HR8799 Coronagraphy Hands–On

1. Background

The HR 8799 planetary system consists of four giant planets 10 – 70 AU of its young main-sequence A5 star, and a debris disk at a distance of 40 pc (Marois et al., 2008, 2010). The planets have not been well characterized at wavelengths longer than 2.5 microns, and JWST should be able to detect planets down to 1 M_J in this system, at least 5 times lower than estimates for the four known planets. The Cycle 1 GTO program 1194 will observe this system to pursue these science objectives, and this exercise is based on that program.

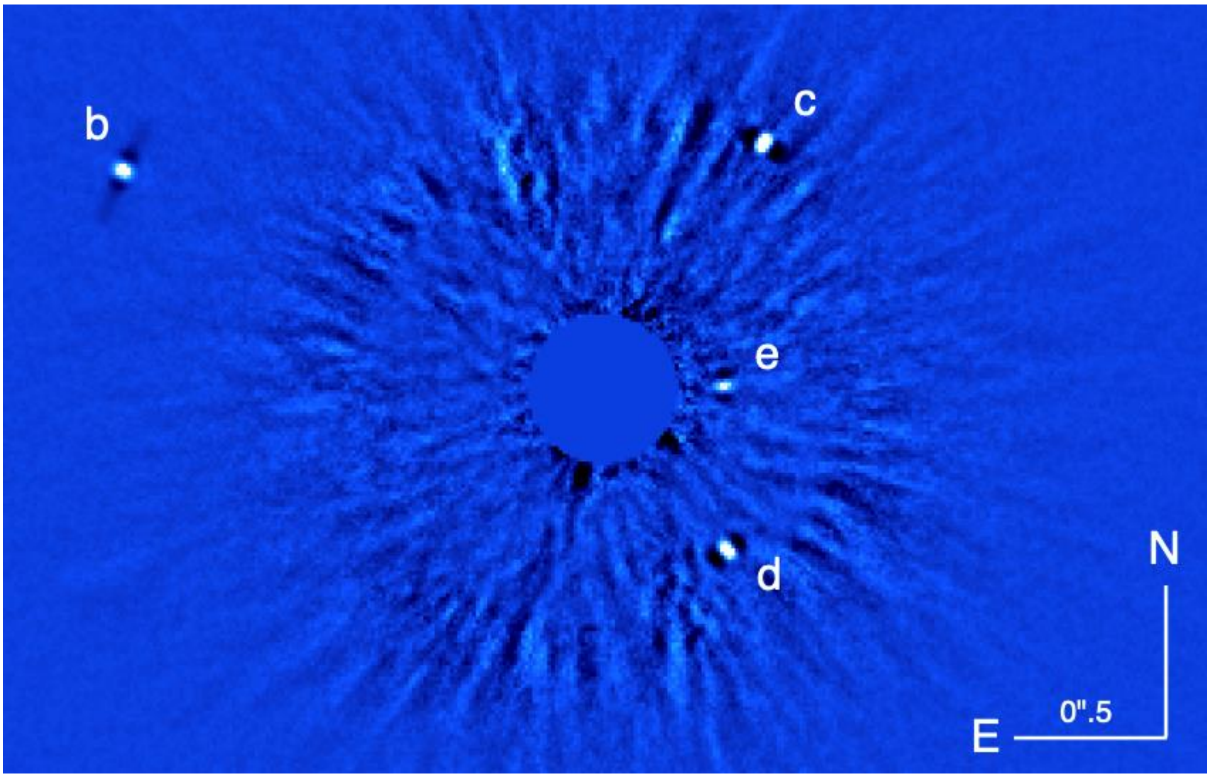


Figure 1: VLT SPHERE H-band image of the HR 8799 planetary system (Wertz et al., 2017)

We will now explain how to perform coronagraphic observations of the system using NIRCam round 430 mask and the MIRI four quadrant phase mask (4QPM) coronagraphs, a subset of the program 1194 observations.

NIRCam Coronagraph and filters

Young planets are expected to have high flux and contrast in the F444W filter (e.g., Linder et al., 2019). Observations in the F356W filter will be used to identify and reject background stars and galaxies. Both observations will be made with the NIRCam 430 round mask. This mask has a large inner working angle (IWA ~ 810 mas but provides high contrast at large separations, ideal for searches for far-out planets. A bright nearby reference star of similar spectral type will also be observed for PSF subtraction.

MIRI Coronagraphs

The HR8799 planets are expected to have high opacities at the wavelengths of the MIRI coronagraphs with brightness temperatures ~200 K lower than their Teq ~ 1100 K values. We will create mock observations using the F1100C four quadrant phase mask (4QPM) and the F2300C Lyot coronagraphs. The 4QPMs offer moderate contrast at small working angles, sufficient to observe close-in planets. The F2300C mask has a large IWA = 2.16,"
adequate for high-contrast searches for distant companions. A bright nearby reference star of similar spectral type and brightness will also be observed for PSF subtraction.

2. Exposure Time Calculator

GOAL: in this section you will examine the ETC workbook that estimates the exposure time needed to observe the HR 8799 planets with the filters and coronagraphs specified above. Go to the ETC and load the workbook which contains the following simulations (all NIRCam ones use the 430R mask). Examine the scenes and sources:

Scene	Sources	Filter / Flux	Comment
1	HR8799 + planets bcde	F356W	For NIRCam F335M
2	HD 220657	mK=3.04	NIRCam PSF reference F8III
3	HR8799 + planets bcde	F444W	For NIRCam F444W
4	HD 218261	mK=5.14	MIRI PSF Reference F6V
5	HR8799 + planets bcde	F1130W	For MIRI F1140C

Now examine the calculations in the workbook:

Calc #	Object	Filter	Subarray/Readout/Groups/Integrations	Comment
5	HR 8799	F335M+ND	SUB64/SHALLOW2/65/1	Target Acq, SNR ~230
6	HR 8799 d	F356W	SUB320/DEEP8/8/5	SNR ~9
7	HR 8799 d	F444W	SUB320/DEEP8/16/5	SNR ~52
11	HD 220657	F335M+ND	SUB64/RAPID/33/1	PSF Ref, TA, SNR~185
12	HD 220657	F356W	SUB320/DEEP8/8/1	PSF Ref
13	HD 220657	F444W	SUB320/DEEP8/16/5	PSF Ref
20	HR 8799	FND	MASK1140/FAST/44/1/1	Target Acq, SNR~300
21	HR 8799 c	4QPM/1140C	MASK1140/FAST/500/1/9	
22	HR8799	FND	MASKLYOT/FAST/44/1	Target Acq, SNR~365

24	HR 8799 c	Lyot/F2300C	LYOT2300C/FAST/80/50/1	
26	HD 218261	FND	MASKLYOT/FAST/44/1	PSF Ref, TA, SNR~380

Note:

- Some pixels are saturated in the HD 220657 PSF reference star's coronagraphic simulations (#12 & 13). Extraction parameters not optimized for this bright star. Ignore for now.

3. APT File Creation

Targets

Copy the HR8799 APT 1194 file to a new one that you will edit. Delete all observations but keep the fixed targets HD 220657, and HD 218261. Create an entry for HR 8799 with the Fixed Target Resolver option. Notice that this target is added as HD-218396 in the Fixed Targets table. Its name, position, and proper motions are automatically entered in the APT file.

Observations

Create the following observations using the pre-existing targets and the ETC exposure parameters (see above table):

1. NIRCam F356W + F444W Observation of HR 8799 system - Roll angle 1
2. NIRCam F356W + F444W Observation of HR 8799 system - Roll angle 2
3. NIRCam F356W + F444W Observation of HD 220657 PSF Reference
4. MIRI 1140C 4QPM Observation of 8799 system
5. MIRI 2300C 4QPM Observation of 8799 system
6. MIRI 1140C 4QPM Observation of PSF Reference
7. MIRI 2300C 4QPM Observation of PSF Reference

Here are some tips for making the above observations in APT:

- Acquire on the objects themselves using the above TA parameters from the ETC. Any coronagraph quadrant can be used for TA, but this should be checked with a high-resolution IR image.
- The second roll angle can be created by specifying a PA offset of 7 -- 14 deg as a "PA Offset Link" special requirement for the HR8799 Roll angle 2 observation.
- All observations should be linked in a non-interruptible sequence in the above order. In the Special Requirements tab in the APT entry of each observation, add "Group / Sequence Observations link."
- All observations should have the No Parallel Special Requirement.
- The NIRCam science observations should have no dithers, but do use dithers for the reference star observations for spatial diversity.
- Link each HR8799 target observation with a PSF reference observation in the "PSF Reference Observations" section.
- MIRI observations have the option of small grid dithers (about 10 mas each) to optimize coronagraphic suppression and reference PSF subtraction. These should be used for the 4QPM science and reference observations to optimize contrast.
- Specify the allowed PA range under Special Requirements if you want a specific system orientation for each observation. The MIRI HR8799 observations in the example APT file are set to 89.2 – 103.55 degrees (aperture PA) to keep the planets away from the 4QPM boundaries (see Coronagraph Visibility Tool below). This limits when the objects can be observed.

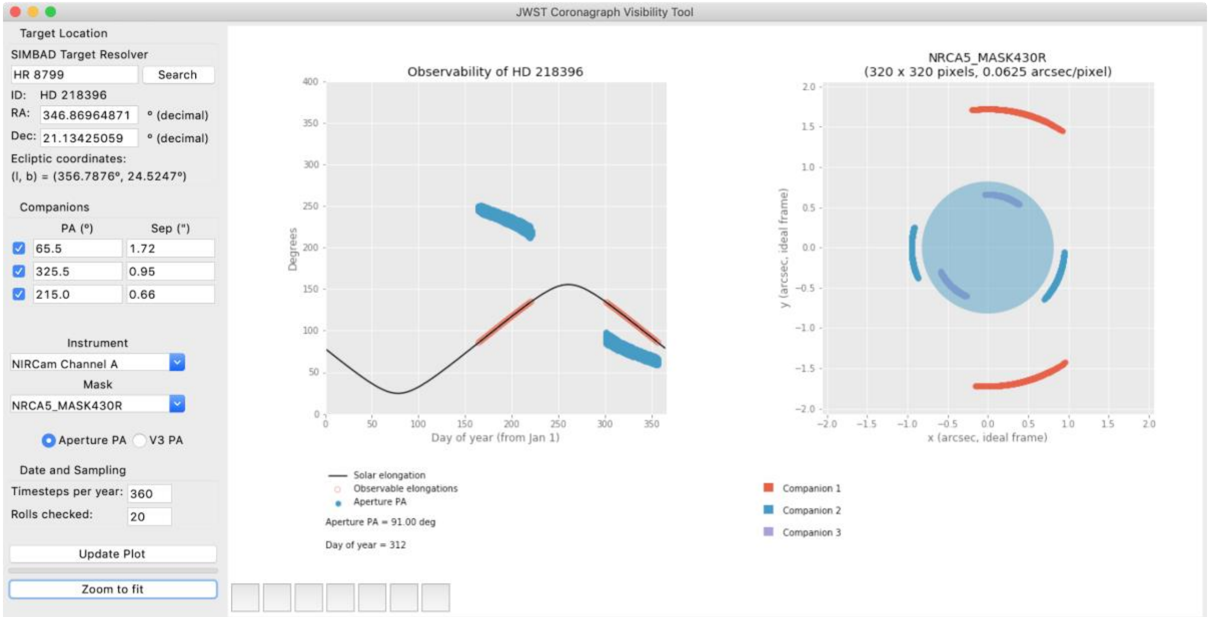
- For simplicity, you can create the MIRI observations with only a single roll angle. APT will give you a warning that you should also create another observation at a second roll angle (but not an error).

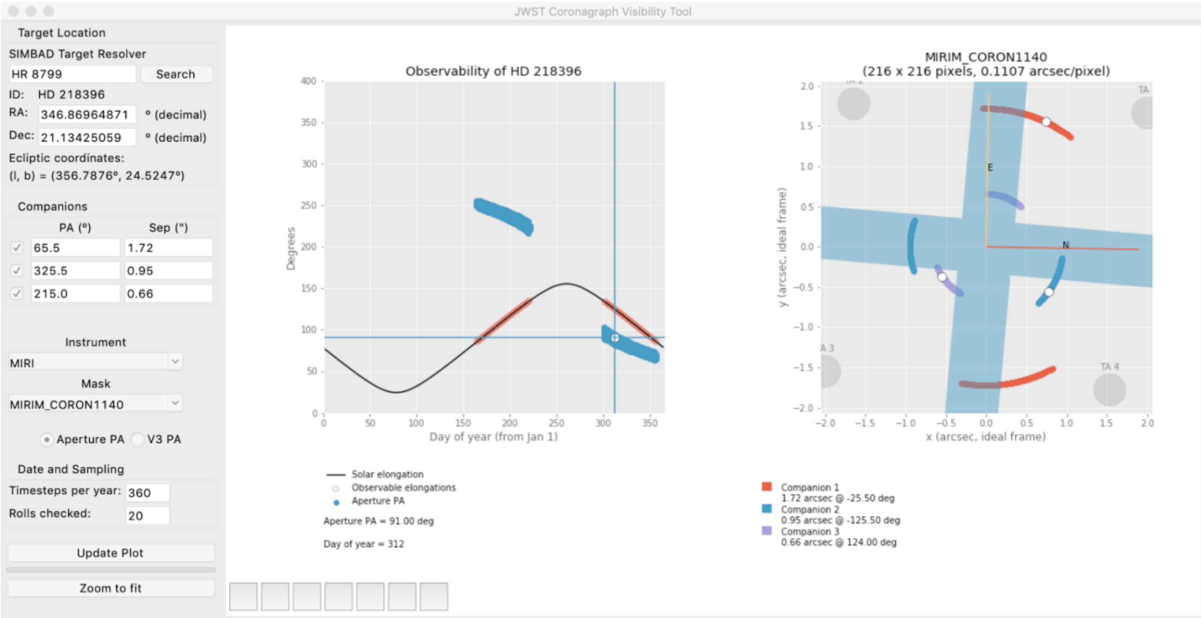
4. Run the Coronagraphic Visibility tool

Run the JWST Coronagraph Visibility Tool (CVT; see link below) to fine tune the orientation of the system in the coronagraphic fields. Enter the following positions of the HR 8799 planets from Table 2 of Maire et al. (2015). Note that these positions were measured in epoch 2013.81 and should be updated for the actual time of the JWST observations:

Planet	Separation ('')	PA (deg)
HR8799 b	1.72	65.5
HR8799 c	0.95	325.5
HR8799 d	0.66	215.0

The CVT figures below show the HR8799 system observed at NIRCam and MIRI aperture PA = 91 deg. Planet d is within the IWA of the NIRCam 430R mask (OK for wide searches) and planets bcd are all away from the MIRI 4QPM boundaries. Planets b and c can be observed at all NIRCam PAs. Planets b, c, and d can all be observed at MIRI PA= 83–95 (V3 PA = 78–90) deg, so enter this range in the Special Requirements of the MIRI 1140C observation in the APT file. Note that these should also be updated for the actual observing period.





Finish the APT file: Run Smart Accounting

After creating the above observations.do a few things to complete the APT file:

- First, click on the Observations folder in the left pane and then select the **Visit Planner** icon at the top of the APT window.
- Then click the "**Run Smart Accounting"** button in the bottom right. This will compute the total execution time correctly, eliminating the slew periods between each observation. This also shows the visibility/observability of the observations given its sky position and any PA or date constraints you entered in Special Requirements. The total time can be seen in the Proposal Information section.

5. Relevant Links:

JWST Coronagraphic Observation Planning:
https://jwst-docs.stsci.edu/methods-and-roadmaps/jwst-high-contrast-imaging/hci-roadmap

NIRCam Coronagraphic Imaging
https://jwst-docs.stsci.edu/near-infrared-camera/nircam-observing-modes/nircam-coronagraphic-imaging#NIRCamCoronagraphicImaging-Coronagraphicmasks
and NIRCam Coronagraphic Imaging Best Practices:
https://jwst-docs.stsci.edu/near-infrared-camera/nircam-observing-strategies/nircam-coronagraphic-imaging-recommended-strategies

MIRI Coronagraphic Imaging:
https://jwst-docs.stsci.edu/mid-infrared-instrument/miri-observing-modes/miri-coronagraphic-imaging
and the MIRI Coronagraphic Imaging Template:
https://jwst-docs.stsci.edu/mid-infrared-instrument/miri-apt-templates/miri-coronagraphic-imaging-apt-template#MIRICoronagraphicImagingAPTTemplate-PSFRefObs

JWST Coronagraphic Visibility Tool:
https://jwst-docs.stsci.edu/jwst-other-tools/jwst-target-visibility-tools/jwst-coronagraphic-visibility-tool-help

6. References:

Linder, E. F., Mordasini, C., Mollière, P., et al. 2019, Astronomy & Astrophysics, 623, A85

Maire, A. L., Skemer, A. J., Hinz, P. M., et al. 2015, Astronomy & Astrophysics, 576, A133

Marois, C., Macintosh, B., Barman, T., et al. 2008, Science, 322, 1348

Marois, C., Zuckerman, B., Konopacky, Q. M., et al. 2010, Nature, 468, 1080

Wertz, O., Absil, O., Gómez González, C. A., et al. 2017, Astronomy & Astrophysics, 598, A83