Exposure Time Calculator Hands-On

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

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 Teff ~ 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.

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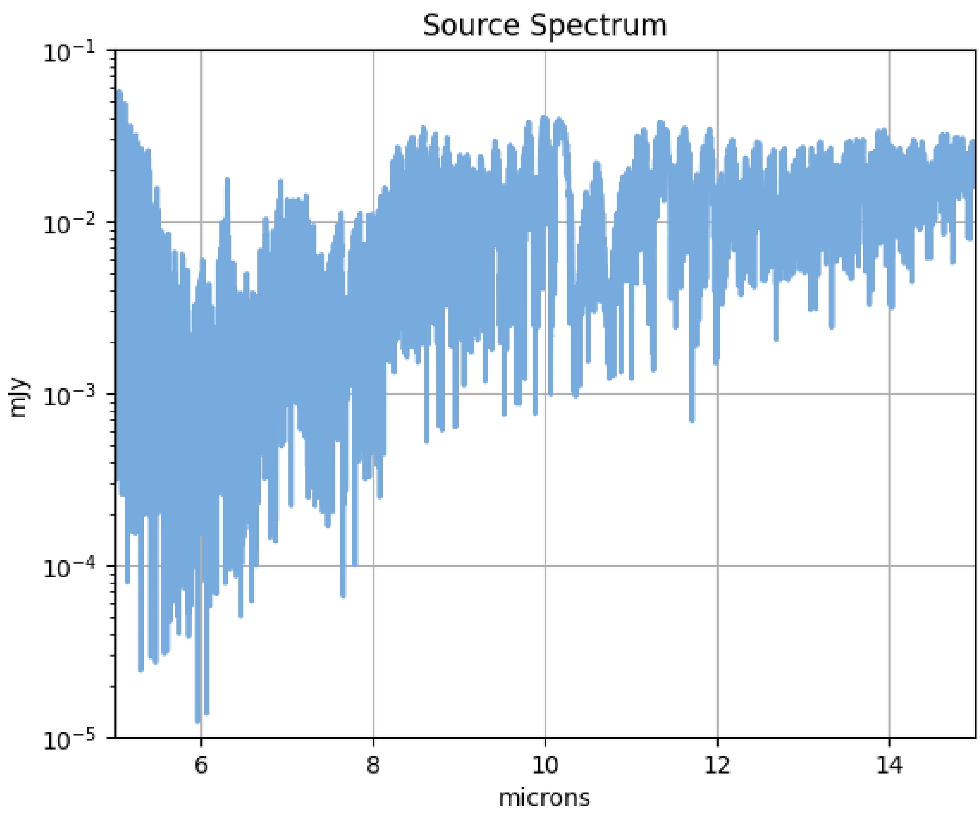


Figure 1: Model spectrum of Y Dwarf, T-450K, log g=4.5, with flux density renormalized to HST/WFC3 F140 mag = 22.3 (model from Morley+ 2014)

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.
    1. 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).
    2. Tip 2: you should aim for integration lengths of around ~300 s. Integrations should be < 1000 s to avoid too many cosmic ray impacts.
    3. Tip 3: Use the “Expand“ feature to explore the SNR variation vs. number of groups or integrations

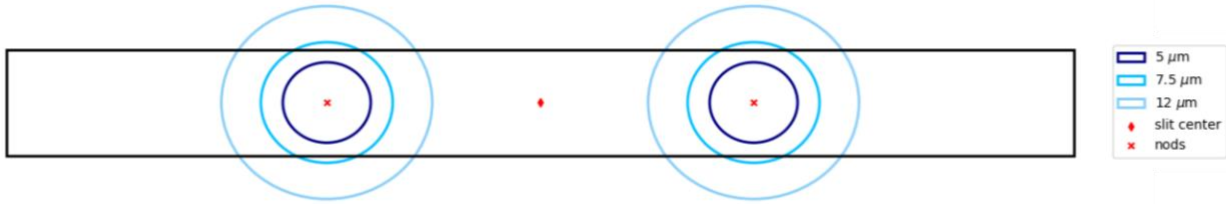


Figure 2: Layout of the LRS "along-slit nod" dither positions. The circles show the size of the Airy disk at 5, 7.5 and 12 µm at each location, to scale. The red diamond marks the slit centre. The slit length and width are approx. 4.7" and 0.5", respectively.

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.

    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).

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?

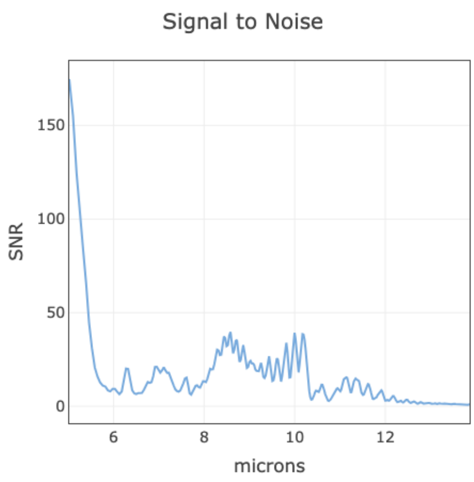


Figure 3: SNR plot of the LRS observation of the Y Dwarf.

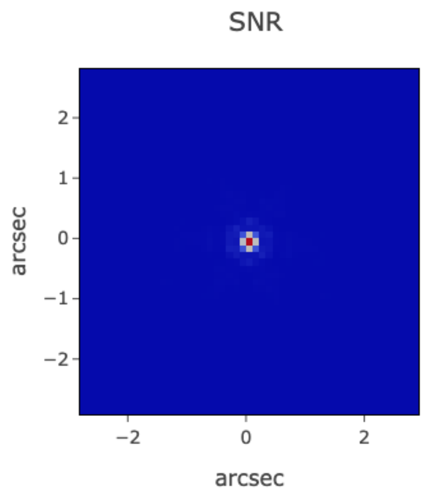


Figure 4: Output image from the ETC MIRI Target Acquisition calculation

ETC Activity IV: NIRSpec Calculations

1. NIRSpec Fixed-slit:
    - Setup a representative background by using the target's coordinates and an example date for the observations derived using the target visibility tool to fall in the Cycle 1 window (2021-09-30-2022-09-30).
    - Required SNR for science:
        - Extracted spectrum S/N>25 at ~ 1μm using PRISM
        - Extracted spectrum S/N>100 at ~ 4.7μm using G395M
    - Derive Ngroups, Nints and Nexp necessary to achieve the above S/N. Choose an
    - adequate detector readout pattern. Consider which nodding/dither pattern to use. Hints:
    - The Nexp defined in the ETC can be translated later as Number of dithers/exposures to be implemented in APT. The SNR given by the ETC assumes full redundancy in the exposures per pixel.
    - For NIRSpec in general do not use integrations longer than ~3000 seconds, to avoid cosmic ray issues.
    - Note that when setting up the detector with subarrays, the only readout patterns available are NRS and NRSRAPID (only traditional mode).

2. NIRSpec Target Acquisition:
    - Set up *WATA* calculations in the instrument setup area
    - Required SNR for Target acquisition:
        - Extracted spectrum SNR>20 at the central wavelength of the selected filter.

Hints:

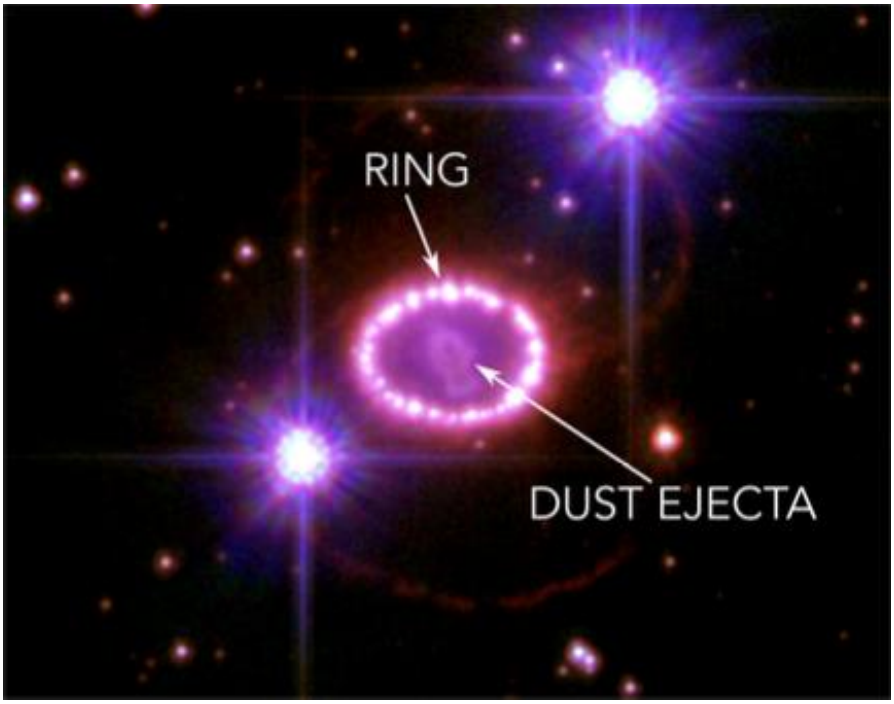
- NIRSpec TA Filters: F110W/F140X/CLEAR from narrower to wider bandpass.
- Use same readout pattern as science, not to be charged extra time

Case II: NIRSpec IFU Observations of SN1987A

Background

SN1987A is one of the best studied SN. It consists of a bright ring, enclosing the dust ejecta from the SNa. One challenge is to detect the ejecta without saturating the ring.

- Ring diameter ~ 1.1 arcsec, with thickness ~0.2 arcsec (the NIRSpec IFU covers a 3”x3” FOV)
- Total emitting area ~ 1.7 arcsec^2.
- Ejecta occupy approx. 4 pixels, i.e. just-resolved.



Goal

Create an ETC workbook that estimates the exposure time needed to observe the SN ejecta and ring using the NIRSpec IFU.

Target information

RA, Dec = 05 35 28.3900, -69 16 15.6025

Scenes and Sources

In the “Scene and Sources” you can create different sources and combine them to make an astronomical scene. Design two sources:

Source 1: Ejecta-alone: a point source centred at (0,0) with Blackbody of 100K normalised to 0.1 mJy at 10 µm .

Source 2: The ring alone: An extended flat-profile source, radius 0.638", with Blackbody spectrum of 400K, normalised to 80 mJy at 10 microns.

Create a scene that contains both sources.

Calculations

1. IFU Verification Image
    - Use the ring + ejecta scene
    - Select the NIRSpec IFU Verification Image mode
    - Find a filter that gives you for 30 groups and NRSIRS2RAPID a reasonable S/N (~ 5 per pixel, without saturating)
        - Look at the pixel S/N in the 2D image rather than the one reported in the plot or chose an adequate aperture radius for this source

2. G235M/F170LP setting (medium resolution)
    - Use the ring + ejecta scene
    - Pick 2.12 µm in the strategy tab, representing the H2 line. We don't actually have the line strength, so for line observations the SNR may be higher.
    - Choose readout mode NRSIRS2 (more information in JDox), 4 exposures of 30 groups 1 integration. The number of exposures will be equivalent to the number of dither positions in APT.
        - Do you get a positive and negative image in your 2D SNR map? Then look at the next point (Hint: what is your current nodding strategy?)
    - Think about your background subtraction strategy[1]: do you need an off-source background? In-scene background subtraction? Use the same detector configuration to cover the NIRSpec wavelength range using:
        - G140M/F100LP
        - G235M/F170LP
        - G395M/F290LP

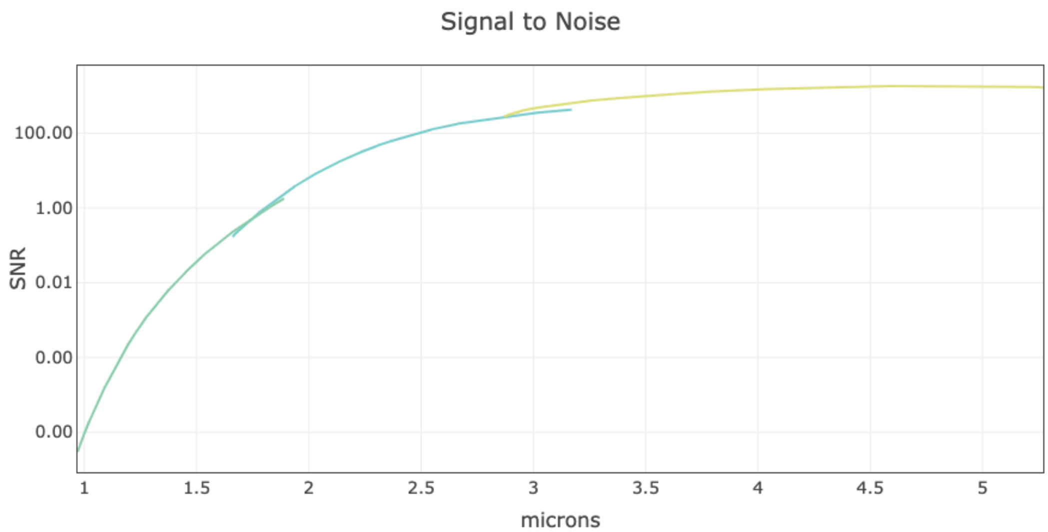


Figure 5: Combined S/N as a function of wavelength for the entire NIRSpec band.

[1] Look at the recommended strategies for background observations with NIRSpec on Jdox: https://jwst-docs.stsci.edu/jwst-near-infrared-spectrograph/nirspec-observing-strategies/nirspec-background-recommended-strategies