



# CHARA OPERATIONS MANUAL

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## Telescope Adaptive Optics Calibration Procedure

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**ABSTRACT:** This report covers the procedure for measuring a reconstructor for the CHARA telescope adaptive optics system using the calibration light source at each telescope.

### 1. INTRODUCTION

This document gives a detailed procedure for calibrating the telescope deformable mirror. The following sub procedures are described in the following sections:

1. Startup of the required software interfaces.
2. Standard beacon alignment before proceeding to the deployment of the calibration source primary mirror.
3. Auxiliary dichroic alignment for finding the lost beacon on LABAO.
4. Tuning up the telescope WFS centroid positioning.
5. Calibrating the telescope deformable mirror.
6. Removing the calibration source primary mirror for science operations or shutting down the system entirely.

This document assumes some familiarity with CHARA systems but is quite verbose and most steps that require engineering versions of GUIs are described in a manner that anyone should be able to follow with minimal searching for the correct buttons.

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## 2. PROCEDURE

For the purposes of the procedure, the S2 telescope is used wherever anything is required in a terminal. Change "S2" to whichever telescope you intend to use.

### 2.1. Start Up Required Software Interfaces

- Start an engineering version of the HUT GUI with controls for the calibration source using the -Er flag:

```
> hutgtk -Er S2 &
```

- Start an engineering version of the telescope wavefront sensor GUI:

```
> wfsgtk -E S2 &
```

- Start LABAO server from the CHARA Servers Menu

- Start an engineering version of the LABAO GUI:

```
> labaogtk -E S2
```

- Start a telescope GUI, here the older version is used, but the new all-in-one GUI also works:

```
> telescopegtk S2 &
```

- Start an acquisition camera GUI either from the telescope GUI, in the all-in-one GUI, or using the command line:

```
> zwogtk S2_ACQ &
```

- Start the blue beacon GUI:

```
> beacontune_gtk &
```

### 2.2. Initial Beacon Alignment

Next, the beacon needs to undergo the normal alignment procedure. If you are familiar with that procedure, skip to the next section. Otherwise, do the following.

- Open the telescope M7 cover from the telescope GUI.
- Open the telescope M5 cover from the telescope GUI.
- Open the beacon flat cover using the BCN OPEN button on the AOB tab of the hutgtk.

## 2.2 INITIAL BEACON ALIGNMENT

- Open the beacon fiber cover using the FBR OPEN button on the AOB tab of the hutgtk.
- Turn on the red beacon using the ON button to the right of the RED LED label on the hutgtk.
- Turn on the blue beacon using the Blue On button on the beacontune\_gtk. Note that the blue laser beacon currently resides on the red channel at S2, so use the Red On /Red Off buttons for S2 blue beacon.
- Start the labao camera by clicking first the START WFS button on the WFS tab of the labaogtk followed by clicking the START DISP button on the same tab of the labaogtk.
- It is easier to see spot pattern on the TWFS camera if the display is larger. Increase the size of the camera display by increasing the Max PixMult field on the ANDOR SETUP tab of the wfsgtk to 5 (recommended).
- Open TWFS camera shutter and start the camera by clicking the SOPEN button on the bottom of the wfsgtk followed by the CAM ON button nearby on the same GUI.
- Start the acquisition camera. If using the standalone acquisition GUI, click the START CAM button. If using the telescope all-in-one GUI, select the ACQ option from the top of the GUI and then the ON button. Note that you may have to click OFF and then ON again for the camera to start.
- Looking at the acquisition camera, align the beacon so that the beacon light goes through the hole in the acquisition mirror using the BEACON (Orange buttons on the AOB tab of the hutgtk).
- Once in the hole, spots will appear on the TWFS camera image shown by the wfsgtk. If they are in the correct boxes, use the ALIGN BEACON button on the wfsgtk ALIGN tab of the labaogtk. Note: If no spots appear on the TWFS camera image, the red beacon is still off, or the TWFS shutter has failed to open.
- Align the dichroic so that the light appears in the boxes on the labaogtk image using the DICHROIC (Cyan buttons on Hutgtk AOB tab). Note, if no light from the beacon appears on the labaogtk image, see the auxiliary dichroic alignment section 2.3.
- Once spots are in the correct boxes, use the SCP DICH button on the ALIGN tab of the labaogtk to automatically align the dichroic the rest of the way. Note: the automatic alignment procedure does not always converge. Use your judgement to determine if alignment is good enough.
- Focus the beacon to the labao using the BEAC FOC button on the ALIGN tab of the labaogtk. Note that the focus term measured by labao drifts a lot if it's average is roughly zero that is good enough.
- Check that tip(X) and tilt(Y) residual terms reported by telescope wfs and labao are still small. If they are not, repeat the beacon and dichroic alignment steps.

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- Focus the telescope acquisition system using the FOCUS WFS button on the ALIGN tab of the wfsgtk
- Once again, confirm that tip(X) and tilt(Y) residual terms reported on the telescope wfs and labaogtk GUIs are small( $\pm 0.03$ ) and if not repeat the beacon and dichroic alignments.
- This concludes the normal beacon alignment.

### 2.3. Auxiliary Dichroic Alignment

This procedure is for when the beacon is properly aligned to the telescope WFS, but no light appears on the labaogtk image. This assumes that the lab alignment laser has been properly aligned for operations.

- Open the M3 cover from the telescope GUI.
- Move the corner cube into the beam path in front of M2 using the CC IN button on the AOB tab of the hutgtk.
- Close the beacon flat cover.
- Set the lab alignment laser filter to 0.3.
- Send the lab alignment laser out to the telescope.
- Turn the power for the telescope deformable mirror on and flatten it.
- Several laser spots should appear in the acquisition camera image at this time.
- Move the brightest / nearest laser spot so that it falls into the hole in the acquisition mirror using the DICHROIC (Cyan buttons on Hutgtk AOB tab).
- The dichroic should now be well enough aligned to proceed with the normal beacon alignment steps.
- Close the lab alignment laser shutter.
- Open the beacon flat mirror cover.

### 2.4. Telescope WFS Centroid Positioning

This procedure is for checking that the centroid pattern location on the telescope WFS camera is well centered behind the hole in the acquisition mirror. This helps ensure that the beam is not vignetted during science operations.

- Load the default centroid pattern using the LOAD CENT button on the WFS/TT tab of the wfsgtk.
- On the ADJUST tab of the wfsgtk use the Up and Down buttons to move the centroid pattern.

## 2.4 TELESCOPE WFS CENTROID POSITIONING

- Move up, realigning the beacon at each step until the spot pattern on the TWFS camera begins to vignette.
- From this position begin moving the centroid pattern down realigning the beacon at each step. Keep a careful count of the number of steps moved. Keep moving until the pattern begins to vignette on the TWFS camera once again.
- Move the pattern back upwards by half the number of steps counted between vignetting on the top and bottom.
- Realign the beacon to the new centroid location.
- Centroid pattern position is now set in the vertical axis.
- Now move the pattern right, realigning the beacon at each step until the spot pattern shows vignetting on the TWFS camera image.
- Move the pattern left, realigning the beacon at each step until the spot pattern once again shows vignetting on the TWFS keeping count of the number of steps made.
- Move the pattern back towards the right by half the number of steps taken and realign the beacon.
- The centroid pattern location is now correct.
- Confirm that the alignment of the beacon flat is correct. If residual X(tip) and Y(tilt) terms are high realign the beacon using the ALIGN BEACON button on the wfsgtk ALIGN tab of the labaogtk.
- Confirm that the alignment of the dichroic is correct to LABAO. If residual X(tip) and Y(tilt) terms are high, realign the dichroic using the SCP DICH button on the ALIGN tab of the labaogtk.
- Confirm that the focus of the beacon is correct on LABAO. If the residual focus term is high, refocus the beacon using the BEAC FOC button on the ALIGN tab of the labaogtk.
- Confirm that the focus of the acquisition system is correct on the TWFS. If the residual focus term is high, refocus the acquisition parabola using the FOCUS WFS button on the ALIGN tab of the wfsgtk.
- Now that the entire AO system is properly aligned, zero the centroids on the TWFS using the ZERO CENT button on the WFS/TT tab of the wfsgtk.
- In a terminal, copy the old default pattern to a new file so that the drift of the pattern can be monitored over time.

```
cp /ctrscrut/chara/etc/wfs_S2_reference_centroids.dat  
/ctrscrut/chara/etc/wfs_S2_reference_centroids_YYYY_MM_DD.dat
```

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In which the YYYY\_MM\_DD denotes the present date and "S2" should be replaced with the proper telescope. Note that the above example code should be a single continuous line in the terminal.

- Now save the new centroid pattern using the SAVE CENT button on the WFS/TT tab of the wfsgtk.

### 2.5. Deployment and Alignment of Calibration Source Primary Mirror

This procedure details how to move the calibration source mirror into the telescope beam between the M3 mirror and the M4/DM mirror of the telescope. It is critical that the telescope elevation be pointing at 90 degrees for this procedure. There is a gravity-actuated mirror cover in front of the mirror and if the telescope elevation is not pointed to 90 degrees, the mirror cover will fail to open. It is also a best practice to deploy the calibration source primary mirror only if the telescope's primary mirror cover is closed. This is just to add a layer of safety in case something fails on the calibration mirror assembly.

- Power on the telescope deformable mirror using the POWER ON button on the WFS/AO tab of the wfsgtk.
- Flatten the telescope deformable mirror using the FLATTEN button on the WFS/AO tab of the wfsgtk.
- Close the fiber cover using the FBR CLOSE button on the AOB tab of the hutgtk.
- On the AOB ENG tab of the hutgtk there is a pull-down list of motors. The first item shown is BEACON\_FOC.
- Scroll to the bottom of the list and select BCART.
- In the field to the left of the pull-down menu enter 777000. This is the number of steps it takes to move the calibration source mirror into place.
- On the same tab of the hutgtk, click the GET button and ensure that the current BCART position is 0. Similarly, confirm that the number in the text field is 777000.
- Open one of the telescope spy cameras from a telescope GUI. You will be able to see the mirror assembly swing into place from either SPY1 or SPY2 cameras.
- If the current BCART position is 0, send the calibration source mirror in using the GOTO button on the AOB ENG tab of the hutgtk.
- The calibration mirror moves quite slowly and it will take some time for the mirror to reach its kinematic mount in the beam. When it does stop moving, the light from the calibration source should appear near the hole in the acquisition mirror seen in the acquisition camera image.
- If you judge the light from the calibration source to be too far from the hole in the acquisition mirror, you can check that the calibration source is locked into place.

## 2.5 DEPLOYMENT AND ALIGNMENT OF CALIBRATION SOURCE PRIMARY MIRROR

- Change the number in the text field on the AOB ENG tab of the hutgtk to 5000.
  - Click the INC button to try to move the calibration source mirror further.
  - The light will vibrate if properly locked but will not end up in a different place than it began.
  - If the light ends up in a different location than it began, the calibration source mirror was not properly locked onto its kinematic mount.
  - Keep moving the calibration source mirror until it stops moving. Vibrating doesn't constitute moving in this case.
  - When the light no longer moves, the actuator position must be set to the locked value. In the field to the right of the selected BCART motor enter 777000.
  - Write this motor position by clicking the pink ENABLE button followed by the pink SET button both on the AOB ENG tab of the hutgtk. You should see the message "Setting motor BCART to 777000" in the status field.
- The calibration source mirror is now in place.
  - Next the calibration source mirror must be aligned.
  - Move the light from the calibration source into the hole in the acquisition mirror using the green Ref+X/Ref-X/Ref+Y/Ref-Y buttons on the AOB ENG tab of the hutgtk. Note that these buttons will not appear on the normal engineering version of the hutgtk, it must be started with the "-Er" flag for these controls to be available.
    - Ref+X / Ref-X buttons will move the spot up / down on the acquisition image.
    - Ref+Y / Ref-Y buttons will move the spot left / right on the acquisition image.
    - A step size of 1000 entered into the text field to the left of the Ref+X button is good for initial alignment.
  - Once the spot disappears into the hole in the acquisition mirror, the beam must be aligned to the pattern on the TWFS camera image. The same buttons are used to get the spots into the centroid pattern.
    - Ref+X / Ref-X buttons will move the spot left / right on the TWFS image.
    - Ref+Y / Ref-Y buttons will move the spot left / right on the TWFS image.
    - A step size of 300 or less entered into the text field to the left of the Ref+X button is good for fine alignment.
  - Once most of the centroid boxes have spots in them, automatic alignment can be used.
  - First, the servo parameters must be checked or set in the SERVO tab of the wfsgtk. Both the CalsourceX and CalsourceY gains should be set to 1000. Once set in the text field labeled "Gain", click the SEND button for each parameter.
  - Start the automatic alignment of the calibration source by clicking the ALIGN CAL-SRC on the ALIGN tab of the wfsgtk.

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- If the alignment fails to reach a satisfactory tip and tilt values a message will appear in the status field saying alignment failed. This is fairly normal, start the alignment over again.
- Check the focus term on the wfsgtk. If the term is greater than +/-0.1, the focus needs to be adjusted.
- Set the DM to the default flat before adjusting the focus. Use the DEF FLAT button on the WFS/AO tab of the wfsgtk.
- use the green R+FOC and R-FOC buttons on the AOB ENG tab of the hutgtk. The text field to the left of the R+FOC button sets the step size to move in focus.
  - 10000 steps of focus are needed per 0.1 in focus term value.
  - R+FOC increases focus term value and R-FOC decreases it.
  - Do not use more than 20000 steps per move or risk losing the light from the calibration source if an actuator is not working properly. A focus move moves 3 actuators, so if one fails the light can land very far away.
  - It is normal for the light from the calibration source to not land back in the acquisition hole after a focus move. Realign with the Ref+X/Ref-X/Ref+Y/Ref-Y buttons if needed as well as the ALIGN CALSRC routine.
- After the focus value is satisfactory, within +/-0.1 of zero, finalize the alignment of the calibration source by running the automatic alignment of the calibration source a final time. ALIGN CALSRC on the ALIGN tab of the wfsgtk.
- The calibration source is now aligned.

### 2.6. Calibrating the Telescope Deformable Mirror

This procedure details the measurement of the interaction matrix for the deformable mirror.

- Begin by saving the default flat and reconstructor that you are going to overwrite to new files for future reference. Note that the flats are saved by DM serial number rather than by telescope. The telescope DM pairings are listed below.

E1	BAX183
E2	BAX185
S1	BAX187
S2	BAX186
W1	BAX184
W2	BAX183

- Save the flat using the correct serial number selected from the table above where once again, S2 is used as the example:



## 2.6 CALIBRATING THE TELESCOPE DEFORMABLE MIRROR

```
cp /ctrscrut/chara/etc/BAX186_FLAT.dat
/ctrscrut/chara/etc/BAX186_FLAT_YYYY_MM_DD.dat
```

- Save the reconstructor using:

```
cp /ctrscrut/chara/etc/wfs_S2_recon.dat
/ctrscrut/chara/etc/wfs_S2_recon_YYYY_MM_DD.dat
```

- In both commands the YYYY\_MM\_DD denotes the present date and "S2" should be replaced with the proper telescope. Note that the above example code should be a single continuous line in the terminal.
- Next attempt to get an optimized flat by closing the loop on the calibration source using the CLOSE SERVO button on the WFS/AO tab of the wfsgtk.
- Save a flat using the SAVE FLAT button on the WFS/AO tab of the wfsgtk. NOTE: If the servo loop does not appear to be resulting in a better flat than you started with, ignore this step.
- Open the servo using OPEN Servo on the WFS/AO tab of the wfsgtk.
- Flatten the mirror using the FLATTEN button on the WFS/AO tab of the wfsgtk.
- Inspect spots shown in the TWFS camera image. It is helpful to look both at the standard image which is shown by default as well as the logarithmic image shown by clicking the TOG DISP button on the ANDOR SETUP tab of the wfsgtk. Click the same button to switch back. Note that the camera can be running for this toggle to work. The outer edges of the pattern are always less well-illuminated than those in the center. If some spots are missing it is necessary to manually adjust some actuators to bring these spots in.
  - Navigate to the DM tab of the wfsgtk. This tab shows the layout of the individual boxes in the pattern shown by an X. It also shows the position of actuators relative to these boxes.
  - In the text field labeled "Value: " enter 0.05. This is the amount of amplitude to add or subtract from an actuator you want to adjust to bring a spot into a missing box.
  - Adjust the scroll field labeled "Act/Zern#" to the actuator you would like to adjust.
  - Use the INC or DEC button to move the actuator in or out.
  - If you want to start over, click the FLATTEN button on the DM tab of the wfsgtk.
  - A normal operation is to move actuators closer to the middle of the pattern in the opposite direction of actuators farther from the center in order to bring spots into their correct boxes.
  - There is a learning curve and some finesse and practice is required to get a feeling for how to move things to get missing spots back.

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- Once you have a spot back and want to keep it, save a flat using the SAVE FLAT button on the WFS/AO tab of the wfsgtk.
- Repeat for each centroid box that requires assistance around the mirror.
- Once completed don't forget to save a flat again using the SAVE FLAT button on the WFS/AO tab of the wfsgtk.
- Make sure that the initial magnitude of actuation used to measure the reconstructor is at the default. On the WFS/AO tab of the wfsgtk, the field to the right of the button labeled POKE should read 0.075 (this is the default value). Click the POKE button. A message reading "Actuator poke = 0.075" should appear in the status field.
- Click the MEAS RECON button on the WFS/AO tab of the wfsgtk. This will start the measurement process which will proceed through each actuator on the DM. There are several parameters affecting the behavior of this measurement which can be changed on the WFS/AO tab of the wfsgtk. These are:
  - #Loops: The number of Loops.....I'm not sure what this one is. The zero is not the actual default number of loops used.
  - #Averages: The number of frames to average over when measuring the displacement of the centroids after an actuator has moved. The default is 10.
  - #Cycles: The number of push-pull cycles to use in reconstructor measurement. The default is 5.
  - #Waits: Specifies the number of frames to wait for the DM to settle after an actuator moves before measuring the spot displacement. The default is 20.
- Once the measurement completes, calculate the new reconstructor matrix by clicking the COMPUTE RECON button on the WFS/AO tab of the wfsgtk. This will display a plot of the sorted eigenvalue mode of the new reconstruction matrix. This plot can be closed by clicking the CLEAR DISP button on the STEP tab of the wfsgtk.
- Close the servo using the new reconstructor by clicking the CLOSE SERVO button on the WFS/AO tab of the wfsgtk.
- Save a flat using the new reconstructor by clicking the SAVE FLAT button on the WFS/AO tab of the wfsgtk.
- Open the servo using the OPEN SERVO button.
- Flatten the mirror using the FLATTEN button.
- If all of the spots appear where they should on the centroid pattern of the TWFS, increase the magnitude of actuation used to 0.090 in the field to the right of the POKE button on the WFS/AO tab of the wfsgtk. Click the POKE button in order to use the larger actuation.
- Measure a reconstructor again using the larger poke value. Click the MEAS RECON button on the WFS/AO tab of the wfsgtk.

## 2.7 REMOVE CALIBRATION SOURCE PRIMARY MIRROR AND SHUTDOWN

- Once complete, click the COMPUTE RECON button to compute the new reconstructor.
- Close the servo using the CLOSE SERVO button.
- Save a new flat by clicking the SAVE FLAT button.
- If time is not a concern, repeat the process with a POKE value of 0.110. MEAS RECON, COMPUTE RECON, CLOSE SERVO, SAVE FLAT, OPEN RECON, FLATTEN.
- The larger the poke value used, the better the reconstruction measurement. However, the poke must not be so large as the spots are moved outside of the centroid boxes.
- If you are satisfied with the behavior of the servo, and the condition of the flat measured, save them.
- Save the reconstructor by clicking SAVE RECON on the WFS/AO tab of the wfsgtk.
- Save the flat as the new default flat by clicking SAVE DEF FLAT on the WFS/AO tab of the wfsgtk.
- Measurement of a new reconstructor and flat is now complete.

### 2.7. Remove Calibration Source Primary Mirror and Shutdown

After a reconstructor and new default flat have been measured, the systems must be reconfigured for science operations or shutdown entirely.

- Make sure that the AO servo loop is open by clicking the OPEN SERVO button on the WFS/AO tab of the wfsgtk.
- Stow the calibration source primary mirror.
  - Select BCART from the pull-down menu of AOB ENG tab of the hutgtk.
  - Enter a 0 (zero) into the text field to the right of the pull-down menu.
  - Click the GOTO button to send the calibration source primary mirror to its stowed position.
- If continuing with science operations the operation is complete.
- If shutting down entirely, continue.
- Close the beacon flat cover by clicking the BCN CLOSE button on the AOB tab of the hutgtk.
- Turn off the blue beacon on the beacontune.gtk.
- Turn off the red beacon by clicking the OFF button to the right of the RED LED label on the AOB tab of the hutgtk.

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- Close the M7 cover from a telescope GUI.
- Close the M5 cover from a telescope GUI.
- Turn off the TWFS camera and close its shutter.
- Turn off the LABAO camera and stop the LABAO server.
- Quit all GUIs.
- The procedure is now complete.