

# MIRI Coronagraphy of GJ 758 b

This article discusses a high contrast imaging science use case using [MIRI coronagraphy](#).

## Introduction

In planning any JWST coronagraphic observation, the following steps should be followed:

1. Choose which instrument(s), filter(s) and coronagraph(s) based on the observer's science goals, and to some extent on the contrast and separation of the science target (e.g. disk, low-mass companion). When assessing feasibility, observers may need to use models to extrapolate shorter wavelength measurements to 3–23  $\mu\text{m}$ , for instance to determine companion contrasts at MIRI wavelengths from far infrared or submillimeter wavelengths—e.g. from Herschel, Spitzer, IRAC, etc. Additionally, the user will want to use the [JWST Coronagraph Visibility Tool \(CVT\)](#) to examine the target's visibility and available position angles versus time.
2. [Select a PSF subtraction strategy](#). The recommended standard sequence is 2 rolls on a science target, followed by a PSF calibrator, all observed back-to-back in sequence.
3. Calculate the necessary exposure times using the [JWST Exposure Time Calculator \(ETC\)](#) coronagraphic capabilities. You may want to upload custom spectral models for cool substellar atmospheres.
4. Select a PSF reference star (See [Selecting suitable PSF reference stars for JWST High Contrast Imaging](#)). This should be based on proximity, brightness, spectral type match, and avoidance of binaries.
5. Set up observations in the [Astronomer's Proposal Tool \(APT\)](#); assess overheads and total program time; iterate as desired. It is important to consider significant overheads: slews and rolls, guide star acquisitions, target acquisitions, etc.

## Characterizing the brown dwarf GJ 758 b

### Science goals

In this science use case, we will observe the brown dwarf companion GJ 758 B using all 3 of [MIRI's four-quadrant phase mask \(4QPM\) coronagraphs](#) . GJ 758 B is one of the coldest sub-stellar mass companions imaged to date. Ground based near-IR photometry and spectroscopy have confirmed an effective temperature of  $\sim 700\text{K}$ , and identified a methane-rich atmosphere. Its host, GJ 758, is within close proximity ( $\sim 19\text{pc}$ ) and is a G9 spectral type star. Multi-epoch coronagraphic imaging indicates an edge-on eccentric orbit, with the companion moving towards the projected star at a projected  $\sim 100\text{ mas/year}$ . While cooling-track-derived masses place this object above the purported deuterium-burning limit, It is an important benchmark since its orbit is favorable for the future determination of its dynamical mass using astrometry or radial velocity. A thorough characterization of its atmospheric properties will provide a key reference point to compare to field substellar objects of similar temperatures. Moreover, understanding its composition will answer fundamental questions regarding the formation of such rare objects (using "metallicity" as a proxy).

The goals of this program are to:

- Characterize the atmosphere of this cool benchmark brown dwarf at long wavelengths.
- Measure effective temperature and atmospheric ammonia absorption.
- Compare to atmospheres of field brown dwarfs and combine with existing shorter wavelength data to retrieve atmospheric properties in detail.

## Observing strategy

*Associated APT File for this Science Use Case:* [GJ\\_758\\_MIRI\\_Coronagraphy.aptx](#)

We will use all three four quadrant phase masks (FQPMs) of MIRI to obtain 10.65, 11.4 and 15.5 micron photometry on this sub-stellar companion. This will allow us to obtain continuum fluxes, temperature, and ammonia absorption. For each FQPM filter, we will follow the recommended coronagraphic [standard observing sequence](#): executing two rolls on the science target (i.e a roll-dither) and one observation of the PSF reference star. Because the companion is moving closer to the star in projected separation, with an expected separation of  $1''$  ( $\sim 2 \lambda/D$  at  $15 \mu\text{m}$ ) by 2019, we will use the [Small Grid Dither \(SGD\)](#) technique in combination with the [KLIP algorithm](#) to build an optimal PSF reference for subtraction from each integration of our observations.

## Choosing a PSF reference star for GJ 758 B

Our science target, GJ 758, is a spectral type G9 star with a K magnitude of 4.49 and celestial co-ordinates of  $19^\circ 23' + 33^\circ 13'$ . Following the [MIRI Coronagraphic Best Practices: Choosing a reference PSF target](#) guidelines, we are looking for a PSF reference calibrator that is:

- Relatively nearby (to ensure scheduability and minimal slew time - which in turn minimizes thermal changes to the telescope and thus changes to the PSF)
- Closely matched in spectral type (less critical at MIRI wavelengths, because the FQPM filters are relatively narrow, but still good to have)
- Close in magnitude (allowing shorter exposure time on PSF star - especially helpful given our choice to use SGDs)
- Is non-binary (and so will appear optically single at JWST resolution)

Searching SIMBAD, we find that HD 190360 (=GJ 777 A) will serve as a good reference as it is nearby (RA: 19 23 Dec: 33 13, i.e., ~9 degrees separation from our science target), has spectral type G7 with K mag = 4.08, and it is a known RV planet host star with extensive observations that rule out binarity. (It does have a suspected co-moving companion red dwarf GJ 777 B, but at a very wide separation that places it outside of the MIRI coronagraphic field of view entirely.) We note that HD 190360 is itself a known exoplanet host star, with a 1.6 MJup planet in a 4AU orbit and is an inner Neptune-mass planet. Neither planet can be spatially resolved by JWST, with projected separations  $<1 \lambda/D$  at MIRI wavelengths. Furthermore, the estimated age of this star is  $> 6-7$  Gyr, putting the Jovian planet below MIRI's detection floor.

## Observing description

For our overall program, we'll be making observations in the three 4QPM filters: F1065C, F1140C and F1550C. We note that there is a degree of freedom involved in the ordering of activities in programs that constitute observations of the same target in multiple filters: for our program we will be choosing to sequentially expose in each filter between spacecraft maneuvers (slews and rolls) in order to minimize overheads. Note that this re-ordering of visits can (slightly) trade efficiency against temporal proximity of the PSF calibrators and science targets in the same filter (see [JWST Coronagraphic Sequences](#) and [MIRI Coronagraphic Best Practices](#)).

1. Slew to the target (1800s)
2. Observe Science target in F1065C (576s science exposure, total time 2218s)
3. Observe Science target in F1140C (576s science exposure, total time 1935s)
4. Observe Science target in F1550C (863s science exposure, total time 2155s)
5. Roll observatory ~10deg
6. Observe Science target in F1065C (576s science exposure, total time 2984s)
7. Observe Science target in F1140C (576s science exposure, total time 1935s)
8. Observe Science Target in F1550C (863s science exposure, total time 2155s)
9. Slew to PSF star (830s)
10. Observe PSF star using a SGD in F1140C (1773s science exposure, total time 3850s)
11. Observe PSF star using a SGD in F1065C (1773s science exposure, total time 3723s)
12. Observe PSF star using a SGD in F1550C (2655s science exposure, total time 4632s)

Note that the total time is dominated by overheads: slews, target acquisition procedures etc. As such, the program contains 2.84 hours of science time and 7.85 hours of total charged time (including all overheads and observatory indirects), according to APT 25.4.0.1.

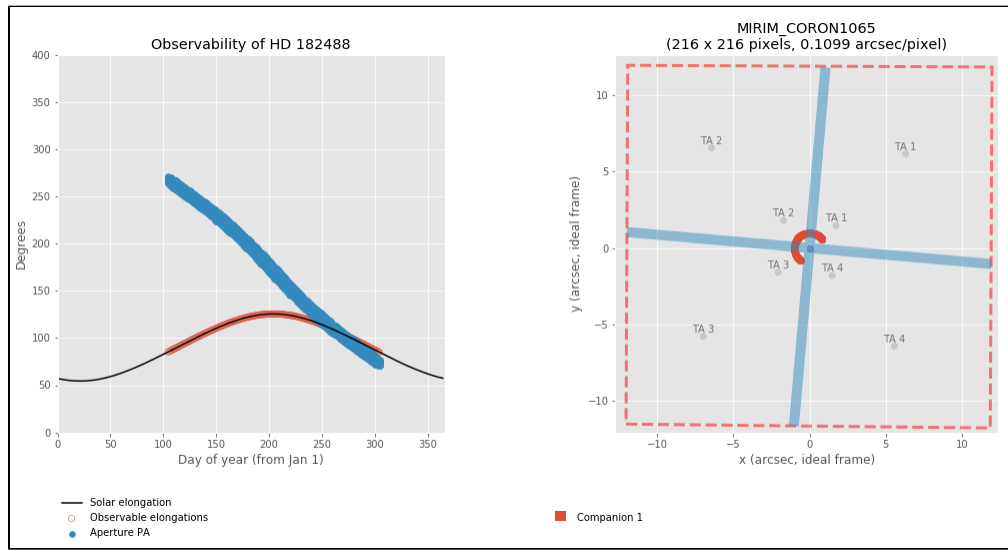
There are three observatory tools that you will want to utilize for coronagraphic observational planning, these are the: JWST Coronagraph Visibility Tool (CVT), JWST Exposure Time Calculator (ETC) and Astronomer's Proposal Tool (APT) — with recommended usage in that order. The CVT and ETC play crucial roles in the planning of any coronagraphic observations with JWST and must be utilized before crafting your actual observing program into APT. We refer the reader to the [JWST Coronagraphic Observation Planning](#) page for the procedures and strategies for planning coronagraphic observations with JWST.

## Using the Coronagraph Visibility Tool

For our science case, we will use the [Coronagraph Visibility Tool \(CVT\)](#) to ensure that the requested orientations on the coronagraph mask avoid placing the companion along any FQPM quadrant boundaries and that the desired roll angle is a possibility over the visibility period. (See also: [JWST Position Angles, Ranges and Offsets](#)).

The companion's PA in the middle of cycle 1 (epoch 2020.0) will be ~215 degree. Following the CVT [step by step guide](#), within the control panel: we resolve GJ 758 with SIMBAD (and cross-reference the SIMBAD ID, RA and Dec) and specify our brown dwarf companion at a PA and separation of 215 degree and 1", respectively. We specify that we'll be using the MIRI instrument with the MIRIM\_CORON1065 mask and ask the CVT to plot the Aperture PA.

**Figure 1. The CVT output for GJ 578 when plotting the detector location of the companion GJ 758 B**



*The left plot shows the target's visibility windows. The red highlights on the solar elongation line indicate the valid windows. The blue tracks show the allowed position angles for the selected instrument and mask over those windows. The right plot shows the selected mask's field of view (red dashed line), whereas the shaded blue regions indicate the locations at which the companion could be obscured by the 4QPMs. The plot shows the companion's positions as a function of time within the visibility window(s).*

The CVT indicates 3 scheduling windows (near days 110, 200 and 290 of the year) in which the companion is positioned well away from the 4QPM. These scheduling windows place the companion in 3 different detector quadrants. We have chosen the middle scheduling window (near day 200 of the year and positioning the target in quadrant 2) because we can get a 12 roll there but at the extremes of the visibility period it's down to 9 degree roll. We will set up the program to use that scheduling opportunity. In particular, this means that we will:

1. Define our range of PA to be between 165–175 degree for our first observations in each filter, which positions the companions in quadrant 2 well away from the 4QPM boundaries. This 10 degree range yields about a 10 day scheduling window.
2. Set our aperture PA offset between the two observations in each filter to the range 11–12 degrees, which is near the maximum available roll.
3. Because we have decided to use a scheduling window that places the the companion in quadrant 2, we can leave the TA in the default quadrant within the APT (i.e. 1).

It's worth noting, that for this particular science case, the choice of scheduling opportunities is not expected to be available in 2019 since day 200 will be during commissioning; thus we would notionally expect such a program to execute in July 2020, about 9 months into cycle 1. Observers should carefully take such scheduling constraints into consideration when planning their programs. In some cases, it may be necessary to add more scheduling flexibility to a program by considering alternate scheduling windows (here for example, we could use the windows near day of the year 110 or 290).

## Using the Exposure Time Calculator

In order to set up our calculations in the ETC, we will first need to [define a single scene](#) in which to associate our sources within the [Scenes and Sources page](#). Once the scene has been created, it should be populated with three [sources](#): one associated with GJ 758, the second associated with GJ 758 b and the third associated with the PSF reference star.

We enter our [source properties](#) into the ETC as follows:

Source name	Continuum		Normalization		Shape	Offset	
	Spectral Energy Distribution (SED)	Spectral type/ Teff/ Gravity	Bandpass	Brightness		X	Y
GJ 758 (target star)	Synthetic stellar spectra from <a href="#">Phoenix stellar models</a>	K0V 5250 K log g = 4.5	Bessel K	4.5 vega	Point	0"	0"
GJ 758 B (companion)	User supplied spectrum, synthetic spectra from the <a href="#">Saumon et al. 2012 dwarf models</a>	T8 750 K log g = 4	Bessel H	18.16 vega	Point	-0.72"	0.72"
PSF star (copy of GJ 758) <sup>1</sup>	Synthetic stellar spectra from <a href="#">Phoenix stellar models</a>	K0V 5250 log g = 4.5	Bessel K	4.5 vega	Point	10"	10"

<sup>1</sup>Note that while we will formally be using GJ 777 A as our PSF reference target, we have defined our PSF reference star as a copy of our target star, GJ 758. This is because the ETC requires the reference star to have identical brightness to the host star, otherwise it will return un-physical, negative SNRs.

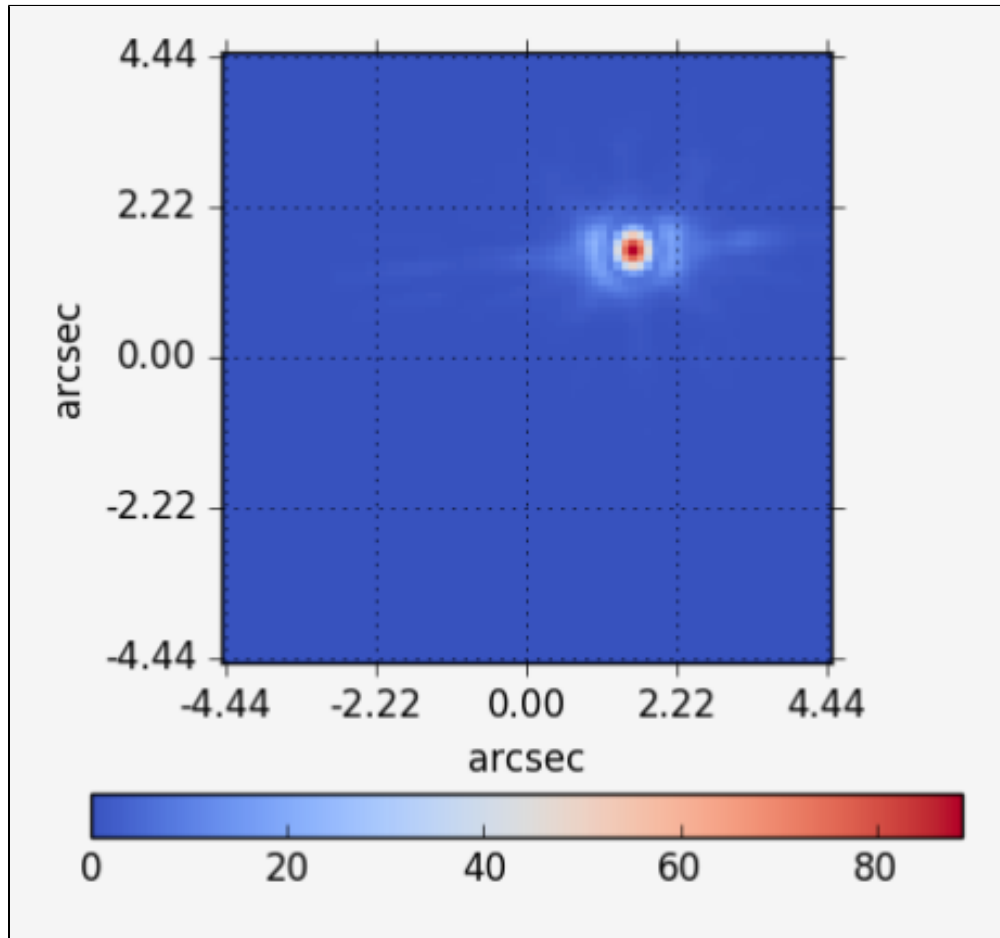
We can now proceed to the [calculations page](#) and begin performing our calculations. For the purposes of this exercise we will perform 4 calculations: target acquisition on the star and MIRI coronagraphy on the companion in each of the three 4QPM filters.

# Target acquisition

The [JWST ETC MIRI Target Acquisition](#) article may be helpful when setting up the calculation dedicated to TA. The star can be defined as the acquisition target using the Strategy tab. Because the target is bright, we will need to use the ND filter to prevent the star from saturating the detector during the subarray exposures used for the target locates. Because it affects the accuracy of the centroiding procedure, the ETC will not tolerate any saturation - If any pixels are found to be either [partially or fully saturated](#) the TA will fail. The user should find a suitable exposure specification, such that the minimum required SNR of NGROUPS is obtained. Any calculations returning a SNR below this threshold will produce a "TA may fail" warning. We recommend the user takes the time to determine the best exposure configuration to optimize their SNR (Tip: proceed by varying NGROUPS in the detector setup - try to strike a balance between high signal-to-noise and low exposure time. You may find [MIRI Coronagraphic Best Practices](#) useful.)

Our results can be used as a cross-reference and are as follows: we find that a high SNR acquisition can be obtained with groups = 45, which yields SNR~260. Given MIRI's pixel scale this high SNR should allow centroiding to 1 mas or better. The exposure time is only 10 s. We checked there is no danger of saturation, which would only happen for exposure times > 100 s. Since there is high SNR and plenty of leeway in the dynamic range we can use the same TA settings for the PSF star too without needing a separate ETC calculation.

Figure 2. 2D SNR image of our TA calculation



SNR per pixel over the our 2D scene.

## Coronagraphy

We proceed by creating calculations for coronagraphy on GJ 758 B in each FQPM filter; this is done by selecting GJ 758 B as the SNR source in the extraction strategy tab and then the appropriate coronagraph in the instrument tab. Each calculation will share the same observation strategy: with only the Referenced Differential Imaging (RDI) PSF strategy available with the ETC, we must choose the PSF subtraction source to be our defined PSF star (copy of GJ 758b) and set the scene rotation to 0. Our extraction strategy will also be consistent throughout the equations: with an aperture radius of 0.45; Sky annulus inner and outer radii of 0.45" and 0.7", respectively; contrast azimuth of 45 degree ccw and contrast separation of 1".

Again, we strongly encourage users to take an opportunity to determine an optimal exposure configuration for each equation on their own. However, for your reference, we make the following findings and considerations:

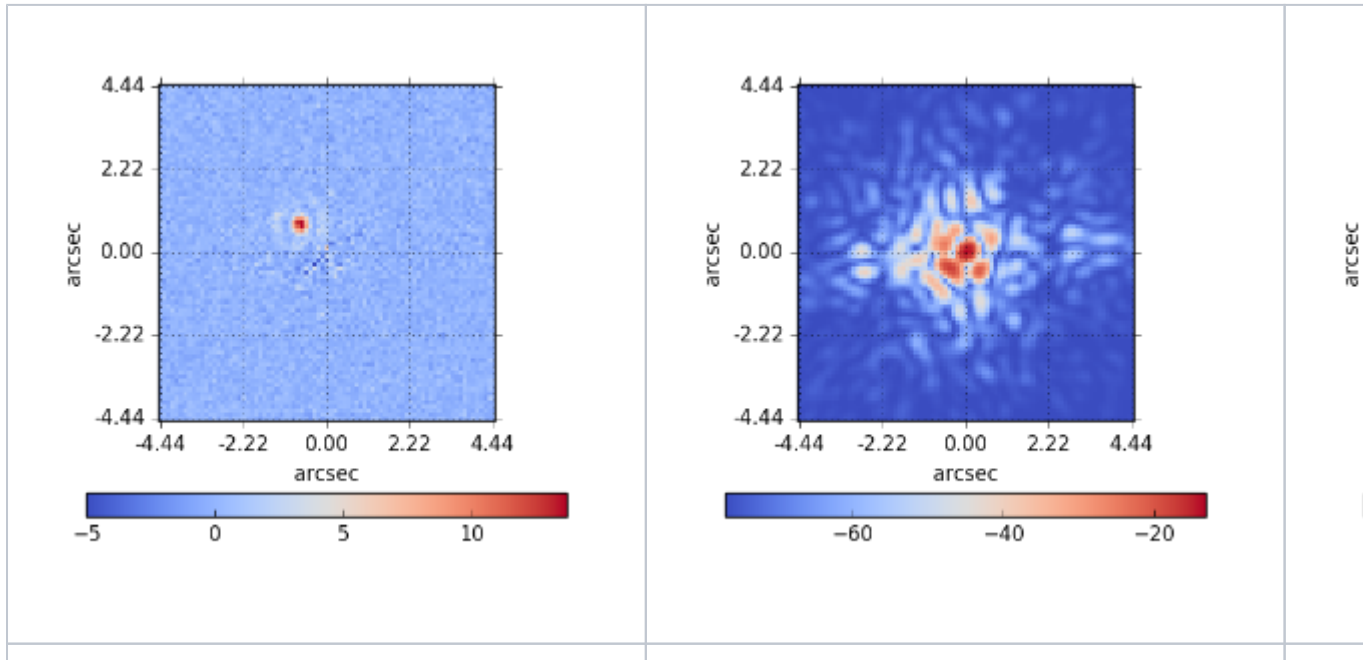
In F1065C and F1150C an exposure time of  $\sim 600$  s yields predicted SNR  $\sim 35$  and  $60$  respectively in one roll, or  $\sim 50$  and  $85$  combined across the two rolls. As our key goal is to compare the  $10.65$  and  $11.4 \mu\text{m}$  measurements to measure the  $\text{NH}_3$  absorption, we use the same readout settings in both filters to minimize systematics between them. We note that these are the optimistic photon-noise-limited SNRs, and in practice systematics from imperfect PSF subtraction and other calibrations (e.g. overall photometric calibration of MIRI) will also contribute limits, plausibly at a level of a few percent; by aiming for photon-limited SNR  $> 50$  in the roll-combined data we seek to ensure the statistical photon noise is low enough to be below the likely systematic noise terms. In F1550 with the much higher thermal background an exposure time of  $\sim 900$  s yields predicted SNR  $\sim 17$  in one roll, or  $24$  in the two rolls combined, which is sufficient for our science goals in constraining the long-wavelength continuum.

For F1065 and F1150 we adopt  $575$  s (Groups =  $300$ , Ints =  $8$  with FAST readout of the coronagraphic subarrays). For F1550 we increase the Ints by  $50\%$  to partially make up for the higher thermal background. The specific exposure settings chosen were verified in the ETC to not produce any warnings. In  $300$  groups the peak pixel will remain  $< 25\%$  of full well so there is no danger of saturation. (Saturation warnings do not appear until above NGROUPS =  $1200$ ). As noted above each filter is repeated in two observations at different rolls.

The PSF star is  $0.4$  mag brighter than the science target ( $=45\%$ ; checked at both 2MASS and WISE bands), so we adjust the integration time to be  $1/1.45 \sim 0.68x$  as long in each filter, to achieve similar peak count per integration in the PSF star as in the science target. Since we are using the 9-point SGD option, we also reduce the number of ints per dither position by  $2x$  to keep the total exposure time from becoming excessive ("excessive" taken to mean PSF exposure time  $\geq 2x$  the total on-source science exposure time summed across the two rolls). Since the full set of PSF calibrator dither positions is combined to generate the KLIP eigenbasis, we do not need to achieve the same SNR per each individual dither position as on the science target. Specifically we expect the SNR of the PSF relative to the science target to be between  $1/\sqrt{2}$ , for individual dither positions, and  $3*\sqrt{2}$ , for the combined KLIP reference library mean PSF mode.



Figure 3. ETC produced Detector and 2D SNR images for coronagraphy calculations



*Both Detector and 2D SNR image for F1065C, F1140C and F1550C respectively.*

## Implementing into APT

We will now discuss how to implement this program into the APT. We encourage that you read the [JWST APT](#) article and its related links to familiarize yourself with its functionality. We assume that the user has reviewed these articles and therefore understands how to construct a basic JWST observing proposal (including how to add targets, observations and visits, use observation templates and folders etc.), as well as how to run the Visit Planner, Smart Accounting and Aladin. Further help with APT training or problem resolution can be found in the [JWST APT Help Features](#) and [JWST APT Training Examples and Video Tutorials](#) articles.

Our program consists of two fixed targets: the science target star HD 182488 (i.e., GJ 758) and PSF reference star HD 190460. We use the [APT fixed target resolver tool](#) to look up both targets from their Archival names and commit them to our proposal (which will auto-populate their J2000 Coordinates). We then enter the following information into the targets' templates:

Number	Name in Proposal	Category	Description (key words)	Proper motion <sup>3</sup>		Epoch	Annual parallax (arcsec)
				RA (mas/yr)	Dec (mas/yr)		
1	GJ 758 (target star <sup>1</sup> )	Star	Exoplanets, G stars, Substellar companions	84.3	162.3	2000.0	0.0645
2	HD 190360 (PSF reference <sup>1</sup> )	Star <sup>2</sup>	Exoplanets, G stars	683.94	-524.7	2000.0	0.6306

<sup>1</sup>Adding designations in the "Name in the proposal" field to clearly indicate which targets are intended for science and which are PSF-reference stars, can be particularly useful down the line!

<sup>2</sup>Note that we are assign the "PSF reference" target the "Star" category. You may be tempted to choose the "calibration" category, *however* this is not appropriate; remember that at this stage you are defining an astrophysical object within a *target entry form*, and this object is fundamentally a *star*. Indicating that this star will be used for PSF calibration purposes will come later in the observation description, since it is a property of the observation, and not a property of the astrophysical object itself.

<sup>3</sup>You can obtain the proper motion of the targets from SIMBAD.

The comment box is available within the target form for any freehand information; here we chose to mention the spectral type and K magnitude for each star, for future reference.

Because we are conducting a non-interruptable sequence of observations at a single epoch, we can collect all of the observations that pertain to our program into a single observation folder (see previous [Observing Description](#) ). We will create a total of 9 observations. We recommend appropriately labeling the observations so that they can be easily identified in the observation folder. They are as follows:

1. Observation of target GJ758 in F1065C at roll angle 1
2. Observation of target GJ758 in F1140C at roll angle 1
3. Observation of target GJ758 in F1550C at roll angle 1
4. Observation of target GJ758 in F1065C at roll angle 2
5. Observation of target GJ758 in F1140C at roll angle 2
6. Observation of target GJ758 in F1550C at roll angle 2
7. PSF reference observation of target HD 190360 in F1065
8. PSF reference observation of target HD 190360 in F1065
9. PSF reference observation of target HD 190360 in F1065

While you may begin crafting these observations in any order, it is essential that you provide the "Observation number" for each observation as stated above (i.e. organized according [Observing Strategy](#) we previously devised). This is because within the APT, observations occur according to *increasing* observation number.

Obviously, MIRI will be chosen as the instrument for each of these observations and we can use the *MIRI Coronagraphic Imaging* template. The appropriate target for each observation template should then be selected. We recommend fleshing out the observation templates for the three science target observations in each filter at *roll angle 1* (i.e. Obs. #1-3), initially; which allows for the opportunity to "duplicate" each of these observation templates to produce identical templates, which can then be used for the science target observations in each filter at *roll angle 2* (i.e. Obs. #4-6). When using the duplication functionality, be sure to re-name each observation at roll angle 2 appropriately. In order to implement the roll dither between these observations, we will need to set special requirements, which we will get onto in a moment.

The TA parameters are determined from our advance work in ETC and CVT are applicable to all of our observations (i.e. Acq Filter = FND, Acq Readout Pattern = FAST, Acq Groups/ Ints = 45 and Acq Quadrant = 1), and so can be entered as such into the "Target Acquisition Parameters" section of each template. For the "Coronagraphic parameters" section, the coronagraphic mask/filter is to be selected – for MIRI, these are directly associated. The exposure time can then be entered for each science observation according to advanced work in the ETC. As mentioned in the paragraph previously, the observation templates associated with roll angle 2 (Obs. #4-5) should be duplicates/ identical to the observation templates associated with roll angle 1 (Obs. #1-3).

For our reference star observations however, we were required by the ETC to define a reference target with identical photometric properties (i.e. a copy of) our science target. As such, the exposure parameters we obtained from the ETC will need to be scaled according to the properties of our actual PSF reference target. Because our PSF star is 0.4 mag brighter than our science target (45%; checked at both 2MASS and WISE bands), we adjust the integration time to be  $1/1.45$  (i.e.  $\sim 0.68$ ) times as long in each filter to achieve similar peak count per integration in the PSF star as our science target. Since we are using the [SGD technique](#), we select the "9-POINT-SMALL-GRID" as our dither type. This causes our exposure time to be increased by a factor of 9; thus we reduce the number of ints per dither position by half in order to keep the total exposure time from becoming excessive (where "excessive" is taken to mean PSF exposure time is more than twice the total on-source science exposure time summed across the two rolls). Since the full set of PSF calibrator dither positions is combined to generate the KLIP eigenbasis, we do not need to achieve the same SNR per each individual dither position as on the science target. Specifically we expect the SNR of the PSF relative to the science target to be between  $1/\sqrt{2}$ , for individual dither positions, and  $3*\sqrt{2}$  for the combined KLIP reference library mean PSF mode — this will of course have to be assessed in practice.

The final section of the observation templates, labeled "PSF Reference Observations", is where we will explicitly set the links between PSF reference observations and science observations to be used in data processing. First, we go through each of the observation templates with which our PSF reference star is the target (i.e. Obs. #7-9) and indicate that they are a PSF reference observations by marking the "This is a PSF reference Observation" checkbox. Then, for each of the dedicated science target observations (i.e. Obs. #1-6), we make an appropriate selection from the "PSF reference observations" list, indicating the observation that should be used for PSF subtraction in the data-processing system. Associations should be pretty straightforward to make because (1) we clearly labeled which observations are PSF references (so won't accidentally select a science observation) and (2) the APT only displays observations with matching coronagraphs/ filters within this list (so we won't accidentally select a PSF reference observation in the wrong filter).

In order to fulfill the guidelines of our [Observing Strategy](#), our program requires the placement of special requirements (SR). These requirements can be placed on the observations through their templates. The SRs placed on our program are as follows:

- All observations shall be grouped by a "**Sequence, Non-Interruptible**" SR to ensure the observations execute together and in the order provided, to (1) minimize possible thermal variations differentially affecting the acquired PSFs and (2) to minimize the number of rolls and slews.
- Because we are performing a roll dither on our science targets, we place an "**Aperture PA offset**" SR between the two science observations in each filter to the range 11 to 12 degree, which is near the maximum available roll. With observation 4 for example, we set an "Aperture PA offset 4 from 1 by 11 to 12 degrees (same offsets in V3)"; then observation 5 will be offset from observation 2 and so on. (Given the "Same PA as" SR below, it may seem redundant to repeat this for all 3 filters, however leaving it off any of them produces a warning in APT.)
- In order to ensure consistent positioning of the target in all 3 filters, we place a "**Same PA as**" SR linking the 3 science observations at each roll angle. In other words, each observation at roll 1 will have "Same Aperture PA as 1, 2, 3" and each observation at roll angle 2 have "Same Aperture PA as 4, 5, 6". This also slightly increases observational efficiency by avoiding rolls between those visits.
- In order to position the companion in quadrant 2, well away from the 4QPM boundaries, we set an absolute "Aperture PA Range" SR to the range 165--175 degree for Observation 1. Putting roll 1 near PA~170 also yields good target positioning in roll 2 as well after applying the offset SR. The ten degree range yields about a 10 day scheduling window.

Once the observations for our coronagraphic sequence have been fully specified, we are able to run the [APT Visit Planner](#) and ensure that our sequence is able to execute in its entirety. Upon verifying the scheduability of our program, we run the [Smart Accounting](#) tool on our observation folder. The tool will identify any excess major slews assumed by APT and reduce them to the minimum needed. Because our set of observations is in a non-interruptible sequence, it will obviously only need one major slew at the beginning of the sequence. Smart Accounting will catch and correct this, thus reducing our reported overheads.

Returning to the Visit planner, it is by selecting the observation folder that we can see how this time is explicitly split up between visits. While we inspect the program overheads, we draw your attention towards the order in which we chose to perform our observations. We chose a strategy in which we sequentially exposed in all 3 filters before spacecraft maneouvers in order to maximise efficiency by minimizing the number of slews. However, depending on the outcome of in-flight stability tests, we may find that other strategies may be advantageous. Such an example would be to place PSF star observations between each the two science rolls; we find the delta time between these two orderings is negligible. We recommend that the user explores how altering the order of observations changes the overall program time (HINT: try grouping together the 3 observations in each filter!)

We conclude, that for this science case, the total time reported by the APT for this program is 7.85 hours; 2.84 hours of which is dedicated science time.

*The associated APT File for this Science Use Case can be downloaded from the following link:*  
[GJ\\_758\\_MIRI\\_Coronagraphy.aptx](#)