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EXPANDING THE FRONTIERS OF SPACE ASTRONOMY

MOS Distant Galaxies Science Example

JWST Master Class, November 2019

Materials adapted from the 2017 ESAC JWST Workshop



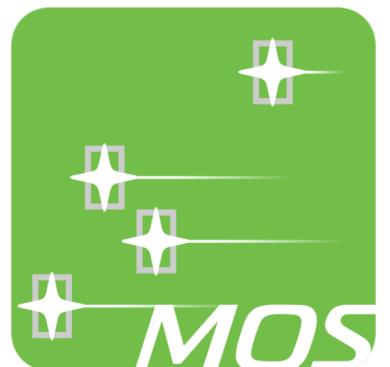
NIRSpec Multi-Object Spectroscopy of distant galaxies

In this guide you will be asked to used the following tools:

- The JWST Exposure Time Calculator (ETC).
- The Astronomer's Proposal Tool (APT) and more specifically the NIRSpec MOS Planning Tool (MPT).

The MPT, which is part of the APT, got its dedicated demonstration and hands-on session during this workshop (D. Karakla and A. Henry)

We will not have the time to exercise the visibility tools.

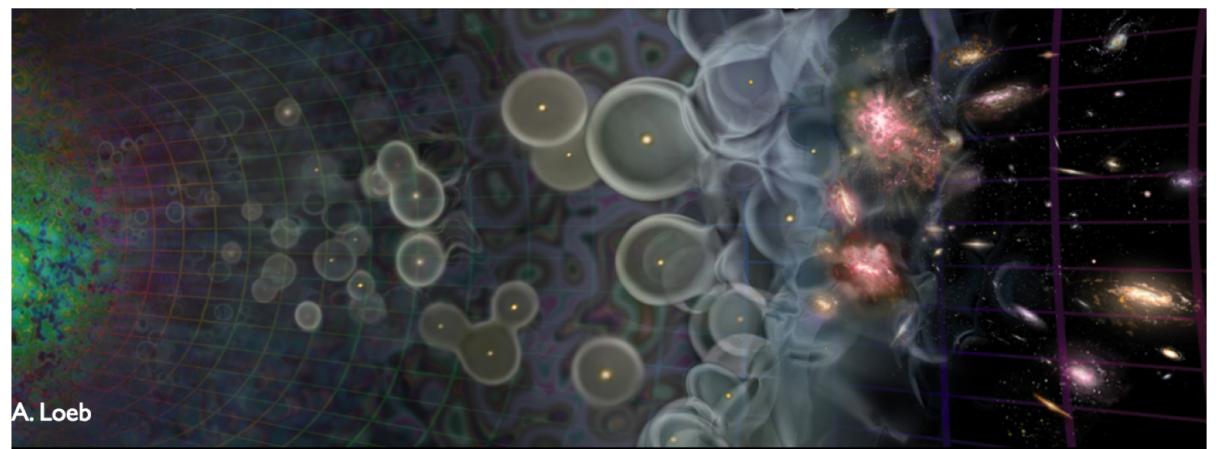




Overview

Goal: This program aims at studying the evolution of galaxies from its first steps ($z>10$), through the end of the dark ages ($z=7-9$) and down to the epoch of galaxy assembly ($z=2-6$).

- Understanding the very early stages of galaxy formation.
- Probing the epoch of reionization and the role of galaxies in the reionization.
- Tracking and understanding the build-up of stellar masses, metals and the build-up of quiescent populations (feedback, quenching).
- Understanding the role of AGNs.
- And look for surprises...





Overview

Methodology: an in-depth program of this type would combine deep imaging (NIRCam) and follow-up spectroscopy (NIRSpec MOS) like the NIRCam-NIRSpec GTO galaxy assembly survey.

In the following, we will use a much simpler example of deep NIRSpec MOS observations at a single “pointing” using an input source catalog derived from existing HST imaging.

- **Planned observations:** single-pointing NIRSpec MOS observations at low and medium spectral resolution.
- **Type of sources:** galaxies over a wide range of redshifts handled as compact objects.
- **Observation strategy:** combination of “nodding” and dithering; 1x3 micro-shutter slitlets.



Instrument configurations

Low spectral resolution (CLEAR/PRISM): sensitivity to continuum; wavelength coverage (0.6 to 5.3 microns in one shot); higher-multiplex MOS thanks to the short spectra

Main drawback(s): lack of spectral resolution...

Medium spectral resolution (F100LP/G140M, F170LP/G235M, F290LP/G395M): clean separation of emission lines; accurate information on the position of the position of the centroid of the lines.

Main drawback(s): 3 configurations required to cover the 1.0-5.2 micron range; high multiplex only possible at the cost of allowing some overlap between the spectra.

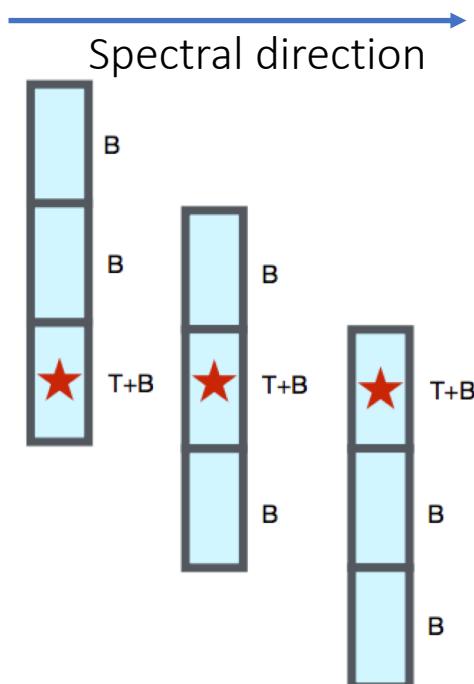
→ Complementary information, going for *all 4 configurations*.



Observation strategy – basic building block

3-shutter nodding pattern: in MOS mode, the recommended basic pattern for faint and compact sources is called a 3-shutter nodding pattern. It will constitute the basic building block for our observation program.

Each object is assigned a slitlet made of 3 shutters.



In this scheme, the number of exposures is a multiple of 3.

The baseline observation strategy is to “nod” i.e. to move the object in each shutter in three consecutive exposures, hence the name of “3-shutter nodding pattern”. For compact objects, this strategy allows powerful exposure-level background subtraction:
$$[T+B] - 0.5 * ([B] + [B])$$



ETC: S/N for an AB=26.5 mag z~6 galaxy observed during 100ks in CLEAR/PRISM

Task: prepare an ETC simulation for a ~100ks NIRSpec MOS CLEAR/PRISM observation of a $z \sim 6$ galaxy of AB=27.5 (or ~50 nJy) around 2 microns.

Scene and source: single point source; use the Blue Compact Dwarf template spectrum from Brown et al, redshift it to $z=6$ and normalize it either to AB=27.5 (over NIRCam/F150W) or to 50 nJy at 2 microns.

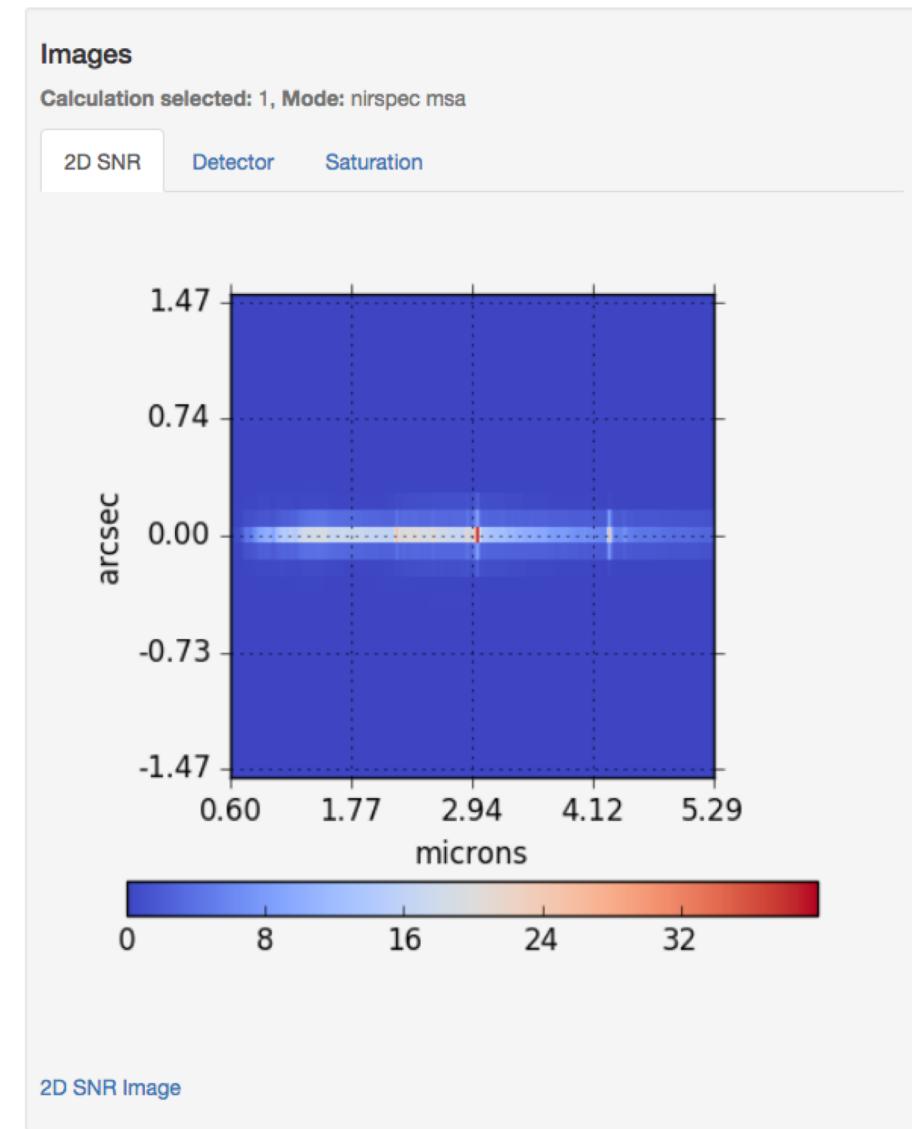
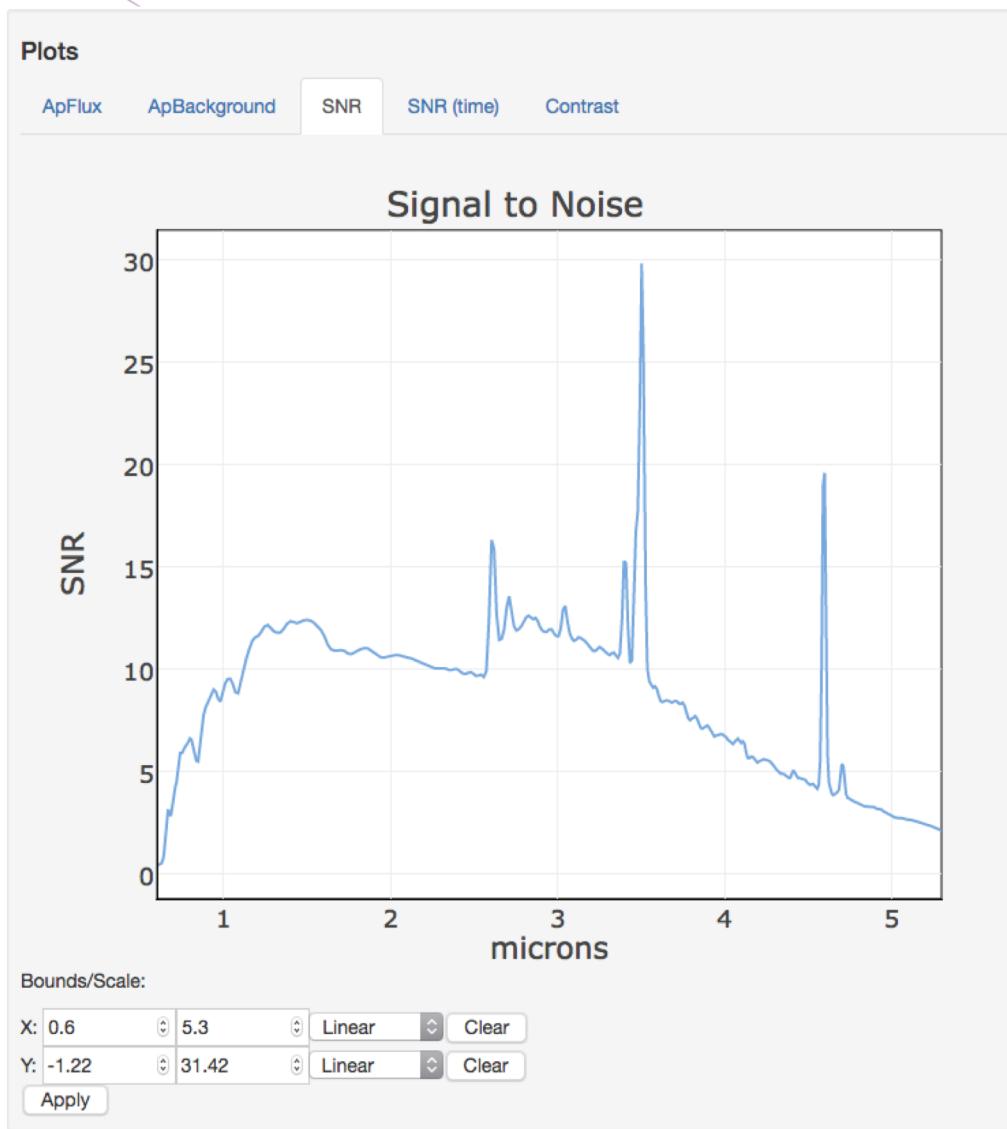
Observation strategy: medium background at 03:32:28.0 -27:48:30; MSA full shutter extraction.

Instrument setup: NIRSpec MOS; CLEAR/PRISM; 3-shutter slitlet; target centered in the microshutter (peak throughput)

Detector setup: NRSIRS2 (recommended for long exposure and faint-object observations); ~1.5ks per exposure = 18 groups; total of 72 integrations or exposures (multiple of 3...).



ETC: S/N for an AB=26.5 mag z~6 galaxy observed during 100ks in CLEAR/PRISM





ETC: S/N for emission-lines observed at medium spectral resolution

Task: prepare an ETC simulation made of 3 calculations for NIRSpec MOS F100LP/G140M + F170LP/G235M + F290LP/G395M observations of emission lines for a total exposure time of ~100ks.

Scene and source: single point source. Create a scene with a single source containing 3 (manually) redshifted emission lines (see at the bottom of the slide).

Observation strategy: medium background at 03:32:28.0 -27:48:30; MSA full shutter extraction.

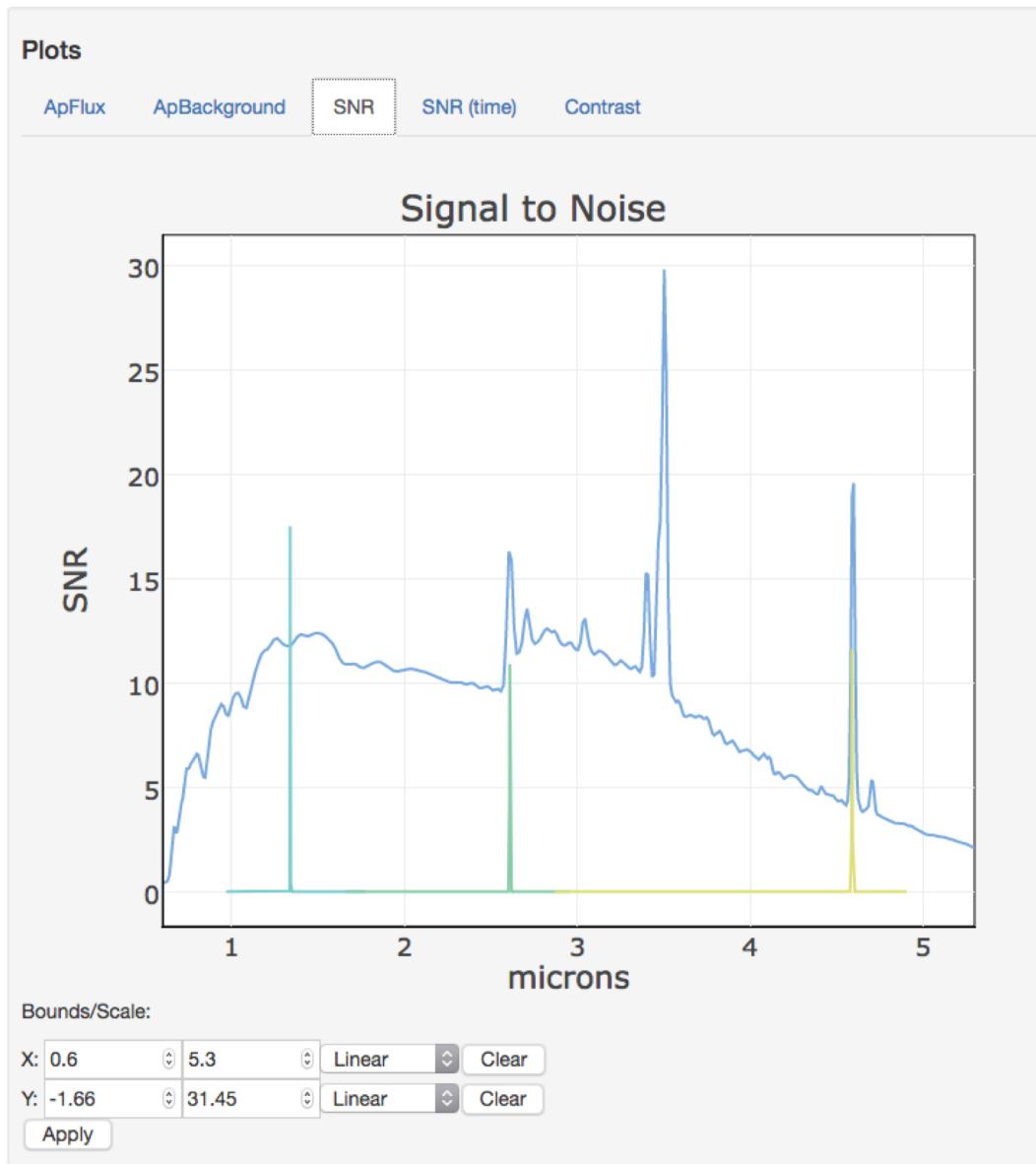
Instrument setup: NIRSpec MOS; F100LP/G140M, F170LP/G235M, F290LP/G395M; 3-shutter slit; target centered in the micro-shutter.

Detector setup: NRSIRS2 (recommended for long exposure and faint-object observations); ~1.5ks per exposure = 18 groups; total of 24+24+24 integrations or exposures.

| Name | Center | Width | Strength |
|--------------|--------|-------|----------|
| [OII] at z=6 | 2.61 | 40 | 7e-19 |
| CIII[| 1.34 | 40 | 2.1e-18 |
| Ha at z=6 | 4.59 | 40 | 5.15e-19 |



ETC: S/N for emission-lines observed at medium spectral resolution





Plan your observation strategy before playing with APT/MPT (stop and think...)

Task: prepare an observation layout that you will implement in the APT/MPT.

Your Inputs: basic building block of 3 exposures corresponding to a 3-shutter nodding scheme; 72 exposures in CLEAR/PRISM; 24 exposures in each of F100LP/G140M, F170LP/G235M and F290LP/G395M

Your not-so-compatible wishes when designing the observations:

- Obtain each group of 3 nodded exposures at a different location on the detectors (i.e. in different slitlets) in order to minimize systematics (e.g. from the flat-field correction) and to work around detector defects (bad pixels...).
- Your goal is to get as many of your objects as possible in all exposures (i.e. your objects should see the complete integration time) and you want to get as many as possible (best possible mutliplexing).

→ When dithering, you reduce your effective field of view which is the intersection of the footprint of NIRSpec fields of view at each dither position.

→ Dithering effectively reduces the number of objects you can observe in all exposures, but is recommended to improve spectral and spatial sampling.



Plan your observation strategy before playing with APT/MPT

Task: prepare an observation layout that you will implement in the APT/MPT.

What you will choose will depend on your science case: here, depth is very important so we will choose to put more emphasis on getting as many common objects as possible between the exposures. We will therefore limit the number of dithers and use the fixed-dithers option in MPT.

Get the layout of the observation: assume that we will limit ourselves to 3 dither positions and that at each of them we will do a 3-shutter nodding. Allocate the exposures of each spectral configuration..

| Dither Position | Nod Position | CLEAR/PRISM | F100LP/G140M | F170LP/G235M | F100LP/G3950M |
|-----------------|--------------|-------------|--------------|--------------|---------------|
| 1 | 1 | | | | |
| | 2 | | | | |
| | 3 | | | | ? |
| 2 | 1 | | | | |
| | ... | | | | |



APT – Get started, Load the Catalog

Get Started: launch the APT and create the skeleton of a JWST proposal. Go directly to the “Targets” folder. (You should be in the Form Editor).

Load in the Catalog. You can choose to use the one provided for this exercise, or your own.

- “HUDF_ordered_cat.txt” (whitespace separated). From Rafelski, 2015.
- Help MPT to identify as many columns as you plan to filter on to make your candidate set. e.g. If you plan to filter on redshift, make sure to declare the column with redshifts.
- Flux units: magnitudes

You will need to click on the catalog to fill in some missing fields:

- Astrometric accuracy: must be <50mas, put 15 mas for this exercise because these source positions were derived from HST WFC3 and ACS data.
- Pre-image: is already obtained, as we are using an existing catalog derived from existing (HST) imaging.

Now, no more red flags...



APT/MPT – Preparing your observation

Setup your observation in the MPT Planner (go to the MSA Planning Tool “Planner” tab):

- For this simple exercise, pick the catalog as a **Primary Candidate list**.
- Select an **Aperture Position Angle (APA)**: 135 degrees (suitable for the selected field and orientation favorable given the footprint of the catalog on the sky).
 - In real life you will have to look at the visibility tools or use APT itself to determine the **suitable range of APA**.
 - **IMPORTANT:** You need to **select an APA** to run MPT, but this angle is NOT fixed for your proposal unless you specify it explicitly as a constraint for your observations. If you do not have any scientific or observational driver to do so, then don't. You will later be allocated an APA once your observation is scheduled.
- Put emphasis on **multiplexing** and do not put strong constraints on the centering of your sources in the shutters (“Entire Open Shutter Area”)
 - We have a fixed-grid of shutters to apply on a fixed distribution of objects on the sky (your catalog) so each object will have a different centering in the shutter. Here we specify that all the selected objects must be within the open aperture of a shutter.



APT/MPT – Preparing your observation

Setup your observation in the MPT Planner (continued):

Dither setup. select the parameters corresponding to what you planned to do earlier.

- We will use the fixed-dither scheme (this is now the recommended scheme) and we will keep the dither sizes small (5 shutters in dispersion and in cross-dispersion; 3 dither points in all).

Gratings/Filters. How to best ensure all same sources in all exposures in each of the gratings?

- Think about the best way to do this.

Define the search grid: Limit the search grid to 40"x40" and a step of 3".

- The size of search grid and its step define the number of positions that will be explored. The grid can quickly become VERY large and may take a while. (However, we have recently vastly improved upon the runtime, so go ahead and experiment!). Try small numbers at first and increase progressively as you figure out how long this is going to take.



APT/MPT – Preparing your observation

Setup your observation in the MPT Planner (continued):

Additional parameters:

- Set the number of configurations to the minimum as you have fully constrained the observation sequence above (you do not want to repeat it several times). How is the minimum computed?

Click “Generate Plan” and look at the results...

- In the Plans tab of MPT, how many of the same sources did you get in all the exposures?
- How many are contaminants? Filtering the results is one way to tell how many there are. Since the entire catalog was used – the count should be realistic.
- Try other planning parameters if you have time. Try with target weights. Do you get better results? How can you tell?

Select the Plan you like and make an Observation: “Create Observation”



APT/MPT – Create your observation

Go to the Observation in the Form Editor:

- Fill in any missing information.
- Exposure duration parameters can be selected here. Recall how you planned to divide up the exposure time. Try to get the right number of exposures that you had planned for.
- look at the number of visits, the overheads...
- You should have a problem for the medium resolution exposures where you need to distribute 8x3 exposures over 3 dither positions and you cannot do it simply in a single observation. You would have to create multiple observations (and may not get the same objects each time). As our time is limited, go for **27 exposures** distributed in **9x3**.
- When assigning a large number of integrations (CLEAR/PRISM) you will get a red flag. Be aware that you can have several lines with the same spectral configuration in the exposure setup table (this should allow you to solve this problem).

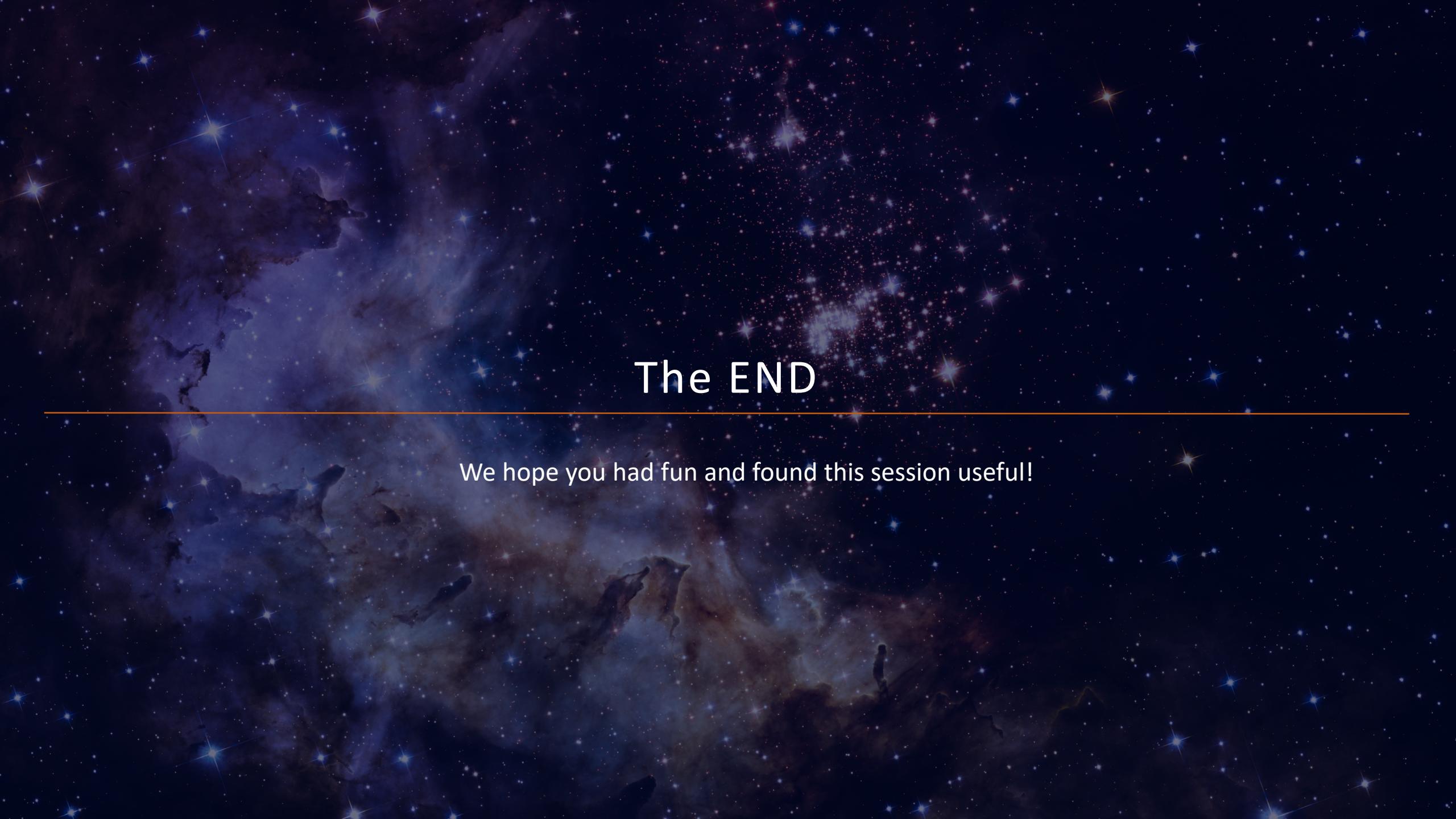


APT/MPT – Create your observation

Note that the MSATA parameters need to be defined. Let's leave this for program update. It requires extra columns in your Catalog, and a list of suitable reference stars.

Do you want Confirmation images?

- Select the parameters that make sense for the brightness of the sources you want to image. These images are limited to 3 groups. There are extra overheads for changing readout patterns in an observation.



The END

We hope you had fun and found this session useful!