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## **JWST Master Class 2019**

### **Moving Target Module**

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## **Moving Targets Level-2 Session: End-to-End Exercise**

In this exercise, you will plan observations of a solar system minor body (asteroid) that would allow its diameter and albedo to be determined. This can be accomplished by measuring its visual magnitude and thermal emission near the peak emission wavelength. Additional characterization of thermal properties can be obtained by also measuring the thermal emission shortward of the peak – extra credit if you can do that while not requiring additional observing time.

### **A. Moving Target Visibility Tool (MTVT)**

The MTVT calculates the visibility of potential targets (when they are within JWST's field of regard (FOR)). It comes packaged with the General Target Visibility Tool (GTVT) and is run from a *conda* environment that includes the *astroconda* and *astroquery* packages. It queries JPL/Horizons for target ephemerides and determines when the solar elongation angle of the target, as seen from JWST (using a best-guess pre-flight ephemeris), is between 85° and 135°. This tool can be used to determine the visibility of planets, satellites (regular and irregular), minor bodies, comets, and un-bound extra-solar objects (e.g., 'Oumuamua). In addition to information in the Ancillary Tools charts from the Master Class, and slides 7 – 12 in the Moving Targets charts, these links may be helpful:

- **JWST FOR:** <https://jwst-docs.stsci.edu/observatory-hardware/jwst-observatory-coordinate-system-and-field-of-regard>
- **JWST orbit:** <https://jwst-docs.stsci.edu/observatory-hardware/jwst-orbit>

- **GTVT:** <https://jwst-docs.stsci.edu/other-tools/target-visibility-tools/jwst-general-target-visibility-tool-help>
- **MTVT:** <https://jwst-docs.stsci.edu/other-tools/target-visibility-tools/jwst-moving-target-visibility-tool-help>
- **JPL/Horizons:** <https://ssd.jpl.nasa.gov/horizons.cgi>
- **Astroconda:** <https://astroconda.readthedocs.io/en/latest/>
- **Astroquery:** <https://astroquery.readthedocs.io/en/latest/>

*In this exercise, you will use the MTVT to determine the observability of a specific asteroid target.* You will analyze and become familiar with the terminal and plot outputs of the MTVT. Information determined in this exercise will be used in later exercises with the ETC and APT.

1. Open a terminal and activate *conda*.  
**Prompt> source activate conda OR conda activate conda.**
2. Run the MTVT for minor body 3041. (Typing `jwst_mtvv -h` will bring up optional arguments and usage information.)  
**Run the MTVT using `jwst_mtvv 3041`. The `--smallbody` flag is not necessary because the number does not overlap with the number for a planet or planetary satellite.**
3. Pick a date during Cycle 1 (c. Oct. 1, 2021 – Sept. 30, 2022) from the output in your terminal when the target is in the JWST FOR. Record this date and the start and end date of this observing window.  
**Two windows available: Feb. 23-April 19, 2022, and July 6-Aug. 30, 2022.**
4. Convert the RA and DEC on that date to hh:mm:ss, dd:mm:ss format for use in the ETC section of this exercise. (Estimating is fine here; just compute hours, minutes for RA, degrees for DEC.)  
**Approximate RA and DEC are 16:40:00 -14:00:00 in Window 1 and 15:40:00 -18:00:00 in Window 2.**
5. Note the valid V3 Position Angle value for the date you chose above.

## **B. Exposure Time Calculator (ETC)**

After evaluating your target's observability from JWST with the MTVT, the next step is to determine the time required to achieve the desired signal-to-noise ratio (SNR) in the desired observing mode using the JWST ETC. Users can upload their own model spectra of a target, in flux or surface brightness units, but for this exercise we will approximate the spectrum using spectral models that are available within the ETC. In addition to the ETC overview charts from the Master Class, and slides 15 – 18 in the Moving Targets charts, these links may be helpful:

- **JWST ETC web application:** <https://jwst.etc.stsci.edu/>
- **JWST ETC documentation:** <https://jwst-docs.stsci.edu/jwst-exposure-time-calculator-overview>
- **Pandemia engine documentation:** <https://jwst-docs.stsci.edu/jwst-exposure-time-calculator-overview/jwst-etc-pandemia-engine-tutorial>
- **Moving targets in the ETC:** <https://jwst-docs.stsci.edu/methods-and-roadmaps/jwst-moving-target-observations/jwst-moving-targets-in-etc>

*In this exercise, you will use the ETC to determine the exposure parameters needed to achieve your desired SNR for a NIRC*am* and a MIRI observation of the target.* Specifically, you will set up two sources that model the reflected and thermal components of the asteroid and determine the observation parameters for NIRC*am* SW Imaging and MIRI Imaging calculations. Information from the MTVT outputs in Section-A will be used.

1. Create and load a new JWST ETC workbook for this session.
2. Model the minor body with one point-source representing the reflected component and one point-source representing the thermal component. (Should the two point sources be offset from one another?) Assume the target has a Johnson V magnitude of 16.5 and a surface temperature of 200 K, normalized to 1 mJy at 10  $\mu$ m. Keep in mind that the reflected component is ultimately from the Sun, which is a G2V star.

**The two point-sources should be on top of each other, since the reflected and thermal flux are coming from the same body. Use the G2V Phoenix**

**Stellar Model for the reflected component and the Blackbody for the thermal component.**

3. Determine the approximate peak wavelength for the thermal component.

**Peak wavelengths are approximately 1  $\mu\text{m}$  and 25  $\mu\text{m}$  for each component.**

4. Create a NIRCam SW Imaging calculation to measure the reflected component near V-band, and a MIRI Imaging calculation to measure the thermal emission near its peak.

**The NIRCam SW filter should be the F070W. The MIRI filter should be the F2550W.**

5. On the Backgrounds tab populate the fields based on the MTVT results.

**The RA and Dec, and approximate epoch for the chosen visibility period should be entered.**

6. Adjust the parameters (subarray, readout pattern, number of groups) on the Detector Setup tab for both calculations for 1 integration and 1 exposure, to achieve the longest integration possible while avoiding saturation and providing the largest FOV possible. (Remember the “Groups Before Saturation” plot and the “Maximum Number of Groups Before Saturation” quantity in the Report.)

**The NIRCam observations are approximately optimized with the SUB640 or SUB400P subarrays, RAPID readout pattern, and 4 groups. The MIRI observations are optimized with the FULL subarray, FAST readout pattern, and 18 groups.**

### **C. Astronomer's Proposal Tool (APT)**

Now that you have determined your observation parameters for the target for both NIRCam SW Imaging and MIRI imaging, you will have to transfer those values into an APT file. The APT includes “templates” for every instrument mode available for science and uses the same instrument and exposure parameters (filter, grating, subarray, readout pattern, groups, integrations, exposures, etc.) as in the ETC. However, some features, such as dithers and special requirements, are not available in the ETC. In addition to the APT overview charts from the Master Class plenary session, and slides 20 – 50 in the Moving Targets charts, these links may be helpful:

- **Moving targets in APT:** <https://jwst-docs.stsci.edu/methods-and-roadmaps/jwst-moving-target-observations/jwst-moving-targets-in-apt>
- **APT Solar System Target Windows:** <https://jwst-docs.stsci.edu/jppom/special-requirements/solar-system-special-requirements>
- **Visualizing Moving Target Observations:** <https://jwst-docs.stsci.edu/methods-and-roadmaps/jwst-moving-target-observations/jwst-moving-targets-in-apt/tutorial-on-visualizing-dither-of-a-solar-system-observation-in-apt>
- **APT Special Requirements:** <https://jwst-docs.stsci.edu/jwst-astronomers-proposal-tool-overview/apt-workflow-articles/apt-special-requirements>
- **ETC to APT interface:** <https://jwst-docs.stsci.edu/jwst-etc-to-apt-interface-support-information>
- **APT Visit Planner:** <https://jwst-docs.stsci.edu/jwst-astronomers-proposal-tool-overview/apt-workflow-articles/apt-visit-planner>
- **General APT documentation:** <https://jwst-docs.stsci.edu/jwst-astronomers-proposal-tool-overview>

***In this exercise, you will create a target specification for the asteroid in APT and design observations of it in the NIRCam and MIRI Imaging templates.***

Specification of moving targets in the APT is different from specification of fixed targets and there are some additional features that will be explored. You will then create NIRCам SW Imaging and MIRI Imaging observations of the asteroid using the relevant parameters from your ETC results in Section-B, specify Solar System Target Windows, and use the Visit Planner in APT to evaluate schedulability. Finally, you will implement constraints to allow subtraction of background sources in your observations (i.e. moving follow-on strategy).

**The associated APT file also provides solutions for this section.**

1. Open APT and create a new JWST proposal.
2. Move to the Targets folder and create a new solar system target. Fill in the fields for minor body 3041.

**Select Level-1 type “Asteroid”. On the “Asteroid Level 1” dialog, enter the minor body number in the Search field and select the resulting target. Click the “Use Horizons” checkbox and continue at the “Warning”.**

3. Now create NIRCам and MIRI observations corresponding to the ETC calculations above.

**Create a new Observation folder, and then 2 observations in it. Select the Instrument, Template, and then set up the exposures to correspond to your final ETC parameters. For NIRCам, Module=B is required in order to select subarrays. Be sure to select 3041 as the target. Smart observers will include dithers, Subarray and/or subpixel for NIRCам, 2-point or 4-point for MIRI. Users will have to decide whether to measure reflected or emitted light in the NIRCам LW channel.**

4. For both observations, require that the target is less than 2.2 au from JWST. **Use the “New Distance Observing Window” Solar System Target Window for the distance constraint. For this constraint, the options should be, from top to bottom: Within, (3041) Webb, JWST, LESS THAN, and 2.2.**
5. Run the Visit Planner for both observations, including setting the Processing Date Range to focus on the Cycle-1 epoch.

**Select the observation folder w/ both observations. Under the Visit Planner menu, select “Set Processing Date Range” to the visibility window from**

**step A.3. (At this time APT will default to a time range before Cycle-1; in the Cycle-1 APT release, the default range will be good and this step unnecessary.)**

6. Examine the Visit Planner results. Would you say these observations are overly constrained? Relax or remove the Distance constraint on the observations and run the visit planner again.

**The observations are probably over-constrained since the observability window is so small for both Window 1 and Window 2. Removing the Distance constraint significantly increases the target's schedulability.**

*Advanced Topics: Moving Follow-on & Visualization*

1. Duplicate the NIRCcam observation you already created and remove the Distance constraint (if you haven't already). Using the results from the `jwst_mvt` run in step A.2, estimate the apparent rate of motion (arcsec/sec) of the target at the beginning and the end of your preferred observing window. Using the slower of those two rates, add a solar system target "New Angular Rate Observing Window" and a "Timing" → "After Observation Link" such that the target will move at least 2 arcseconds but no more than 10 arcseconds between the 2 observations.

**At the beginning of the first window (Feb. 23-Apr. 19, 2022), the target is moving at 0.0088 arcsec/s; at the end it is moving at 0.0038 arcsec/s. At the beginning of the second window (July 6-Aug. 30, 2022), the target is moving at 0.0050 arcsec/s; at the end it is moving at 0.0086 arcsec/s. For the first window, the observations will need to be spaced no less than 526 seconds apart, but no more than 2631 seconds apart, assuming a rate of 0.0038 arcsec/s. For the second window, the two observations should be spaced between 400 and 2000 seconds apart, assuming a rate of 0.0050 arcsec/sec. The Angular Rate constraint should have parameters set to, in order: Within, (3041) Webb, None Selected, JWST, LESS THAN, and either 0.0038 or 0.0050 arcsec/s. The After Observation Link parameters set to, in order: NIRCcam observation, MIRI observation, 526/400 secs, and 2631/2000 secs. There is no need to check the "Exclusive Use of Instrument" box, since parallel observations cannot be paired with moving target observations.**

2. Create a new fixed target for the open cluster M35, select it as the target for your NIRCам observation, and view it in Aladin. Add a "Position Angle" -> "PA Range" special requirement to constrain the V3 position angle to be the range indicated in your MTVT results. Note how the Aladin display changes. In Aladin, change the Frame for the display to "Ecliptic" and overplot the coordinate grid. Make sure that the subarray and the dither pattern you have selected don't put the target into a gap between the SW detectors. If that happens, adjust the observation such that the target is on one SW detector for all dither positions.

**For the first window (Feb. 23-Apr. 19, 2022), the PA ranges should be set to approximately 261°-283° for the NIRCам observation and 266°-288° for the MIRI observation. For the second window (July 6-Aug. 30, 2022), the PA ranges should be set to approximately 96°-113° for the NIRCам observation and 101°-118° for the MIRI observation. Be sure to first check the "Set using V3" box, then input the range of position angles.**