PyWFS night time operation

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1 Component list

PyWFS: Pyramid wavefront sensor.
SAPHIRA: The infrared camera used as the detector for the PyWFS.
Modulator: PyWFS modulating mirror, also used for limited field steering.
KPIC: Keck Planet Imager and Characterizer (of which the PyWFS is a part).
FIU: Fiber Injection Unit, a sub-system of KPIC.
CRED2: FIU infrared tracking camera.
NIRC2: Keck II facility near infrared imager.
NIRSPEC: Keck II facility near infrared spectrograph.
PRTC: The PyWFS Real Time Controller.
WC: Wavefront Controller (for the Shack-Hartmann WFS).
FSMs: Field Steering Mirrors.
DM: Keck II deformable mirror.
DTT: Keck II tip-tilt mirror (Downstream Tip Tilt).

2 Introduction

The Keck Pyramid WFS (PyWFS) is a new wavefront sensor for the Keck II adaptive optics bench. It was installed in September 2018 and operated in demonstrator/shared risk mode for the next 1.5 years.

Key points

- The Keck PyWFS is an **infrared WFS**, doing the detection in **H-band**. It currently operates on stars as faint as H = 12.
- **NGS** operation.
- Dedicated real time controller (RTC) used to process the PyWFS signals and drive the AO system.
- Designed for operation with **NIRC2 and FIU-NIRSPEC**. The FIU is a new Fiber Injection Unit, part of KPIC (the Keck Planet Imager and Characterizer).
- **Facilitization of the PyWFS will currently incorporate only NIRC2 operations**.

PyWFS configuration

- Standard NIRC2-NGS config with an additional **PyWFS pickoff in front of NIRC2**. There are two pickoff options:
    - **DICHROIC**: For NIRC2 operation, sends 90% of J and H band to the PyWFS.
    - **MIRROR**: For FIU-NIRSPEC operation, sends all the infrared light to KPIC.

Note: Regardless of the AO instrument the TELESCOPE should always be configured for NIRC2 when using the PyWFS. The final instrument configuration is then done at the PyWFS/ AO Acq level.

3 GUIs and tools

The **main night time operation GUIs** are accessed from the `k2aoserver` background menu:

`K2 AO Tools > PWS OPS > Night time ops`

This will open the following GUIs:

- Acquisition GUI (section **3.1 PYWFS – AO ACQ**):
  - `PyWFS – AO Acq`
- Monitoring GUIs (section **3.2 MONITORING TOOLS**):
  - `PyWFS intensity display`
  - `PyWFS image`
  - `PyWFS Tip/Tilt display`
  - `PyWFS DM correction`
- Control GUI (section **3.3 CONTROL TOOL**):
  - `PyWFS loop control`

Additional tools can be accessed through the `PyWFS – AO Acq` and `PyWFS loop control` GUIs (see section **3.4 ADDITIONAL MONITORING AND CONTROL TOOLS**). In this section we describe the different GUIs and there functions.

3.1 PyWFS – AO Acq

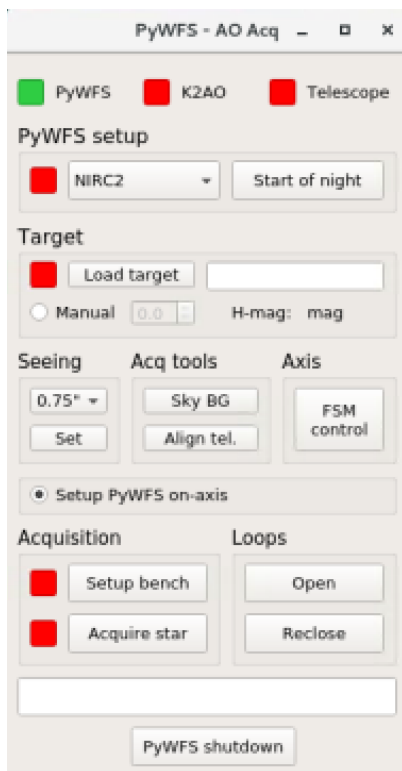Access: `K2 AO Tools > PWS OPS > AO Acq`

Figure 1: PyWFS AO Acquisition GUI

Status lights

	PyWFS	K2AO	Telescope
Green	Camera and reconstruction processes on.	K2AO processes OK and loops closed.	Configured for NIRC2 and offload on.
Yellow	Setting up.	K2AO processes OK, loops open.	Configured for NIRC2 and offload off.
Red	Camera or reconstruction processes off.	Error in K2AO processes (WFS mode, WC state or DM state).	Not configured for NIRC2.
Before **Start of night**	**Red**/ **green**	**Red**/ **yellow**	**Yellow***
After **Start of night**/ before **Setup bench**	**Green**	**Yellow**	**Yellow***
After **Setup bench**/ before **Acquire star**	**Green**	**Yellow**	**Yellow***
After **Acquire star**	**Green**	**Green**	**Green***

* Unless in simulation mode/ daytime tests (can be red).

To identify the source of any red lights consult the `PyWFS Status` GUI (see section **3.2 MONITORING TOOLS**).

PyWsS setup: Start of night

The **Start of night script for the PyWFS and the selected science instrument**. This sets the positions of the PyWFS optics, starts the PyWFS camera and reconstruction processes and connects the PyWFS to the K2 AO system. **Note: this is only the start of night for the PyWFS. The standard AO night time script must still be run from MAORI.**

Target

Sets the H-band magnitude of the target. Can be loaded from the star list or set manually. The `Setup bench` procedure will use this value to configure the PyWFS.

Seeing

Sets the seeing parameter. This will set the appropriate loop gains and PyWFS modulation. This value can be updated at any time during operation and will be applied once the `Set` button is pressed.

Acq Tools: Sky BG

Opens the AO loops (if closed), offsets the telescope and **takes a sky background for the PyWFS camera.** Will reclose the loops (if the loops were closed at the start). Used if star is not apparent on the PyWFS.

Acq tools: Align tel.

Aligns the telescope with the PyWFS. Should be used if a large tip-tilt offset is observed before acquisition, to avoid saturating the tip-tilt mirror.

Axis: FSM control

Opens the `PyWFS FSM control` GUI (see **3.3 CONTROL TOOL**) which is used to control the FSMs. Only limited off-axis motion is currently available.

Setup PyWFS on-axis

If this box is checked the FSMs (field steering mirrors) will be set to a pre-defined 'on-axis' position during `Setup bench`. If this box is unchecked the FSMs will be left in the current position: this may be required if the FSMs are adjusted during operation (i.e. **4.8 OPERATION WITH QACITS AND NIRC2'S VORTEX** coronagraphs).

Acquisition: Setup bench

Configures the PyWFS for the selected instrument and checks the appropriate pick-off optic is in the path.

Acquisition: Acquire star
Takes a sky background, aligns the telescope and closes the AO loops and offloads.

Loops: Open
Opens the AO loops.

Loops: Reclose
Closes the AO loops.

PyWFS shutdown
Shutdown of the PyWFS and removes the PyWFS pickoff.

Differences between simulation and on-sky mode

	Simulation	On-sky
Telescope status light	− Ignore red/orange status.	− Red status: telescope not configured for NIRC2.
Sky background	− Blocks the white light source to take a bench background for the PyWFS.	− Offsets the telescope to take a sky background for the PyWFS.
Align telescope	− Does nothing	− Aligns the telescope with the PyWFS.
Acquire star	− Takes a bench background rather than a sky background before closing the loops.	− Takes a sky background. − Aligns the telescope before closing the loops. − Starts offloading after loops are closed.

3.2 Monitoring tools

PyWFS intensity display
Access: `K2 AO Tools > PWS OPS > Intensity display`

Figure 2: PyWFS intensity display during on-sky operation.
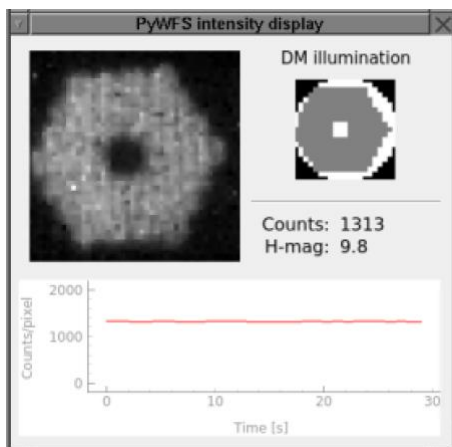
- Displays the PyWFS intensity map during operation. Used to confirm there is light on the PyWFS.
- Shows the DM illumination. On-sky this should follow the hexagonal shape of the Keck pupil.
- Shows a plot of the median count (per pixel per frame) on the PyWFS detector over the last 30 seconds.
- Displays the median count and an estimate of the H-band magnitude.
- **FIGURE 3** shows examples of the intensity display with no light, during daytime tests and on-sky.
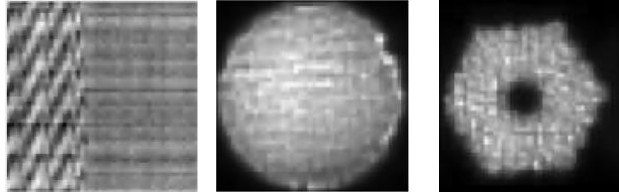
Figure 3: Example PyWFS intensity maps. No light (left), during daytime calibrations with the white light source (center) and during on-sky operation (right).

PyWFS image

Access: `K2 AO Tools > PWS OPS > PyWFS image`

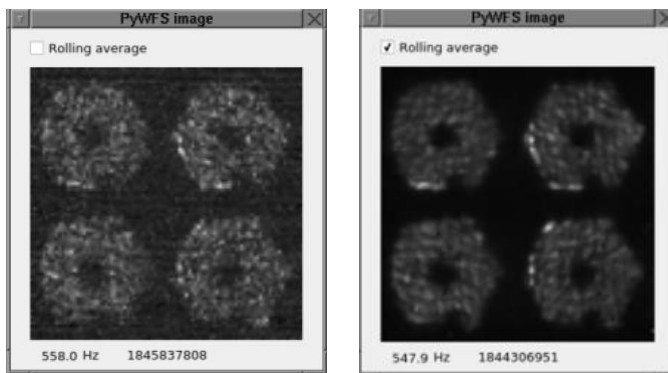- Shows the `PyWFS image`.
- Option to show a single frame or a `Rolling average` (check box), which is useful in the case of faint stars.
- Displays the frame rate and frame number below the image.

Figure 4: PyWFS image display, with missing Keck segment.

PyWFS Tip/Tilt display

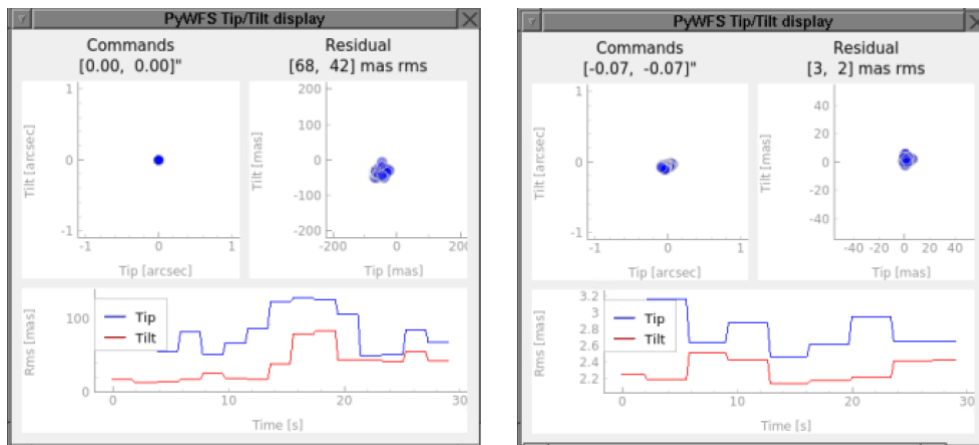Access: `K2 AO Tools > PWS OPS > AO displays`

Figure 5: PyWFS Tip/Tilt display with the TT loop open (left) and closed (right).

- Scatter plots: display the last 10 tip/tilt commands and the tip/tilt residual measurements (made by the PyWFS).
- Linear plot: shows the rms of the tip and tilt residual over the last 30 seconds.
- x/y axis limits: The user can right click on each plot and select 'auto' for the axes to automatically scale the axes to the data. Alternatively, you can enter your own manual limits.
- Used to monitor the state of the TT loop:
  - Check TT mirror is not railing (range of ±0.8").
  - Quality of correction. Typically for bright stars (H ≤ 8) a residual rms ≤ 5mas is expected for median/good seeing.

PyWFS DM correction display

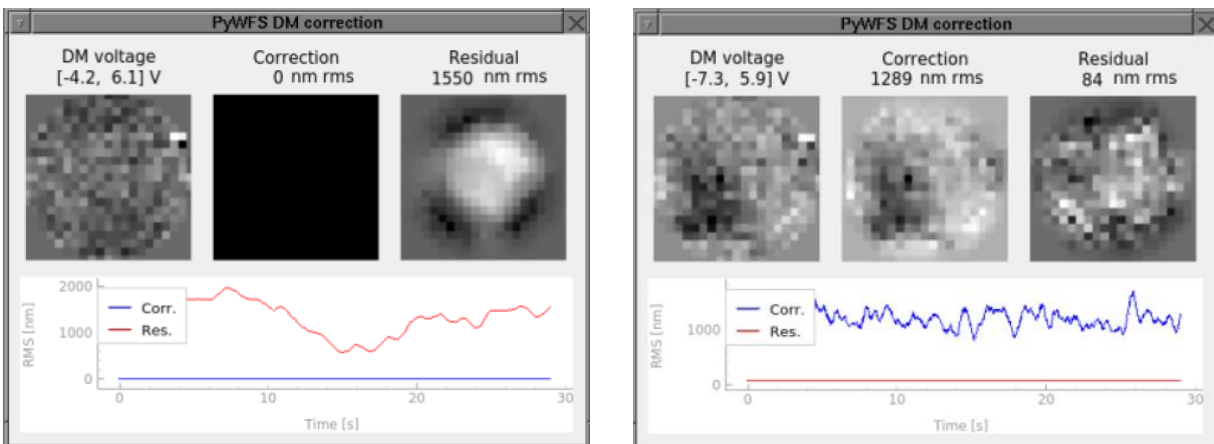Access: `K2 AO Tools > PWS OPS > AO displays`

Figure 6: PyWFS DM correction display with the AO loops open (left) and closed (right).

- Displays 3 DM maps:
  - The total voltages applied to the DM, with the maximum and minimum displayed above. The final voltages sent to the DM are capped at +/-10V. The voltages displayed here show the uncapped values: if they show very large values the gains should be reduced.
  - The correction applied to the DM and the current measured residual.
- Linear plot: shows the rms (in nm) of the correction and measured residual over the last 30 seconds.
- Used to monitor the state of the DM during closed loop:
  - Check that the system is correcting (residual << correction).
  - Typically for bright stars and good/median seeing conditions the residual in closed loop should be between 70 – 130 nm rms.
  - Check for instabilities (see **FIGURE 7**). These are shapes which can buildup on the DM and disrupt the correction. See section **4.4 DEALING WITH DM INSTABILITIES** for more details.
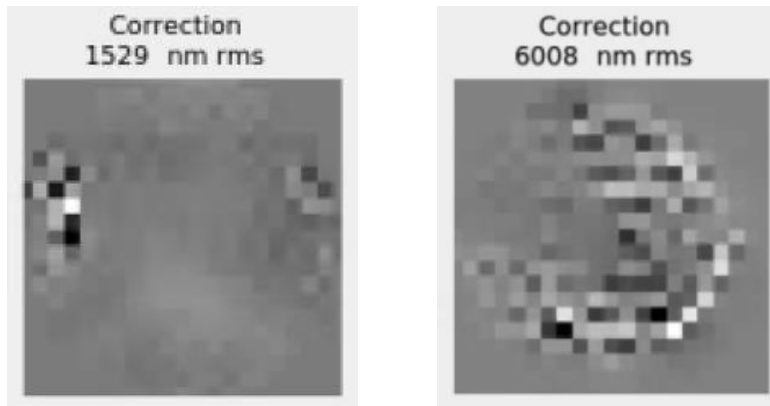
Figure 7: Examples of the DM correction with instabilities building in the DM loop. Left: Instabilities confined to one area of the pupil. Right: High frequency mode building on the DM.

PyWFS night time operations terminal

In addition to the tools described above, the terminal window (titled `prtcNightTimeOperations`) appears when the `Night time ops tools` are started. This can be used to monitor the status of the scripts executed within the GUIs.

Figure 8: Night time operations terminal.

Comments on AO metrics/ residuals

- The residual measurements (wavefront and DM correction) are used to guide the AO user on the current performance of the PyWFS/AO loops based on past performance and the expected numbers given in this document.
- There are **several caveats to these values and so caution should be used when quoting these numbers as the 'true' wavefront residuals.**
  - Both the DM and TT residuals shown in the displays are the PyWFS measurements of the residual. The PyWFS has a small range of linear operation and can significantly underestimate the wavefront if it is large, i.e. in the case of large seeing.
  - The DM conversion from volts to nm of wavefront is achieved using a single number (600nm/V) and does not take into account the shape of the DM influence functions.
  - The DM residual and correction includes only those shapes which the DM can produce, it does not include the higher order fitting errors.
  - The DM residual and correction are filtered of tip-tilt.

- The residuals shown are the instantaneous noisy measurements.

3.3 Control tools

PyWFS loop control

Access: `K2 AO Tools > PWS OPS > PyWFS loop control`

Figure 9: PyWFS loop control GUI, showing the AO control tab. Note: 1 segment missing (seen in pupil illumination map).

- Allows the user to directly control of the AO loop and PyWFS.
- **Illumination map (FIGURE 9)**
  An intensity map of the illuminated pixels: the sum of the four pupil images of the PyWFS averaged over 1 second.
- **H-mag (FIGURE 10)**

  Figure 10: Configuration magnitude (top) and measured magnitude (bottom).

  - The top value shows the magnitude the PyWFS is currently configured for.
  - Bottom value shows the current magnitude estimate, based on the light on the PyWFS.
  - The magnitude estimate will be highlighted green, yellow or red depending on the difference between the estimate and configuration magnitudes:
    - **Green**: Difference < 1 for bright stars (H<10) and < 0.5 for faint stars (H>10).
    - **Yellow**: Difference between 1 – 2 for bright stars (H<10) and 0.5 – 1 for faint stars (H>10).
    - **Red**: Difference >2 for bright stars (H<10) and >1 for faint stars (H>10).
  - If large difference persists (i.e. not just passing clouds) the user should re-configure the PyWFS for the measured magnitude.
- **Target**
  Name of the current target.

The different tabs give access to different operational aspects:
- **AO control (FIGURE 9)**
  - Allows the user to control the loop directly, opening the TT and DM loops and setting the gains.
  - When opening/closing the TT should be closed first and the DM opened first.
  - Default gains can be set. These use the selected seeing to set the gains from a lookup table.

- Access to the `PyWFS gain ctrl` GUI (see **FIGURE 15**). This allows more control of the gains.
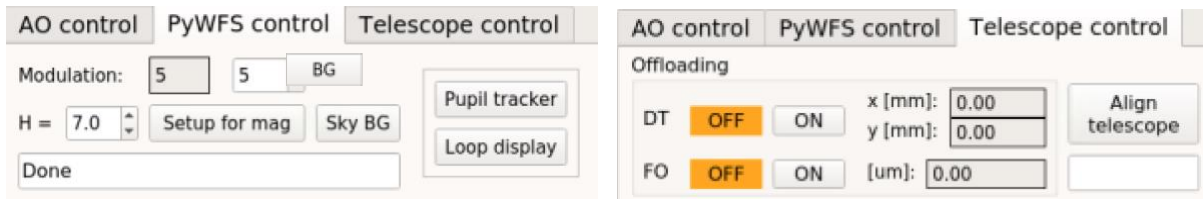

Figure 11: Loop control GUI - PyWFS and Telescope control tabs.

- **PyWFS control (FIGURE 11)**
  - Allows the user to set the PyWFS modulation and configure the PyWFS for a given magnitude (`Setup for mag`).
  - After configuring the PyWFS camera a new sky background should be taken (`Sky BG` button). This offsets the telescope, takes a background and remove the offsets.
  - A separate background button (`BG`) will take a background without offsetting the telescope.
  - Access to additional monitoring tools: `Loop display` and `Pupil tracker` (see section **3.4 ADDITIONAL MONITORING AND CONTROL TOOLS**).
- **Telescope control (FIGURE 11)**
  - Monitor offloading: on/off and offloading values.
  - Align the telescope with the PyWFS (`Align telescope`).

PyWFS Statatus GUI

Access: `K2 AO Tools > PWS OPS > PyWFS status`

Figure 12: PyWFS Status GUI.

- Shows the statuses of different components and processes for PyWFS operation.
- First place to look in case of problems during acquisition.
- **Green** = OK, **yellow** = setting up/idle, **red** = error.
- `More` buttons access basic recovery processes or provide information.
- See section **5.2 STATUS ERRORS** for information on what to do in the case of **red** statuses.

3.4 Additional monitoring and control tools

As well as the main night time operation GUIs additional monitoring and control tools can be accessed from the `PyWFS - Ao Acq` and `PyWFS loop control` GUIs.

PyWFS loop display

Access: `PyWFS loop control` > `PyWFS control` > `Loop display`.
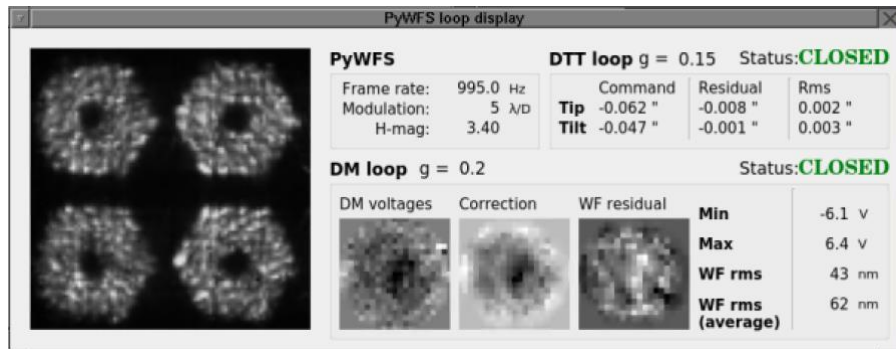
Figure 13: PyWFS loop control GUI during on-sky operation.

- Displays real time data about the PyWFS and AO loops.
- **PyWFS**
  - Shows the PyWFS image.
  - Displays the `Frame rate`, current `Modulation` and the PyWFS measurement of the H-band magnitude (`H-mag`).
- **DTT loop**
  - Shows the DTT loop gain (`g`) and `Status` (`OPEN`/`CLOSED`).
  - Displays the current applied tip/tilt (`Command`), the PyWFS measured `Residual` and the `Rms` of the residual.
- **DM loop**
  - Shows the DM loop gain (`g`) and `Status`.
  - Shows 3 DM maps: the total `DM voltages`, DM `Correction` and the `WF residual`.
  - Displays the minimum and maximum `DM voltages`. These are the unclipped values: the final voltages sent to the DM are clipped at +/-10V.
  - Shows the rms of the current `WF residual` and a rolling average.

PyWFS FSM control

Access: `PyWFS - AO Acq.` > `Axis` > `FSM control`

Small modifications of the pointing can be provided using the `PyWFS FSM control` GUI, allowing adjustments to the positioning on NIRC2.

- Full off-axis operation is still under development and is not offered as a facility mode (as of June 2020).
- The GUI allows individual moves in arcseconds between 0.05" and 0.5".
- The direction of the move is oriented to NIRC2.
- Multiple moves can be made, with the accumulated move displayed.
- If an accumulated move > 0.5" is desired the TT loops must be closed during the move and sufficient time between moves should be left to allow for offloading the tip/tilt to the telescope.
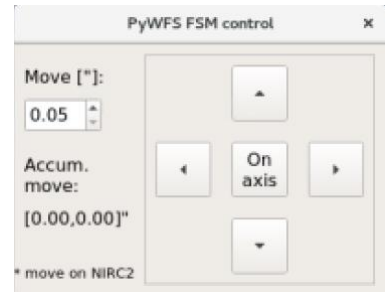

Figure 14: PyWFS FSM control GUI.

PyWFS gain control

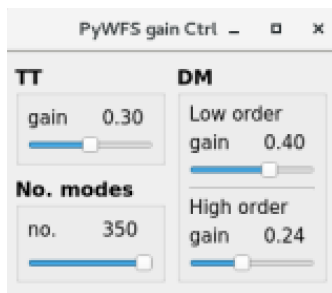Access: `PyWFS loop control` > `AO control` > `Gain ctrl`

Figure 15: PyWFS gain controller.

- More control of the loop gains.
- The DM gain is split into gains for `Low order` modes (i.e. focus, astigmaytism) and `High order` modes (the high spatial frequencies of the DM).
- Used in the case of instabilities in the DM correction, in which lowering the high order gains is often required.
- The higher order gains should be < the low order gains.
- Adjustment of the number of modes controlled in closed loop (max 350).

PyWFS pupil tracker

Access: `PyWFS loop control` > `PyWFS control` > `Pupil tracker`
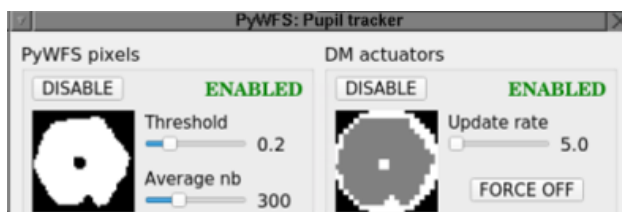
Figure 16: PyWFS pupil tracker GUI. Note: 1 segment missing.

- Displays the illumination of the `PyWFS pixels` and `DM actuators` which are controller in closed loop.
- On-sky this will resemble the hexagonal Keck pupil.
- Can enable/disable tracking of the pupil (`PyWFS pixels`) and update of the reconstructor (`DM actuators`).
- Can adjust the `Threshold` (determines if a pixel is classed as illuminated or not) the number of images to average over (`Average nb`) and the `Update rate` of the reconstructor.
- This should be used in the case that the DM illumination (as shown on the PyWFS Intensity display, **3.2 MONITORING TOOLS**) does not resemble the Keck pupil.
- If too few actuators are classed as illuminated **decrease** the `Threshold`.
- If too many actuators are classed as illuminated **increase** the `Threshold`.

4 Night time operations

4.1 Standard night time procedure

See **5 TROUBLESHOOTING** if any errors occur.

1. **Switch the AO system to the PyWFS mode.**
   - Currently carried out by a software engineer.
   - The procedure for switching the software between `PyWFS` and `SHWFS` is found on the Twiki: https://www.keck.hawaii.edu/twiki/bin/view/Main/PyWfsOpsRevert.

2. **Configure the telescope for NIRC2.**

3. **Night-time setup.**
   - Run the **standard night time setup script** for `NGS-AO`:
     `MAORI > Night-time setup`

4. **Launch the PyWFS operational tools.**
   - From the background menu:
     `K2 AO Tools > PWS OPS > Night time ops`

5. **Confirm operational tools (see FIGURE 17).**
   Confirm the following GUIs and displays are open:
   - `PyWFS - AO Acq`.
   - Loop monitoring tools: `PyWFS intensity display`, `PyWFS Tip/Tilt display`, `PyWFS DM correction` and `PyWFS image`.
   - `PyWFS loop control` GUI.
   - Night time operations terminal.
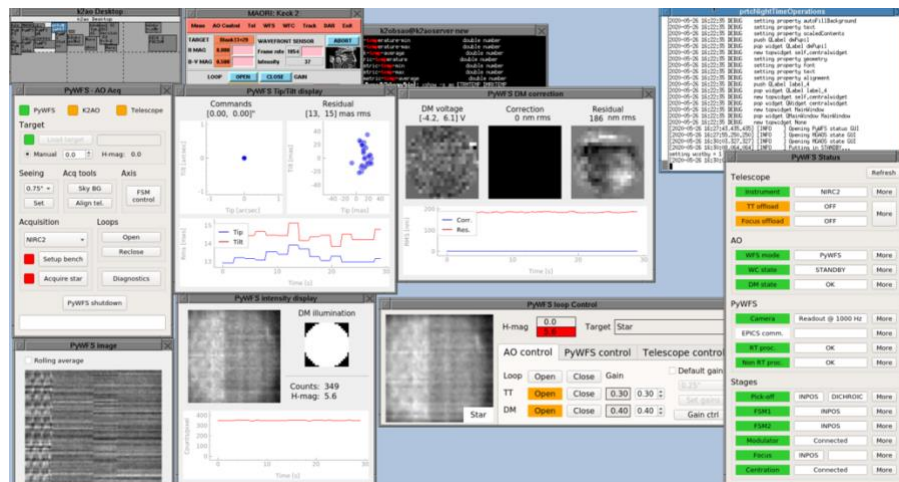   - `PyWFS Status` GUI.

Figure 17: Example PyWFS desktop at the start of the night.

6. **Check Telescope status.**
   - Check `Telescope` status light in `PyWFS – AO Acq.` Should be **yellow** at this stage.

7. **PyWFS start of night.**
   - Check `PyWFS` status is **green** or **red** (**yellow** = PyWFS setting up).
   - `K2AO` status should be **red** or **yellow**.
   - **Select the instrument** from the pulldown menu.
   - `PyWFS – AO Acq.` > `Start of night`.
   - After `Start of night` the associated status light should be **green**. **If not**:
     – Check for error messages in the terminal window.
     – Check the `PyWFS status` GUI for red lights.
     – See **5.1 OPERATION ERRORS**.
   - Confirm `PyWFS` status is **green** and `K2AO` is **NOT red**.

8. **Select target and begin slew to star.**

9. **Set H magnitude.**
   - `PyWFS – AO Acq.` > `Target`. Load from star list or set manually.

10. **Set the seeing parameter.**
    - `PyWFS – AO Acq.` > `Seeing` > `Set`. This can be updated at **anytime** during the operation and whilst the loops are closed.

11. **Setup PyWFS on-axis or not.**
    - The `Start of night` will initially setup the PyWFS on-axis.
    - If the axis (FSMs) have been adjusted after the `Start of night`:
      – **Check** `Setup PyWFS on-axis` to return to the on-axis position during `Setup bench`.
      – **Uncheck** `Setup PyWFS on-axis` if the observer wants to preserve any FSM adjustments.

12. **Setup bench.**
    - `PyWFS – AO Acq.` > `Setup bench`.
    - After `Setup bench` the associated status light should go **green**. **If not**:
      – Check for error messages in the terminal window.
      – Check the `PyWFS status` GUI for red lights.
      – See **5.1 OPERATION ERRORS**.

13. **Acquire star using the guider and send to the NIRC2 pointing origin.**

14. **Confirm star is on the PyWFS.**

- Check the `PyWFS intensity display`: you should see the hexagonal illumination of the Keck pupil.
- If the star is not apparent take a sky background: `PyWFS – AO Acq` > `Sky BG`.
- If star is still not apparent see **5.1 OPERATION ERRORS**.

Note: On subsequent acquisitions, when you are confident the star will land on the PyWFS once sent to the NIRC2 pointing origin, you can skip this step.

15. Acquire star.

- `PyWFS – AO Acq.` > `Acquire star`.
- This will take a sky background, align the telescope with the PyWFS, close the AO loops and switch on the offloading.
- After acquisition all the status lights should be **green**.
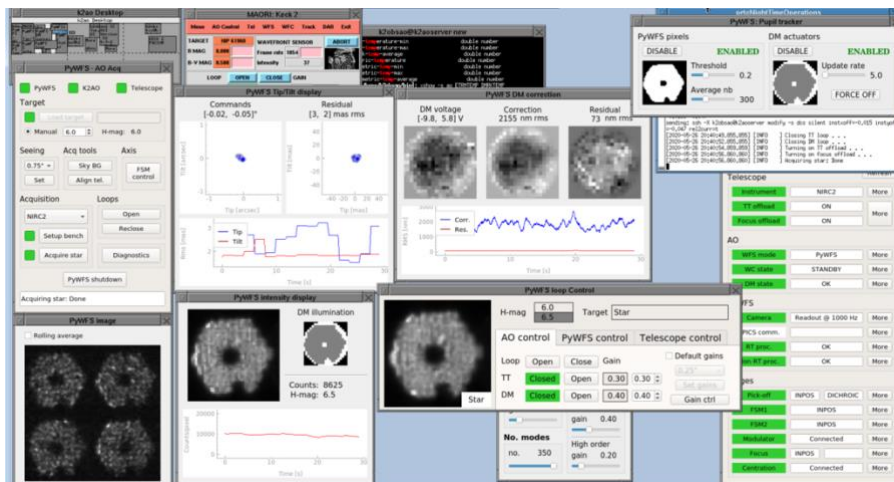
Figure 18: Example PyWFS desktop after acquisition. Note: missing segment in Keck primary.

16. Monitor performance.

- **Monitor the closed loop performance** using the loop monitoring tools (see **4.2 MONITORING THE AO PERFORMANCE**).
- Check in the `PyWFS loop control` GUI that the **measured magnitude is close to the setup magnitude**. If it is not you may want to re-configure the PyWFS for the measured magnitude (see section **4.6 VARIABLE CONDITIONS PROCEDURE**).

17. Change of target.

- Open loops and slew to new target.
- Repeat steps **8 – 16** for the new target.

Note: If the target is a similar magnitude no need to redo the setup bench. For a bright star (H<10) this is a mag difference < 1, for a faint star (H>10) this is a mag difference < 0.5.

18. End of night.

- Open the loops and shutdown the PyWFS: `PyWFS – AO Acq` > `PyWFS shutdown`.
- Run the AO `End of night` script from `MAORI`.

4.2 Monitoring the AO performance

During operation the OA should monitor the performance of the AO system and take action if any unstable behavior is observed or if the correction is not as good as expected (see section **4.3 GETTING THE BEST PERFORMANCE** below). The table below summarizes typical residuals for good – median seeing conditions.

Correction	Monitoring GUI	H-mag	Typical residuals
Tip/tilt	`PyWFS tip/tilt display`	H <= 8	<5 mas rms
		8 < H <=10	<10 mas rms
		10 < H <=11.5*	<20 mas rms
DM correction	`PyWFS DM correction`	H <= 8	<130 nm rms
		8 < H <=10	< 250 nm rms
		10 < H <=11.5*	< 400 nm rms

* The correction quickly degrades between H = 11.5 and H = 12. See section **4.5 FAINT STAR PROCEDURE**.

4.3 Getting the best performance

The key to getting the most out of the PyWFS is setting the gains correctly. A look up table is used to set the gains depending on the seeing parameter and H-band magnitude and these should typically be used. However, there may be cases where the OA should adjust the gains manually, either by resetting the seeing parameter in the `PyWFS AO – Acq.` GUI or manually using the `PyWFS gain ctrl` GUI (**FIGURE 19**). Here are some tips to achieve the best performance:
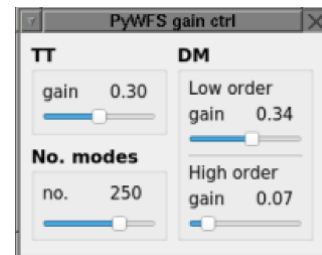
Figure 19: PyWFS loop ctrl GUI.

- Setting the gains is a balance between better correction (favors high gains) and guarding against instabilities (favors low gains).
- General approach: push the gains as high as possible before instabilities develop.
- Typically gain limits:
  - DM gains <=0.5.
  - TT gains <=0.4.
  - High order DM gains < low order DM gains.
- **Large seeing:** increase TT and low order DM gains, decrease high order DM gains.
- **Lower seeing:** decrease TT and low order DM gains to prevent oscillations, increase high order DM gains but keep < low order gain and watch for instabilities.
- **Fainter stars:** decrease gains.
- **Brighter stars:** increase gains.

- The DM correction should look like turbulence. If the correction is oscillating or you observe large 'spikes' in the correction map or rms this may be a sign of instabilities. In this case the gains should be reduced (see section 4.4 DEALING WITH DM INSTABILITIES).
- It may be necessary to take regular sky backgrounds, particularly for fainter stars.

Intensity

1. **Difference between measured H-mag and PyWFS configuration.**
   When to act: If the measured H-mag is highlighted **red** in the PyWFS loop control GUI or if it is consistently highlighted **yellow** (i.e. over several minutes). **More crucial if the target is fainter** than the configuration than if the target is brighter than the configuration.
   Action: Re-run `Setup bench` for the measured magnitude.

Figure 20: Example of H-mag display for star fainter than the current configuration.

Tip/tilt correction

1. **Bad correction.**
   When to act: If the residuals are larger than expected (see table above).
   Action: Try tuning the TT gains. If the residual remains large check that the TT mirror is not saturating (see below) and that the offloading is on (`PyWFS loop control` > `Telescope control`). If the residuals remain high check if high winds or large seeing could be the cause.

2. **Saturation of Tip/tilt mirror.**
   When to act: If the TT commands are saturating (+/-0.8" or close to this). The commands in the `PyWFS Tip/Tilt display` will be highlighted **red**.
   Actions: Check that the offloading is on, if not switch it on and monitor Tip/tilt. If saturation continues open the loops and align the telescope with the PyWFS (`PyWFS loop control` > `Telescope control` > `Align telescope`). Reclose the loops and check that the Tip/tilt remains stable.

DM correction

1. **Bad correction.**
   When to act: If the residuals are larger than expected (see table above).
   Action: Try tuning the DM gains. If the DM correction is saturating (see below) or resembles a focus mode check that the offloading is on (`PyWFS loop control` > `Telescope control`). If the residuals remain high check if high winds or large seeing could be the cause.

2. **DM saturation.**
   When to act: If the DM commands are consistently much greater than +/-10V (will be highlighted **red** in the `PyWFS DM correction` GUI).
   Action: After checking that the focus offload is on try reducing the DM gains. If the correction remains stable but is still saturating the DM it could be a case of large seeing.
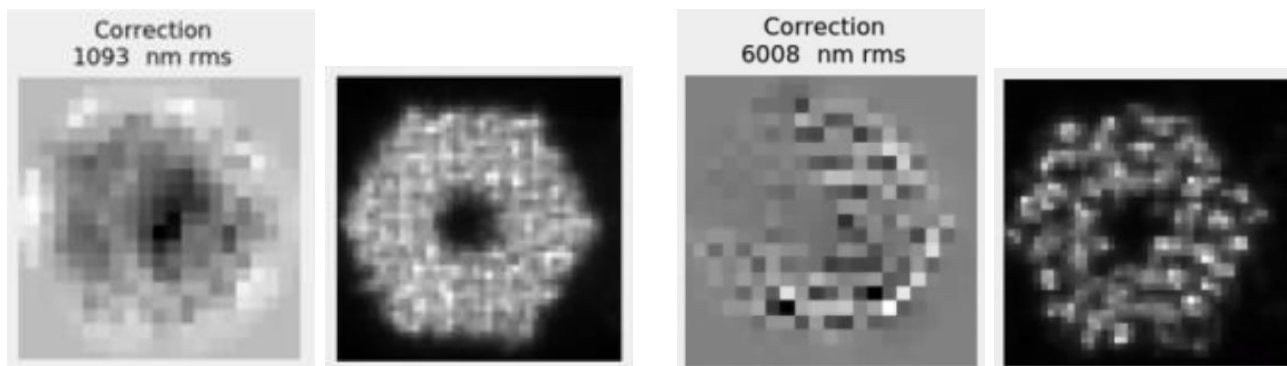
3. **Instabilities.**
   See section 4.4 DEALING WITH DM INSTABILITIES.

4.4 Dealing with DM instabilities

In some cases, instabilities can develop on the DM, particularly during high winds or when the seeing is large. Examples of the system with **stable correction** and **with instabilities building on the DM** are shown in **FIGURE 21**. If such instabilities occur and persist the operator should:

- Try setting the seeing parameter to a larger value:
  `PyWFS – AO Acq.` > `Seeing`
  I.e. if initially set at the default of 0.75" try 1".
- Manually lower the gains, particularly for the high order modes.
  - Open the `PyWFS gain ctrl` GUI:
    `PyWFS loop control` > `Gain ctrl`.
  - Reduce the high order gain.
  - If the system is still unstable reduce the lower order gain.
  - If the system is still unstable reduce the number of modes.
- If issues persist it may be necessary to re-run the `Start of night`, `Setup bench` and `Acquire star`.

a) Stable DM correction (left) and the equivalent intensity map (right).

b) Instability in DM correction (left) and the impact on the intensity map (right).

Figure 21: Examples of instability (left) and normal operation with the PyWFS.

4.5 Faint star procedure

Often we will be using stars with the PyWFS that are bright at H-band but very faint in the visible. In some cases it can be hard to acquire these on the guider and in the past we have used NIRC2 to acquire the target:

1. Try to acquire the star on the guider, or using a reference star if provided by the observer.
2. If you are not able to see the star on the PyWFS check the location of the star using NIRC2. Once the star is located adjust the telescope position to center the star on NIRC2 (i.e. using the `mov` command). The star should now be visible on the PyWFS.

3. If the star does not appear on the NIRC2 narrow cam, try using the wide cam.

In the case of stars at the faint end of the PyWFS operation (H > 11.5) there is a fast drop off in AO performance and it can become challenging to acquire and keep the star. In these cases it is often easiest to acquire manually after the `Setup bench`, to avoid losing the star during the different acquisition steps:

1. Take a sky background (`PyWFS AO Acq.` > `Acq tools` > `Sky BG`). Check the star is visible on the PyWFS.
2. If the star looks well centered try closing the TT loop from `PyWFS loop control`. If not run `PyWFS AO Acq.` > `Acq tools` > `Align tel.` and then close the TT loop.
3. Adjust the TT gains until the residual and commands look stable. Typically we reduce the gains for fainter targets.
4. Close the DM loop and adjust the gains for stability if necessary, typically lowering the gains, especially of the higher order modes.

Note: Vortex operation (i.e. high contrast) is not recommended for very faint targets.

4.6 Variable conditions procedure

In the case of varying conditions it will be necessary for the OA to monitor the loops and take action where necessary.

1. **Clouds/ varying extinction**
   - Monitor the H magnitude estimate in the PyWFS loop control GUI.
   - If this is consistently (i.e. over several minutes) in the **yellow** state you may want to reconfigure the PyWFS for the measured magnitude, particularly if the AO correction is impacted.
   - Take action more quickly if the H-mag estimate is in the **red** state.
   - To reconfigure the PyWFS rerun the `Setup bench` for the desired magnitude and then `Acquire star`: this will take the necessary sky background now the PyWFS camera is in a new configuration.
   - In addition to monitoring the estimated magnitude you should monitor the illuminated pupil shown in the `PyWFS intensity display`. If this does not resemble the hexagonal Keck pupil it may be necessary to adjust the `Threshold` on the illumination criterion using the `PyWFS pupil tracker` GUI (See **FIGURE 22**):

     `PyWFS loop control` > `PyWFS control` > `Pupil tracker`

Figure 22: Examples of the PyWFS pupil tracker. Left: Threshold too small leading to too many actuators selected. Right: Threshold adjusted to better select the illuminated actuators.

2. Varying seeing/ windspeed

In the case of varying atmospheric conditions (windspeed and seeing) it may be necessary to adjust the gains of the TT and DM loops throughout the night. Have the `PyWFS gain ctrl` GUI open and ready to adjust the gains:

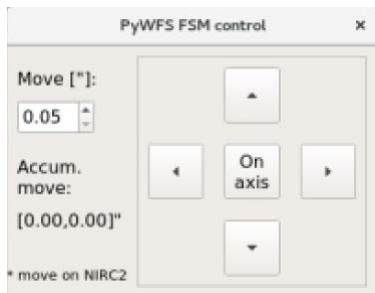> `PyWFS loop control` > `Gain ctrl`

4.7 Field steering

Figure 23: PyWFS FSM control GUI.

- Limited field steering is currently provided.
- The field steering on NIRC2 can be achieved using the PyWFS FSM control GUI: `PyWFS AO – Acq` > `Axis` > `FSM control`.
- The field can be steered by a maximum of 0.5" at a time and should be done in closed loop.
- Check that the majority of the accumulated tip/tilt on the TTM has been offloaded to the telescope before making a subsequent move.
- Avoid accumulated field steers > 2": the FSMs are still under development.
- If unstable correction develops return to the on-axis position (`On axis` button).

4.8 Operation with QACITs and NIRC2's Vortex coronagraphs

- QACITs is an automated procedure used with NIRC2's vortex coronagraph. The script is **executed by the observer** and will open the loops in order to take a sky background for the science image. It then centers the star on the vortex using offsets to the PyWFS modulator.
- Before QACITs can be launched the pointing must be adjusted to center the star on the vortex coronagraph. After the loops have been closed the observer should ask the OA to **adjust the pointing using the PyWFS FSMs**, giving them the offset value in arcseconds and the direction of the offset in terms of desired motion of the star on NIRC2 (i.e. up/down, left/right).
- The OA should apply the offsets using the `PyWFS FSM control` GUI: `PyWFS AO – Acq` > `Axis` > `FSM control`.
- Once the offsets are applied ask the observer if they want to maintain this pointing for subsequent stars. If yes, **uncheck** the `Setup PyWFS on-axis` box. If they want to return to the on-axis position **check** `Setup PyWFS on-axis` box.
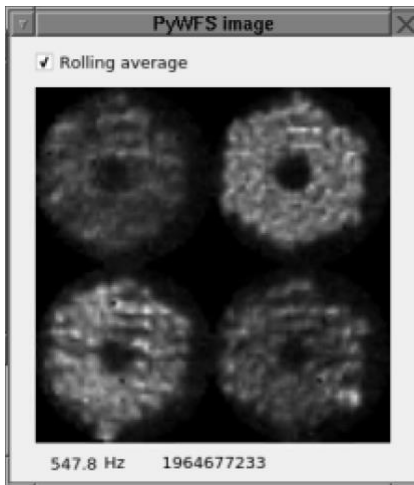
4.9 Binary stars

Figure 24: Example PyWFS image when operating with a binary star.

- The PyWFS can work very well with binary or multiple star systems, providing the separation of the stars is either > 2 arcseconds (the field of view of the PyWFS) or <0.5 arcseconds (range of linear operation of the sensor).
- If the separation is between 0.5 and 2", and the stars are of relatively similar flux, the PyWFS correction will degrade and an uneven illumination of the PyWFS image will be observed (see **FIGURE 24**).
  - Correction should be stable but will not be good.
- As the flux ratio increases the impact is diminished.

5 Troubleshooting

5.1 Operation errors

PyWFS status RED (after Setup bench)

- Check the `PyWFS` status `PyWFS status` GUI.
- If the any of the statuses are **red** click on the appropriate `More` buttons to access the recovery proceedures. Begin with the camera (if this is **red**).

K2AO status RED (after Setup bench)

- Check the `AO` status in the `PyWFS status` GUI.
- If the AO mode is not `PyWFS` the AO system needs to be configured for `PyWFS`.
- Is the WC state set to `standby`? If not set click on the `More` button and use the GUI to set the state to `standby`.

Telescope status RED

- Check the `Telescope` status in the `PyWFS status` GUI.
- If the instrument is not `NIRC2` the telescope needs to be configured for NIRC2.

Don't see light on the PyWFS

- First take a sky background for the PyWFS camera: `PyWFS – AO Acq.` > `Sky BG`.
- If the star is now visible proceed with the acquisition.
- If the star is NOT visible:
  1. Check the guider and confirm location of star. If star is too faint in the visible you should use a reference star or you can use NIRC2 for the final positioning of the star.
  2. Are you configured for the correct H-band magnitude? Are there clouds which could require configuration for a fainter source? Rerun the `Setup bench` for a fainter target if necessary.
  3. Check the NIRSPEC dichroic is not in the beam.

4. Check the location of the star using NIRC2. This should be used if the position on the guider is uncertain (i.e. star too faint in the optical). Once the star is located adjust the telescope position to center the star on NIRC2 (i.e. using the `mov` command). The star should now be visible on the PyWFS.

5.2 Status errors

- After the PyWFS `Start of night` all the lights in the `PyWFS Status` GUI should be either **green** or **yellow**. If the operator notices any **red** lights this indicates an error.
- Further information and access to recovery procedures can be accessed through the `More` buttons.
- **If the PyWFS camera has faulted, restart this first**: the frame rate of the camera is the trigger for various processes.
- The **second priority error is the EPICs communication**: restart this to ensure the status GUI correctly reflects the current state of the instrument.
- After executing any recovery procedure check that the error no longer appears in the status GUI: if the error persists more in-depth trouble shooting may be required.

Telescope

- **Instrument**
  For PyWFS operation the telescope must be configured for `NIRC2`.
- **TT/ focus offload**
  The status should be **yellow** (offload off) or **green** (offload on). If state in the EPICS channel is anything else the status will be **red** (unknown).

AO

- **WFS mode**
  The status will be **green** if the AO software is configured for `PyWFS`, otherwise it will be **red**. The procedure for switching the software between `PyWFS` and `SHWFS` is found on the Twiki: https://www.keck.hawaii.edu/twiki/bin/view/Main/PyWfsOpsRevert.
- **WC state**
  For PyWFS operation the Shack-Hartmann wavefront controller (WC) must be in `STANDBY` (if it is in `NORMAL` it is possible for both the Shack-Hartmann and PyWFS to send commands to the DM at the same time). The `More` button will open a GUI (see **FIGURE 25**) which allows the user to set the WC to `NORMAL` or `STANDBY`.
- **DM state**
  The status will be **red** if the DM commands contain nans, **yellow** if they are all zeros and **green** otherwise. The `More` button will open the `DM recovery` GUI (see **FIGURE 25**) for use to reset the DM in the PRTC channels when they contain nans.
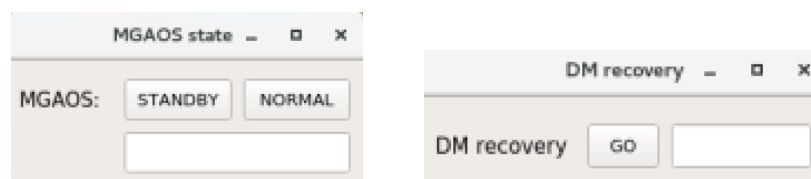

Figure 25: Recovery procedure GUIs for AO processes.

PyWFS

- **Camera**
  The status will be **green** if the camera is running, **yellow** if it is in the process of setting up and **red** if the camera has been shut down or if the frame is corrupted. The `More` button opens the `SAPHIRA state` GUI (see **FIGURE 26**) which:
    o Shows the key SAPHIRA camera parameters.
    o Can display the live camera frame at different processing stages: used to check for live camera images.
    o Can reboot the SAPHIRA camera (if camera is off/in case of a corrupted frame).
- **EPICs communication**
  If EPICs communication with the PRTC fails the status will be **red**. To restart the communication, click the `More` button and use the `PyWFS EPICs comm.` GUI (**FIGURE 26**).
- **RT processes**
  If any of the real time (RT) processes fail this status will be **red**. To restart use the `RT processes` GUI (**FIGURE 26**), accessed through the `More` button.
- **Non-RT processes**
  If any of the non-RT processes fail this status will be **red**. To restart use the `Non-RT processes` GUI (**FIGURE 26**), accessed through the `More` button.
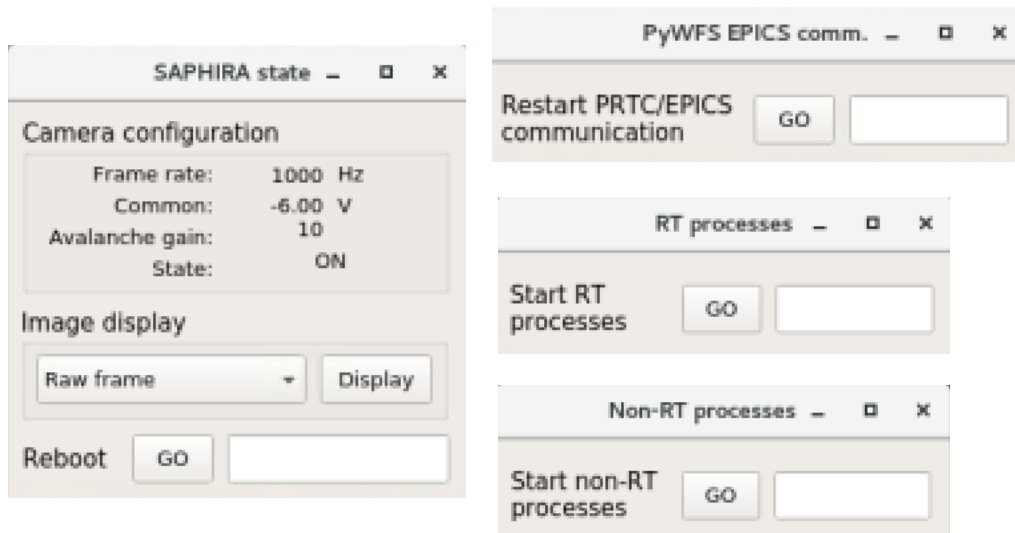

Figure 26: GUIs for PyWFS processes.

Stages

The current state of each of the PyWFS stages is shown, highlighted **red** if there is a fault, orange if the stage is moving and green if it is in position. For each stage the `More` button opens a dedicated GUI for that stage, allowing bypassing of faults and direct access to the positioning of the stage.

5.3 Other errors

Tip-tilt railing

If the tip-tilt commands are railing (constantly 0.8") this typically indicates an issue with the tip-tilt offloading, usually an issue with the values being sent to the telescope. To resolve this:

- Open the loops.
- Reset the offloading:
  > `PyWFS Status GUI` > `Non-RT proc. –More`
  > `Start non-RT processes – GO`
- Reacquire the star: `Acquire star.`
- If railing persists check the AO communication with the telescope.

DM non-responsive

In rare cases the commands sent to the DM can overheat and a manual shutoff will be triggered, stopping commands being sent to the DM. If this occurs:

- Run the DM recovery script:
  > `PyWFS Status GUI` > `DM state –More` > `DM recovery – GO`
- Reacquire the star: `Acquire star.`
- Check instabilities on the DM and reduce the DM gains to avoid a repeat of the problem. Monitor the temperature of the DM.

6 Simulation mode

A simulation mode for the PyWFS AO Acq. Tool is used for testing and training during the day. To compliment this a simple tool is used to simulate night time conditions using the AO bench:

1. Simulates a given magnitude star using the white light source. The possible H-mag is determined by the available ND filters.
2. Simulates atmospheric turbulence by applying shapes to the DM. This is characterized by a value of the seeing and windspeed.

6.1 Night time simulation procedure

1. **Switch the white light source on.**
   - From the background menu:
     > `K2 AO Tools` > `Calibration Tools` > `Light Source Control`
   - Switch light on.
2. **Start the PyWFS night time simulation.**
   - From the background menu:
     > `K2 AO Tools` > `PWS OPS` > `Simulate night time ops`

- A popup warning that the tool is in simulation mode will appear (**FIGURE 27**).
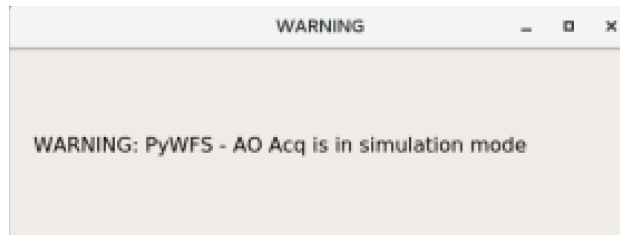

Figure 27: Warning popup

- Confirm that the following windows have appeared:
    i.   The `PyWFS – AO Acq.` GUI.
    ii. The loop monitoring tools: `PyWFS intensity display`, `PyWFS Tip/Tilt display`, `PyWFS DM correction` and `PyWFS image`.
    iii. The `Nighttime simulator` GUI.
    iv. The `PyWFS loop control` GUI.
    v.   The `PyWFS Status` GUI.

3. **PyWFS start of night.**
    - The `Telescope` status may be **red** – ignore this in the simulation mode.
    - Before running the `Start of night` the `PyWFS` status should be **red** or **green** and the `K2AO` status should be **red** or **yellow**.
    - Run the PyWFS `Start of night` script from the `PyWFS – AO Acq.` GUI:
        > `PyWFS – AO Acq.` > `PyWFS setup` > `Start of night`
    - Once the script is complete the associated status light should go **green**, the `PyWFS` status should be **green** and the `K2AO` status should be **yellow**.
    - You should now see live data in the PyWFS monitoring tools: the PyWFS camera is running.

4. **Simulate star**
    - Select the desired magnitude of star to simulate in the pulldown menu on the `Nighttime simulator` GUI.
    - Click the `Set` button to apply the appropriate ND filter. An error message will appear if the light is not on or if the sfp (light source) is not in the 'pws' position.

5. **Simulate turbulence**
    - Select the desired atmospheric conditions (seeing and windspeed) in the `Nighttime simulator` Gui.
    - Click the `Go` button to begin applying the turbulence to the DM. A display will appear showing the shape applied to the DM.
    WARNING: the turbulence simulator will not work if the PRTC is not connected to the AO system. This is done during the Start of night process.

6. **Setup bench**

- On the `PyWFS - AO Acq.` GUI select the magnitude of the (simulated) star using the manual magnitude box.
- Click on the `Setup bench` button. The status light next to the button will go **yellow** during the setup. Once the setup is complete it will go **green** (setup complete) or **red** (error during setup).
- After the `Setup bench` is complete confirm the `PyWFS` status is still **green** and the `K2AO` status is still **yellow**.
- Click the `Sky Background` button. This will block the white light source and record a background image for the PyWFS camera.
- Confirm there is light on the PyWFS (i.e. on `PyWFS intensity display`).

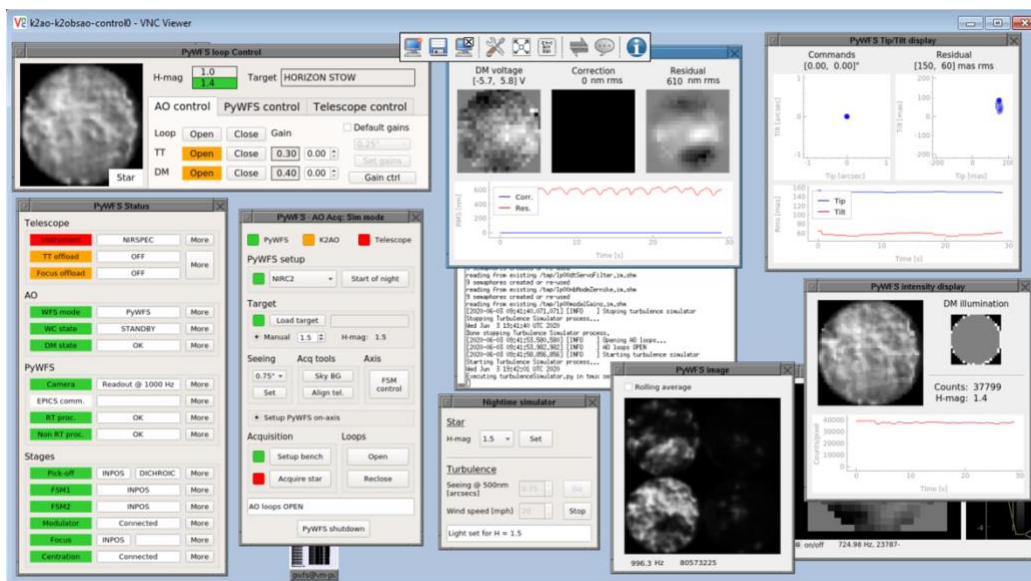*Figure 28: PyWFS night time simulation after Setup bench and before Acquire star.*

7. **Acquire star**
   - Click on the `Acquire star` button in the `PyWFS - AO Acq.` GUI. The system will take a sky background and then close the loops.
   - After `Acquire star` process is complete all the status lights should be **green**, with the exception of the `Telescope` status (see **FIGURE 29**).

8. **Monitor performance.**
   - Monitor the closed loop performance using the intensity, Tip/Tilt and DM correction display tools.
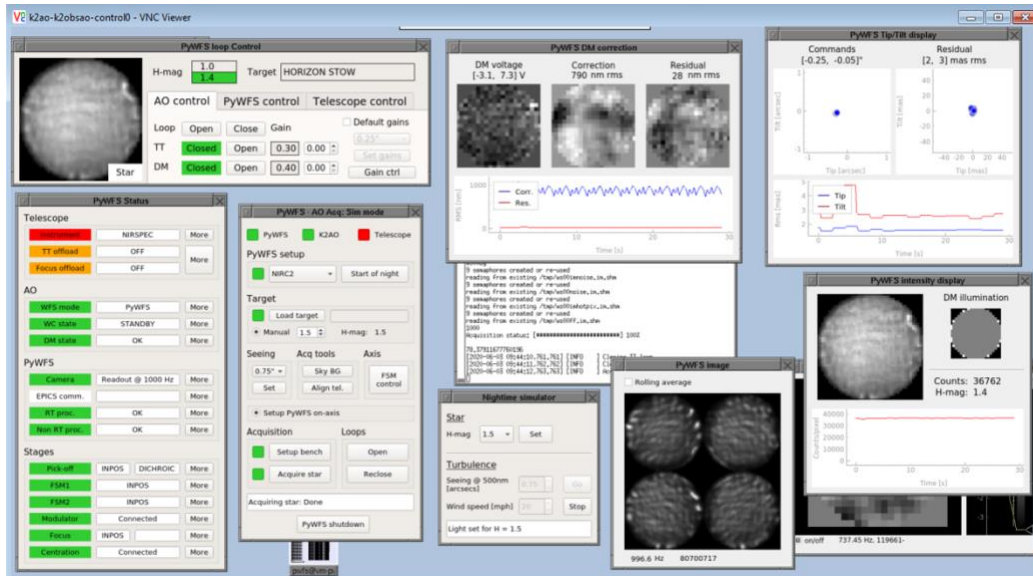
Figure 29: PyWFS night time simulation after Acquire star.

9. End the simulation

- Open the loops.
- Click the stop button on the `Nighttime simulator` Gui.
- Shutdown the PyWFS: `PyWFS – AO Acq.` > `Shutdown PyWFS`.
- Turn off the light.