Hands-on Session for an AMI/NIRISS Proposal

1. Science Case – Detecting a Sub-Stellar Companion to a Nearby Star[1]

We will design a program to search for a companion around a nearby young star showing long-term radial velocity trends suggestive of the presence of a large-separation planetary-mass companion. Ground-based observations with Keck at 2.2 microns have not detected any companion between 40 and 1000 mas. So, if a companion exists, it must be very red, i.e. very low temperature, and its SED must peak at around 4.5 microns like Y-type brown dwarfs. The primary star is nearby enough that its brightness is within range of the AMI mode (AMI's throughput is 15% that of a non-masked regular imaging). The RV trending suggests apparent separations larger than 70 mas.

The star name is Gl 232. It has a magnitude W2=7.49. It is a nearby M dwarf with significant proper motion (including PM and parallax will be important). According to atmosphere and evolutionary models, we expect a companion to be colder than 500 K, so have a W2 > 14.5, a star/companion flux ratio of ~630 (or contrast of 1.6e-3). Also, the F430M – F480M color puts strong constraints on the actual T_{eff} of such a cool object. We expect that color to range between 0 and 1 mag. So, the contrast in F430M could be as much as 0.6e-3. We aim to constrain the color to better than about 0.2 mag, say 10% precision per band (SNR=10), to devise a T_{eff} to within about 50K.

[1] Purely hypothetical case. The star was chosen because of its magnitude (neither too bright or too faint) and large proper motion. In fact, the calibrator star is hinted to be a binary. One would not pick it as a single star calibrator.

2. Step-by-Step Guide for Designing AMI Observations

Follow these steps to design an AMI observation:

1. Estimate the expected contrast and the rough integration time (completed in section 1)
2. Choose a calibrator star (section 3)
3. In the ETC (section 4), check for saturation and determine Ngroup and Nint for the NRM observation of both targets (science and calibrator).
4. In the ETC (section 4), find the Ngroup and Nint for target acquisition as well as for the direct imaging exposures, for both targets.
5. Enter the observation in the APT (section 5).

3. Choosing a Calibrator Star

Finding a star, that is single and close to our science target on the sky, can be more challenging than it appears. Unless you specifically know such a star, you will have to take a chance on a random field star. A good bet is to shoot for a distant giant star. Should it have a companion, it would be on such a small apparent separation that it would still qualify as being single. The next step is to minimize chance alignment by foreground or background star. The only remedy is to stay away as far as possible from the galactic plane. ESAsky is an excellent tool for this purpose (https://sky.esa.int).

- Go to https://sky.esa.int
- Enter the GL232 target and identify its position
- Load the mid-R Allwise survey as your image
- Look for stars in the field with equal or higher brightness
- You can display the Allwise catalogue and click on candidate stars to get their W2 magnitude.

We quickly identified HD 44926 (06:25:32.62, +23:26:31.6). It is a bright K giant star about 10 arc minutes away. *Its magnitude of W2= 3.77 saturates so we will pretend it is magnitude W2 = 5.0 → F430M ~ 5.0 for this hands-on exercise. You may see a message in Simbad that this star is a double or multiple star. Obviously, this would not be a valid single star calibrator. We picked it regardless for the purpose of this demonstration only.*

4. Integration Time Estimation

The canonical equation to devise the number of photons to gather depending on the contrast required is: $N_{photons} = 100 / (contrast)^2$. For the F480M filter, a contrast of 1.6e-3 results in $N_{photons}$ = 3.9e+7 photons. For the F430M filter, a contrast of 0.6e-3 results in $N_{photons}$ = 2.8e+8 photons.

The next step is to estimate the photon flux for our target (and single star calibrator). That is done in the JWST ETC (https://jwst.etc.stsci.edu/).

ETC – Science Target Observation with NRM

1. In Scene and Source → Continuum, select a Phoenix model for an M0 V.
2. → Renorm → Normalized in bandpass, 7.49 vegamag in the NIRISS F480M filter.
3. Click save.
4. In Calculation → create a NIRISS+AMI calculation.
5. In Instrument Setup, select F480M and leave the default detector setup for now.
6. Calculate.
7. In the bottom-middle Pane (Plots), look at the ApFlux value: 291k photons/sec (those detectors' photon yield is generally 1 e- for 1 photon). To reach 3.9e+7 photons will therefore require only 134 seconds. That number depends on the aperture size set in Strategy (top right tab → Aperture radius, 2.5 arcsec by default here).
8. Try to increase the radius and see the results. We'll keep the default aperture.
9. It is always good to check saturation. In the bottom left Pane (Images), select the Groups before saturation tab and scroll towards the center of the image. Saturation occurs at N_{group} = 78. We want to remain at no more than 40% of saturation, so N_{group} < 31.
10. The integration time is $T = N_{group} \times N_{int} \times T_{frame} = 31 \times N_{int} \times 0.07544$ sec. So N_{int} = 57.
11. You can finally enter N_{group} = 31 and N_{int} = 57 in the Detector Setup pane and Calculate. Note the small discrepancy between the ETC reported integration time (138.77 sec) and our expected 133.3 sec. This is because the ETC computes the clock time integration which includes a 0.07544 sec reset at every integration.
12. Repeat the steps above as a new calculation for F430. You can copy and paste a calculation from the edit menu at the very top of the screen. You'll need to change the filter in Instrument setup. With a flux of 356k e-/sec, reaching 2.8e+8 photons requires 786 seconds. Saturation occurs at N_{group} = 52 so we aim for N_{group} = 20. This leads to N_{int} = 521.

ETC – Calibration Target Observation with NRM

Repeat the steps used for the science target but this time use a magnitude of W2 = F430M = F480M = 5.0 (equating these magnitudes is not strictly right, but good to probably ~0.1 mag, depending on the spectral slope).

You can first

1. In Scene and Source → select the Gl232 source and copy it (from the edit menu at the very top), rename it (ID → Source Identity information: HD 44926)
2. Edit it. Continuum → phoenix model: K0 III. Renorm → Normalized in bandpass, 5.0 vegamag in the NIRISS F480M filter.
3. Click save.
4. Make sure that the source is highlighted in yellow in the "Select a Source" middle pane, then in the "Select a Scene" pane, click New, make that scene yellow by clicking on it then Add source. Your scene 2 should get source 2 associated to it.
5. Back to the Calculations Pane, copy a science target calculation, then in the right-hand Scene Pane, select Scene 2 (Source is HD 44926). Then edit the Instrument Setup and Detector Setup to select the appropriate filter and Ngroup + Nint.
6. The calibration target should catch at least as many photons as the science target, ideally more. If you choose Ngroup appropriately, then Nint for this calibration should

be equal to Nint for the science times that factor. Here, since our calibrator is so bright, a factor of ~5 is chosen.

7. Repeat step 5 for the two filters.
8. For the F480M filter, the optimal detector setup is Ngroup=3, Nint=285. For the F430M filter, Ngroup=2, Nint=2605.

ETC – Target Acquisition

Target acquisition for both AMI and SOSS modes is performed in a 64x64 subarray. The bright mode crosses the F480M with the NRM. The faint mode crossed the F480M and the CLEARP. There is a special NIRISS mode in the ETC (NIRISS Target Acq.) that you use to create a new Calculation. One calculation per target is required (so 2 in our case).

1. In Instrument Setup, you need to choose between faint or bright. In our case, both our science and calibrator qualify as bright. So, select SOSS or AMI bright. Pick the Ngroup that is the highest without saturating. Ngroup=19 for both our science and calibrator targets.

5. Filling the APT for an AMI Observation

Defining the Science Target:

- Add a Fixed Target Resolver: GL232 (or Ross 64)
- For best positioning on the NIRISS detector, make sure that the Gaia DR2 RA/Dec are used with epoch 2015.5. Make sure that proper motion is filled.
- Manually add the parallax in arcsec
- Optionally, you can edit the "Name in the Proposal" of this target for use in your proposal.

Defining the Calibration Target:

- Repeat as for the Science Target
- HD 44926 (06:25:32.62, +23:26:31.6).

Exposure Table obtained from the ETC:

Observation	Ngroup	Nint
Science NRM F430M	20	521
Science NRM F480M	31	57
Calibrator NRM F430M	2	2605
Calibrator NRM F480M	3	285
Science Target Acquisition	19	1
Calibrator Target Acquisition	19	1

Create the Observation for the Science Target

1. Click "**new Observation Folder**"
2. In Observation 1, edit the **Label** to say: "GL232 – Science"
3. Select **Instrument** NIRISS
4. Select **Template** Aperture Masking Interferometry
5. Select the GL232 as the **Target**.
6. Select the NIRISS **Aperture Masking Interferometry Tab** and fill the **Target Acquisition parameters**:
   6.1. Use GL232 as the **Acq Target**
   6.2. Use the **AMIBRIGHT** Target Acquisition because our target has W2~F430M=7.49 (Table 1 at https://jwst-docs.stsci.edu/near-infrared-imager-and-slitless-spectrograph/niriss-operations/niriss-target-acquisition gives the range of magnitudes for TA modes). This uses the F480M and NRM crossed.
   6.3. For the integration time, you have no choice but use the **NISRAPID** readout and a canned **number of groups** (3 to 19). Select 19 as devised in the ETC steps. You are forced to use a single integration.
   6.4. Optionally, you can add your **ETC workbook** number for your own reference. It will NOT be used by STScI.
7. Select the **AMI Parameters** pane:
   7.1. **Primary dithers** and **Subpixel positions** should be set to **None**. This recommendation could change in the future.
   7.2. For most targets, the **Subarray** should be **SUB80**. Using the FULL detector could only come handy if the target is faint and field stars could be of interest for some reason (e.g. for phase calibration in the way a single star calibrator is used).
   7.3. Finally, **Add filters** and set the NGROUPS and NINT for each according to the numbers found in the ETC. The Groups/Int is large because of the small size of the subarray (One read takes only 0.07544 sec). The filters you use depend on the science case. All integrations will be obtained before inserting the next filter.
8. Select the **Direct Imaging Parameters** pane:
   8.1. It is recommended to obtain a direct image (nor NRM) to put your AMI observation into context (e.g. absolute flux calibration). One such image per filter used will be obtained and with the same subarray. **Check True**.
   8.2. **Image Dithers** should be **None**.
   8.3. Enter the **Groups/Int** and **Integrations/Exp** found in the ETC step.
9. Select the PSF Reference Observations pane:
   9.1. This is where a reference to the Calibrator star observation is made. You need to create the Calibrator star AMI observation first, then come back here.
   9.2. If the Calibrator star observation exists then you can select it by checking the box.
   9.3. Make sure that the Calibrator star has the box "This is a PSF Reference Observation" checked in its PSF Reference Observations pane.
   9.4. A yellow warning will remain: it is good practice to **add an explicit observing constraint** (observe the calibrator and science targets immediately one after the other) in the **Special Requirements tab**. If you don't then other programs may be scheduled in between and chances are increased that your calibrator may not properly function as the optics could fluctuate between your science and calibrator observations.
10. In the **Special Requirements** tab:

10.1. Timing → Group/Sequence Observations Link → check both observations in the Observation List and check the **Non-interruptible box**. This should clear the yellow warning.

Create the Observation for the Calibration Target

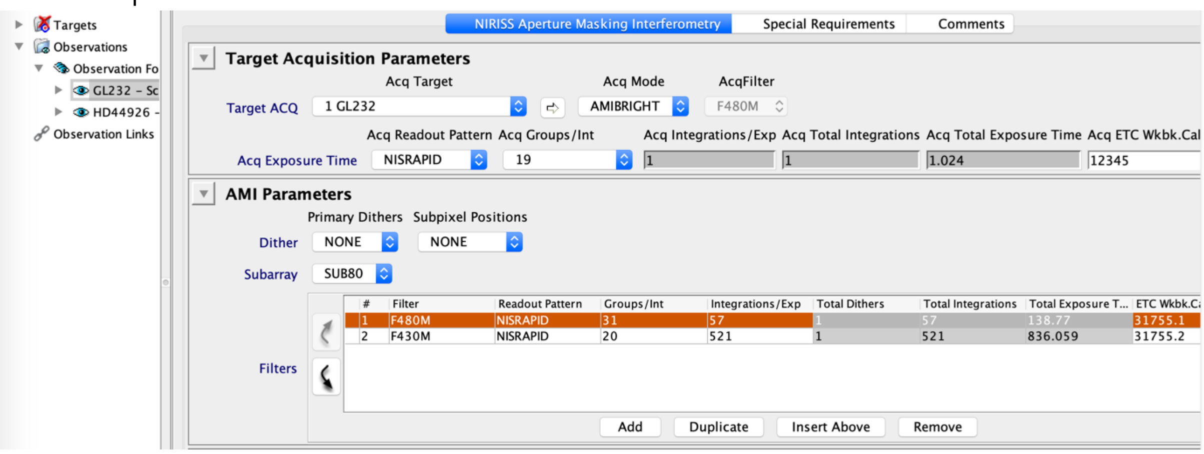
1. In the Observation Folder, **Add** a new observation
2. In Observation 2 edit the **Label** to say: "HD44926 – Calibrator"
3. **Proceed as in steps 3 to 8** of the Science Observation. Use the following values for the various parameters:
   3.1.
4. Select the PSF Reference Observations pane:
   4.1. This is where you define this observation as the PSF calibrator observation, by clicking the "This is a PSF Reference Observation" box.
5. You can then complete the Science Target Observations (steps 9.2 and on).

Finalizing the APT

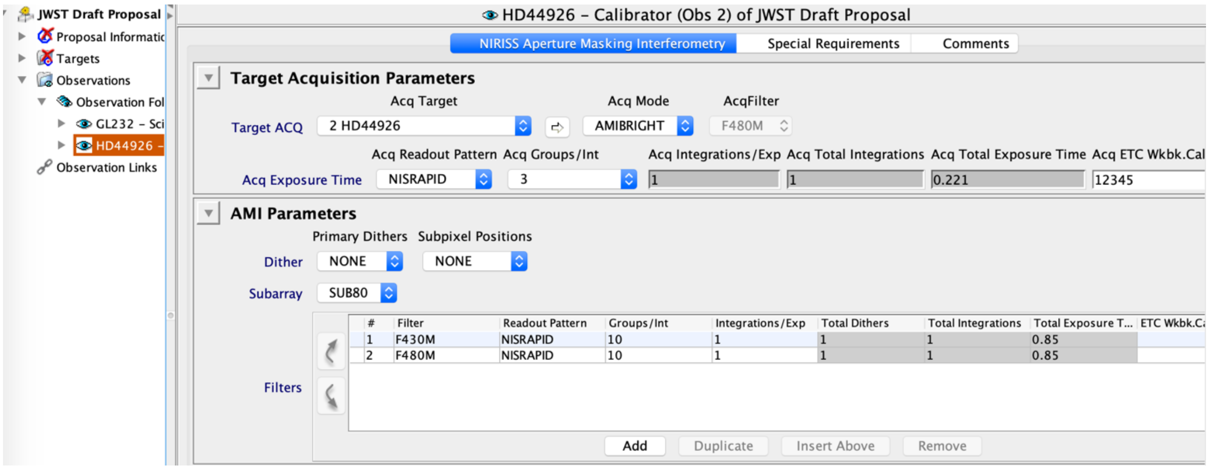
At this point, the **Observations** folder should still contain 2 yellow warnings. You need to run the **Visit Planner** (top icon). Simply click the **Update Display** button near the bottom of the screen. This checks if all constraints can be met. Green check marks appear. All is well.

The Science and Calibrator observations should look like the following two screen shots.

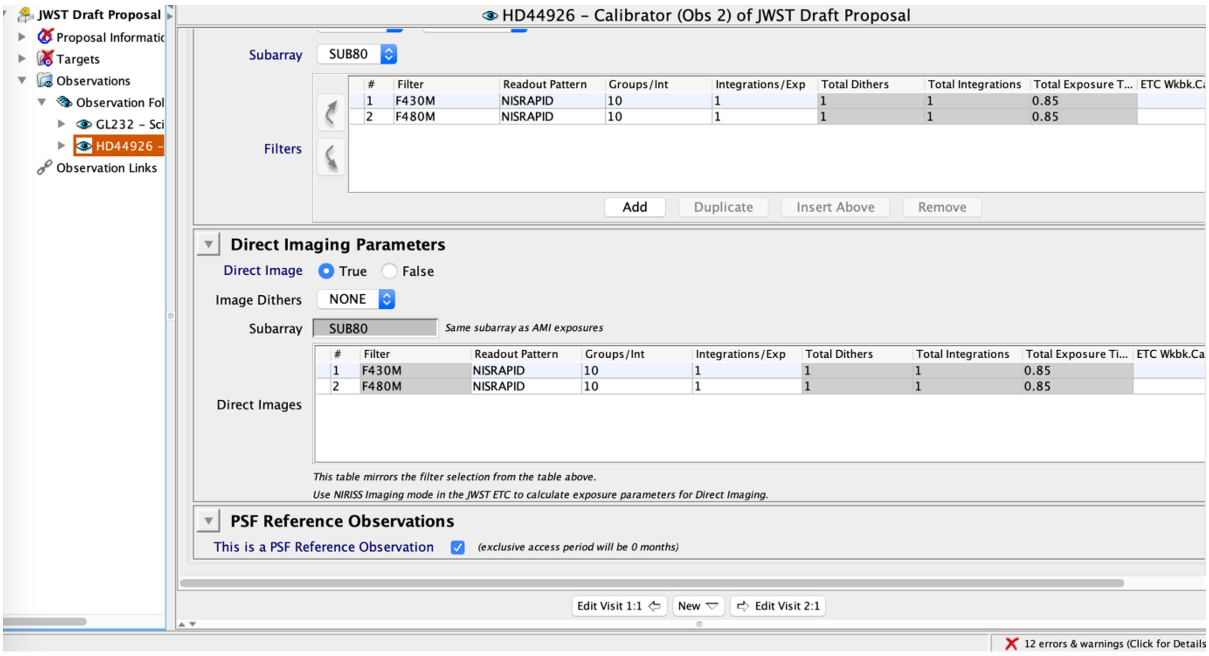
Science – part 1



Science – part 2



Calibrator – Part 1



Calibrator – Part 2