Exposure Time Calculator Hands-On

1. Introduction

In this activity, you'll become familiar with the features and functions of the JWST Exposure Time Calculator (ETC). The goals of these activities are:

- Learn how to translate "typical" science cases into ETC calculations
- Generate realistic scenes and sources using the spectral templates or user-uploaded spectra
- Approach the calculation from different angles: configuring exposure settings to reach given signal to noise ratio (SNR) on a target; or calculate the SNR from a set exposure time.
- Learn about target acquisition calculations
- Examine and interpret ETC outputs

2. Case I: Mid-infrared spectroscopy of a Y dwarf

Background

Y dwarfs represent a relatively recently discovered class of very cool brown dwarfs. First detected with the WISE mid-infrared satellite (Cushing et al 2011; Kirkpatrick et al 2012), these objects bridge the gap between T dwarfs at temperatures to T_{eff} ~ 500K and the temperatures typical of gas giant planets (e.g. T_{Jup} ~ 124 K). Only a few dozen Y dwarfs are known. Studying them is important for several reasons, including:
- Characterizing the bottom of the stellar mass function
- Their atmospheres may be simpler analogues of larger exoplanets (but lacking the irradiation from a nearby star)

Several Guaranteed Time programs will observe Y Dwarfs in the Solar neighbourhood, with a variety of observing modes. In this activity, we will calculate exposure settings for observations of a representative Y Dwarf with the MIRI Low-Resolution Spectrometer. Atmospheric modeling has shown that broad-coverage infrared spectroscopy will allow us to determine the temperature, gravity (and hence mass) of objects, and study their atmospheric composition and cloud properties. In the wavelength range covered by LRS, the dwarf spectrum is characterized by broad absorption features from water, ammonia and methane.

Note that the Slit Spectroscopy hands-on activity will discuss near-infrared observations of this target.

Target information

The target we use in this activity is based on the Y Dwarf WISE J035000.32-565830.2.
RA, Dec = **03:50:00.328, -56:58:30.23**
Spectral type = Y1
F140W (HST/WFC3) = 22.3 ± 0.20 (Vega mag)

To create the source, we have provided you with a high-resolution model spectrum from Morley et al (2014) (see **Error! Reference source not found.**) - note that these properties are not fully representative of the above object. The model spectrum has already been converted into appropriate units for ETC ingestion.
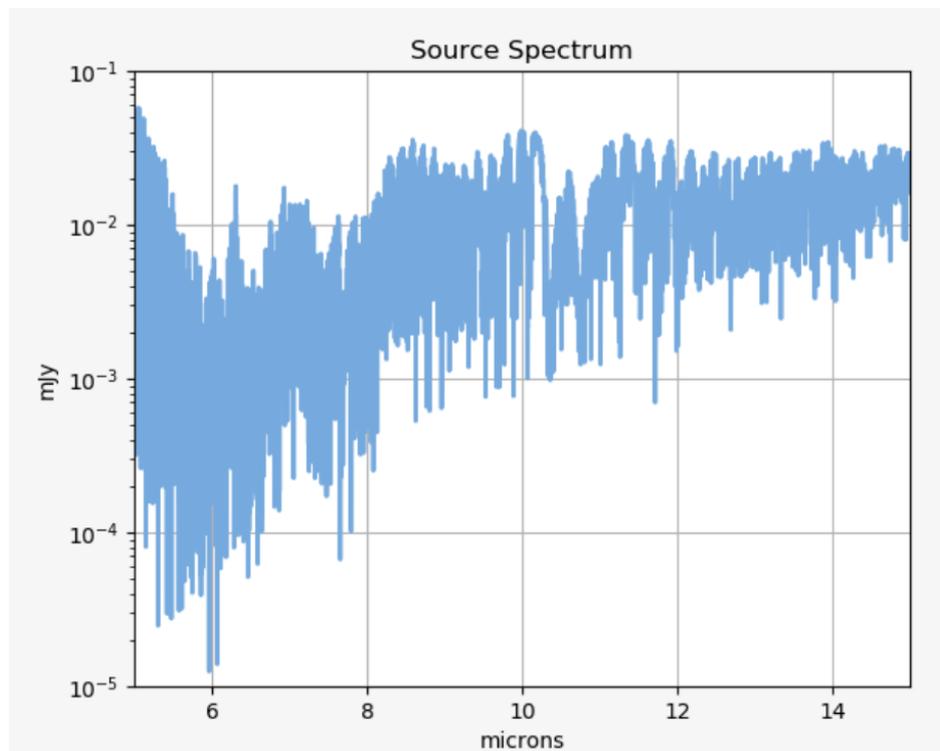

Figure 1: Model spectrum of a Y Dwarf, T=450K, log g=4.5, with flux density renormalised to HST/WFC3 F140 mag = 22.3 (model from Morley+ 2014).

ETC Activity I: Creating the scene and source

1. Upload the target spectrum to the ETC, and associate the default source with the spectrum. Ensure that the source flux is renormalized to the appropriate magnitude (see above).

    a. Inspect the spectrum in the plotting panel. Does the wavelength coverage and flux density match what you expected?

2. Set the target size to "Point source"

ETC Activity II: Setting up the calculation

1. Navigate to the Calculations tab, and create a new calculation for MIRI Low Resolution Spectroscopy, using the slit (LRS in slitless mode is a dedicated time-series mode).

    a. Check the different options under "Backgrounds", "Instrument Setup", "Detector Setup" and "Strategy". You will notice that certain selections have already been

made, others require input.

2. Enter the background settings. Use the target coordinates, and select Medium for the background level.

3. Under Instrument Setup, no further setup is required. The LRS uses a double prism as disperser, which is designated "P750L" in the filter wheel of the MIRI imager. The wavelength coverage and total system throughput is plotted in the tab.

4. In the Strategy tab, you will see that the "Aperture spectral extraction" option is pre-selected (this is the only option for slit spectroscopy). Check that the aperture is centred on the correct target. Check that the extraction aperture half-height and the sky sample region are appropriate for this wavelength regime.

5. Under Detector Setup, the subarray menu is set to FULL (the only option for LRS slit observations), and the readout pattern to FAST, again the default (and appropriate) setting. **Work out an exposure configuration (groups, integrations, exposures) that will achieve a SNR of ≥ 10 around 7.5 μm.**

   a. **Tip 1**: the LRS standard point-source dither pattern consists of 2 pointings along the slit, which are combined by the pipeline. This pattern is simulated by setting "exposures per specification" to 2 (see Figure 2).
   b. **Tip 2**: you should aim for integration lengths of around ~300 s. Integrations should be < 1000 s to avoid too many cosmic ray impacts.
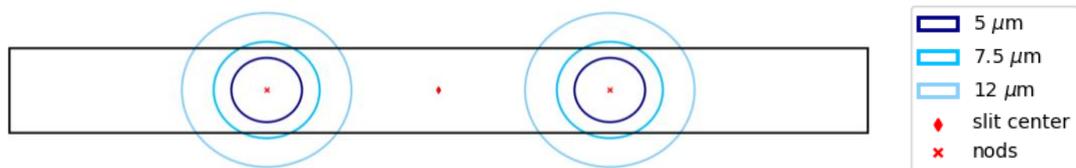   c. **Tip 3**: Use the "Expand" feature to explore the SNR variation vs. number of groups or integrations

Figure 2: Layout of the LRS "along-slit nod" dither positions. The circles show the size of the Airy disk at 5, 7.5 and 12 μm at each location, to scale. The red diamond marks the slit centre.

ETC Activity III: Configure the Target Acquisition Exposure

MIRI LRS requires very accurate placement of the target in the slit to achieve the best calibration. The TA exposure must be specified by the user in APT, alongside the science observation. You can investigate the best TA settings using the dedicated "Target Acquisition" calculation in the ETC. For best results with MIRI LRS, you should aim for **SNR > 20** on the TA image (thresholds are specified per instrument, so check the documentation for each instrument and mode). Note: this is an imaging observation.

1. In the Calculations tab, create a new calculation from the "MIRI" menu, "Target Acquisition" option.

2. Enter the same settings under "Backgrounds" as for the science calculation.

3. Under Instrument Setup, select the appropriate option for MIRI LRS Slit observations. Four filters are available; you can visualize their throughput in the plot panel. Verify the choice of filter against the spectrum of the target. Tip: the neutral density filter should only be used

for very bright targets that would saturate the detector in < 3 groups with other filters.

4. Under Detector setup, **identify the detector readout mode and group number that will deliver the required minimum SNR**. The maximum number of groups is 10 (with 1 integration and 1 exposure) due to on-board storage facility.

   a. **Tip:** despite the limitation of maximum 10 groups, the exposure time can be extended by choosing a different readout pattern. The FASTGRPAVG* modes average together 4, or a multiple of 4, groups; i.e. time(FASTGRPAVG8 group) ≈ 2 * time(FASTGRPAVG group) ≈ 8 * time(FAST group).
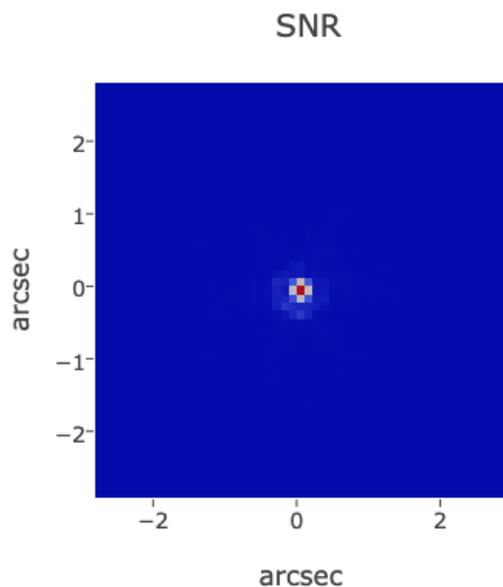
5. Activity complete!

Figure 3: Output image from the ETC MIRI Target Acquisition calculation
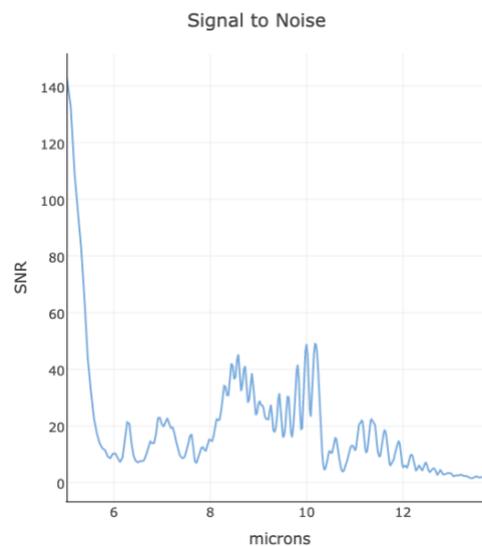
Figure 4: SNR plot of the LRS observation of the Y Dwarf

Summary

In this activity, you've demonstrated:

- How to upload and use a model spectrum for JWST exposure time calculations
- How to create a simple scene and source with appropriate normalization
- How to configure a "realistic" spectroscopic strategy
- How to explore the groups/integrations parameter space to configure an exposure for a given SNR.
- How to create and configure a MIRI target acquisition calculation

Optional extra exercises

- Vary the background settings, and see how this impacts the mid-IR SNR
- Reconfigure the observation to achieve a SNR of 10 at 12 μm – how much extra time would be needed?

- Repeat setting up the observations with the MIRI Medium Resolution Spectrometer. How does the required exposure time vary? What would be the pros and cons of using an integral field spectrometer instead of a slit spectrometer for these observations?

3. Case II: Near-Infrared Multi-Object Spectroscopy of a Distant Galaxy

Background

In this exercise, we will prepare a NIRSpec Multi-Object Spectroscopy (MOS) observation of a Deep Field populated with numerous distant galaxies. The goal of such a program is to study the evolution of galaxies from the earliest times (z > 10) through the end of the dark ages (z ~ 7-9) to the epoch of galaxy assembly (z ~ 2-6).

This exercise is complementary to the MOS Planning Tool hands-on activity (day 2). The output from this exercise will be used in that session.

A "full" program would include NIRCam imaging of the field, followed by NIRSpec MOS observations. This exercise uses a *simplified approach* focusing on the latter component, focusing on a **single galaxy in the field at z ~ 6**.

We will calculate exposure settings for both low- and medium-resolution spectroscopy with NIRSpec – 4 calculations in total.

Observation strategy

In NIRSpec MOS mode, the recommended observing strategy for faint and compact sources is called a "3-shutter nodding pattern". In this approach, three adjacent shutters are stacked into a "slitlet". In 3 consecutive exposures, the target is moved between the 3 shutters (see Figure 5). This allows powerful exposure-level background subtraction.
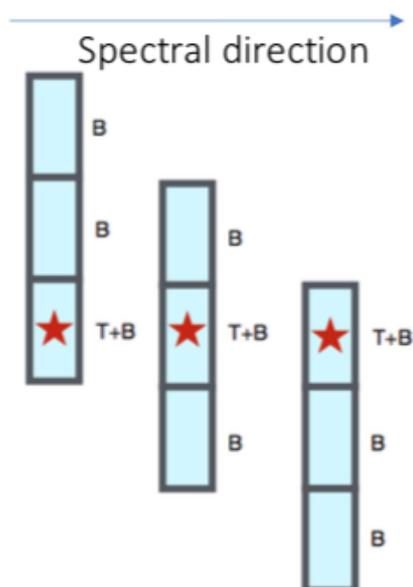

Figure 5: The 3-shutters approach used to create a "slitlet" for MOS with NIRSpec, and the implementation of the nodding pattern for background subtraction.

In this activity, we will configure the ETC to compute the SNR of 4 separate observations of the same target in a set exposure time (10_5 seconds):
- Low-resolution spectroscopy covering 0.6 – 5.3 µm (disperser/filter pair "PRISM/CLEAR"): this combines good continuum sensitivity with wide instantaneous wavelength coverage, at

the expense of spectral resolution. This also allows a higher level of multiplexing due to shorter spectra on the detector.
- Medium-resolution spectroscopy of 3 wavelength regions with disperser/filter combinations: G140M/F100LP, G235M/F170LP, G395M/F290LP. The higher spectral resolution provides accurate information on line centroid and width.

ETC Activity I: Low-resolution spectroscopy of a z~6 galaxy

- **Configure the Target**

  - o Model the target using one of the provided Brown et al template spectra for a Blue Compact Dwarf galaxy. Assume the galaxy is a point source.
  - o Set the redshift to 6
  - o Normalise the flux to AB mag = 27.5, or 50 nJy at 2 μm.

- Create a new calculation for a NIRSpec Multi-Object Spectroscopy observation

- Assume coordinates of RA, Dec = 03:32:28.0, -27:48:30 for Background settings, and choose "medium" background.

- **Instrument Setup**

  - o Configure the instrument to use the PRISM/CLEAR disperser/filter combination, with a 3-shutter slitlet shape. For the MSA location setting accept the default.
  - o Check that the throughput plot is as expected.

- **Detector Setup**

  - o The recommended readout pattern for faint compact sources with NIRSpec is NRSIRS2.
  - o Configure an observation totaling ~100k seconds. Tips:
    - ▪ Aim for ~1.5 ks per exposure
    - ▪ Exposures should be multiples of 3
    - ▪ Keep the number of integrations per exposure to 1.

- **Strategy**

  - o Select the MSA Full Shutter Extraction strategy, and enter 2 μm as the wavelength of interest
  - o Verify the default settings in other fields.

- What SNR do we expect for this observation of a z~6 galaxy at low spectral resolution?

ETC Activity II: Medium-resolution spectroscopy of an emission line galaxy at z~6

In this part of the activity, we will model observations of the same galaxy, focusing on several emission lines. As the instantaneous wavelength coverage of each medium-resolution filter/disperser combination is limited, we will perform a dedicated calculation for each of the emission lines.

- Target (see Figure 6)

- o Create a new scene and source. Choose the "no continuum" setting, and add emission line properties as specified in Table 1.
- o Remember to set the redshift
- o Assume the galaxy is a point source.

Name	Centre (µm; z=6)	Width (km/s)	Strength (erg/cm$_2$/s)
[OII]	2.61	40	7e-19
CIII]	1.34	40	2.1e-18
Hα	4.59	40	5.2e-19

Table 1: Emission line properties for the z~6 galaxy

- Create new calculations for NIRSpec Multi-Object Spectroscopy observation.

- Assume coordinates of RA, Dec = 03:32:28.0, -27:48:30 for Background settings, and choose "medium" background.
  - o Tip: you can save time by copying calculations, which will carry over common settings.

- Instrument setup: configure the 3 calculations to use the following 3 medium-resolution disperser/filter combinations, each matched to one of the emission lines. In the Strategy section, ensure that the wavelength of interest is set to the corresponding centre wavelength of each line.
  - o G140M/F100LP -> CIII] line
  - o G235M/F170LP -> [OII] line
  - o G395M/F290LP -> Hα line

- In Detector Setup, copy the exposure settings you determined from the low-resolution spectroscopy calculation for this galaxy – again to simulate a 100 ks, multi-exposure observation.
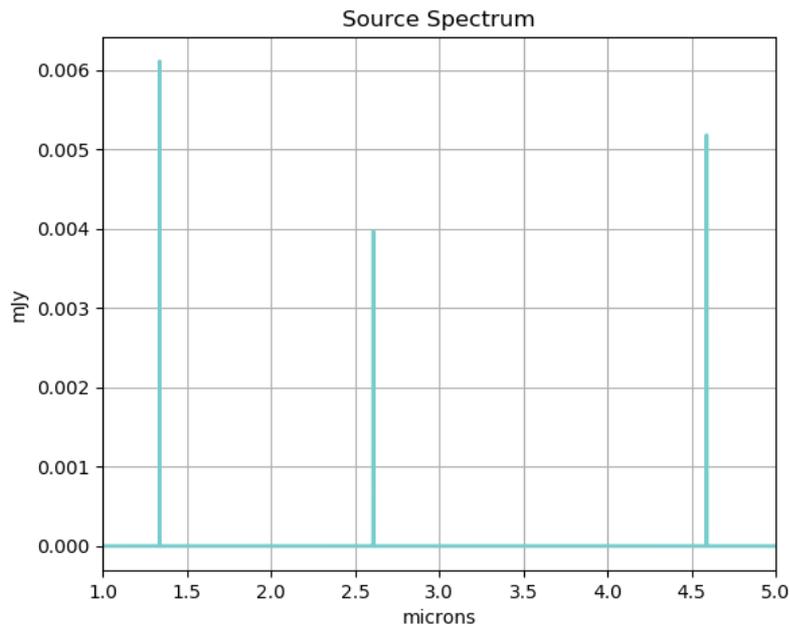
Figure 6: Source plot for the z~6 emission line galaxy

- Under Strategy, ensure that the MSA Full Shutter Extraction is selected.

- Run the calculations, and check the SNR of the lines you can expect from this exposure time.

Summary

In this activity, you've demonstrated:

- How to model a galaxy at high redshift, using either the ETC-provided templates and the emission lines feature
- How to configure an observation with NIRSpec MOS for a given exposure time
- How to trade off resolution and coverage in different spectroscopic modes to get information on either emission lines or continuum (or combine observations to obtain both).

This particular science case will be explored in more detail in the MOS Planning Tool Hands-on Activity (Day 2).

Optional extra exercises

- Create an appropriate target acquisition calculation for the NIRSpec MOS observations. (background reading: NIRSpec Target Acquisition in JDox).
- In the continuum case, we configure the observation with a single integration per exposure, taking many exposures. What would be the pros and cons of reaching the same overall on-source time, with a higher number of integrations/exposure (and fewer exposures)?
- Using the ETC, calculate the minimum observing time to reach a SNR of 10 for each of the emission lines.

- Repeat the medium-resolution calculations with the high-resolution disperser settings. Can these observations be performed at the highest spectral resolutions with NIRSpec?