

# SAM User Guide

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# 1 How to use this guide

This document is written for *SAM operator* – the person who operates the SOAR Adaptive Module during observations. It does not explain how SAM works (except for the brief introduction in the next Section 2) because the operator knows this already. The operator is also familiar with the Instrument Control Software (ICS) and knows something about SAM Imager, SAMI. Technical support of SAM, its calibration and preparation for the run are done by someone else.

Go directly to the observing procedure in Section 3 and execute it step-by-step. For more information, follow the links to more detailed explanations here and in other documents. Once you are very familiar with SAM, just consult the *cheat sheet* with most frequently used commands and numbers.

## **Information about SAM:**

SAM web page (denoted as `~SAM/` throughout this guide):  
<http://www.ctio.noao.edu/new/Telescopes/SOAR/Instruments/SAM/>

SAM document navigator (SAMdocs): `~SAM/samdocs/samdocs.html`

SAM manuals: `~SAM/ao_fl_archive.html`

Instrument Control Soft User Manual: `~SAM/archive/ICsoft-UserManual.pdf`

Adaptive Optics tutorial at CTIO:  
<http://www.ctio.noao.edu/~atokovin/tutorial/index.html>

## 2 SAM at a glance

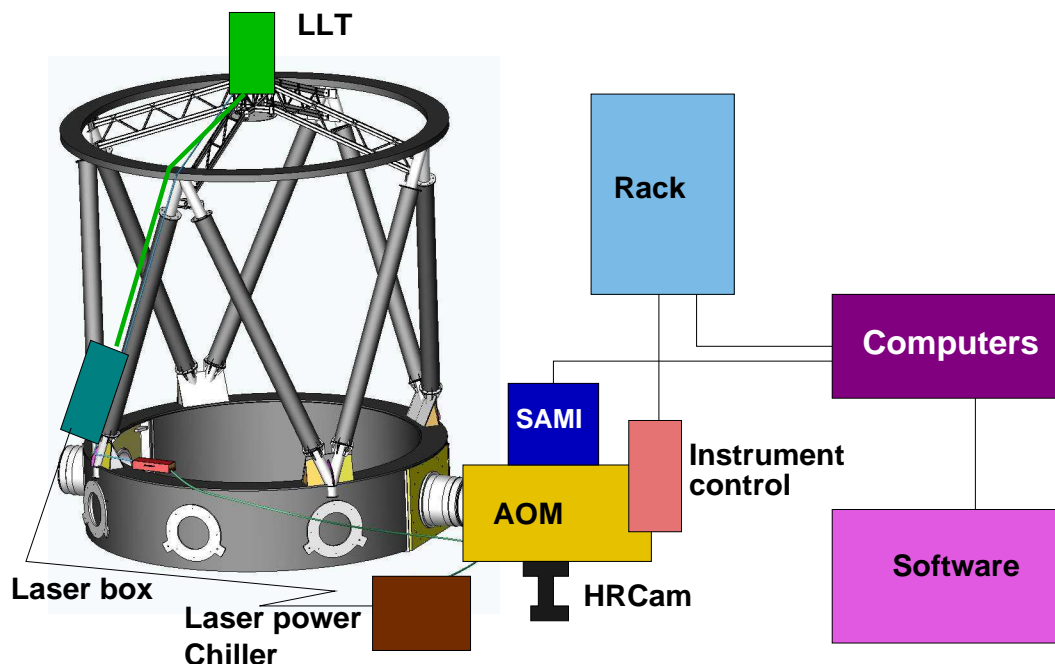


Figure 1: Main components of SAM

The main part of SAM, Adaptive Optics Module (AOM), is attached to the optical ISB of SOAR. It delivers turbulence-corrected images to the built-in imager, SAMI, or to the visitor instrument (HRCam), see Fig. 1 (“clickable” version of this Figure is on the SAMdocs page). The electronics of AOM is located in boxes attached to it and in the SAM rack. SAM uses 3 PC computers and several software modules running on those PCs.

The ultraviolet laser guide star (LGS) is created by the 10-W UV laser attached to the SOAR truss (inside the laser box). Its beam goes towards the Laser Launch Telescope (LLT) behind the SOAR secondary mirror and is launched in the sky. The laser power supply and chiller are located in a rack attached to the SOAR fork.

The light path inside AOM (Fig. 2) shows how turbulence is compensated. The first active element is the SOAR tertiary mirror M3 that corrects tip-tilt, like in other SOAR instruments. However, SAM does not use the standard ISB guider and has its own two guide probes inside the AOM, right at the focal plane. The light of science target is then re-imaged on the CCD by means of two off-axis parabolic mirrors (OAPs) and a deformable mirror (DM) which corrects defocus and other wavefront deformations. After OAP2, the corrected image can be directed either to SAMI or to the visitor instrument by a movable output-selector mirror.

The LGS is created at 7 km, so its image in SOAR is formed behind the normal focus (in fact close to OAP1). The ultraviolet LGS light is reflected by OAP1 and DM, and then is separated from the science beam by a dichroic. Special optics collects the LGS light in the wave-front sensor (WFS) to measure how flat is the wavefront and to adjust the DM shape accordingly.

Figure 3 illustrates major software modules of SAM. The RTC and HRCam computers are located in the SOAR computer room, the AOM computer is housed in the rack on the SOAR platform.

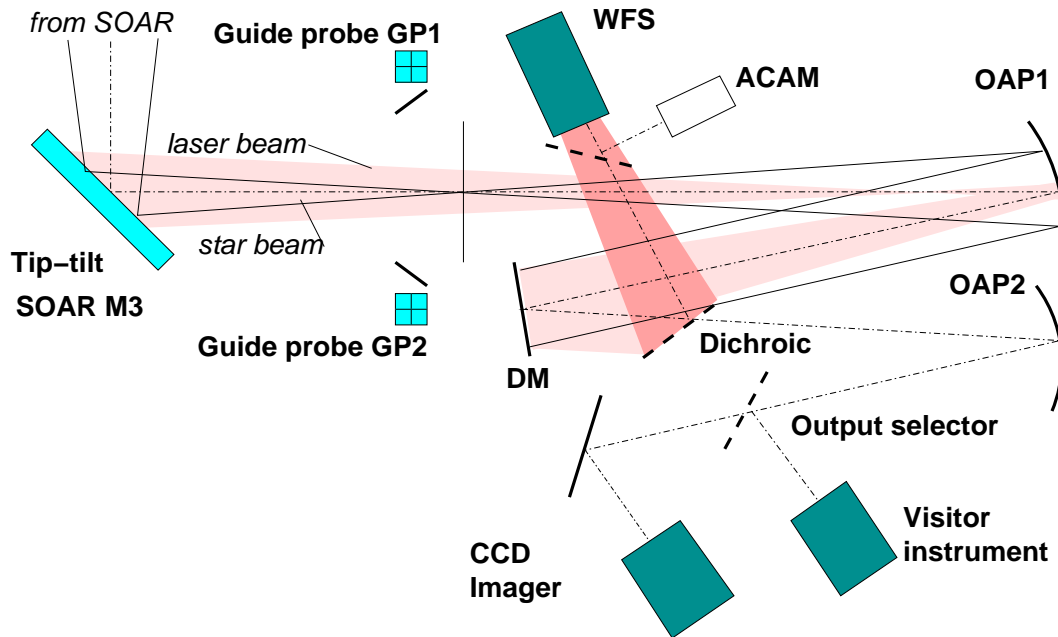


Figure 2: Schematic diagram of the SAM AOM.

Software modules communicate between themselves and with the outside world (e.g. with the SOAR TCS) via common Internet. In addition, each computer has its own connections to the SAM hardware by fibers, serial links, and dedicated Ethernet lines (these connections are not shown in the Figure).

Four different software applications run on the AOM, but the user normally interacts only with the top-level module, Instrument Control Software (ICS). The low-level applications control the AOM and LGS components, respectively. The LCH application imposes restrictions on the laser propagation. All applications are accessed via VNC, in separate work-spaces, and all must be running to operate SAM.

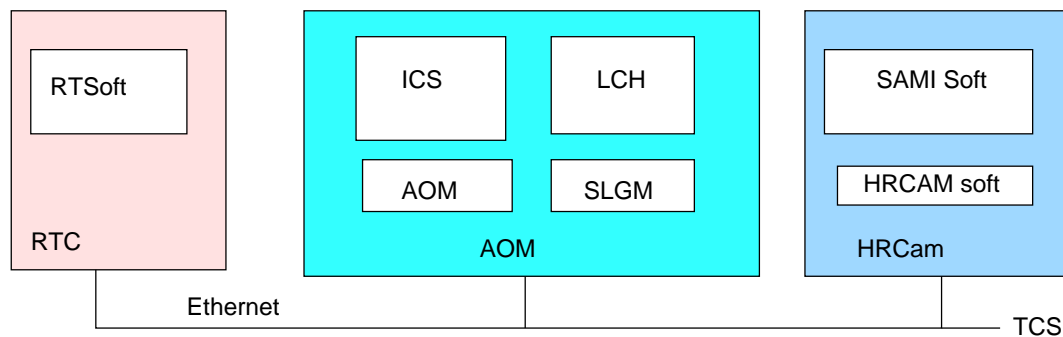


Figure 3: Computers and main software modules of SAM.

The astronomer takes data with SAMI using SAMI soft (SIMAGER), in coordination with the SAM operator. SAMI is also used by the SAM operator to determine pointing corrections for the guide-star acquisition.

Figure 4 shows the main features of the SAM user interface (read the ICS manual to learn more!).

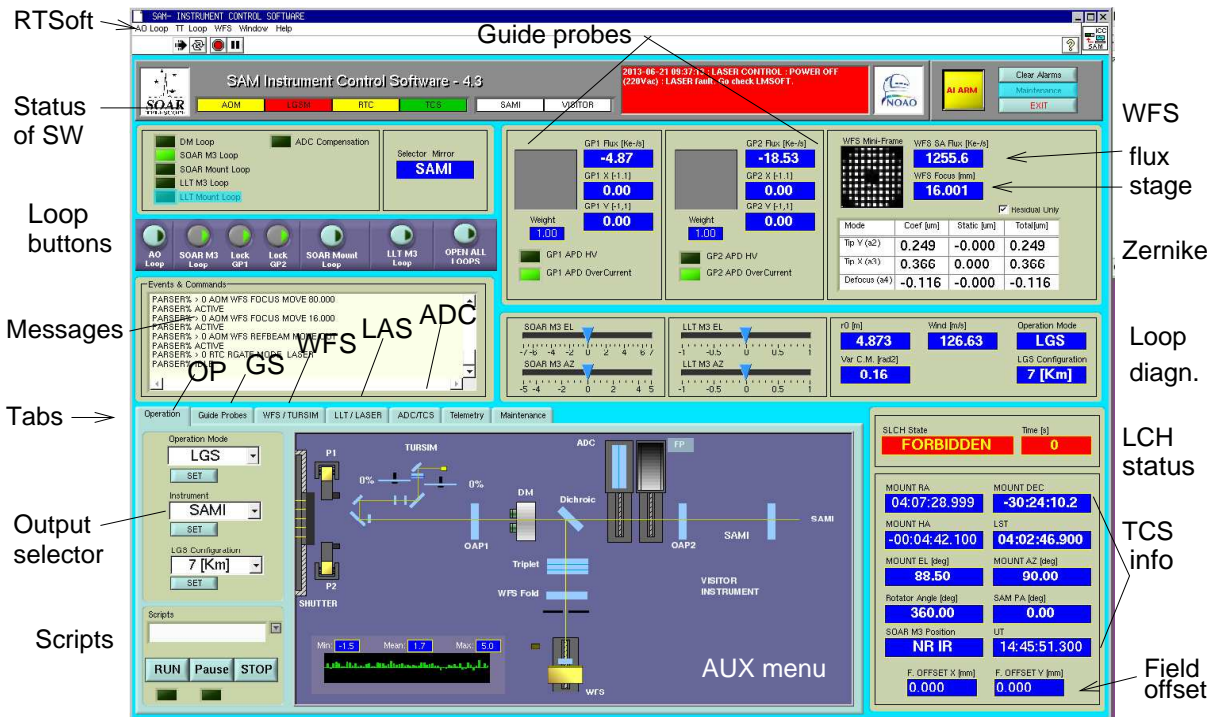


Figure 4: The user interface to SAM – ICS GUI.

The lower-left part of the GUI has various tabs with different information and controls. You will use 4 tabs: OP-TAB (shown in the figure, with a pictogram of SAM), GP-TAB (guide-star acquisition), WFS-TAB (WFS and TurSim), LAS-TAB (LLT and laser control), and ADC-TAB (ADC and TCS commands). The remaining two tabs are informative or technical. We refer to these TABS below in this short-hand notation. In the OP-TAB, various menus are available by pointing the mouse on a component and right-click. The additional AUX menu is available by clicking in the empty right corner of the operational diagram. These menus are denoted here as, e.g., OP-TAB-WFS, OP-TAB-DM, etc.

The remaining part of the ICS GUI is always visible (independently of the tabs) to inform the user of the current system status and performance. SAM has four servo loops in total. Tip and tilt (tt) are compensated by the SOAR M3 and off-loaded to the telescope mount. The LGS spots are maintained centered by the LLT loop. And, finally, turbulence is compensated by the AO loop. Opening/closing all loops is done by the loop buttons in the middle-left part of the ICS GUI.

### 3 Observing Procedure

SAM is a complex system. It should be prepared for each run (switched on and checked) by a trained person. We assume here that this is done and that SAM is up and running, ready to be used at night.

### 3.1 In the evening

**Targets.** During the day, load the Predictive Avoidance Maintenance (PAM) file in the LCH software.<sup>1</sup> These files are received by the `soarpam` e-mail alias from the Laser Clearing House (LCH) in response to our requests. The target coordinates for the night cannot be changed. Yes, you can point the telescope anywhere, but the laser propagation is only allowed in the direction of PAM targets during authorized PAM time windows. The target coordinate list (for this night or for the whole run) must be also loaded in the SOAR TCS (send the list to `soarops@ctio.noao.edu`).

**Software connections, power-up.** Connect by VNC to the ICS,<sup>2</sup> verify that the ICS GUI is running and not showing error messages. One error message about “WFS not reading frames” will certainly be displayed. Reset the WFS (OP-TAB-WFS) to fix it.

Switch on power to the “sensitive” SAM electronics: DM driver, Pockels cell driver, APD power (VNC to `soarenv:1`, use Op-Nasmyth-Left tab in the power-control GUI).

It is a good idea to refresh the WFS bias (see Sect. 5.1), to flatten the DM (Sect. 5.3), and to take the corrected image of GP1 with SAMI (Sect. 5.5).

**Laser.** If this is the first night of the run, insert the key in the laser power-supply rack (access from the IR platform) and turn it ON. However, this should have been done already while the SAM laser was tested for the run.

About 30 minutes before the start, energize the laser (220V ON in the LAS-TAB). Wait about 1 min. before the laser status begins to display, then switch the laser diodes on, for warming up. The lighted sign in the SOAR control room now shows that the laser is working. The laser shutters must be closed at this time. Call the LCH<sup>3</sup> and announce the time when the laser will be propagated (expected start and end propagation time, UT).

**Wake-up SAM.** When the SOAR dome is opened and the telescope active optics is being tuned, open the LLT cover (energize the LLT, then open the cover in LAS-TAB, then turn the LLT power off), also open the SAM environmental cover (OP-TAB-SHUTTER). You can use the `Wake` script accessible in the OP-TAB-SHUTTER menu. SOAR must be configured for work with SAM (M3 points to the optical Nasmyth, M4 in the optical ISB is in the IN position).

To prepare for the night, open the GMAP GUI (button `GMAP Catalogs` in the GS-TAB). Also open the viewer of the LGS acquisition camera, ACAM. Click the buttons `Acquisition camera` and `ON` in the WFS-TAB, wait a few seconds. The small GUI of the viewer appears, connects to the camera, and shows its identification. Then click on the “eye” icon to open the live camera display (see Fig. 5 below).

**Set range** to 7km and and gate to 0.1km in the LAS-TAB. Switch on the Pockels cell HV and “arm” the gate pulses. Also issue the command `SpotOffset` in the OP-TAB-AUX menu (this introduces a correction in the spot offsets needed for better performance with the LGS).

### 3.2 Pointing the target

Point telescope to the science target. The LCH status (on the right in the ICS GUI) normally becomes green (laser propagation is authorized) and shows the time remaining until the next closure, in seconds.

It is necessary to determine the exact telescope pointing for the guide-star (GS) acquisition (see Sect. 4 for details). Using SAMI, take a short-exposure (10s to 30s) in open loop and without guiding,

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<sup>1</sup>See `~SAM/archive/SAMLGS-UploadingPAMfiles-v1.docx.pdf`

<sup>2</sup>Cpmpuater IPs listed at `~SAM/samdocs/computers.html`

<sup>3</sup>See instruction for LCH communication

in some broad-band filter. Display this image in IRAF. Note that the SAMI +X axis points to the East (at SAM position angle  $0^\circ$ ), so to image orientation in DS9 with the GMAP, invert the X-axis in the DS9 display (Menu **Zoom - Invert X**). The orientation of both SAMI and GMAP images depends on the SAM position angle.

Identify a star in the image with a star in the GMAP display (preferably close to the center), click on the star in GMAP to get its coordinates. Then go to the SAMI GUI, point the cursor in the GUI, and press F3. Point this same star in the DS9 display, press 'c'. Then go back to GMAP and press 'FO'. The newly determined values of “field offset” (pointing offset in the image plane, in mm) are displayed in the lower-right part of ICS GUI. Typical values of FO are under 5 mm.

### 3.3 Guide-star acquisition

Acquire two guide stars and close the tip-tilt loop. See detailed instructions in Sect. 4. The “slider” display in the middle of the ICS GUI shows that the M3 position is changing in response to the tt control signals.

Once the tt loop is closed, also close the mount loop to off-load M3 tilts to the SOAR mount. Telescope operator should verify that the TCS is receiving correction “pulses” from SAM.

### 3.4 LGS acquisition

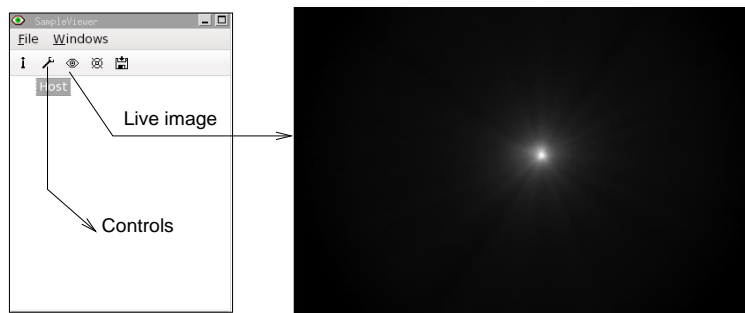


Figure 5: LGS acquisition and centering with ACAM. The camera control window (on the left) opens the image display. The un-gated LGS image is a fuzzy spot with some “rays” around it.

Energize the LLT motors (in LGS-TAB; it takes a few seconds). Move the reference-beam mirror in the WFS beam (in the OP-TAB-WFS menu or with buttons in the WFS-TAB). Propagate the laser (open shutter in the LGS-TAB). You will see the fuzzy LGS spot in the ACAM display (Fig. 5). Center it on the green cursor with LLT M1 X,Y motions (arrows in the LLT-TAB). First use the medium speed (..), then the small speed (.). The arrows are inverted: if the LGS is on the right side, press the right arrow to center it. After each correction command, the system becomes non-responsive for a few seconds while the LLT-M1 motors move.

Remove the reference mirror. The WFS should now “see” the laser light (do not forget to arm the range gate and to power the Pockels cell). Close the LLT M3 loop to center the spots. Then close the main AO loop. At this moment the LLT motors are automatically switched off. Wait for at least  $\sim 10$ s to verify stable AO loop operation and then authorize the astronomer to take the data.

### 3.5 Focusing in closed loop

Focusing in closed loop can be skipped if you are sure of the focus. Focus should to be adjusted or checked to compensate for filter thickness in SAMI or when the air temperature changed substantially.

To check the focus, take two sky images with SAMI (exposure 10s to 30s) *in closed loop* with the WFS stage positions of 12 mm and 20 mm, thus bracketing the nominal setting of 16 mm. You do not need to open the AO loop while moving the WFS focus in the WFS-TAB.

The idea is that two intentionally defocused images should have equal resolution if the 16-mm stage setting (in the middle) is correct. Display each image in IRAF (command `mscd`) and measure FWHM of the same isolated star (command `mscexam`). Let  $z_1$  and  $z_2$  be the two stage positions,  $S_1$  and  $S_2$  – the measured FWHMs. Then the correct focus  $z_0$  can be found as

$$z_0 = z_1 + S_1 / (S_1 + S_2) \times (z_2 - z_1) \quad (1)$$

The IRAF script `samifocus.c1` does this calculation assuming that the stage positions are 12 and 20. Just type `c1> samifocus S1 S2` and read the answer.

If the best focus  $z_0$  differs from the nominal value by more than 2 mm, something is wrong. You need to examine (and possibly adjust) the LGS range. To change the WFS stage position by +1 mm, decrease the range by 30 m (with LGS near 7 km).

Once the focusing is done, take the in-focus sky image in closed loop and measure the FWHM of the star. This informs you how well SAM is performing tonight.

### 3.6 Target observation

Once all 4 loops are closed and work stably and the focus is verified, the astronomer can take science data with SAMI. It is almost equivalent to classical imaging, with a few caveats. The SAM operator monitors the loops and informs the astronomer of relevant events.

**LCH interrupts** switch off the laser, typically for less than a minute. Time remaining until the next interrupt (in seconds) is displayed in the middle-right part of ICS GUI. The number turns yellow 60s before the interrupt. The science exposure should be stopped or paused, the DM and LLT loops should be opened before the laser switches off. Otherwise, the DM voltages usually go into saturation (to fix this, just open the AO loop). When the laser comes back, it is usually sufficient to simply close again the LLT loop (spots appear in the WFS), then the AO loop. Sometimes you will need to re-acquire the LGS using ACAM (Sect. 3.4).

**Recording loop data** during normal science operation is always a good idea (to document SAM performance and gather statistics). To do this, go to the OP-TAB-AUX menu and use the command `REC`. Record loop data on each target at the beginning, then every 0.5 hour or so.

**Unexpected malfunction** may happen for several reasons. Insecure connection to the TCS causes the loss of tt guiding, the WFS flux may drop due to cirrus clouds, the AO loop may go wild (diverge) because of this, etc. All such events require actions on the part of SAM operator to bring the system back to normal operation (Section 6).

**Dither** of science images may be required. To dither, go to the ADC-TAB, enter the dither value in arcseconds. It has be small (e.g.  $2''$ ), so that the displacements of guide probes do not bring them outside allowed range. This risk is higher if one of the GPs is already close to the edge. To dither, simply press the arrows in the ADC-TAB and watch how the tt loop is opened, probes and telescope are moved, and the loop is closed again automatically. The dither takes about 15 s, during this time no science data can be taken.



**Open-loop observations** are possible, with some precautions. You need to tune the DM and focus the telescope for optimum OL performance. After pointing the target, do ROTFLAT in the OP-TAB-DM menu (this compensates for the natural DM flexure at current Nasmyth rotator position). Use the LGS in open loop (but with the closed LLT loop) to measure the defocus ( $a_4$  coefficient is displayed under the WFS image in the upper-right part of the ICS GUI). If the telescope is well focused, the coefficient fluctuates around zero (estimated average less than  $\pm 0.3$  microns). If the average is not zero, adjust the SOAR focus (apply offset in ADC-TAB). If  $a_4 > 0$ , apply positive focus offset, roughly 50-100 times the  $a_4$  value. The tt loop must be closed!

**ADC** is not normally used with SAM, but is available if needed. The caveat is that ADC distorts the measurement of the field offset, so it should be removed during pointing. Once the guide stars are acquired, you can move the ADC IN and use AUTO SET command in the OP-TAB-ADC menu. Do not forget to move the ADC OUT for the next target!

**Clouds** or strong high-altitude turbulence (hence poor resolution) can make observations with SAM worthless. In such cases, switch to the backup science program.

### 3.7 Ready for the next target?

Once the observations of the target are finished, the SAM operator prepares for the next target. Open all loops (the button OPEN ALL LOOPS does this). Close the laser shutter in the LGS-TAB. Switch off the high voltage of GPs and move them out of the field. To do this, you can use the item DONE TARGET in the OP-TAB-DM menu. This script also moves the reference mirror in the WFS IN, preparing for the next LGS acquisition.

### 3.8 At the end of the LGS night

Close laser shutter. Switch off the laser diodes, then the 220V power to the laser (in LAS-TAB). Run the SLEEP script (available in the OP-TAB-SHUTTER and OP-TAB-AUX menus). This script turns off the Pockels cell gating and switches off its high voltage. It switches off the high voltage to the GPs and moves them to the park positions. The DM voltage is set to zero. The ACAM is powered off (the live-display image disappears). The SAM environmental shutter is closed. Finally, the script energizes the LLT, closes its shutter, and turns the LLT power off. Watch the messages to make sure that the “sleep” sequence finished successfully, otherwise do it manually.

The SAM operator has to switch off the power to the DM driver, the Pockels cell driver, and the APD power supply in the `soarenv:1` power control GUI.

Call the LCH to announce the time when the laser operation stopped. Do not forget to submit the end-of-night report.

### 3.9 At the end of SAM run

The last night of the SAM run is over. Exit ALL software of SAM (otherwise the modules stay connected to the TCS, increase the communication load, and may interfere with operation of other instruments). However, do not switch off SAM computers!

Go to `soarenv:1` and switch off all SAM hardware, except the PXI chassis (the chassis runs always).

Go to the IR platform, turn the key in the laser rack off, remove it, and leave hanging.

## 4 Acquisition of guide stars (details)

Acquisition of guide stars in SAM is one of the most difficult tasks, owing to the small capture field of each probe – only  $3''$ . Accurate determination of telescope pointing through field offset (see Sect. 3.2) is the key to success.

### 4.1 Field geometry and GMAP software

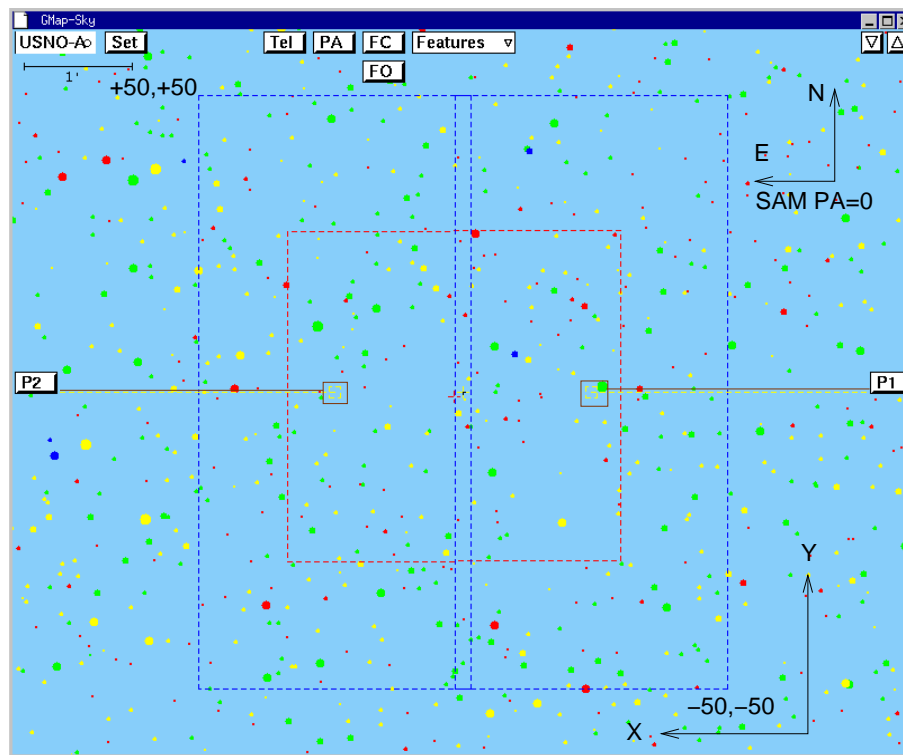


Figure 6: Sky map displayed by the GMAP software and the geometry of the SAM guide probes.

Invoke the GMAP software by the button **GMAP Catalogs** in the GS-TAB of ICS. A small grey window appears. In this window, select the **Skymap** from the File menu to display the stars.<sup>4</sup> This display is shown in Fig. 6. Click on the **TEL** and **PA** buttons to refresh the pointing. Select **USNO-A** from the catalogs menu in the upper-left. You can adjust the scale by the small up/down triangles in the upper right corner. When the SAM position angle on the sky is  $0^\circ$ , North points up and East to the left in GMAP. To match the orientation in the SAMI image, invert the X axis in the DS9 display.

The technical (patrol) field of the SAM guide probes has a size of  $100 \times 100$  mm. The X,Y coordinates of the probes (in mm) are counted from the field center, X points to the left (to the East at  $PA=0^\circ$ ), Y points up. The lower-right corner of the patrol field (blue dashed line in Fig. 6) has coordinates  $(-50, -50)$ , the upper-left corner has coordinates  $(+50, +50)$ . The GP1 patrols the first half of the field (negative X), GP2 patrols positive X. The patrol fields of both probes overlap near  $X=0$ . The red dashed square shows the science field of SAMI. The probes can go inside the science

<sup>4</sup>GMAP description at [~SAM/archive/GS3-UserManual-211110.pdf](http://~SAM/archive/GS3-UserManual-211110.pdf)

field, in which case they partially block the image (however, they must not be closer than  $30''$  to the center, otherwise they start blocking the LGS). Current positions of the probes are marked by yellow lines in the display.

## 4.2 Guide probes and their control

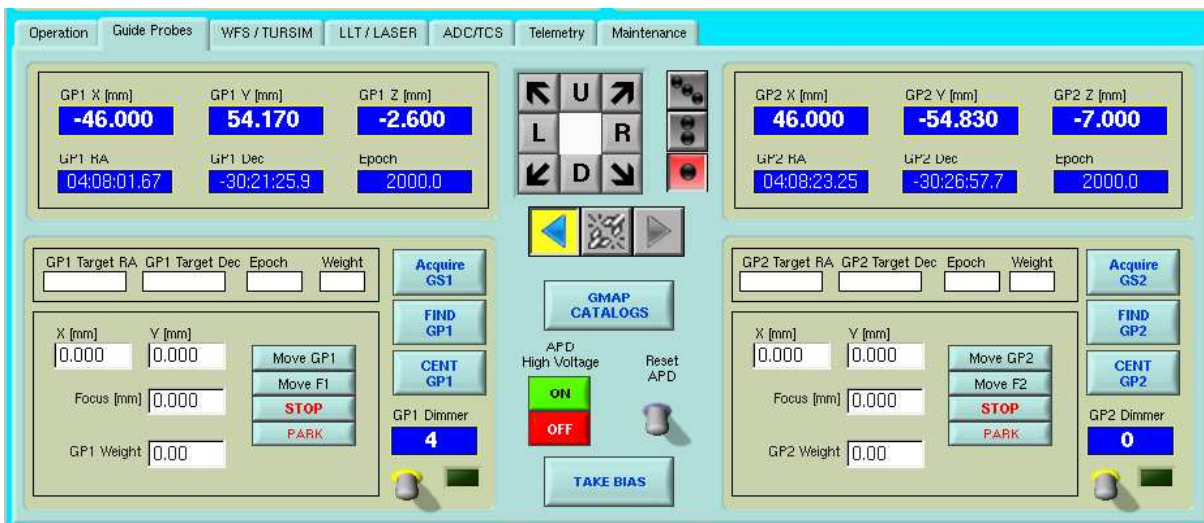


Figure 7: The GP tab of the ICS GUI.

Each guide probe (GP) consists of a  $2 \times 2$  array of lenslets coupled by fibers to the avalanche photodiodes (APDs) which detect the light of a guide star. When the star is centered at the lenslet crossing, the four signals are equal. Normalized differences of the fluxes in two directions,  $e_x$  and  $e_y$ , are the error signals that drive the SOAR M3 during closed-loop guiding.

The APDs detect light (i.e. count photons) only when they are powered (HV switched on). Excessive light can permanently damage the APDs. There is a hardware protection against over-light, but you should not rely on it and operate the probes carefully, avoiding over-light. *Never switch on the HV during daytime and during telescope slewing!*

The control of GPs is done via the GP-TAB (Fig. 7). Its left and right halves refer to the GP1 and GP2, the controls in the middle apply to one or both probes by selecting the option under the arrows (the left-pointing yellow triangle means that GP1 is controlled). To switch on the HV, first press the green button **APD High Voltage**. The upper indicators in the upper-central part of the main GUI (Fig. 4) become green. Then toggle the **Reset APD** switch, and the APDs start counting (the numbers change). With the HV off, some constant negative count is displayed.

When the GPs point to blank sky (or even in the dark), the count rate is not zero. For correct calculation of  $e_x$ ,  $e_y$ , the background signal must be measured. This is done by pointing the sky, switching the HV on on both probes, and toggling the **TAKE BIAS** button in the GS-TAB (Fig. 7). Bias calibration takes few seconds, after this the displayed counts show fluctuations near zero. The bias can change, depending on the sky brightness (especially when the Moon is up), its calibration must then be repeated.

### 4.3 Select and acquire a guide star

Select a suitable guide star in the GMAP (click on it). Useful brightness range is between  $R = 18^m$  (faintest) and  $R = 11^m$  (too bright, can trigger the over-light protection). Remember that the magnitudes in GMAP can be wrong by  $1^m - 2^m$ .

Suppose that the star is in the right half of the field. Click on the P1 button in GMAP to “send” the star coordinated to GP1. Go to GS-TAB and press the **Acquire** button of GP1. The probe will be positioned on the star (see the messages and note the X,Y coordinates of the probe).

Turn the HV of GP1 on. If the probe “sees” the star, the flux will increase and an image of a star will appear in the GP1 window in the upper-central part of the ICS GUI. This image is fake, it only shows conveniently the  $e_x$  and  $e_y$  signals by positioning the fake star in the black square. The signals and the flux are displayed.

To center the star, select the GP1 control and use the arrows in the center of GP-TAB. The medium and low speeds (two and one points) are most useful. Move the probe “towards” the fake star. Each correction takes a few seconds, during this time the arrows are greyed out to prevent further commands.

The tt loop can use only one probe, GP1 or GP2, but normally it guides on the average signal of both probes. Select one or both probes by toggling **Lock GP1** and **Lock GP2** buttons among the loop buttons (near the **SOAR M3** button). When you close the tt loop, the sliders showing the M3 position start to move.

What if we are unlucky and the GP1 “sees” no signal? Then press the **FindGP1** button. This script moves the SOAR M3 on a circular pattern with increasing radius of  $1''$ ,  $3''$ , and  $5''$ . If the star is close, it “sweeps” over the probe and the signal modulation is detected. The probe is moved automatically towards the star, and the message of success is displayed. If it fails, the star is not close to the probe, and it makes little sense to look for it by moving the probe around randomly and slowly.

Note that when we use **FindGP1** or **FindGP2**, the tt loop must not yet be closed (to allow M3 circular motion). So, if you found the star for GP1 and start acquiring the second star for GP2, do not yet close the tt loop!

If you guide on two stars, the system tries to keep the average error signal near zero. When the centering of the probes is not accurate, we see that the two fake stars are displaced from the center in opposite directions. To correct, move one of the probes slightly (no need to open the tt loop). But never move the GPs during science exposure, this will smear the image!

### 4.4 What can go wrong with GS acquisition?

A failure to acquire guide stars happened in SAM more than once, for various reasons.

Most likely, the field offset was wrongly determined because either (i) the star was not identified correctly between the GMAP and SAMI image or (ii) the star had wrong coordinates, e.g. it moved away since the catalog was made.

The correspondence between the coordinate origin (X,Y=0,0) in the GP plane and pixels in the SAMI is given by the parameters **SAMIFCX**, **SAMIFCY** in ICS (they are written in the **icsoft.ini** file). These can change because of temperature, flexure, or DM tilt. It is a good idea to verify the field center before the run by taking the image of a fiducial source in GP1 (Sect.5.5).

Set the rotator angle at 0 and issue the **ROTFLAT** command in the OP-TAB-DM menu. Place GP1 at the center by the **Center-GP** command in the OP-TAB-GP1 menu. Turn on the dimmer, set intensity to 4%. Take SAMI image with 0.2s exposure in the  $r$  or  $V$  filter. Display the image in IRAF and measure the coordinates of the “star” (IRAF reports them in un-binned pixels even when binning

is effective). Enter the new coordinates in the command line of the Maintenance tab in ICS:

```
SET SAMIFCX 1891
```

```
SET SAMIFCY 2027
```

The calculated GP positions use the SAM position angle as reported by the TCS. The actual angle might differ by as much as  $1^\circ$ , which leads to an error of  $\sim 1$  mm at the edge of the technical field. Note that the angle between the SAMI Y-axis and the GP Y-axis is only  $0.14^\circ$ .

The guide star selected from the GMAP-USNO catalog may not exist on the sky! Try a different star. Or, better, try a different catalog (e.g. load the 2MASS catalog from on-line server in the catalog-selection menu of GMAP).

If the scripts `FindGP` report failure, it usually means that there is no star in the vicinity of the GP.

## 5 Calibrations and tests

For training and troubleshooting, a number of useful procedures can be performed, as covered briefly in this Section.

### 5.1 WFS bias

Open “remotely” the RTSoft WFS GUI by using the buttons on top of the ICS GUI. Select `Tools -- Bias calibration` and run the calibration while the WFS receives no light (e.g. when the laser is shuttered or the reference mirror blocks the beam). This image is subtracted from every WFS frame, so it is important to get it right. As the bias is not very stable, we recommend to re-calibrate it every night.

### 5.2 TurSim

SAM has a built-in simulator of the laser source, TurSim. It is used for checking the health of the AO system and for internal flattening of the DM.

Deploy the TurSim arm by the command `TurSim-In` in the OP-TAB-TurSim menu. Set the LGS to 7 km with a wide gate of 0.5 km to get more photons (in the WFS-TAB). If the laser is off, use the `Auto` setting in the same TAB to simulate laser sync pulses. The “star” should be visible in the WFS. If it is not there, deploy the reference mirror (WFS-TAB, button `Ref. BEEAM IN`), center the source with ACAM, and move the mirror out again.

Center the source roughly by the “jog” arrows in the WFS-TAB, trying to get the first two Zernike coefficients (as displayed under the WFS spot image) under 0.5 in absolute value. Note that the jog directions change.

Close the AO loop and watch how the  $a_4$  (defocus) becomes zero, while  $a_2$  and  $a_3$  are not affected. You can also simulate turbulence by moving in the `Disk#1` and making it rotate with 40% speed (by commands in the OP-TAB-TurSim menu). Recording the loop data and WFS spots (command `REC` in OP-TAB-AUX menu) can be done to document the loop performance. Do not forget to move the disk out and to stop its rotation.

### 5.3 Flat DM

While the AO loop is closed on TurSim (without any disk in the beam), you can record the “flat” DM shape. Use the command `Record as flat` in the OP-TAB-DM menu. Always record flat with the

rotator angle at  $0^\circ$ , otherwise the correction of the DM flexure will not be right. Also try to record the flat after the DM had been powered and kept “flat” (or working in closed loop) for about 30 min or more. This is important because the DM has a hysteresis and creep.

The DM focus depends strongly on temperature, so a “flat” recorded on one day can show defocus on another day. Exact calibration of the flat DM is important only for observations in the open loop (in closed loop, the DM shape is adjusted automatically).

## 5.4 Interaction matrix

When the TurSim source is in the beam (without disks) and centered and the DM is reasonably flat ( $|a_4| < 0.2$ ), you can measure the reaction of the WFS to the changing voltage on each DM electrode. This is called *interaction matrix* and used to control the AO loop.

Open remotely the RTSoft AO Loop control GUI (topmost buttons in the ICS), select the Interaction matrix calibration from the menu, and execute it with 5 V amplitude. Watch how the spots move when the electrodes are “poked”. When this operation is finished, you need to save the interaction matrix, to compute the new reconstructor (use threshold of 0.01), to apply, and to save the reconstructor. All these operations are done from the same AO loop RTSoft GUI. Close it when done.

## 5.5 Imaging GP1 with SAMI

The guide probes have fiducial light sources that can be projected inside SAM and imaged with SAMI. This helps to check the quality of the optics (including the “flatness” of the DM) and to determine the correspondence between SAM pixels and GP coordinates.

Set the rotator angle at 0 and issue the ROTFLAT command in the OP-TAB-DM menu. Place GP1 at the center by the Center-GP command in the OP-TAB-GP1 menu. Turn on the dimmer, set intensity to 4%. Take SAMI image with 0.2 s exposure in the  $r$  or  $V$  filter. If needed, adjust the focus of the GP1 ( $z$ -coordinate) to get the sharp image. If the FWHM of this “star” is less than 2.5 un-binned pixels, the SAM optics is tuned well.

# 6 Troubleshooting

Tips are given in this Section for solving common problems occurring during SAM operation.

**SAMI gets “empty” sky image.** Check the output selector mirror on OP-TAB, verify that SOAR and ISB are configured for SAM.

**LGS is not seen.** Check that the laser is powered (both 220V and diodes) in LAS-TAB, that both shutters are opened, and that the LCH status is “green”. Check that the LLT cover is opened. To verify that the laser is actually emitting, go to the SLGM GUI and see the signal of the LLT M2 photo-diode (should be around 2.4). If you do see the LGS with ACAM and can center it, but see no spots in the WFS, check the Pockels cell settings (HV and range gate). To test the Pockels cell, use the reference beam in the WFS (OP-TAB-WFS menu) or TurSim.

**Laser power control does not respond to the commands.** The control of the laser 220V power is capricious, insist by repeating the command. Sometimes the status of 220V laser power is reported wrongly.

**A motor refuses to move** when commanded, the message “Command rejected on state active” appears in the ICS GUI. Open the AOM GUI, select the motor, and issue the **Stop** command. This usually fixes the problem. If not, try exiting AOM and re-starting it again.

**“Crazy” counts in the APDs** are displayed in the ICS GUI even when APDs are not powered. This happens when the PXI chassis is not connected to the RTC. Power-cycle the chassis, reboot the RTC, start again RTSoft.

**AO loop diverges** (voltages on the DM go to saturation, spots disappear). Is the LGS still on, or shut down by the LCH? Check that the DM driver is powered (look in the SAM rack if necessary). Check that the LLT loop is closed *before* the AO loop, so that the spots are well centered. If the loop diverges still, check that it works with TurSim (Sec. 5.2).

**Tip-tilt loop diverges** when the information on the SAM position angle received from the TCS is wrong. This happens rarely. Try to close the loop again, repeat the last science exposure that was spoiled by divergent tt (stars with “tails”).

**Mount offoad does not work:** the SOAR operator does not see the corrections in the TCS GUI, the SOAR M3 sliders slowly drift to saturation. The reason is in SOAR TCS, its fixes are not documented so far.

## 7 Other topics

To be covered here or in separate documents: SAM checklist, SAM cheat sheet, LCH communication instructions, Observing Tool.