] line at redshifts 5 < z < 6. We use the NRSIRS2 detector readout pattern, which reduces correlated noise and is recommended for long exposures.

We find that 22 groups, 8 integrations, and 3 exposures, are optimal, totaling 10 hours and 48 minutes. The choice of 22 groups gives ramps of 1600s, below the recommended ~2000 second maximum set by the rate of cosmic rays. In practice, we have some leeway on the breakdown of groups and integrations. Below 2000 seconds, longer ramps (more groups) are preferred to more integrations because they yield lower read-noise and less overhead. For example, 25 groups, 7 integrations, and 3 exposures would give about the same S/N in the ETC. However, in both cases, we find that each nod would have more than 13,000 seconds of exposure, longer than JWST's maximum allowed exposure time of 10,000 seconds. Therefore, we must break these exposures into two. In order to maintain the same exposure time in each, we choose an even number of integrations. Hence, in the ETC we conclude that 22 groups, 4 integrations, and 6 exposures will meet our S/N goal.

For Hα, we create our scene as follows. We specify a flat continuum that is normalized to be 27 mag (AB) in the HST WFC3/IR F140W filter. We specify an extended source which is a 2D Gaussian with semi-major and semi-minor axes of 0.17 arcseconds. We assume the source is centered in the slit. We do two ETC calculations: one for G235M/F170LP at 2 µm and another for G395M/F290LP at 4 µm, again, using the NRSIRS2 readout pattern. In order to reach a continuum S/N of 0.12, we find that 15 groups, 1 integration, and 3 exposures (3326 seconds) are required for G235M/F170LP. Likewise, 22 groups, 1 integration and 3 exposures are needed for G395M/F290LP (4851 seconds).

References

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