JWST Master Class | Time Series Observations (TSO)

Abstract of the project

In this 2-hour Level 2 TSO project, JWST Master Class attendees will work on a proposal to observe transit(s) of the habitable-zone exoplanet K2-18 b. The scientific objective of the proposal is to confirm the water signature in its atmosphere observed by the Hubble Space Telescope (HST; Benneke et al., 2019; Tsiaras et al., 2019) with JWST. Usage of the official JWST proposal preparation tools (e.g., General Target Visibility, Exposure Time Calculator) will be made, and specific tools for transiting exoplanet observations (most of which can be used for other time-series observation scientific cases) will be introduced, such as PandExo and the tools at the ExoCTK website. The general objectives of this workshop are for attendees to a) *understand* the JWST (imaging and spectroscopic) modes for time-series observations in order to *discriminate* the optimal modes for a given scientific case, b) make use of existing tools useful for JWST proposal planning of time-series observations so they can *incorporate* them into a proposal planning workflow and c) *identify* and *analyze* the relevant data/information from these tools needed for submitting a successful JWST proposal for time-series observations.

1. Packages & Dependencies for the TSO Master Class

The bulk of the TSO Master Class requires tools already installed and/or used during the homeworks (e.g., the JWST General Target Visibility tool and Exposure Time Calculator). Aside from this, attendees should install two additional python libraries that will come in handy for the session:

- Astropy (https://www.astropy.org/).
- Astroplan (https://astroplan.readthedocs.io/en/latest/installation.html#id2).

2. TSO Master Class Outline

The hands-on activity for the TSO Level 2 Master Class (whose activity worksheet is appended at the end of this document) will be divided into three blocks that answer different sets of questions, and build the road towards a successful JWST transit spectroscopy proposal:

1. **Observability of the target during Cycle 1**. Are there transits of the target in Cycle1? Is the target observable by JWST? Are there transits of the exoplanet in the JWST observability window? Is there significant contamination in the aperture from nearby objects? (Tools to use: Astropy/Astroplan, General Target Visibility tool, ExoCTK contamination tool). **Step-by-step solution attached as "TSO_MC_part1.pdf".**

2. **Simulating transiting exoplanet observations for Cycle 1**. Are the features we are trying to see actually detectable with JWST? What is the "best mode" to use in our

case? Do we need to ask for only one transit or many transits? What observational parameters (groups, integrations), optimize our observations? Is spectroscopy (spectrophotometry) the optimal strategy for our science case, or is it precise photometry (via imaging) the way to go? (Tools to use: PandExo, ExoCTK Group & Integration calculator, JWST ETC --- ExoCTK: Atmospheric Forward Models). **Step-by-step solution attached as "TSO_MC_part2.pdf".**

3. **Writing the TSO proposal in APT for Cycle 1**. How do we input all the information we have gathered into APT? Scheduling flexibility. How do we provide multiple observing windows? (Tools to use: APT). **Solved APT file attached as APT-solved.aptx. Also explained in the presentation.**

3. Schedule of the TSO MasterClass

The total scheduled time for this MasterClass is two full hours. The activity will be an (almost) fully hands-on one with solutions at the end of each step, so we all move together to the next topics which depend on knowledge obtained from previous steps. The schedule of the class will be as follows:

1. **Introduction to the program/problem (15 mins).** A definition of what "time series observations" (TSO) means and what are the challenges associated with it will be introduced. Next, possible scientific cases will be introduced and the scientific motivation for the Master Class activities will be outlined (exoplanet atmospheres and their observable imprints --- transit, emission and phase-curve observations). With this, the possible modes for time-series observations available with each instrument will be introduced --- their advantages and disadvantages for the scientific case at hand, including photometry (imaging modes) and spectrophotometry (spectroscopy), will be briefly discussed. Finally, we will introduce the case for K2-18 b, why it is an interesting target and what the scientific objective of the Master Class exercise is: the confirmation of the water feature detected by HST (in which 8 transits were used) by JWST.

2. **Work on target observability (20 mins).** Here we will first work on checking if transits do occur during Cycle 1 for this long-period exoplanet. A brief introduction to the parameters that define a transit will be given (as not everyone is a transiting exoplanet expert). The ephemerides of the planet will be given, and tools will be recommended to predict transits of the exoplanet in Cycle 1. Then, the question of whether the target is observable with JWST will be posed (as well as a reminder on why targets can't be observed by JWST all the time) --- the class will have to use the JWST GTVT tool to find this out. Finally, the problem of contamination of nearby objects for TSO will be introduced to the class, and we will use the contamination calculator from ExoCTK to find the optimal dates among the observable transit dates to observe the target, as these dates define the range of Position Angles available for the observations. This will thus define the optimal dates to observe the target with JWST.

3. **Work on simulations with PandExo, ExoCTK & JWST ETC (45 mins).** The next step is the most time-consuming, because it implies presenting and using a lot of new tools on top of already familiar tools to the attendees (via the homeworks). First, we need to have a transit spectroscopy model. Here we will briefly introduce ExoCTK's tools to generate forward models, but will give the class the model for K2-18 b as it is not the main objective of the Master Class to go in depth about modelling exoplanet atmospheres. Then, to simulate spectroscopic observations of the transiting exoplanet with JWST, we will use (the online version of) PandExo. This will allow us to find out the optimal readout strategies (groups, integrations) that would maximize our scientific objective without saturating the detector, and also observe what the different modes provide in terms of the wavelength ranges and precision of the simulated observations. We will make sense of the results this tool give with JWST's ETC, which will in turn give insights into what PandExo does in the background when optimizing the groups and integrations. This will in turn provide a good reminder of how groups and integrations work with JWST observations. Having mastered how groups & integrations work, we will use the JWST ETC to generate a simulation for the target acquisition exposure, which is not provided by PandExo. Finally, we will turn to the JWST imaging modes for time-series observations, and use the JWST ETC to figure out if ideas using these modes are feasible to do given the scientific objective at hand.

4. **Work on APT-related problem (20 mins).** The final step of the class will be to apply all what was learnt about the scheduling and observability for TSO observations to the APT. To this end, the class will be given an APT file which will contain a number of pre-defined errors that they will have to spot. A link to the JWST documentation will be given so they can have a guide to input the missing TSO information on APT.

5. **Final remarks and discussion (20 mins.)** To conclude the class, we will re-visit all the tools we have learned to use as a wrap-up of the class. In addition, we will use this part of the class to remind the attendees that the "prescriptions" given above are to be used as guidelines, but not as the final words as different scientific cases might need special considerations. For example, we use throughout the class the idea that saturation cannot happen at all to perform the optimizations, but there might be cases in which some groups/frames might saturate without a significant loss of the scientific output of the observations. We will revisit the steps to follow to reach a successful JWST proposal. If time allows, we will end the class with a Q&A.

Activity Worksheet

In this 2-hour Level 2 TSO project, you will work on a proposal to observe transit(s) of the habitable-zone exoplanet K2-18 b with JWST. The objective of the proposal is to confirm the water signature in its atmosphere that was observed by the Hubble Space Telescope (HST; Benneke et al., 2019, arXiv:1909.04642; Tsiaras et al., 2019, Nature Astronomy, Adv. Acc. Pub.) using data from 8 transits of this exoplanet.

1. *Target & Transit Observability*

   a) Your first task will be to know when the transits actually happen during JWST Cycle 1 (September 2021 to September 2022). Use Astroplan (https://astroplan.readthedocs.io/en/latest/tutorials/periodic.html) to figure out what transits happen during Cycle 1. The period of this exoplanet is P = 32.940038 days, the transit duration is t_{dur} = 0.14 days and the time-of-transit center is t_0 = 2457527.91121.

   b) From the homework solutions, you are most likely aware that JWST must remain shielded from the sun, which imposes observability constraints on the portions of the sky it can observe during the year (https://jwst-docs.stsci.edu/observatory-hardware/jwst-target-viewing-constraints). Using the JWST General Target visibility tool, find out when K2-18 is observable during Cycle 1 and cross-match those observability windows with the transits you found on part a). Are all transits observable? If not, which ones are?

   c) One important consideration to observe transiting exoplanets with slitless modes is that nearby stars can contaminate your spectra. Use the ExoCTK Contamination Calculator tool (https://exoctk.stsci.edu/contam_visibility --- note the tool only supports NIRISS SOSS in the meantime) to check what Position Angles (PA) are optimal to observe the target. Cross match this with what you found on b) to find out the best dates to observe the transits of K2-18 b. (Make note of the PA constraints --- you might need them for your APT proposal!)

2. *Simulating Transiting Exoplanet Observations*

   a) Use PandExo (https://exoctk.stsci.edu/pandexo/) and a model of K2-18 b's transmission spectrum that you can find in the activity package attached to this activity sheet (k218_model.txt) to simulate JWST transit observations for this exoplanet; let PandExo optimize the groups and integrations of the observations. Try the most promising JWST instrument modes shown in the webpage for the detection of any of the water features predicted for this exoplanet: I) what is the best instrument to use for this objective?, II) what is

the exposure time of the integrations? Consider the recommendation that saturation happens at 70% of the full well capacity for MIRI and 80% for NIRCam, NIRISS and NIRSpec (note: *this recommendation might change in the near future!*).

b) Using JWST's Exposure Time Calculator (ETC), model a frame using the setups recommended by PandExo for any of the modes you tried in a). Do the numbers reported by the tool (e.g., maximum electron count, exposure times, etc.) match the ones given by the JWST ETC tool? What happens if you use one or several fewer groups than the one recommended by it? What if you use one or more groups? Use the ETC to generate (and optimize) a Target Acquisition exposure.

c) So far we have focused on *spectroscopic* time-series observations of K2-18 b. However, MIRI and NIRCam offer time-series *imaging* (or combination of imaging + spectroscopic) modes that could be useful for our scientific case as well. I) Based on their wavelength ranges, which would be the best instrument to target the water features predicted by the HST observations? II) Using your response in I) and guided by the JWST Documentation, propose an observational idea to target any of the said water features with the selected instrument.

d) Check if your idea in d) is feasible using the JWST ETC. For this, model a frame using the instrument and mode(s) you selected as the best for the science case at hand, and calculate the approximate photometric precision per minute you would achieve with that mode. For this, write down the extracted flux F in electrons per second reported by the ETC and the standard deviation S reported in the same units by it: obtain the ratio S/F and multiply it by a million. This will give you the approximate photometric precision (in parts-per-million, ppm) *per second*. As a rule-of-thumb for giant exoplanets like K2-18 b orbiting main sequence stars such as K2-18, the transit depth error given a precision *per minute* is 1/10 this precision (e.g., if the precision per minute you calculated is 300 ppm, then the transit depth error will be approximately 300/10 = 30 ppm).

3. *The APT Challenge*

In parts 1) and 2) you have managed to get all the information necessary to write a full TSO proposal for JWST, at least in terms of the instrumental setup and observability constraints.

For this last activity, imagine the following situation: the deadline for JWST proposals is tomorrow, and a colleague of yours, knowing you attended the Master Class, sends you the APT file to perform observations of K2-18 b that you can find in the attached material (TSO_level2_MC19.aptx). Using the JWST Documentation's "Step-by-Step APT Guide for NIRISS SOSS Time-Series Observations of HAT-P-1", spot and correct **5 errors your colleague made in the APT file**. Consider only errors made in the "Observations" form and ***not*** on the "Proposal Information" form. Use the space below to write down what the errors were, why they are important and how did you fix them:

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Error 5

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