# User manual for offset guiding with the HJST coude autoguider

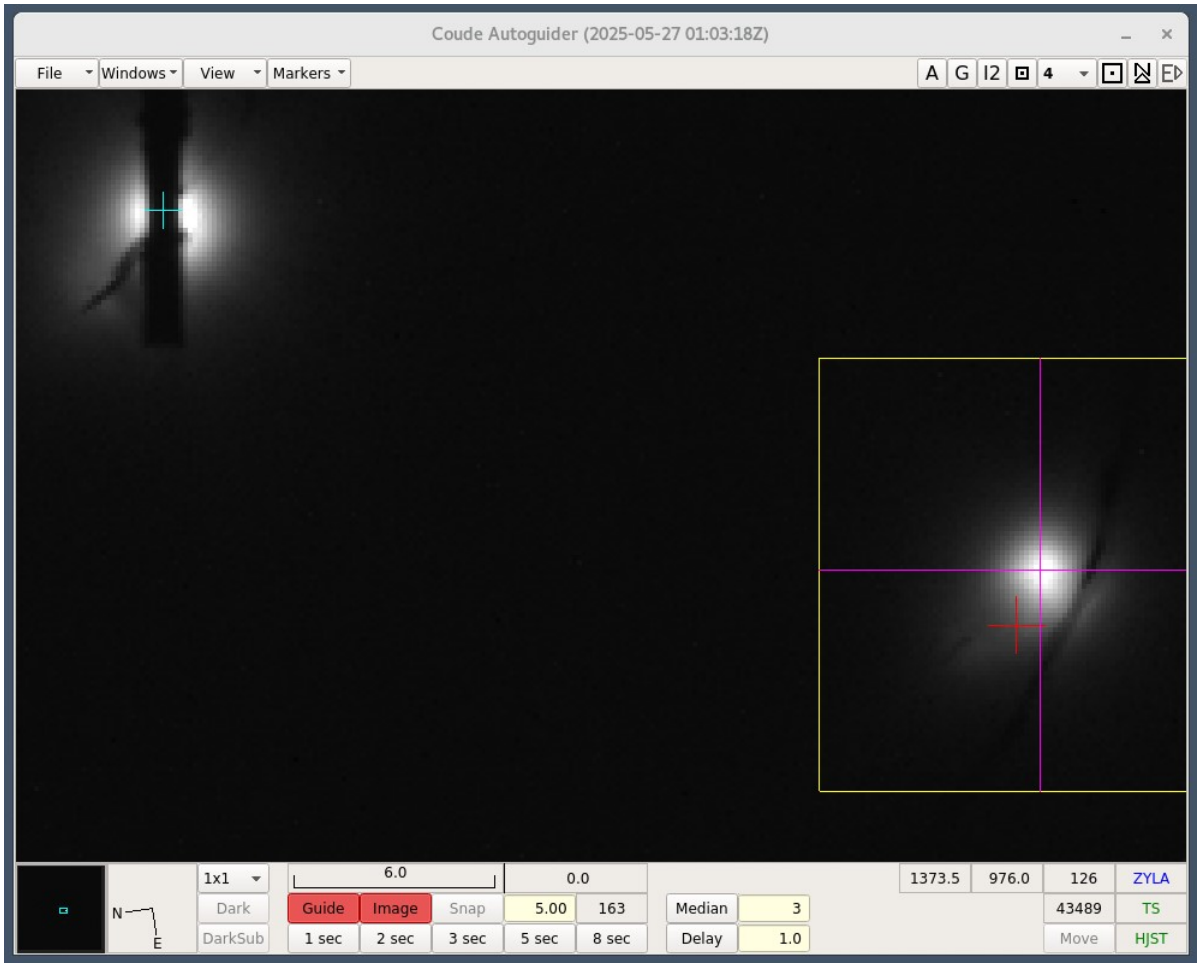


**Figure 1:** A science target star on the center of the spectrograph slit (cyan marker) with a guide star on the guiding fiducial (magenta marker) within the yellow guide box. The guide star was on the red marker when off-axis guiding started.

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## 1 Introduction

TS2 on the HJST (Tull Spectrograph 2 on the Harlan J Smith Telescope)is primarily used for observing stars. The spectrograph autoguider keeps the star being observed on the spectrograph entrance slit by using the light of that star that does not go through the slit into the spectrograph. Please see the manual on the autoguider. Guiding on the program star is an advantage due to the spectrograph entrance slit being at the coude focus of the telescope. At a coude focus the image rotates about the center of the field by 360 degrees in one sidereal day (23hr 56min). The TS2 slit is located at the center of the field rotation, and so the axially symmetric image of the star rotates around its center and so the guider does not have to account for image rotation.

Observing a single star is a special case. The generalized case would be wanting to observe some arbitrary point embedded in a complex image. An example (see figure 2) would be observing the location of a black hole in the core of a globular cluster, which is likely a confused image location unsuitable for guiding. In this case offset guiding can be used. The location of scientific interest is centered on the slit and the guiding is done on an isolated star somewhere out in the field of view. In off-axis guiding mode, the autoguider will compensate for the field rotation that is causing the off-axis guide star, as seen over time, to move in a circle around the central slit.

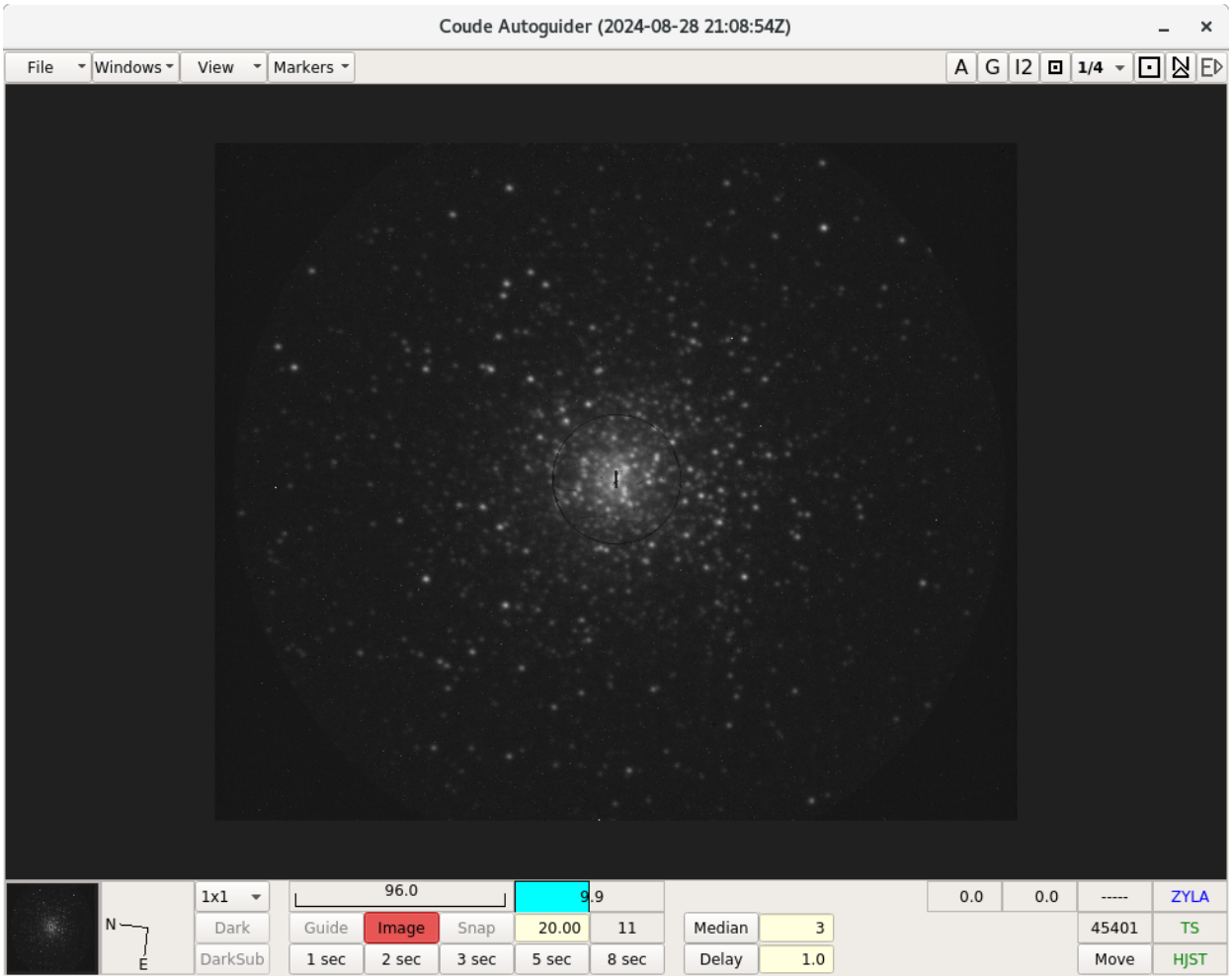



**Figure 2:** a guider image of globular cluster M15. An isolated brighter star in the outer field can be used for off-axis guiding when any particular point such as the black hole location in the cluster core needs to be observed.

## 2 Basic operating procedure

Five steps are used in the autoguider software to configure and use offset guiding. This procedure is fairly simple and quick, but it does take quite a few words to describe with some thoroughness. The five steps are:

1. A marker called *Slitcenter* is accurately placed in the guider image on the center of the slit. This is usually done during afternoon setup of the instrument
2. The observer moves the telescope to accurately place the target location on the *Slitcenter* marker location
3. The observer selects a suitable guide star somewhere in the guider image and draws the guide box around that star
4. The observer enables the offset guiding mode, and starts the guiding
5. The observer performs checks on the guiding

The details of these steps are in the following subsections. The order of the operations is important.

### 2.1 Procedure for setting the *Slit* marker (step 1 of 5)

- During the afternoon make sure the guider is in focus with the guide filter that will be used at night (see the guider manual for that procedure)
- Take a guider image using either 1) the telescope looking at the illuminated dome per the guider focus procedure, or 2) the Th-Ar lamp in the calibration system. Make sure the integration time is long enough that there are at least 7,500 data units (DUs) of signal in the image near the slit
- Zoom in on the spectrograph slit in the guider image so individual pixels can be seen (see figure 3)
- Place the *Slit* marker accurately on the center of the slit (see figure 3)
    - An initial marker position can be done starting from the *Markers* drop down menu, moving into the *Create* submenu within *Markers*, selecting *Slit* (not 'Slit 1' or 'Slit 2'), and left-mouse-button clicking on the center of the slit in the guider image
    - The *Slit* marker position can be refined using the '*Slit Center Location*' feature at the bottom of the *Settings* window when the *Fiducial* tab is selected (see figure 4). The x and y position of the *Slit* marker can be changed numerically, and the marker position is updated when the adjacent *Set* button is clicked. An accurate position will be set to a few tenths of a pixel.
- Notes
    - The *Slit* marker can be removed from the image display using the *Markers* drop down menu, the *Delete* sub-menu, and clicking on *Slit*
    - If the *Slit* marker has been previously set, then erased from the display, it can be redisplayed using the *Settings* window by clicking the *Set* button for the *Slit Center Location*.


**Figure 3:** A zoomed in image of TS2 slit #4 showing the cyan colored *Slit* marker. The light source used for this image was the ThAr lamp in the calibration system. The various irregular marks around the vertically oriented rectangular slit are scratches due to mishandling of the slit during its lifetime.

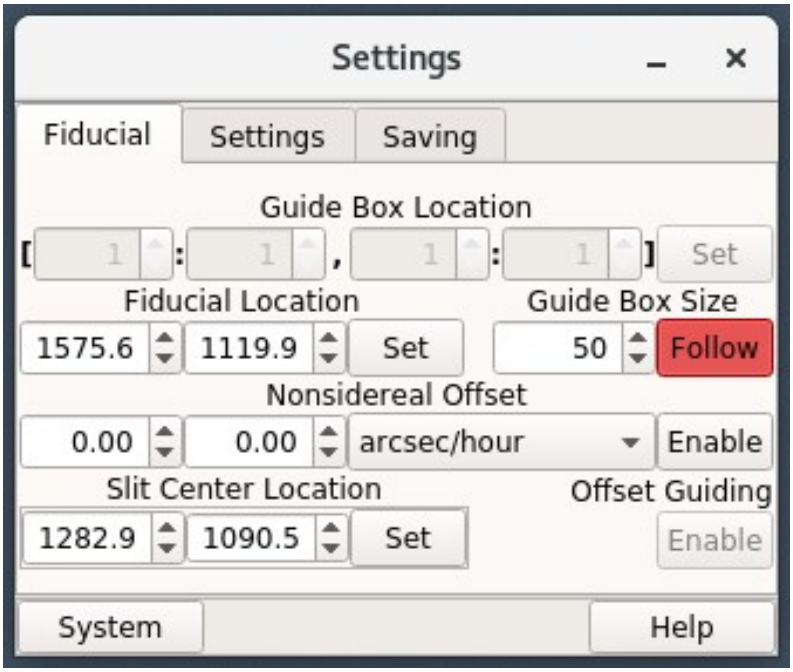



**Figure 4:** The guider *Settings* window, with the 'Fiducial' tab selected. The *Enable* button for Offset Guiding is greyed out (and so cannot be enabled) at this step in the procedure.

### 2.2 Procedure(s) for moving the science target onto the slit (step 2 of 5)

Different procedures are used to move different types of target onto the slit or Slitcenter marker. Below are three common types, where numbers 2 or 3 will normally be used for offset guiding.

1) **Move Centroid to Fiducial**
   If the science target is an isolated star for which a centroid position can be reasonable determined, and if the guider fiducial is defined (the magenta cross-hair in the yellow guide box), then position the mouse pointer on or close to the center of the star, hold the Control key down, and right mouse click. This will cause the telescope to move the centroid position of the star to the position of the fiducial. This procedure is normally used for guiding on the star to be observed (with the guiding fiducial centered on the slit).

2) **Move Mouse-pointer-position to Slitcenter marker**
   If the science target is a position in the image where there is object confusion, then zoom in on the required target point, accurately position the tip of the mouse pointer on that target point, hold down the Control and Shift keys, and right mouse click. The telescope will move the mouse pointer position to the *Slitcenter* marker position.

3) **Move Centroid to Slitcenter marker**
   If the science target is an isolated star for which a centroid position can be reasonable determined, and if the *Slitcenter* marker is defined, then position the mouse pointer on or close to the center of the star, hold the Control and Alt keys down and right mouse click. Then, position the mouse pointer close to the center of the *Slitcenter* marker and again do Control-Alt-right-mouse click. The telescope will move the centroid position of the star to the *Slitcenter* marker.

### 2.3 Designating the Guide star (step 3 of 5)

Soon after step 2 is complete the guide star should be designated with these three steps:

1) Select a guide star based upon the suggested criteria given below
2) Draw a guide box roughly centered upon the guide star (see below)
3) Refine the size of the guide box if necessary based upon the criteria given below

Criteria for the guide star include:

1) The star should be bright but not saturated (its core should be less than about 55,000 DU)
2) The star should be sufficiently isolated in the field so that no other bright object is within at least 25 pixels, and better 35 or 40 pixels
3) Given a choice of guide stars, probably choose the star closest to the slit

Creating the guide box and guide fiducial

1) Position the mouse pointer very appropriately 30-50 pixels aways from the guide star to the star’s upper left
2) Click and hold down the left mouse pointer
3) Drag the mouse to approximately 30-50 pixels away from the guide star to the star’s lower right
4) Release the left mouse button
5) A yellow rectangle should now be seen around the guide star with the magenta guide fiducial (cross-hair) centered on the guide star (see the image on the cover page)

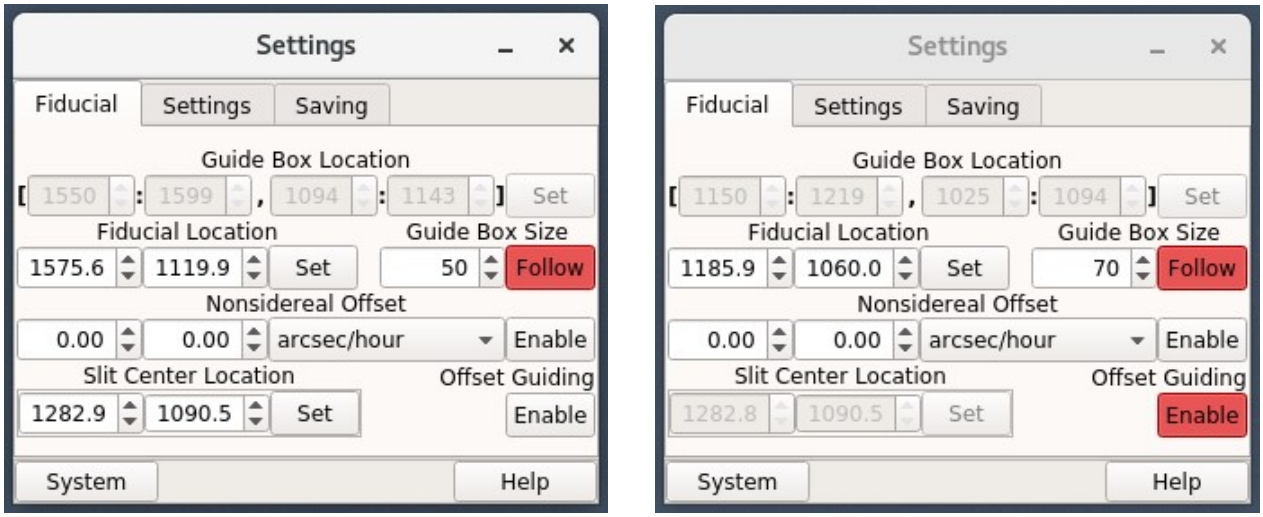
6) If the *Follow* button is pressed (Red) on the Fiducial tab of the Settings window the guide box will snap to a square shape centered upon the guide star, and the box's dimensions will be the *Guide Box Size* number seen next to the *Follow* button

Criteria for the yellow guide box size

1) The only significant object in the guide box should be the guide star. Any other objects or background in the guide box should be much fainter than the guide star
2) The full star image should be in the box and there must also be some dark background pixels within the box (at least 3x, and better, >10x the number of background pixels relative to the number of guide star pixels)
3) A normal guide box in an uncrowded field is about 80-100 pixels in size. In a crowded field the guide box may need to be small to exclude other nearby objects. A 70-pixel down to about 50-pixel guide box size may sometimes be needed
4) Adjust the guide box size by modifying the *Guide Box Size* number on the *Fiducial* tab of the *Settings* window. The Up and Down arrows can be clicked to change the size, or the number can be highlighted and overwritten. Once the number has been changed, click the *Set* button to the left of the number

### 2.4 Starting guiding (step 4 of 5)

1) Once the guide box has been created in the previous step, the *Enable* button for *Offset Guiding* on the *Fiducial* tab of the *Settings* window will no longer be greyed out (see figure 5a). Click that *Enable* and it should turn red (see figure 3b), allowing offset guiding
2) Click the *Image* button at the bottom of the main guider window if it is not already red (see figure 1). A suitable integration time are not less than 5 seconds.
3) Click the *Guide* button at the bottom of the main guider window so it turns red (see figure 1)
4) Make sure the parameters governing the guiding are set reasonably. They are in the *Settings* tab of the *Settings* window as shown in figure 6. These values are normally different for offset guiding compared to on-slit guiding. Pay attention to *Percentage of Correction Used*, and *Maximum Correction*. Reasonable values are 50% and 0.4-0.5 arcsec, respectively.
5) Click the *Clear* buttons on each of the guider windows titled *Scatter Plots* and *FWHM Plot* (figure 7). These plots give useful information on telescope tracking and guiding, plus seeing conditions




**Figures 5a and 5b:** the *Settings* window with *Offset Guiding* able to be enabled (left), and enabled (right). When enabled the *Slit Center Location* is greyed out to prevent the location being changed.

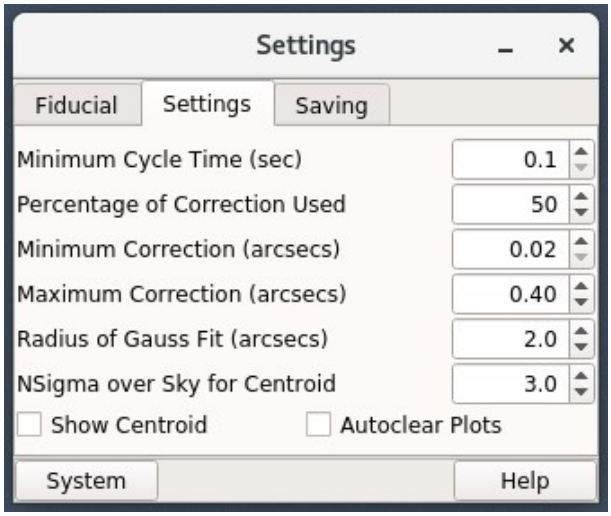



**Figure 6:** The *Settings* tab of the *Settings* window. Image quality degradation due to image motion (the image bouncing around a little from image to image) can be minimized with suitably chosen values of *Percentage of Correction Used* and *Maximum Correction*. The power spectrum of the image motion peaks around 0.5 to 1 Hz, so to average the image motion in each guider image the minimum guider integration time while guiding is recommended to be 5 seconds (sometimes more). The previously mentioned parameters should not be too high, otherwise the guider will chase the image motion out of phase, degrading the image quality.

### 2.5 Checks on the guiding (step 5 of 5)

Better quality guiding can be achieved by paying attention during guiding to these two details:

1) The centering of the science target on the *Slitcenter* marker
2) Optimizing the telescope track rate

The details of these steps are in the following subsections.

#### 2.5.1 Adjusting the science target centering while guiding

While guiding the observe might notice by watching multiple guide images that the science target isn't quite on the *Slitcenter* marker. The guiding can be adjusted to center the science target, and the observer might choose to make such an adjustment. Here is an example:

The target appears on average to be 2 guider pixels left of the *Slitcenter* marker. The observer may choose to:

1) Click the Offset Guiding *Enable* button in the *Settings* window (it will go from Red to Grey)
2) Edit the X (left) value of the *Fiducial Location*, increasing it by 2 pixels
3) Clicking the *Set* button for the *Fiducial Location*
4) Clicking the Offset Guiding *Enable* button

After 3-or-4 guide cycles the target should have moved onto the *Slitcenter* marker. Do this procedure quickly, preferably within a single guider integration time. Don't bother adjusting the position for moves of about a pixel or less.

### 2.5.2 Adjusting the telescope track rate

Better guiding can be achieved by making small adjustments to the telescope track rate. The track rate is a weak function of where the telescope is pointing and the telescope temperature. A procedure for this follows.

1) Clear the *Scatter* plot after guiding has started by clicking *Clear*
2) After a number of guide corrections have been made (say >20), estimate the left-right centering of the cloud of data points on the *Sky* scatter plot (see figure 7, where the cloud is reasonably centered on the origin, indicating a good track rate)
   a. If the center is to the left of the origin, the average RA correction has been negative, which is the guider systematically trying to decrease the RA, equivalent to trying to move the telescope farther west. This means the telescope is tracking too slow and the track rate needs to speed up
   b. By similar logic, if the center is to the right, the telescope is moving too fast, and the track rate needs to slow down

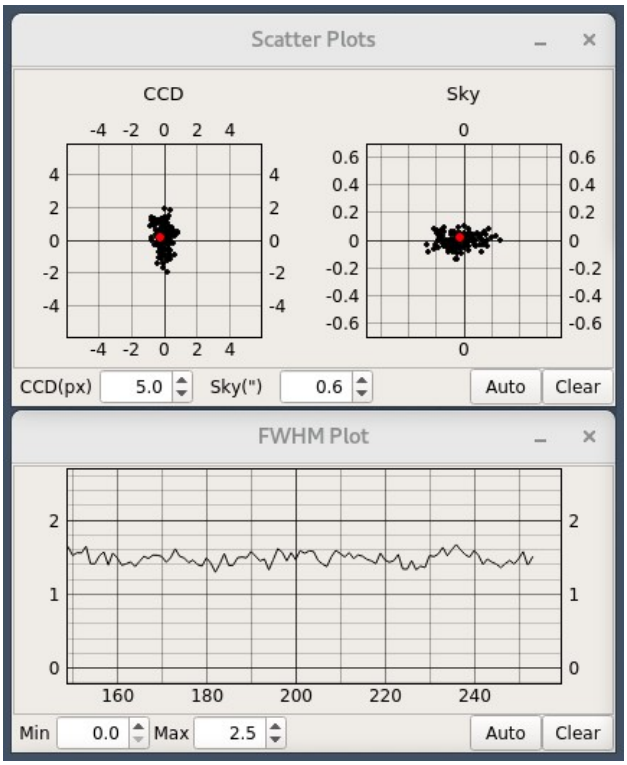



**Figure 7:** Guider *Scatter* and seeing Full Width at Half Maximum (*FWHM*) plots. The scatter plots show the pointing corrections sent to the telescope, with the latest correction shown in red. In the *Sky* plot corrections that move the telescope north are positive, as are corrections that move the telescope east.

3) To adjust the telescope track rate:
   a. click on the *Rate* button (see figure 8) that is lower center on the TCS GUI window. A window will popup titled *Telescope Track Rates*
   b. The value to change is the *HA Rate Multiplier*. Left mouse click in its Value Entry Box, and edit the value. The value will normally be between 1.00120 and 1.00150. The values are often named by the last 3 digits as 120 to 150. Change the value in steps of 5 (and perhaps 10 for large errors), for example, from 130 to 135.
   c. The is important: you must mouse click out of the Value Entry Box somewhere else in the popup window in order for the new value to be used
   d. Click the *OK* button to close the popup window

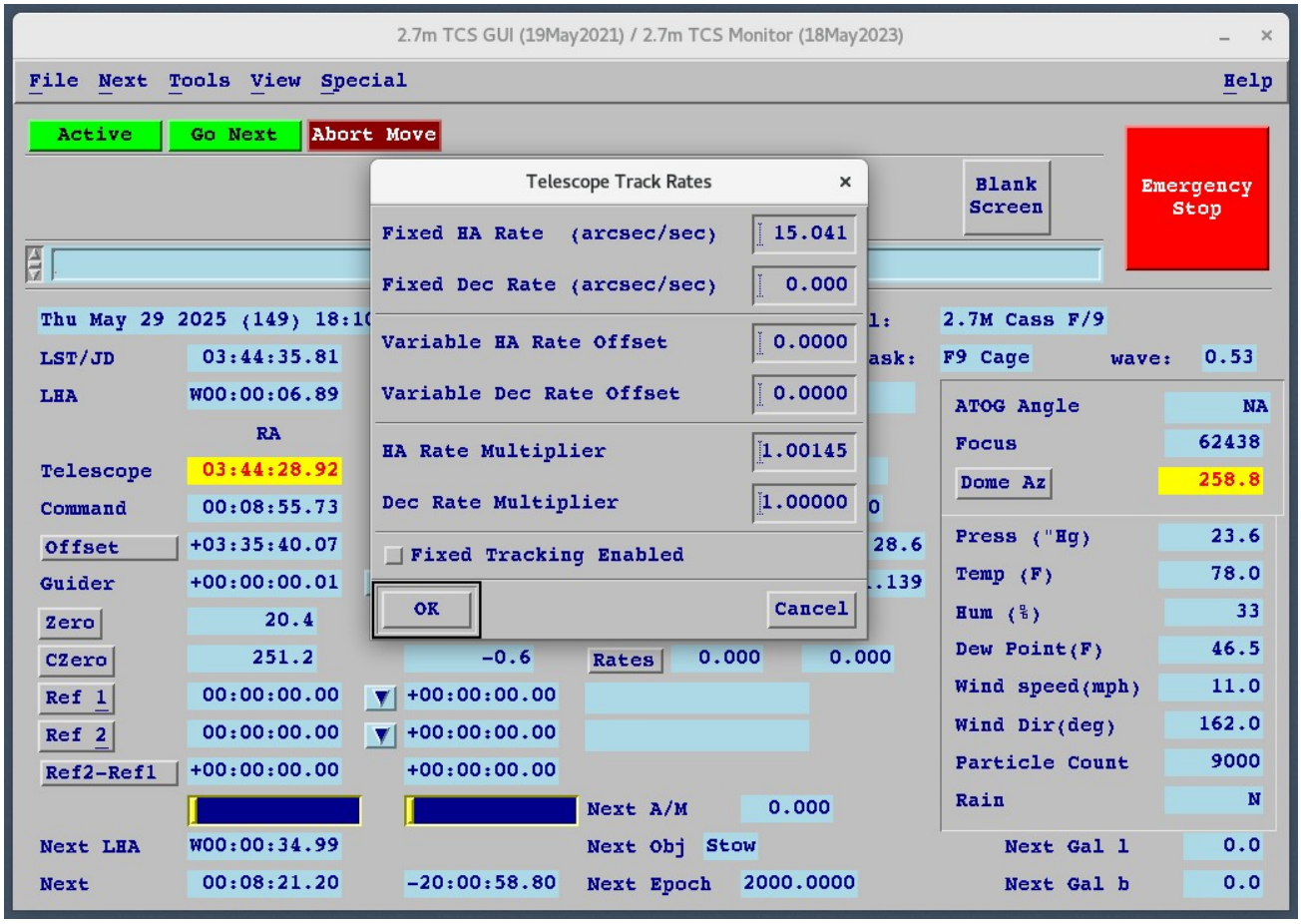



**Figure 8:** The Telescope Control System (TCS) GUI after the *Rates* button has been mouse clicked to popup the *Telescope Track Rates* window. The *HA Rate Multiplier* can be modified to speed up or slow down the telescope tracking. A nominal value is around 1.00130 and the value might range from about 1.00120 to 1.00150

## 3 Other information

1) The field of view rotates anticlockwise as seen on the guider
2) Keep the telescope in focus to avoid the magnification of the image changing too much. Such a change will degrade offset guiding.

## 4 The Project Group

The offset guiding function of the TS autoguider system was designed and implemented in May 2025 by

- Sam Odoms, Senior Software Engineer
- Phillip MacQueen, Senior Research Scientist