PHD2 v2.6.13

User Guide

December 22, 2023

Table of Contents

Introduction

PHD2 is the second generation of Craig Stark's original ***PHD*** application. ***PHD*** became a fixture of the amateur astronomy community with more than a quarter million downloads. From its inception, it has successfully embraced three seemingly conflicting objectives :

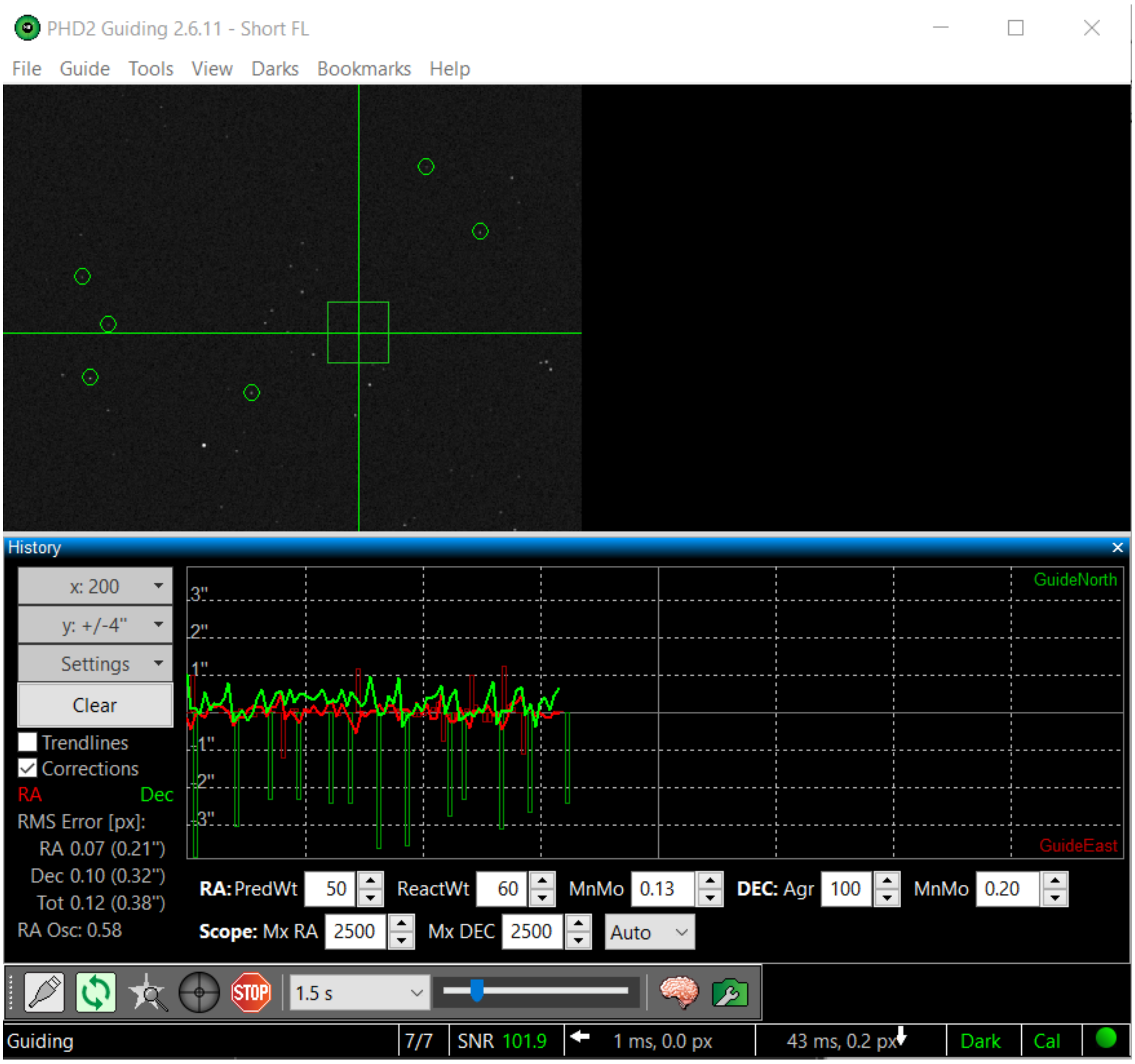
- For the beginning or casual imager, to deliver ease of use and good guiding performance "out of the box".
- For the experienced imager, to deliver sophisticated guiding algorithms, extensive options for tuning, and broad support for imaging equipment.
- For all users, to consistently exhibit a commercial level of quality while being available free of charge.

Since the original code was released to open-source in 2013, it has been completely overhauled to make it more extensible and supportable. With the restructuring in place, substantial new features and capabilities have been added, many of which focus on helping you achieve better guiding results. Users of ***PHD2*** can be confident it will remain committed to the three objectives that made the original application so successful.

Main Screen

The *PHD2* main window is designed for ease of use and clarity. Its intent is to support a quick and natural sequence of interactions to start and control guiding. The basic steps for doing this are as follows:

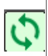
1. Connect to the PHD2 configuration profile that establishes your guide camera and mount connections
2. Start a sequence of guide exposures to see what stars are available in the field of view
3. Let PHD2 auto-select suitable stars and calibrate the guider
4. Continue guiding on the target stars while using various display tools to see how things are going
5. Stop and resume guiding as necessary



The majority of the screen is taken up by the display of the image from your guide camera - under normal nighttime conditions, that will show the stars available for guiding. The display is automatically adjusted for size, brightness, and contrast so you can view the available stars. However, these adjustments are done only for display purposes. Internally, *PHD2* operates on the raw, un-adjusted data in order to maximize guiding accuracy. This display can also be used to manually select a guide star by clicking on it although it's better to use the 'Auto-select star' feature.. You can adjust the slider control to see even the faintest stars in the field.

Basic control

Near the bottom of the screen are the main controls. *PHD2* is largely controlled by these buttons and sliders, with additional pull-down menus at the top of the window for more detailed functions. Moving from left to right in the window, the primary buttons are as follows:

	**Connect equipment button** Activates the PHD2 profile that defines your equipment connections. If you want to connect the same equipment that was last connected, you can **shift-click** this button.
	**Loop exposures button** Starts a sequence of repeated guide exposures with the guide camera (*looping*), with each resulting image (guide frame) being displayed in the display window. If guiding is subsequently started, clicking on the **Loop Exposures** button again will pause guiding while continuing to take guide exposures.
	**Auto-select Star button** Triggers an automatic selection of the best guide star candidates in the display window. This selection is done quantitatively, taking many things into account - star saturation, minimum star size, signal-to-noise ratio, proximity to other stars, proximity to the edge of the display window. etc. You can **shift-click** on this button to de-select the star.
	Guide button

	Starts calibration, if needed, and then starts guiding on the selected stars.
	**Stop button** Stops both guiding and looping.
	**Exposure duration drop-down** A drop-down list of exposure durations in seconds (**Auto**, **0.01s** to **15s**, and a **Custom:** option which you can assign your own value to using the **Edit Custom...** option). Use this drop-down to set the guide camera's exposure duration. If your camera does not support an exposure duration, ***PHD2*** will do its best to emulate that duration. For example, if you use a short exposure webcam, your maximum true exposure duration might be only 1/30th of a second. If you select one second as the exposure time, ***PHD2*** will automatically acquire images for one second and stack them to create a composite image for guiding.
	**Gamma adjustment slider** A slider control for adjusting screen stretch and contrast, essentially a "gamma" adjustment. ***PHD2*** automatically adjusts the display to account for the darkest and brightest pixels in the image, and the slider is used to fine-tune the display to better see the stars. This may be useful, for example, if you are trying to focus the guide camera for the first time and need to see the large, out-of-focus star image. Moving the gamma slider only makes the display brighter or dimmer for your viewing. ***PHD2*** always uses the raw pixels from the camera for guiding, and moving the gamma slider has no effect on guiding. A display of completely white or completely black is usually an indication that no stars are available in the field of view or the camera is out-of-focus. The automatic gamma-stretching of the image is a very common source of confusion for users because they do not adjust the gamma slider properly to see faint stars on the display window.
	**Advanced settings (Brain Button)** This brings up the **Advanced Settings** dialog for making detailed adjustments to the guiding operations. An important design goal of ***PHD2*** is to minimise your need to change these parameters, but there are adjustments available here that can help you understand and improve your guiding.
	**Camera settings buton** Depending on the camera, this button may be enabled to provide access to a configuration dialog unique to the camera.

Menus

The pull-down menus above the main guider display are used to access a variety of functions. These are described in the Darks, Tools and Utilities, and Monitoring Tools sections of this help document.

Status Bar

The status bar at the bottom of the main window is used to display messages and status information that will help you keep track of guiding operations.

Near the center of the status bar are fields showing the current state of the guide stars. The leftmost field shows the number of guide stars currently being managed. In some cases, the first number may be one - that happens during stabilizaton periods and when the guide star list is being re-evaluated. The next field to the right shows the SNR of the primary (or single) star in the guiding star list. If the SNR value drops below 10, its value will be shown in yellow as a warning that you may encounter some 'lost-star' events. In single-star guiding mode, if the guide star is saturated, the field to the left of SNR will show 'Saturated' in a red typeface.

To the right of the star status fields are two text fields showing the latest RA and Dec guide commands. These show the size of the guide pulse, the guide star displacement size in pixels, and an arrow showing the direction. The arrows follow the usual compass conventions: Dec up/down corresponds to north/south, RA left/right corresponds to west/east. All of this information is captured in the log files and displayed in the various graphical tools, and those are what you should use for visualizing your guiding performance. These status fields are there only to give you a quick visual clue when something is behaving unusually.

The rightmost panels in the status bar show icons that give you visual clues about the current state of PHD2. These icons are color-coded to give you a dashboard view of current status and have the following meanings:

'Dark' - red means neither a dark library nor a bad-pixel map is being used, green means one or the other is in-use. If you're using a bad-pixel map, the text will say 'BPM' rather than 'Dark'

'Cal' - shows the state of calibration. Red means the mount is currently uncalibrated, while yellow means there is a calibration but it isn't being adjusted automatically to account for scope pointing position. This will happen when you aren't using an ASCOM or 'aux' mount connection in PHD2 or if you have mistakenly disabled declination compensation. If the icon is yellow, you will generally need to recalibrate when you move the scope to different declination positions.

"The Ball" - shows whether all the equipment in your profile has been successfully connected. If the ball is yellow, some components are not connected, while green means everything is connected.

If you hover the mouse cursor over any of these status icons, you'll see details about the current state.

Using *PHD2* Guiding

There are five basic steps to start guiding.

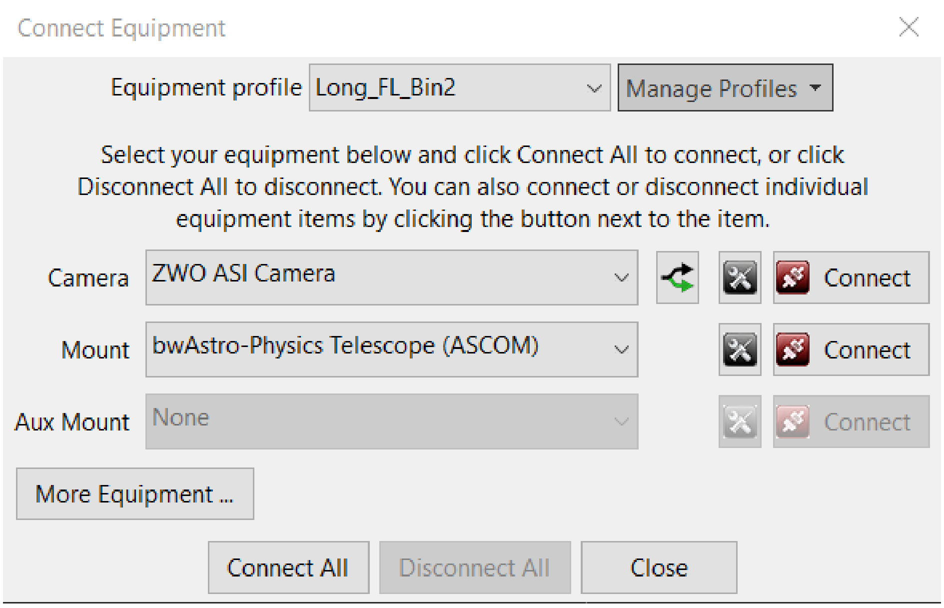
1. Open the Connect Equipment dialog by pressing the USB-icon button and select the configuration profile you created with the New Profile Wizard. Connect to the camera and mount.
2. Pick an exposure duration from the drop-down list.
3. Hit the loop button and look at the available stars, adjusting focus if necessary. Move the mount or adjust the exposure duration until you can consistently see usable stars.
4. Click the 'Auto-Select Star' icon to choose the best guide stars available.
5. Press the *PHD2* Guide button.

Details of these operations will be described in the sections below.

- Equipment Connection
- Exposure Time and Star Selection
- Calibration
- Guiding

Equipment Connection

In order to begin guiding, *PHD2* must first connect to your hardware: the guide camera, the mount, and, optionally, an 'aux' mount, an adaptive optics (AO) device, and a rotator. When you click on the USB icon, you'll see a dialog that looks something like this although the equipment details will differ. The various choices in this dialog are discussed below.



Equipment Profiles

At the top of the 'Connect Equipment' dialog are controls for managing equipment profiles. All of the guider settings in *PHD2*, default or otherwise, are automatically stored as part of an equipment profile. This includes calibration data and the last three Guiding Assistant reports. The only significant data not stored in the profiles are the dark libraries and bad-pixel maps which are stored in the file system. If you have only one guiding setup - you use the same camera and guide scope combination each time - you will only need one profile. But you may have multiple equipment configurations - for example, an off-axis-guiding arrangement for a long focal length scope and a separate guide scope/camera configuration for a shorter focal length imaging scope. The *PHD2* guide settings for those configurations will be different, so you should use separate equipment profiles. The controls at the top of the 'Connect Equipment' dialog let you choose the profile you want to use and to create/edit/remove profiles as you see fit. When you select a profile and connect to its associated equipment, all of the settings last used with that profile are automatically reloaded. Once you've established the profiles you need - perhaps only the default one - you can simply click on the 'Connect All' button and you're ready to move ahead. If you already have a suitable default equipment profile and you simply want to connect to the equipment just as before, you can do a <shift>-click on the main screen 'USB' button and *PHD2* will automatically re-connect to your hardware. Your profile information will be retained when you install new releases of PHD2 so long as you don't first un-install. Un-installing PHD2 is almost never necessary and will simply create complications - it is not a useful trouble-shooting step. More information about managing profiles can be found here: - Managing Equipment Profiles

New-Profile-Wizard

The best way to create a new profile is to use the "Wizard" capability, and for new users, this is a critical first step. The wizard takes you through a sequence of windows that explain the various settings and help you decide how to set them. It will also calculate baseline algorithm settings that are likely to work reasonably well for your set-up. Creating a profile this way is faster and less error-prone than doing it by hand in the 'Connect Equipment' dialog. When you run PHD2 for the first time on your system, this wizard will be automatically launched. Subsequently, you can use the new-profile wizard by clicking on the 'Manage Profiles' field in the 'Connect Equipment' dialog, then choosing 'New using wizard...'.

The wizard asks a number of questions that are important for getting your profile built correctly. The explanatory text in each pane of the wizard should make clear what is being asked and what needs to be done. But here are some additional tips to help you through the process:

1. **Connection Options:** As you make selections for the various devices, you will usually see a prompt asking if the device is already connected and ready to communicate with PHD2. If you say 'yes', PHD2 will try to connect and then fill in some of the data fields with information read from the device. Saying 'no' simply means you'll have to enter the data by hand. If PHD2 tries to connect with the device and fails, you'll still be able to proceed by just entering the data manually. Device-connection in the wizard is basically a convenience feature that makes it easier to fill in the fields with accurate values. You won't see the prompt if PHD2 already knows the device can't return useful information - for example, if the mount choice is 'on-camera.'
2. Camera connection pane: unbinned pixel size. If you said 'yes' to the connection prompt, this information will usually be filled in automatically and the control will be disabled. If you said 'no' or if the device doesn't report its pixel-size, you'll need to enter the value by hand. You should be able to get the *unbinned* pixel size from the camera spec sheet or the manufacturer's web site. If the pixels aren't square, just specify the larger dimension or the average value if you prefer. This won't have any effect on your actual guiding results, but it will allow PHD2 to know the image-scale for your set-up. This is used for setting baseline guiding parameters, doing sanity-checks on calibrations, reporting guiding performance, and getting support on our forum..
3. **Camera connection pane: binning level.** If your guide camera supports binning (some do not), you can specify what level of binning you want to use for this equipment profile. If you want to use the same equipment set-up with different binning levels, it's best to create separate profiles for each binning value. If your guide camera has very small pixels and you have also specified a long focal length, you may see a 'warning' icon next to the Pixel Scale field. That is telling you the specified image scale is probably too small and you should bin the camera if possible.
4. **Camera connection pane: guide scope focal length**. This seems to be a common place for mistakes, so it's worth being careful and getting it right. The correct value is not the aperture of the guide scope, it is the *focal length*. For example, if you're guiding with a 50mm finder scope, the focal length will not be 50mm - it will probably be something closer to 150-175mm. A 60-80mm refractor guide scope will probably have a focal length in the range of 240-500mm, not 60-80mm. Similarly, if you're guiding with an OAG on your main imaging scope, the focal length will be that of the main scope. In some cases, you may be using a small threaded focal reducer on the guide camera, so that must also be taken into account. Like the pixel-size entry, the focal length doesn't demand a great deal of precision, but you should get as close as you can. Otherwise, the performance numbers may not reflect your actual results and the baseline guiding parameters may be sub-optimal.
5. **Mount connection pane: mount guide speed**. This is another area that seems to cause confusion. **The guide speed is a parameter set *in the mount* or *in the mount driver*, it's not something controlled by PHD2**. PHD2 never sets the mount guide speed, it only reads it. It is usually expressed as a multiple of the sidereal rate and is typically in the range of 0.5x - 1x sidereal. Despite what you may read elsewhere, it's usually best to use guide speeds in this range rather than much lower speeds. Higher guide speeds can help to clear backlash more quickly and may help to overcome stiction problems. If you say 'yes' to the connection option prompt, PHD2 will attempt to read the current guide speed from the mount. If this fails for some reason, you'll need to enter the guide speed manually. PHD2 uses this value to automatically set the calibration step-size and to aid in checking calibration results; but the guide speed information is not important for the actual guiding. If you're using different guide speeds on the RA and Dec axes, enter the larger value. If you really can't determine what the guide speed settings are in the mount, leave the setting at the default value of 0.5X. This pane also has a checkbox regarding the presence of high-precision encoders in the mount. These devices are sometimes included on expensive, high-precision mounts, and you are likely to know if you have them. Most users will leave this box unchecked.

In the last pane of the wizard dialog, you're given two options: 1) To automatically restore the PHD2 calibration whenever the profile is loaded and 2) to immediately build a dark library when the new profile is saved and the wizard completes. The first option is only presented if your profile uses an ASCOM or INDI mount connection. It is a convenience item especially for users with permanent setups. You can also use this option if you can insure that the guide camera orientation in its adapter tube remains the same from one night to the next. If you're in doubt or don't want to bother with how the guide camera is oriented, leave the box unchecked. You should always select the option to build a dark library unless you already have a compatible dark library that you're going to import from a different profile. If you are changing cameras and want to keep the dark libraries and bad-pixel maps associated with the old camera, you should create a separate profile for the new camera. When a camera selection is changed in an existing profile, the previously built dark library and bad-pixel map data will no longer be usable. That also applies to using the same camera with different binning values. Setups using different binning factors should be kept in separate profiles because the dark library and bad-pixel maps depend on the binning factor.

Camera Selection

The Camera drop-down list shows all the camera types natively supported by *PHD2* in addition to all the ASCOM cameras you have already installed. In all cases, the OS-level drivers for the camera must be installed correctly in order for PHD2 to connect to the device. If the camera uses an ASCOM interface, you'll also need to install the corresponding ASCOM driver for the camera. If you don't see your ASCOM-compatible camera shown in the drop-down list, you probably don't have the ASCOM driver installed. Neither the ASCOM nor OS-level drivers are included with PHD2, so they must be located, downloaded, and installed separately. For non-ASCOM cameras, the PHD2 distribution does include the additional application libraries (SDKs) needed by PHD2 to use the camera. In some cases, the camera may have both ASCOM and native interfaces and you're free to choose whichever you prefer. In some cases, the two different versions may operate the camera in a slightly different way or expose different sets of camera properties. The camera vendors update their drivers and SDKs frequently so you need to keep track of this and keep your camera drivers current. In some cases, a release update to PHD2 may require the latest camera driver software so you should also be aware of that.

It is not practical to provide an exhaustive list of cameras that are supported by PHD2. In many cases, camera vendors extend their product lines by updating their lower-level drivers without having to change the application libraries used by PHD2. In those cases, we aren't aware of the changes unless a user reports problems. The list shown below should be interpreted as follows:
1. If the camera vendor is completely absent, it is unlikely that the camera is supported, or it may only be supported using a web-cam interface
2. If the camera model is shown in the list, it is supported unless there are unresolved problems with the vendor's drivers
3. If the specific camera model is absent but earlier models are shown, it is likely the camera is supported
4. If the camera uses an ASCOM interface, it is supported

Since the PHD2 download is free, the simplest course of action is to install it and see if your camera is shown in the PHD2 drop-down list. Alternatively, you can check for camera support info in the Wiki on the PHD2 Google forum: https://github.com/OpenPHDGuiding/phd2/wiki/CameraSupport

Finally, you can always post a message on the open-phd-guiding forum asking if anyone has experience with the camera. Access to the forum requires a user log-in so you should establish an account in order to get help with any guiding problems you encounter.

Baseline list of supported cameras:

Windows:

- ASCOM v5/6 compliant cameras
- Altair
- Atik 16 series, color or monochrome
- Atik Gen 3 color or monochrome
- CCD-Labs Q-Guider
- Fishcamp Starfish
- iNova PLC-M
- MagZero MZ-5
- Meade DSI series: I-III, color and monochrome
- OpenCV
- Orion StarShoot DSCI
- Orion Starshoot Autoguider
- Orion Starshoot Planetary Imager and Autoguider
- QHY 5-II
- QHY 5L-II
- SAC4-2
- SBIG
- SBIG rotator
- Starlight Xpress SXF / SXVF / Lodestar
- Svbony
- ToupTek
- Webcams (LXUSB, parallel, serial, OpenCV, WDM)
- ZWO ASI

Mac:

- Fishcamp Starfish
- KWIQGuider
- Meade DSI series: I-III, color and monochrome
- Orion Starshoot Autoguider
- SBIG
- Starlight XPress SXV
- The Imaging Source (DCAM Firewire)
- ZWO ASI

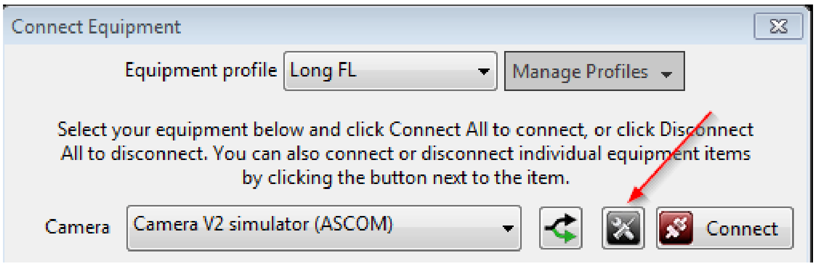
USB cables and computer ports are typically used to communicate with the guide cameras. These components can be the source of problems for a variety of reasons. Inexpensive, poor quality USB cables - even the ones supplied with the cameras - often have very small conductors and are therefore prone to being damaged. The connectors and cables are generally not intended for outdoor use although that's where we're using them. Finally, Microsoft Windows releases starting with version 10 will, by default, try to conserve power by suspending USB ports when the OS senses periods of inactivity. All of these things can interfere with imaging and guiding operations and you should be aware of them and devise strategies for avoiding them. If you encounter these problems, you should follow the instructions in the Trouble-shooting section - Camera Connection Problems

Support for SBIG Dual-chip Cameras

Many cameras from the Santa Barbara Instrument Group (SBIG) have two sensors - a primary one for imaging and a second, smaller one for guiding. While the two sensors are physically separate, they share electronics inside the camera and more importantly, share a single USB data link to the computer. This means that downloading of data from the two sensors must be coordinated - you can't retrieve a guider image while an image from the main sensor is being downloaded. Beyond that, Windows will only allow one application at a time to connect to the camera over the single USB link. These are physical and architectural restrictions that can't be circumvented by PHD2. However, it is possible for the camera-controlling (image capture) application to implement an interface for PHD2 to get data from the guide chip - essentially, a "side door" mechanism that won't violate any of the above rules. With this arrangement, the image capture application is acting as a traffic cop to coordinate access to the two camera sensors. One imaging application that does this is Sequence Generator Pro (SGP). If you use SGP as your main imaging application, you can also use their "SGP API Guider" module, which allows PHD2 to access the guide chip on the SBIG camera.

ASCOM Camera Properties

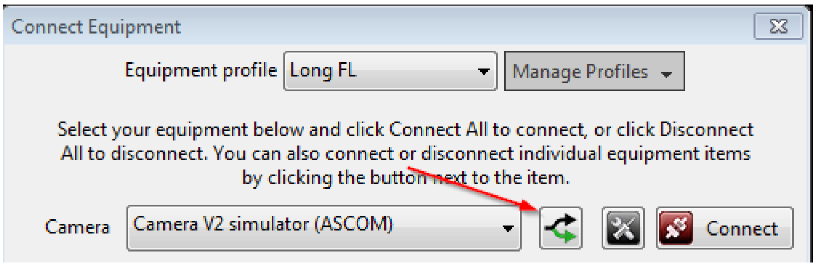
If you choose an ASCOM camera, you'll also be able to access the ASCOM setup dialog for that camera by clicking on the properties button immediately to the left of the 'Connect' button:



Depending on the camera, this may provide access to properties that are not controlled by PHD2.

Multiple Cameras of the Same Type

If your computer is connected to multiple cameras from the same manufacturer, you'll usually need to specify which camera should be used by PHD2. You can do that by clicking on the 'fork' button to the right of the camera drop-down list:



Clicking this button will show a list of the available cameras and you can choose the specific one you want. PHD2 will remember the choice and save it as part of your equipment profile, so you should only need to do this once. An alternative is to simply connect one of the cameras, the intended guide camera, at the time you build your equipment profile.

Some camera manufacturers don't do a good job of staying connected to the right camera and may switch from the guide camera to the imaging camera without any notification. If you see PHD2 alert messages warning you that the camera sensor geometry has changed and you need to re-build your dark library, the likely source of the problem is that PHD2 has been connected to the imaging camera. These problems are caused by the camera drivers, there's nothing PHD2 can do to prevent them.

Mount Selection

The Mount drop-down list displays options for connecting to your mount. There are generally two ways to do this:

1. Use an ASCOM-compatible (or INDI) telescope driver that sends guide commands to the mount over a serial cable (or more commonly, a USB/Serial connection). This is the recommended approach for the reasons explained below.
2. Use the ST-4 compatible guide port interface on the mount with a specialized cable and an intermediate device like a camera or a Shoestring box

The ASCOM interface relies on third-party drivers to communicate with the mount. These drivers are available from the ASCOM web site

(ASCOM Standards) or from the mount manufacturer - they are **not** distributed with *PHD2*. So the drop-down list will be populated by only those ASCOM drivers you already have installed on your system. **If you can't find your mount in the list, you either haven't installed its driver correctly or it only supports ST-4 guiding**. The ASCOM driver must support the 'PulseGuide' interface, which has been a requirement for ASCOM compliance for many years and is widely supported. With this type of mount control, guide commands are sent from *PHD2* to the mount over the serial interface. The high-level *PHD2* guide commands (e.g. "Move west 500 mSec") are translated by the mount firmware into the appropriate motor control signals to execute the command. With the ASCOM interface, *PHD2* can also obtain the pointing position of the telescope, especially the declination and side-of-pier, which can be used as factors in guider calibration and provide greatly improved ease-of-use.

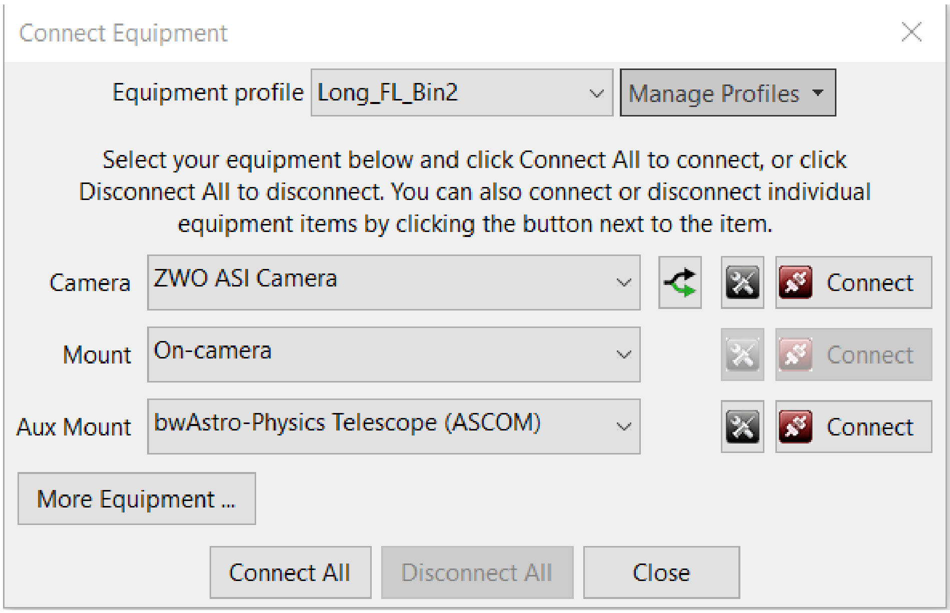
The "Guide-port" interfaces use a specialized, hardware-level control port available on most mounts. To use this type of interface, there must be another device in the link between *PHD2* and the mount:

1. Any of the guide cameras which have an ST-4 compatible "on-camera" guider interface. Use the 'on camera' mount choice for these setups.
2. Any of the Shoestring GP-xxx devices
3. A supported AO device with a guide port interface

With this style of interface, *PHD2* guide commands like "Move west 500 mSec" are translated by the intermediate device (camera, Shoestring box, AO) into electrical signals necessary to drive the mount motor for the correct length of time.

Aux Mount Selection

If you are forced to use the ST-4 style of guiding in the 'mount' section, PHD2 will not be able to use that interface to determine the scope's pointing position. As a consequence, guider calibration won't be automatically adjusted for declination, nor will it be automatically flipped when the side-of-pier changes. You can restore these features by specifying an "aux" mount connection that will be used to get the telescope pointing information. An example is shown below:



For Windows users, the "aux" mount can use any of the ASCOM-compatible mount drivers, while Linux users can take advantage of INDI drivers. The "aux" mount choice will be used only if the primary mount interface cannot return pointing information - it will otherwise be ignored. Note: some mounts (e.g. Celestron and iOptron) have a separate hardware port also labeled 'Aux' - DO NOT USE THIS for guiding - it is completely unrelated to the 'Aux' connection in PHD2. The last entry in the list of 'Aux mount' connections is labeled "Ask for coordinates." This can provide a rudimentary aux-mount facility if you can't use an ASCOM or INDI connection to your mount. If you need to pursue this option, you can read about the details here: Ask-for-coordinates.

Most ASCOM mount drivers use a serial port interface, so the driver expects to use one of the Windows 'COM' ports. Since most personal computers no longer have serial port connectors, you can use one of the USB ports and a USB-serial adapter. Newer mounts may include such an adapter or have one built in. The software that comes with the USB-serial adapter will create a software COM port, and that's the one you'll use with the ASCOM driver. The first time you connect to the mount with ASCOM (either as 'mount' or 'aux-mount'), you'll need to tell the driver which COM port to use. That's part of the driver's setup dialog, and you can quickly open that window by clicking on the 'properties' icon just to the left of the 'Connect' button in the above image. Once you've done this, the COM port will be saved as part of the equipment profile

Benefits of Using ASCOM (or INDI) connections

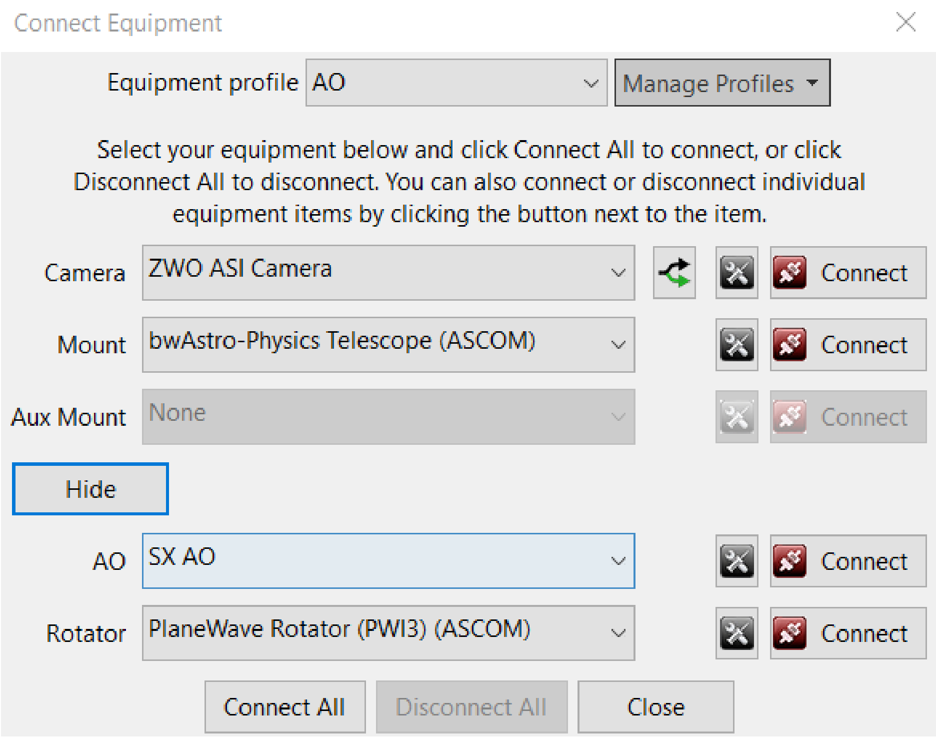
If you're running on a Windows platform, you'll probably be better off using an ASCOM connection for guiding your mount. On other operating systems, your best choice is likely to be an INDI connection if one is available. This advice may be contrary to some old-school experience or folklore on the Web and probably isn't what you'll hear from the manufacturer of the guide camera. But the benefits of doing so with PHD2 are substantial, and you should use this alternative unless you have specific and credible information against it. Here are some of the primary benefits:

1. A drastic reduction in the number of calibrations you'll need to perform. Changing targets will **not** require another calibration because PHD2 can know where the scope is pointing and automatically make adjustments to the guider calibration. Most users get a good calibration and then re-use it until they make hardware changes of some kind.
2. Automatic adjustment for meridian flips - no need to remember to manually flip the calibration data.
3. Automatic adjustment of RA calibration to handle targets in different parts of the sky (declination compensation)
4. Elimination of the ST-4 guide cable as a point of failure - this is a surprisingly common problem because the cables can be damaged or confused with similar-looking cables (e.g. telephone cables)
5. Elimination of a moving cable that can snag, drag, or bind as the scope is moved around.
6. Improved ability for PHD2 to sanity-check calibration results and warn of possible problems before you waste hours of imaging time.
7. Better diagnostic and trouble-shooting information, which is particularly helpful if you need to ask for assistance
8. Availability of scope-slewing options during drift alignment which can further speed the process of polar alignment

A common misconception, sometimes seen on Web forums, is that ST-4 guiding is hardware-based and thus more accurate or efficient. For any of the modern mounts you're likely to encounter, this is no longer true - there will always be software running at each end of the cable, just like ASCOM guiding. The bottom line is this: if you have an ASCOM or Indi driver available for your mount, you should probably use it.

Adaptive Optics and Rotator Selections

With *PHD2*, you have the option of controlling the Starlight Xpress adaptive optics unit and/or any ASCOM-compatible camera rotator. These can be specified by clicking on the 'More Equipment..." button in the above dialog:



If you don't have these devices, just leave the selections at 'None.' If these devices are connected, you'll see additional tabs in the 'Advanced Settings' dialog that provide access to various device-related properties. Adaptive optics (AO) devices generally require some study before use and you should familiarize yourself with their operation before trying to use them. Some background information can be found here: Using an AO . PHD2 does not control a rotator, but it will read the current angle setting from the rotator and adjust the guiding calibration if needed. Rotators are used to control the orientation of the imaging camera with respect to the sky - perhaps to keep the orientation the same on opposite sides of the pier or to create a favorable composition of the objects in the field of view. If the rotator is part of an off-axis-guider assembly, its rotation will affect the PHD2 calibration. In this situation, PHD2 should be connected to the rotator so the calibration can be adjusted automatically.

Simulators

All of the *PHD2* devices - camera, mount, AO, rotator - include built-in simulators. Don't confuse these with any of the ASCOM simulators which may be installed on your system - those will have 'ASCOM' in their names. Although you can connect to the ASCOM simulators, they don't provide the necessary feedback to PHD2 for guiding and calibration. As a result, they're only useful for limited types of testing and experimentation. But you can use the built-in simulators to explore how *PHD2* works and to decide how you want to use the program. Virtually all of *PHD2*'s features, including full calibration and all the graphical display options, will work properly when the built-in device simulators are used. You'll even see fairly realistic guiding performance to give you some idea of what to expect in the field. To get started using the simulators, use the new-profile-wizard, choosing 'Simulator' for the camera type and 'On-camera' for the Mount type.

Remember, the simulators are **not** useful for trouble-shooting any problems you encounter with your real mount and they can't be used for testing your actual hardware. Both the camera and the mount must be real devices in order to diagnose problems or otherwise get your gear calibrated and working. In that sense, what you see when using the simulators is realistic but "fake" behavior. The simulators can be useful in some cases for reproducing PHD2 application problems, but not for anything having to do with your actual guiding equipment.

Exposure Time and Star Selection

The guide stars are selected while "looping" is active. The best approach is to let PHD2 Auto-select the guide stars for you by clicking on the 'Auto-Select Star' icon in the main window. In nearly all cases, it will do a better job of star selection than you can do manually because it takes a number of things into account - for example, lack of saturation, qualification as a "real" star, proximity to other stars and to the edge of the field, etc. Using the 'Auto-Select' function is also the only way you can take advantage of multi-star guiding. If you don't use the auto-select feature, you can select a guide star candidate by clicking on it but that will result in using only that single star for guiding. After that is done, a green box will appear to frame the star. If you pick a star that is too bright (saturated), the status bar will show a red 'SAT' label and you should choose a fainter star. You should adjust the gamma slider to the left to see fainter stars. Most new users are fooled by this and often choose the brightest star they happen to see in the field of view. But that choice is often a saturated star, not a good choice for auto-guiding. In other words, if you know the name of the star, it's almost certainly too bright to be used for effective guiding. All of these pitfalls can be avoided by using the auto-select feature. The choice of exposure time will depend entirely on your equipment, sky conditions, and the available stars. The exposure time you choose has several implications:

1. It affects the signal strength (brightness) of the selected star - a brighter star will stand out better from the background and will generally produce better guiding results so long as it is not saturated.
2. It also determines the frequency with which guide commands are sent to the mount - guide commands cannot be sent any more frequently than once for each exposure cycle. Some mounts need frequent small guiding adjustments while others do not - you may need to experiment to understand what works best for your situation.
3. It has a strong effect on the sensitivity of the guide algorithms to seeing conditions. As the exposure time is increased up through 2-4 seconds, the effects of seeing are smoothed out. This is particularly noticeable if you are guiding with a long focal length setup. Of course, the convenience of using longer exposures must be traded off against the need for the mount to get sufficiently frequent corrections. For mounts that have too many high-frequency errors in RA, you may need to work with 1-sec or even 0.5-sec exposures in which case using multi-star guiding becomes even more important. If you're not familiar with the concept of astronomical seeing, you can get more info here: Astronomical Seeing

As a starting point, try using exposure durations in the range of one to three seconds. If you want to de-select a star without choosing another one, you can do a shift-click anywhere on the image display window.   If you are just starting with your equipment set-up, it's critical that you carefully focus the guide camera. You can use the Star Profile tool to help with that process or whatever other focusing tool you are comfortable with - a focusing mask, a camera app like SharpCap, etc. Just trying to do it "by eye" is rarely going to produce good results.   If you're using a small guide scope, like a finder-scope, the focus may react strongly to small adjustments. It's important to spend the time to get a good focus because poorly focused guide stars can lead to poor guiding results.

The camera exposure control displays a wide range of pre-set exposure times. Exposure times smaller than 0.5 second are intended for use with adaptive optics devices or in other special situations - they are not recommended for use with typical guide camera set-ups. There is also a 'custom' exposure option at the bottom of the list that lets you specify a value not already displayed. Again, this is intended for special applications, for example where an unusually long exposure time is needed.

There is also an Auto exposure time selection available. When exposure is set to Auto, PHD2 will attempt to adjust the exposure to keep the selected guide star at a consistent signal-to-noise ratio (SNR) value while working within the exposure limits you choose. This is a specialized measurement used by PHD2 to determine how well the star can be distinguished from the background - it is similar but not identical to the signal-to-noise ratio used in photometry. The Auto setting is intended for use in automated imaging or for AO users who want to minimize the exposure time without losing the guide star.   Automated imaging involves slewing and subsequent unattended guide star selection, and failure to find a bright-enough star will cause the automated session to fail. In such cases, a "long" exposure time may be preferable to finding no guide star at all. The settings to control Auto-exposure are on the Camera Tab of the Advanced Settings dialog.

Multi-Star Guiding

Most guiding configurations can benefit from guiding on multiple stars rather than just one. This results in using a weighted average centroid position of multiple stars rather than just the centroid of a single star. Multi-star guiding is enabled using a check-box on the Guiding Tab of the Advanced Settings dialog - one that is "checked" by default. When this option is enabled, the Auto-select function will identify up to 12 stars in the field of view that have adequate sizes and SNR values. No more than 9 of these will be used at any one time, but the remainder will be used to replace secondary stars that are lost or rejected for some reason. The "primary" star is the single best candidate, the same one that will be selected if multi-star guiding is disabled. As guiding proceeds, some of the secondary stars may be rejected because they are too dim or have drifted outside the field of view. This is of no concern, the algorithm handles the secondary list automatically. When multi-star guiding is active, the PHD2 image display will show the usual rectangle around the primary star plus circles around the secondary stars. All other UI features associated with a guide star - brightness properties, SNR, FWHM, etc - relate to the primary star, not the entire list. Multi-star guiding can be enabled or disabled while guiding is active. However, enabling the feature will force another 'auto-select' procedure. The multi-star algorithm uses the secondary stars to refine the measurements of guide star movement and lower their volatility, so there is essentially no way for it to degrade guiding performance compared to single-star guiding. The benefit it provides to your overall guiding will depend on many factors including image scale, star and background sky brightness, star size, focus, tube currents, and camera noise. Because of the way the algorithm is implemented, your best option will be to try it and decide for yourself. **Note: if you don't use the auto-select function and instead choose a guide star manually, multi-star guiding will be inactive.**

Automatic Calibration

Conventional Mounts

Two things need to be measured by *PHD2* as part of guider calibration:

1. The angular orientation of the camera sensor relative to the right ascension and declination axes of the mount and the sky
2. The length of the guide pulse needed to move the telescope by a specific amount

PHD2 handles these measurements automatically by sending guide pulses to the mount and watching how far and in which direction the star moves between guide camera images. This process begins after you have selected a star and then clicked on the PHD2/Guide icon button. Yellow cross-hairs will appear over the original location of your guide star and PHD2 will start to move the mount in various directions, tracking how the star moves as a function of what move commands were sent to the mount. The status bar will display the commands as they are sent to the mount, along with the incremental movements of the guide star relative to its starting position. *PHD2* will do this on both axes, first moving east and west, then north and south. *PHD2* typically wants to move the star up to 25 pixels in each direction in order to get an accurate calibration. Once this is complete, the crosshairs will turn green and guiding will start automatically. Because this is a measurement process that is subject to various kinds of mount and atmospheric effects, the most accurate results will be gotten when the scope is pointing within 20 degrees of Dec = 0 (near the celestial equator) and at least 60 degrees above the nearest east/west horizon (i.e. within 2 hours of the celestial meridian). Calibrations can be done in other pointing positions if required by conditions at your site but they will be subject to somewhat more measurement uncertainty. You **cannot** do calibrations pointing very close to the north or south celestial poles, and the mount must be tracking at the sidereal rate. **If you encounter difficulties completing a calibration, you should immediately retry using the** Calibration Assistant .

Although PHD2 moves the guide star in all four directions, only the west and north movements are actually used to compute the guide rates and camera angles. The east and south moves are used only to restore the star roughly to its starting position. Before the north moves are begun, you will see a sequence of pulses that are intended to clear backlash. PHD2 takes only a moderate approach to clearing this backlash, watching for a clear pattern of movement in a single direction with no reversals. If your mount has a large amount of Dec backlash or you're guiding at a long focal length in poor seeing conditions, this phase of calibration may not remove all the backlash. Your best option to avoid this problem is to use the Calibration Assistant. You may also see that the south pulses leave the guide star well-short of its starting position - this is another visual clue that you have significant declination backlash in your mount but it does not invalidate the calibration. If you see evidence of sizable backlash, you can run the Guiding Assistant tool and measure it directly.

In most cases, calibration will complete automatically without any user involvement, particularly if you are using the Calibration Assistant. If the mount doesn't move sufficiently in the west or north directions, you will get an alert saying the calibration has **failed**. Failures of this type are pretty uncommon but they can occur if some part of the hardware is simply not working (e.g. a bad guide cable) or if you haven't followed all the recommendations in the Calibration Assistant.

If you're using an ASCOM (or Indi) connection for either the 'mount' or 'aux-mount', a good calibration can be re-used for a long time, and that is the preferred way to operate. These connection options allow PHD2 to know where the telescope is pointing, so a calibration done at one point in the sky will be automatically adjusted as you slew to different targets. The old rule of having to re-calibrate whenever you slewed the scope or switched the side-of-pier is a thing of the past so long as PHD2 has pointing information. With this type of set-up, you would only re-calibrate if you rotate the position of the guide camera by more than a few degrees or make other major changes to the hardware configuration. If you chose 'auto-restore calibration' when you built your profile or chose that option in the Guiding tab of the Advanced Settings dialog, you can simply connect to your gear, auto-select your guide stars, then begin guiding immediately. Beginners will probably have more success if they do a fresh calibration at the start of each night's session. Finally, if you're using an instrument rotator as part of your equipment profile, PHD2 can use the 'Rotator' connection to adjust the calibration data based on the angular position of the guide camera - one less reason for re-doing a calibration.

You can always review the results of your last calibration by using the 'Tools' menu and clicking on 'Review Calibration Data' That will open a dialog that shows a graphical representation of the mount's movements along with the values that were computed for guiding your mount. This window is described elsewhere in the Calibration Details section of the help file. As a quick quality check, you can open this window and confirm that 1) the RA and Dec lines are roughly perpendicular and 2) the plotted points are roughly linear with no significant curves, bends, clumping of points, or reversals in direction. If you do see these kinds of odd patterns in the graph, you should probably re-do the calibration. Even with high-end mounts, calibrations can occasionally go awry because of environmental conditions, especially wind and bad seeing.

After a calibration is completed, PHD2 will "sanity check" the results to be sure the calculations at least look reasonable. If they don't, you will see an advisory message at the top of the main window that describes the situation. You can choose to ignore the alert or click on 'Details' to get more information. It is generally advisable to pay attention to these alerts because there is no point in trying to guide using a significantly bad calibration.

Adaptive Optics Devices

If you are using an adaptive optics device, there are actually two calibration processes that must complete. The first handles calibration of the tip/tilt optical element in the AO and calculates the magnitude and direction of the adjustments as they relate to displacements of the guide star. The second calibration is the one described above, dealing with guide commands that need to be sent to the mount. Known as "bump" commands, these will be issued when the guide star has moved beyond the range of corrections that can be achieved with the AO alone.

Guiding

Once guiding has begun, diagnostic messages will be displayed in the status bar to show what guide commands are being sent to the mount. *PHD2* will continue guiding until you click on the 'Stop' icon. To resume guiding, simply start looping exposures again, auto-select your stars, and click on the 'Guide' button. You will not need to repeat the calibration in order to resume guiding.

In some cases, *PHD2* may **lose the guide star** and you'll be alerted by an audible beep and flashing orange crosshairs. There are several reasons this might occur:

1. Something may be obscuring the star - clouds, the observatory roof, a tree, etc.
2. The star may have abruptly moved out of the tracking rectangle because something shifted in the mount/camera/cabling infrastructure - cable snags can cause this
3. The star may have "faded" for some other reason, perhaps because it is overly faint, the camera is not well-focused, or the star size and brightness is fluctuating above and below the thresholds for acceptability.
4. The star's brightness may be fluctuating enough to trigger the star-mass checking feature. If this happens frequently, the feature should be disabled (Advanced Settings/Guiding tab)

Obviously, you'll need to identify the source of the problem and fix it. It's important to understand that *PHD2* will **not** start moving the telescope trying to relocate the guide star. It will simply continue to take exposures and look for a guide star to reappear within the bounds of the current tracking rectangle. If the lost star condition persists for a considerable time, your mount will probably drift signiificantly off-target. In that event, a later recovery of a guide star in the tracking region is likely to be a different star and your imaging target won't be properly centered. If you're doing unattended imaging, the imaging application should handle this situation by recentering the frame after star recovery has occurred - this is not something that can be done by PHD2. Isolated or intermittent lost-star events do not usually cause poor guiding or ruined images. But extended periods of lost-star events can allow the mount to go too long without guiding corrections and the image quality may suffer.

When you first start guiding, you may see an 'alert' dialog at the top of the window if no dark library or bad-pixel map is being used. You can choose to ignore this warning and continue with guiding, but you will probably get better results if you spend the few minutes needed to construct a dark library for future use.

If you are using a German equatorial mount (GEM), you will usually have to do a "meridian flip" around the time your image target crosses the meridian. This means you (or your imaging application) will move the telescope around to the opposite side of the pier and then resume imaging. Doing this invalidates the original calibration, typically because the declination directions are now reversed. If you are using an ASCOM (or 'aux') mount interface, your calibration will be adjusted automatically and you can simply resume guiding (assuming you haven't also rotated the camera or focuser). If you aren't using an interface that returns pointing position, you will need to take action to adjust the guider calibration. You can, of course, simply do another calibration on the current side of the pier, a process that will typically take only a couple of minutes. Or, you can use the pull-down menu item under 'Tools/Modify Calibration' to "Flip Calibration Now" and then resume guiding immediately. **Note**: 'flip calibration data' will have no effect if PHD2 is using an ASCOM or 'aux-mount' connection.

In some cases, you may want to force a re-calibration. For example, you may have rotated the guide camera as part of resolving a cable problem. You can do this by clicking on the 'Brain button', moving to the 'Guiding' tab, and clicking the 'Clear mount calibration' checkbox. Or, you can simply do a <shift>click on the 'Guide' button on the main screen and *PHD2* will start a calibration run.

Once you have started guiding, you will almost certainly want to know how things are going. You can of course watch the star in the guide camera display but in many cases you won't be able to see all the small adjustments that are taking place. PHD2 provides many tools for measuring and displaying your performance, as described in the Monitoring Tools section. Several of the guiding algorithms have limit settings for the maximum guide correction that can be issued with a single command. If these values are smaller than what is needed to correct the mount's position, you will see an alert dialog at the top of the main window advising you of the situation. If this is a recurring problem and you haven't reduced the max-move parameters below their default values, the source of the problem probably lies with the mount.

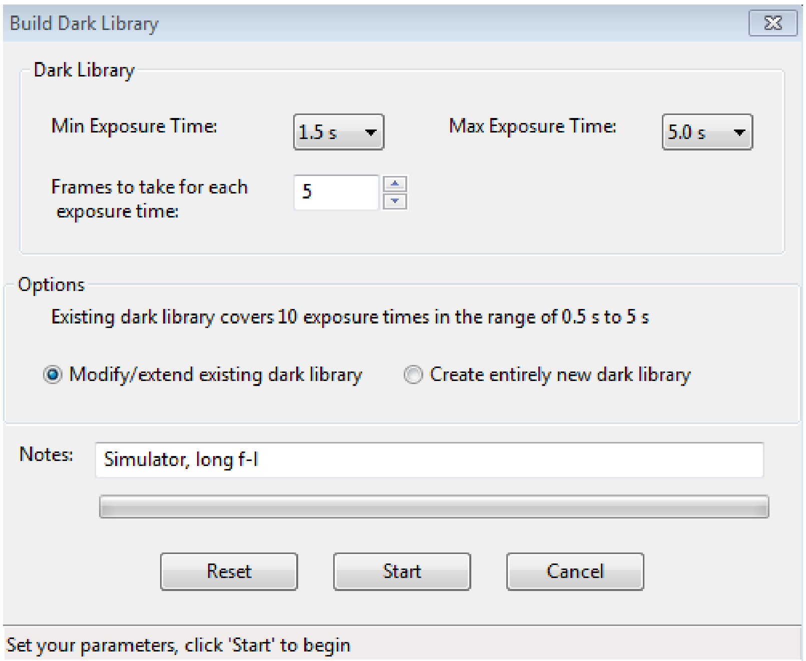
Dark Frames and Bad-pixel Maps

Introduction

Cameras used for guiding are typically not temperature-regulated and may produce images that appear quite noisy. As a result, guide exposures frequently show obvious defects in the form of hot (or "warm") pixels or regions with spurious brightness levels. If there are too many of these defects, PHD2 may have trouble identifying and selecting guide stars. Even after guiding has begun, a spurious hot pixel close to the guide star can disrupt the calculations needed for smooth guiding and may cause the software to "jump" between the real star and the hot pixel. These sorts of problems can be mitigated by using either of two approaches in PHD2: dark frames and bad pixel maps. All functions related to dark frames and bad-pixel maps are located under the top-level 'Darks' menu.

Dark Frames

PHD2 will build and use a library of dark frames that match the range of exposures you use for guiding. Once the library is built, it will be saved automatically and will be available for use across multiple PHD2 sessions. As a result, you can spend a modest amount of time to build a good dark library, then use that library for an extended period of time. Once you have connected to your camera, you can build a dark library from the 'Dark Library...' item under the top-level 'Darks' menu. That will start a dialog that looks like this:



You use the two controls at the top to specify the minimum and maximum exposure times that will be used to acquire dark frames. The starting, ending, and intermediate values match the exposure times used in the main PHD2 window, so you can acquire dark frames that will match any exposure time you choose for guiding. The third control specifies the number of dark frames that will be acquired and averaged for each exposure time. The averaged image is referred to as a "master dark frame." Historically, PHD has used 5 dark frames for this purpose, but you may want to increase that number to improve the quality of the master dark frame. You can also add a note or comment if you wish - this will be embedded in the header of the master dark frames for later reference.

The two radio buttons above the Notes field let you specify whether you want to modify/extend your current dark library or build a new library from scratch. If you've gotten alert messages saying the dark library must be rebuilt, you should choose the 'Create entirely new dark library' option. This insures that all of the master dark images match the format of the camera you're currently using. Otherwise, you can simply refresh or expand the current dark library by taking new dark frames at the specified exposure times

Once you've set your parameters, click on 'Start' to begin the process. If your guide camera does not have a shutter - most do not - you'll be prompted by PHD2 to cover the guide scope. To get the best results, be sure there is no light leakage into the guide camera - doing this in daylight is not likely to work well. PHD2 will systematically work through the range of exposure times you've chosen, taking the specified number of frames for each exposure time. Progress will be displayed on the status bar at the bottom of the window. Once you've started the process, the 'Cancel' button above will change to a 'Stop' button. You can click on this if something goes wrong or you want to change the parameters before the entire sequence completes. Stopping in this way will discard whatever data has already been collected, so you'll need to make your corrections and then restart the process. Once all the frames have been collected, PHD2 will compute the master dark frames, store them in a dark library data file, then show a message box summarizing the results. If your camera has no shutter, you'll also be prompted to uncover the guide scope so you can return to normal imaging.

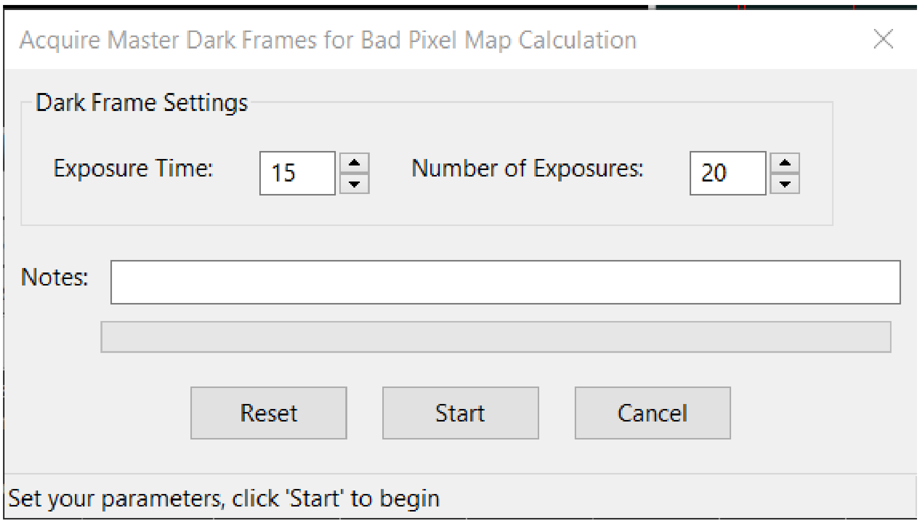
Once your dark library has been built, you control its use by the 'Use Dark Library' item under the 'Darks' menu. The checkbox on the menu item will toggle on or off each time you click on it. The setting of the item is retained across program executions, so if you choose to leave the menu item checked, PHD2 will automatically load the dark library and resume its use the next time you run the application. The dark library itself is retained on disk until you build a new library, so you can freely change the setting on the 'Use Dark Library' menu item without loss of any data. If you are using a dark library and there is no master dark frame that exactly matches your guide exposure time, PHD2 will use the nearest fit. However, you should use matching master dark frames for best results. If you have a dark library that has missing exposure times, you can simply acquire the missing data and it will be added to the existing dark library - there is no need to start over. By changing the setting of the 'Use Dark Library' menu item, you'll be able to see the effect of using the dark library and determine whether your guider images are sufficiently improved.

Remember that a dark library is associated with a particular camera and binning level. PHD2 will check to be sure that the dark library matches the camera you are currently using. If it does not, you will see an alert message telling you the dark library can't be used and must be rebuilt. This can happen when you've changed cameras inside an existing equipment profile, something you shouldn't do unless you have upgraded your guide camera and have no plan to return to using the old camera. The dark library also depends implicitly on the camera gain level, so you should rebuild the dark library if you've made a significant change in camera gain - also something you really shouldn't do once you've gotten familiar with the camera behavior.

Bad-pixel Maps (Defect Maps)

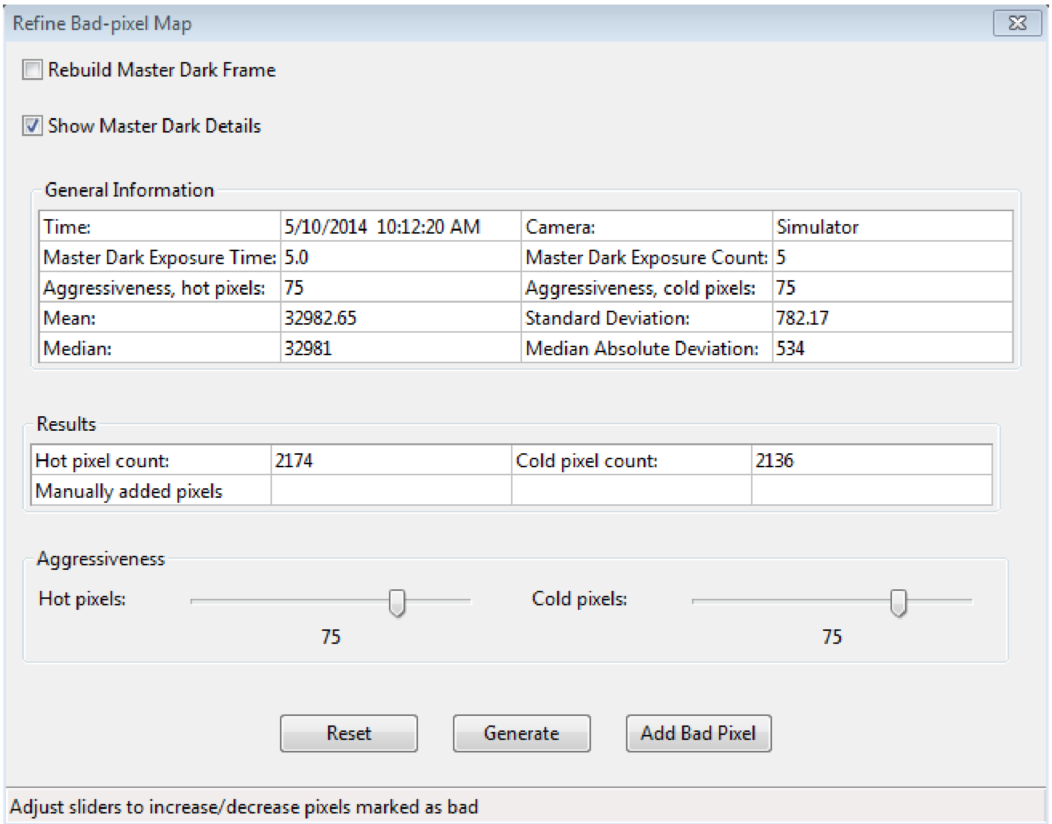
For some guide cameras, dark frames don't do an adequate job of removing the defective pixels that are visible in the guide frame. In those situations, you can probably get better results by building and using a bad-pixel map. This approach directly measures and compensates for specific areas of the sensor that produce false signal (hot/stuck pixels) or don't respond correctly to incoming light (cold pixels). Such a "map" is created by taking a sequence of comparatively long dark exposures (e.g. 15 seconds), averaging them, then statistically analyzing the resultant frame to identify the locations of defective pixels. These pixel locations are saved for future use. During normal guiding, each of these pixel locations on the guide image is replaced by a statistical sample of the surrounding pixels, thus eliminating all or most of the effect of the "bad" pixel. The final result is usually an image with a smoother background and fewer obvious defects. For any defects that remain, PHD2 also provides a way to manually click on bad pixel locations and add them to the map. This entire process of obtaining and analyzing dark frames is handled for you by PHD2, so it's easy to build a bad-pixel map.

Building a bad-pixel map is done by clicking on the 'Bad Pixel Map...' item under the top-level 'Darks' menu. If you are doing this for the first time, you will be prompted to obtain a sequence of dark frames for analyzing your camera sensor and building the map:



This is a slightly different version of the dialog used for obtaining dark frames, described in the previous section. Because the analysis is based on statistics, you should use relatively long exposure times (> 10 sec) and at least 10 frames. Since the bad-pixel map can be re-used for fairly long time periods, you won't have to repeat this operation very often, and it's worth spending some time to get higher quality data.

Once the dark frames have been captured, PHD2 will compute the statistics and identify an initial set of defective or suspect pixel locations. After a short delay, you'll then see a dialog that looks something like this:



The 'General Information' section shows a summary of the statistics computed by PHD2 during the identification of bad pixel locations. Normally, you won't need to look at these, and you can hide this portion of the display by clearing the 'Show Master Dark Details' checkbox. The "Results" group shows the counts for hot and cold pixels based on the current settings of the two "Aggressiveness" sliders below them. If you're doing this for the first time, the aggressiveness sliders will be set at their default values, 75 within the range of 0 to 100. You'll need to experiment or make some judgment about whether the counts look reasonable based on what you see on your normal guide frames. If you adjust the aggressiveness sliders left and right, you'll see the hot and cold pixel counts change. The sliders control how "aggressive" PHD2 should be in identifying suspect pixels and flagging them as being defective - so higher aggressiveness settings will result in higher pixel counts. Once the settings are where you want them, click on the 'Generate' button to compute and load the new defect map.

At this point, you'll probably want to examine the results. The main window of PHD2 is still active, so you can take a normal guide exposure to see how things look. If you want to quickly see the result of using the defect map, just toggle the 'Use Bad-pixel Map' menu item under the 'Darks' menu. Keep in mind that you don't need to achieve a perfectly smooth, black background in the guider image - you just need to have a sufficiently small number of remaining hot/cold pixels that neither you nor the PHD2 guiding algorithms will mistake a bad pixel for a star. If you over-correct with very aggressive settings, you may create so many bad pixel areas that they interfere with detection of usable guide stars. It's easy to make adjustments with the sliders - just change the slider settings, click on 'Generate' again, and look at the results in the main PHD2 window.

You may find this approach still leaves some hot pixels that you'd like to eliminate. Since the default approach relies on statistics and needs to apply to a wide range of cameras, it isn't a "fire-and-forget" operation - you will often need to fine-tune it using the steps below.

Step-by-Step Guide to Refining a Bad-pixel Map

The following steps are recommended for refining a bad-pixel map to control pixel-level artifacts in your camera:

1. Cover the guide scope and start looping 5-second exposures
2. Open the Refine Bad-pixel Map window (Menu/Darks/Bad-pixel Map), then drag it to the side of your screen so you can see both the BPM and guiding windows
3. Adjust the gamma slider in the main window until you can see the hot pixels - this may require a brighter image than you are accustomed to seeing
4. Select the option "Show defect pixels." With the box checked, red dots will appear for any hot pixels that are already known.
5. Slowly drag the hot-pixels aggressiveness slider left and right until most of the hot pixels are covered by a red dot, with a much smaller number (or even zero) hot pixels not covered. Click the 'Generate' button
6. Now pick up the remaining hot pixels by manually adding them to the bad-pixel map

    - Un-check the "Show defect pixels" checkbox
    - Select a hot pixel in the guiding window by clicking on it
    - Click on 'Add bad pixel' in the BPM window
    - Repeat as necessary until you satisfied most of the bad pixels have been handled

- Close the BPM window - DO NOT click 'Generate' again because that will undo the manual pixel selection

Once your bad-pixel map has been built, you control its use by the 'Use Bad-pixel Map' item under the 'Darks' menu. This setting is retained across program executions, so leaving it checked will tell PHD2 to automatically load the defect map and use it for all guide exposures. The settings for 'Use Dark Library' and 'Use Bad-pixel Map' are mutually exclusive - you can use one or neither, but not both at the same time. As with the dark library, the bad-pixel map data file is stored permanently, so you can disable its use without losing any data. Both of these data structures can be used for extended time periods, but it's worth remembering that camera sensors do change over time. As a result, you may want to rebuild the dark library or bad-pixel maps at periodic intervals or when you start to see a degradation in the appearance of your normal guide images. In these cases, it is also advisable to click on the checkbox for 'Rebuild Master Dark Frame', which will tell PHD2 to reacquire the underlying dark frames and recompute a baseline bad-pixel map. You'll then need to refine the map as you did before until you're happy with the results. There is no reason you should need to interact with either the dark library or bad-pixel map data files, but you can find them located in the 'AppData\Local' logical directory used by your operating system.

Like dark libraries, bad-pixel maps are associated with a particular camera and binning level. PHD2 will check to be sure that the bad-pixel map matches the camera you are currently using. If it does not, you will see an alert message telling you the bad-pixel map can't be used and must be rebuilt. This can happen when you've changed cameras or binning factors inside an existing equipment profile, something you shouldn't do unless you have no need for the old settings.

Reusing Dark Frames and Bad-pixel Maps

If you're using the same camera in multiple profiles, you may want to re-use the dark libraries or bad-pixel maps you built for that camera. This can be accomplished by importing the camera-related data files into a profile that doesn't already have those files. For example, suppose you built an original profile - call it Profile1 - that uses your Lodestar guide camera, and you built both a dark library and bad-pixel map for it. Some time later, you create a new profile, Profile2, that has different mount or focal length properties but still uses the original Lodestar camera. In that case, you would connect your gear using Profile2, then use the 'Import From Profile...' menu item under the top-level 'Darks' menu. You would select Profile1 as the source of the import function for the dark library, bad-pixel map, or both. You will be shown only those profiles that have a camera with compatible sensor geometry (sensor size, pixel size, binning). Clicking on 'Ok' will copy the dark/bad-pixel map files and will associate them with your new profile, Profile2. Since they are copies, changing the data files in one profile will not affect other profiles. Keeping them synchronized, if that is what you want to do, will require a subsequent 'import' operation.

Monitoring Tools

PHD2 provides numerous monitoring and display tools to help you see how your guider is performing. All of these tools are accessed under the 'View' pull-down menu and are described below.

- Overlays
- Graphical Display
- Stats Display
- Star Profile and Target Displays
- AO Graph
- Dockable Windows

Overlays

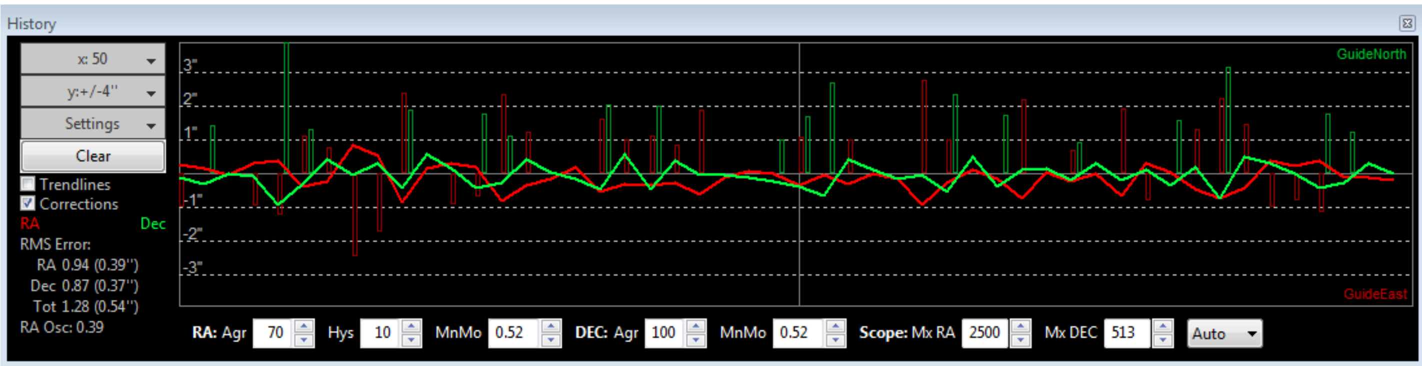
The simplest display tools are grid overlays superimposed over the main guider display window. These are quite straightforward and include the following choices:

- Bullseye target
- Fine grid
- Coarse grid
- RA/Dec - this shows how the telescope axes are aligned relative to the axes of the camera sensor. This is a visual confirmation that there is no need or benefit to worrying about trying to align the camera axes with RA and Dec.
- Spectrograph slit/slit position - for spectroscopy users, this will overlay a spectrograph slit graphic on the main display window. The size, position, and angle of the graphic can be adjusted to match the optical configuration.
- None

You can just click on the various overlay options under the 'View' menu and choose one that suits you.

Graphical Display

The graphical display window is one of the more powerful tools for judging guiding performance, and you will probably learn to rely on it. A typical example is shown below:



The major portion of the window shows the detailed displacements of the guide star for each guide exposure, plotted left-to-right. Normally, one line shows displacements in right ascension while the second line shows declination displacements. However, you can use the 'Settings' button to the left of the graph to switch to camera (X/Y) axes if you prefer (not recommended). You can also use the 'Settings' button to switch between display units of arc-seconds vs. camera pixels or to change the colors of the two graph lines. The range of the vertical axis is controlled by the second button from the top, labelled y:+/-4" in this example. The range of the horizontal axis - the number of guide exposures being plotted - is controlled by the topmost button, labelled x:50 in this example. This scale also controls the sample size used for calculating the statistics you see in the lower left part of the graph window. These values show the root-mean-square (RMS or standard deviation) of the motions in each axis along with the total for both axes. These are your best estimators of guiding performance because they can be directly compared to star sizes and seeing conditions. The 'RA Osc' value shows the odds that the current RA move is in the opposite direction as the last RA move. This is a carry-over statistic from the original PHD software and its usefulness is limited. If it consistently runs above 0.5, you may be chasing the seeing because of a Min-Move value that is too low. There are two other checkboxes to the left that can help you evaluate guider performance. Clicking on the 'Corrections' box results in an overlay showing when guide commands are actually sent to the mount, along with their direction and magnitude. In this example, these are shown as the vertical red and green lines appearing at irregular intervals along the horizontal axis. This shows you how "busy" the guiding is - under optimal conditions, you should expect to see extended intervals when no guide commands are sent at all in Declination. The other checkbox, labelled 'Trendlines', will superimpose trend lines in both axes to show if there is a consistent overall drift in the star position. This is primarily useful for drift aligning where the declination trendline is used extensively. But the RA trendline can show if your mount is tracking systematically slow or fast (or is seeing the effects of flexure) and can help if you are trying to set up custom tracking rates. The trend line for Dec is also useful if you're trying to choose the correct direction for uni-directional Dec guiding. If dithering commands are issued, usually by an external imaging application, a 'dithering' label will be superimposed on the graph in the appropriate time interval. This tells you the star displacements being graphed are being influenced by the dithering operation. The RMS statistics do not include the large excursions associated with dithering and settling.

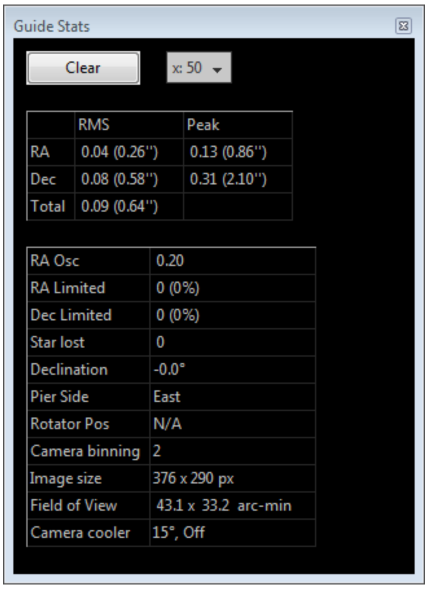
The guiding graph will also show the directions (GuideNorth, GuideEast) associated with the guide commands, as shown in the example above. This can be helpful if you are looking at overall drift and want to determine how to set uni-directional guiding for declination. These directions show how the guide star is drifting away from the lock position. For example, if the Dec position of the guide star is moving upward in the graph, the guide star appears to be drifting "north" on the camera sensor. This means that south guide pulses will be needed to move it back to the lock position. Similarly, a downward drift in RA location means the the guide star is moving "east" on the camera sensor and west guide pulses will be applied. For the purpose of setting up uni-directional Dec guiding, these rules apply:
    Dec drifting upward => select Dec guide mode = South
    Dec drifting downward => select Dec guide mode = North
For various mount and hardware reasons, these directions may not correspond to actual directions in the sky, particularly for Dec, but that doesn't matter.

The recommended way to look at guiding performance is to use units of arc-seconds rather than pixels. Doing this allows an equipment-independent way of evaluating performance because it transcends questions of focal length and image scale. To do this, you need to provide *PHD2* with sufficient information to determine your guider image scale: namely, the focal length of the guide scope, the size of the guide camera pixels, and whatever binning level you're using. Using the new-profile-wizard is the best way to insure these settings are correct.

At the bottom of the graph window are active controls for adjusting guiding parameters "on the fly". The guiding algorithm selections you've made will determine which controls are shown. These controls have the same effect as those in the 'Brain' dialog, and they eliminate the need to stop guiding and navigate to another window to adjust guiding parameters.

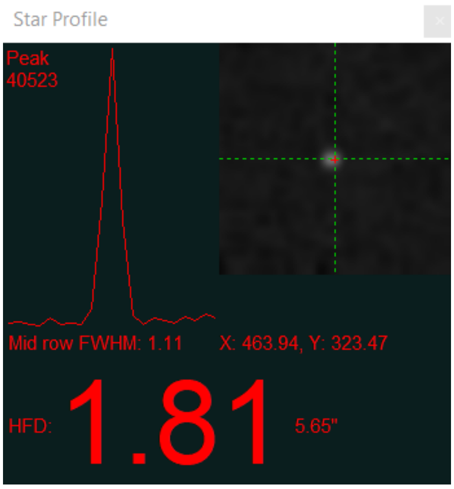
Although these controls are prominently displayed, it is generally not productive to change them substantially during guiding. Guiding improvements normally require long guiding intervals and careful analysis using the PHD2 LogViewer tool. Poor guiding results usually arise from user error, from mechanical problems in the mount, or from movement of the gear on the mount. Blindly changing guiding parameters doesn't help with any of these things and usually makes matters worse.

Stats

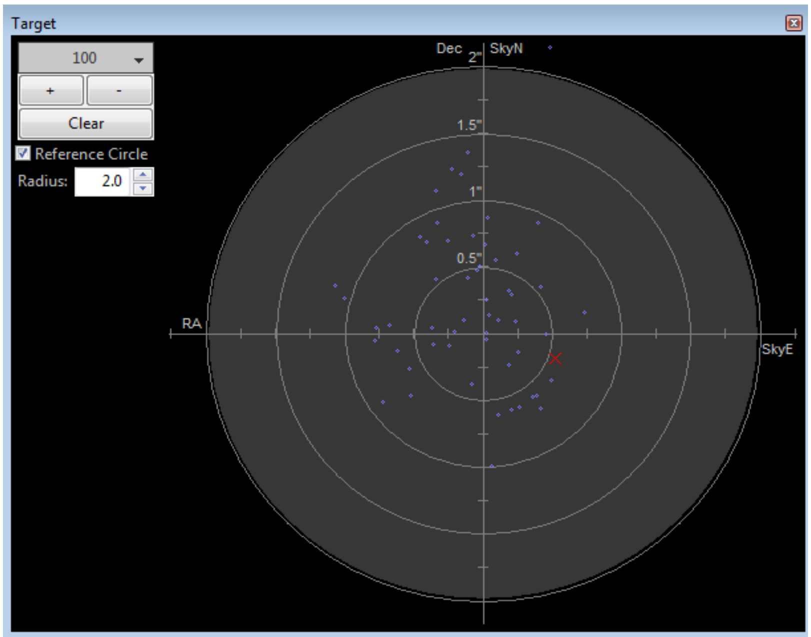


If you want to monitor guiding performance without necessarily having the graph window open, you can click on the "Stats" menu item. That will display the salient statistics with controls for clearing the data or changing the number of guide exposures used to compute the statistics. The tracking statistics are the same as those in the Graph tool, and like those, don't include the effects of dithering and settling. This window is also useful for confirming camera binning, monitoring the guide camera temperature, and getting a quick calculation of your guide camera's field of view.

Star Profile and Target Displays

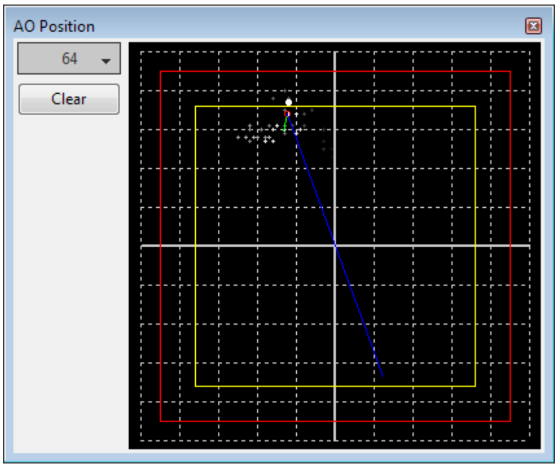


The star profile display shows the cross-section of the guide star along with measurements of its full-width-half-maximum (FWHM) and half-flux-diameter (HFD). HFD is generally a more stable measure of the star size since it doesn't require curve fitting or any assumption about the overall shape of the star image. If you see substantial fluctuations in this parameter or wildly varying star profiles, it may be an indication that the star is too faint, the exposure time is too short, the camera is out-of-focus, or the seeing is poor. This tool can help with focusing the guide camera, a procedure that can be tedious if you're using an off-axis-guider or a small finder-scope. For purposes of focusing, the HFD number is shown in a large font so you can see it from a distance while focusing your guide scope/camera. Just un-dock the Star Profile window and expand it until you can see the HFD number easily. If you are starting well out-of-focus, you'll probably see only a few fuzzy stars in the frame, so just choose the smallest one that is clearly visible. Use exposure times of at least 2 seconds if possible so you don't chase the seeing. At the same time, don't let the star become saturated, showing a distinctive flat top. Now adjust the focus so the HFD gets consistently smaller - but stop as soon as HFD reverses direction or seems to plateau. At that point, the star may be saturated, so move to a dimmer star in the field. Since you have already improved the focus, you can hopefully see a dimmer star. Continue in this way until you've reached a focus point that shows a minimum level of HFD for the faintest star you can use. At each point in the focusing process, you'll probably want to watch the HFD values for a few frames so you can mentally average out the effects of seeing. Bad focus is a common issue for beginners, leading to problems in calibration or poor guiding results. You can also use a Bahtinov focus mask or another app like SharpCap for focusing. In general, you can't reach critical focus by simply looking at the stars in the image display - you need some sort of measurement help to get a good result. During guiding, you can use the Star Profile tool to be sure the star doesn't have a flat top (saturation) and shows a tapered shape like the example shown above. If the star profile window is large enough, it will also show the decimal X/Y coordinates of the star centroid.



The target display is another useful way to visualize overall guider performance. The red 'X' shows the star displacement for the most recent guide exposure, while the blue dots show the recent history. You can zoom in or out with the controls at the upper left of the window, as well as change the number of points shown in the history. If you are using an ASCOM connection for either the 'mount' or 'aux-mount', PHD2 will also show the directions (SkyNorth, SkyEast) associated with the star movement, as shown in the example above. This can be helpful if you are looking at overall drift and want to determine how to set uni-directional guiding for declination. The up/down convention used in this graph has nothing to do with the camera orientation or N-S-E-W movements in the field of view.

Adaptive Optics (AO) Graph



The AO graph is equivalent to the 'target' display, but shows the history of corrections relative to the axes of the adaptive optics device. The red rectangle indicates the outer edges of the AO device, while the interior yellow rectangle shows the "bump" region. If the star moves outside the yellow rectangle, *PHD2* will send a sequence of move commands to the mount - the "bump" - to smoothly place the guide star back near the center position. When this occurs, green and blue lines will show the incremental bump and the remaining bump respectively. The white dot on the display shows the current AO position, and the green circle (red when a bump is in progress) shows the averaged AO position. The button in the upper left controls how many points will be plotted in the history.

Dockable/Moveable Graphical Windows

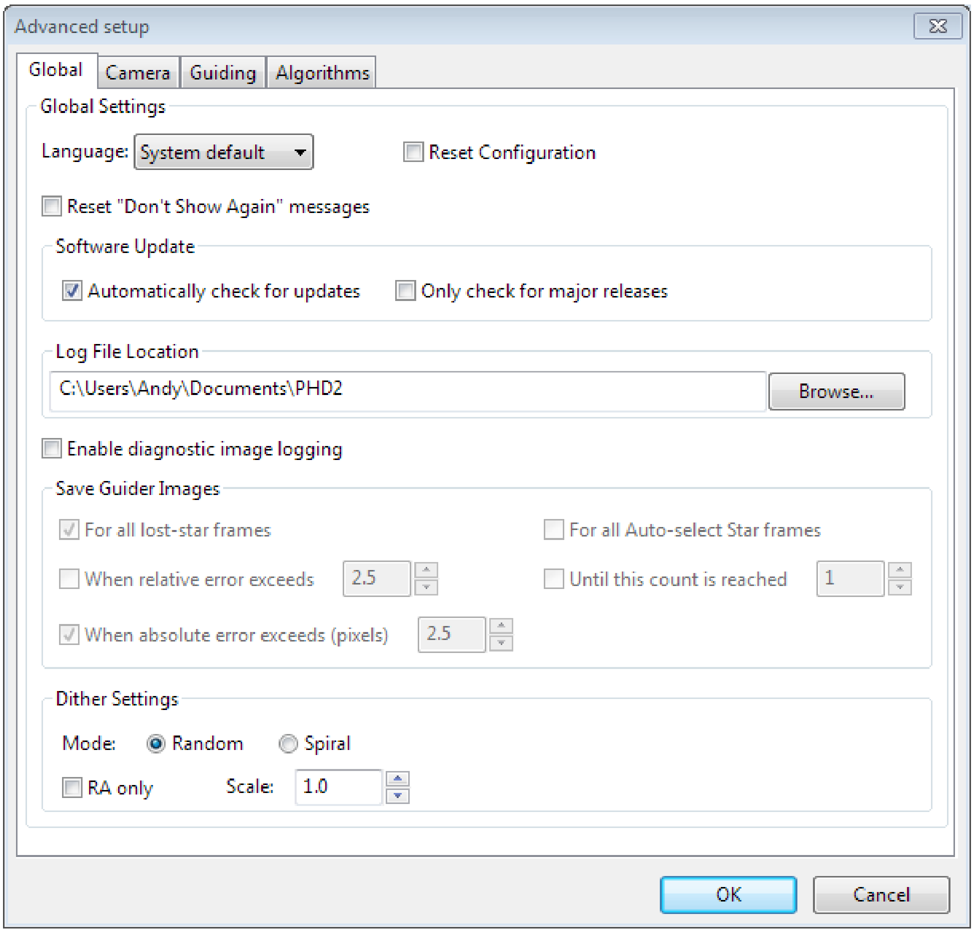
When the various performance windows are initially displayed, they are "docked" in the main window. This means they are sized in a particular way and are aligned with two edges of the window - they are entirely contained within the bounds of the main *PHD2* window. However, you can move them around and resize them by clicking and dragging on the title bar of the window you want to examine. This will often let you get a better view of the details being shown in the graphs. They can be re-docked by dragging the title bar to the general region in which you want them docked - bottom, right, etc. With just a bit of practice, it's easy to place them where they are most convenient.

There is also a menu item under the 'View" pulldown menu labeled 'Restore window positions.' Clicking on this menu item will automatically restore all of the dockable/moveable windows to their default, docked positions. This can be useful , for example, if you are switching between screens with different resolutions and one or more of the dockable windows has been "lost." This function also restores the main PHD2 window to its default size, with a position near the upper lefthand corner of the screen.

Advanced Settings

Advanced settings are accessed by clicking on the 'Brain button' in the main display. *PHD2* has a large set of parameters that can be adjusted to optimize your guiding experience. Although these are called "advanced" settings, they are not particularly difficult to understand, and there may be situations when you need to modify them. All of the fields on these forms include "tool tips", small message windows that describe each field in some detail. Simply "hover" the cursor over the field to see the tool-tip. In many cases, this will provide all the information you need. Because there are so many parameters available, the Advanced Dialog in *PHD2* is organized into notebook tabs that are activated by clicking on the tab names. All of the tabs share a common set of 'Ok' and 'Cancel' buttons at the bottom of the form. Clicking on 'Ok' means that changes made to any of the tab fields will be put into effect. Clicking on 'Cancel' discards any changes that were made.

Global Tab



The controls on the 'Global' tab are well-described by their respective tool-tips, but they are summarized here for completeness:

- 'Language' - determines the language used in the *PHD2* user interface, subject to available localization. Changing this requires a program restart.
- 'Reset Configuration' - restores all settings to their initial values as if *PHD2* had been freshly installed.
- 'Reset Don't Show Again messages' - restores the display of alert messages if you have previously chosen to not show them.
- Software Update
  - Automatically check for updates - allow *PHD2* to check for software updates when the program starts up. If no internet connection is available, checking will be deferred until the next time PHD2 is run.
  - Only check for major releases - don't include development builds when checking for software updates.

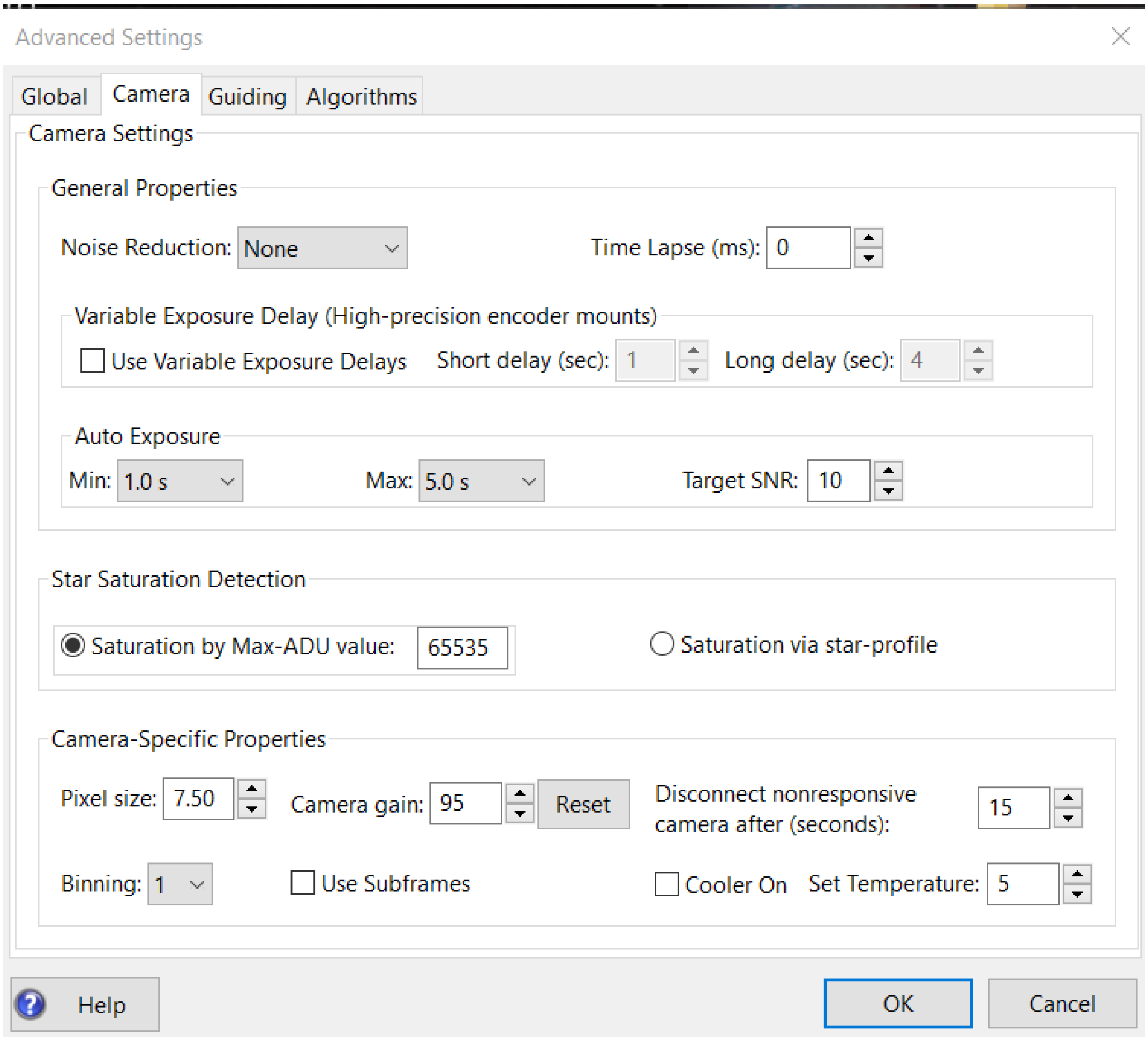
  See the Software Update section for more information about *PHD2* software updates.
- 'Log File Location' - specifies a directory where PHD2 guide logs, debug logs, and any diagnostic image files will be stored. The default location on Windows is the "My Documents" folder associated with the logged-in user..
- Dither Settings
  - 'Random mode' - tells PHD2 to use a random-number generator to compute both the size and the direction of the dither, subject to any constraints imposed by RA-only mode or by the Dec guiding mode being set to 'Off'.

- 'Spiral mode' - tells PHD2 to dither with fixed-size amounts in a clockwise spiral pattern. This can be a good choice when the imaging camera has significant fixed-pattern noise or the mount has a troublesome amount of Dec backlash.
- 'Dither RA only' - tells PHD2 to dither only on the RA axis.
- 'Dither scale' - an optional multiplier used to adjust the maximum-dither amount specified by the image application. See Dithering Operations

- 'Enable diagnostic image logging' - used primarily for product support and diagnosis of problems dealing with the guide camera or PHD2 star-recognition and measurement. Guide frame images are captured and logged in a FITs format subject to the filter/trigger controls in the group-box. Images are saved in sub-folders of the PHD2 logging directory with the date and time encoded as part of the sub-folder name. For example, a folder named 'PHD2_CameraFrames_2022-03-03-184542' refers to a logging event that began on March 3, 2022 at 18:45:42 local time. Individual guide frames are saved with filenames that indicate the time the image was captured and the reason the frame was saved. Since the guide frames are saved in a FITs format, the header will include other useful information such as exposure time. Because the logging function is primarily used for trouble-shooting, the image sub-folders are automatically removed after 30 days. If you wish to keep the images for your own purposes, you should either rename the sub-folders or copy/move them to a different directory. When logging is triggered by one of the "events" - e.g. lost star or large errors - a group of images (an *image set)* will be saved, centered in time on the image that triggered the event. This provides a record of guider images that will show what the guide star and guide frame looked like both before and after the unusual condition occurred. The various triggering and filtering controls are described below and are also shown in the tooltips for the controls:
  - 'All lost star frames' - logs the image set for any lost-star events, regardless of the reason for the lost star (low SNR, mass-change, etc.)
  - 'All auto-select star frames' - logs the image set for any frames used for auto-selection of the star, regardless of outcome. Note that any failed attempts to auto-select a star will always result in a logged image, regardless of choices made in the user interface.
  - 'When relative error exceeds' - logs the image set when the star deflection on the current frame exceeds the running-average error by the factor chosen in the adjacent spin control. For example, if the average (RMS) error is 0.5 pixels and the current frame's error is 1.5 pixels, the relative error is 3.
  - 'When absolute error exceeds' - logs the image set when the star deflection exceeds the number of pixels specified in the adjacent spin control.
  - 'Until this count is reached' - logs images until the count matches the value of the adjacent spin control. The counter is reset to zero when the limit is reached.

  Since the images are saved in an industry-standard format, there are many astronomy-related applications that can display or analyze them, many of which are free. Most of the image-capture and image-processing applications can do that along with other, more specific tools that can perform detailed measurements on the stars and the optical quality of the field of view. You can just do a web search to find a list of applications that support the FITs format for whatever platform you're using. If you simply want to look at the images to check focus or see the general quality of the images being returned from your camera, you can use PHD2 for that. With PHD2 in an idle state - neither looping nor guiding - just drag-and-drop one of your saved FITs image onto the main window. The display will then update to show the image you just dropped. There's no need for PHD2 to be connected to any of the hardware. You can adjust the gamma slider, select a star (manually or automatically), and use the Star Profile tool to view the HFD and profile of the selected star.

Camera Tab



The controls on the 'Camera' tab are used as follows:

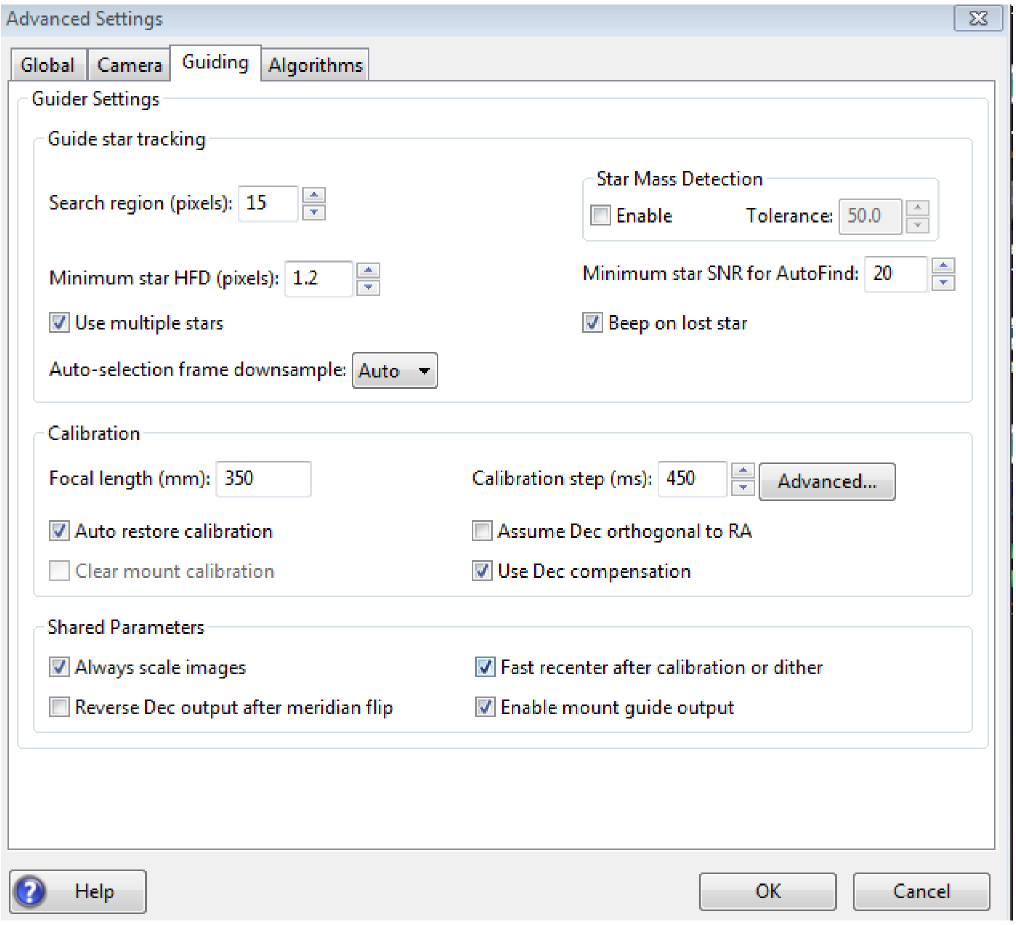
- 'Noise reduction' - specifies the algorithm to use for handling noisy guide camera images - those for which dark frames are not sufficient. Choices include None, 2x2 mean, and 3x3 median. Both 2x2 mean and 3x3 median will reduce the noise considerably. 3x3 median is especially effective at removing hot pixels and neither will significantly affect guiding accuracy. However, creating a bad-pixel map is likely to be a better solution with less impact on your ability to detect faint stars.
- 'Time lapse' - imposes a fixed delay between guide exposures. This can be useful if the guide exposures are very short and you don't want to overload either the mount or the camera link with very high traffic rates.
- Variable Exposure Delay - very precise/encoder-equipped mounts often benefit from conservative auto-guiding. This can include use of medium-long exposure times (4+ seconds) and an additional delay between guide camera exposures. The goal is to create a slow guiding "cadence" that is only reacting to tracking changes that aren't already being handled by the mount encoders or by its pointing model. Details of the approach can be found here: Variable Delay Guiding The variable exposure delay controls provide a way to achieve these goals while avoiding unnecessary delays when the system is engaged in actions other than "steady-state" guiding for imaging/science operations.
  - 'Use Variable Exposure Delays - enables the feature
  - Short delay (sec) - sets the exposure delay when PHD2 is looping, star-selecting, calibrating, dithering and settling, or running the Guiding Assistant. For some mounts, this value should be non-zero to give the mount encoders enough time to complete their position adjustments.
  - Long delay (sec) - sets the exposure delay when PHD2 is guiding and not in any of the other states named above. This delay actually defines the time between the completion of the last guide command, if any, and the start of the next camera exposure.
  - For both the long and short delay scenarios, the interval between successive guide camera exposures (and guide commands) will be exposure_time + guide_pulse_times + delay_value.
- 'Auto Exposure' - these are the settings that control Auto exposure time:, useful for automated imaging or AO guiding:
  - Min Exposure - the minimum exposure time. PHD2 will not set the exposure time less than this value, even if the guide star SNR is higher than the target SNR value. If the minimum exposure time is set too low, you are likely to chase seeing effects and thereby get poor guiding results. Users of adaptive optics units might set this to a lower value since rapid small corrections are more manageable with an AO. Lower values, down to 0.5-sec, can also be tried if multiple guide stars are normally available in the field of view.
  - Max Exposure - the maximum exposure time. Before a guide star is selected, PHD2 will set the exposure time to the maximum value. After selection is completed, PHD2 will then incrementally decrease the exposure time until the desired SNR is reached. The setting should be sufficiently small to allow PHD2 to adequately handle the tracking errors in your mount.
  - Target SNR - this is the average SNR value that PHD2 will attempt to achieve by adjusting the exposure time. SNR often fluctuates

from frame to frame even with a fixed exposure duration, so be sure to account for that when choosing a target SNR value. PHD2 will always reject frames when SNR drops below 3.0. The default value of 6.0 may provide enough of a cushion to prevent fluctuations from causing the SNR to go below 3.0 - but double-digit values are recommended. As mentioned in the 'Basic Use' section, SNR is similar but not identical to the signal-to-noise ratio used in photometry.

- 'Star Saturation Detection' - when identifying candidate guide stars, PHD2 tries to avoid saturated stars in order to get the most accurate calculations of their positions. You can assist this process by specifying how the assessment of saturation should be done:
  - Saturation by ADU value - this is the default option because it relies on the brightness levels measured by the guide camera sensor. Most guide camera drivers return image data in either 8-bit or 16-bit formats even if the camera electronics natively work in 12-bit or 14-bit modes. An 8-bit camera will saturate at a brightness level of 255 while a 16-bit camera will saturate at levels above 65000. If you are uncertain about your camera's behavior, you can use the Star Profile tool to measure the brightest pixel level when taking exposures of a very bright star. This will quickly tell you if the camera is returning values in the range of 0-255 or 0-65K and you can set the saturation value accordingly.
  - Saturation via star-profile - this relies on a less accurate judgment of saturation based on whether the star profile has a flat top. It is not recommended for normal applications.
- 'Pixel size' - The guide camera pixel size in microns. This is needed by *PHD2* to compute the guider image scale and thus report guider statistics in units of arc-seconds. Refer to your camera documentation to determine the correct value for pixel size. If your camera has non-square pixels, just choose one of the dimensions or input the average of the two. The pixel size has no effect on guiding accuracy, so a small amount of imprecision in this parameter won't cause any problems. If you're using the binning setting in this dialog to control camera binning, the pixel size should be the native, un-binned size. **Note: this control may be disabled** if the camera and camera driver can report the pixel size to PHD2 (most can). In that case, the value displayed in the disabled control represents the device-reported pixel size - it is what it is. If you're also specifying a binning factor at the camera driver level rather than in PHD2, the reported pixel size may change as a result. It is generally better to use PHD2 to set binning (see below).
- 'Camera gain' - Sets the gain level for the cameras that support this feature. Reducing this parameter can help to reduce the noise level or may allow use of a bright star without saturation. The range of values and their specific effects are dependent on the individual camera, so this PHD2 parameter is treated as a percentage of the range between the minimum and maximum gain values supported by the camera. For example, if the camera uses absolute gain values in the range of 40 to 80, a PHD2 gain value of 50% would translate to a camera gain of 60. Adjusting the gain level is not usually required once the configuration has been stabilized, and doing so will require replacement of dark libraries and bad-pixel maps.
- 'Disconnect nonresponsive camera after (seconds) - Camera malfunctions will sometimes occur, often because of faulty USB connections. In many cases, the camera will not return the requested image data, and PHD2 will appear to "hang." This parameter determines how long PHD2 should wait for a response after the expected exposure time has expired. For example, a timeout value of 5 seconds in conjunction with an exposure time of 2 seconds will tell PHD2 to wait up to 7 seconds for a response. If the data are not received within that period, PHD2 will attempt to halt the operation, disconnect the camera, display an alert message in the main window, then try to reconnect the camera. Since a hardware/power problem is nearly always the underlying issue, this recovery attempt won't always succeed. You should be generous with these timeout values to avoid spurious recovery actions. Also, if you are using a guide camera that shares electronics with the main imaging camera, you should set this timeout to a large value, well above the maximum expected time for a full-frame download from the main imager. This is a consideration for users of some of the SBIG dual-chip cameras. Regardless of whether PHD2 is able to handle the situation gracefully, the underlying problem is almost certainly in the hardware or the camera driver and will need to be resolved before guiding is continued.
- Binning - for those cameras that support on-chip (hardware) binning, you can specify the binning that will be used while taking guide exposures. Detailed information is available here: Use of Binning. This control will appear only if the camera is capable of on-chip binning and only if the camera is connected to PHD2. You should always use a separate PHD2 profile for each different binning setting because it affects many downstream guiding parameters, too many to try to adjust manually.
- 'Use subframes' - For cameras that support this feature, *PHD2* will download only a subframe of each guide exposure. The subframe shows the region around the star bounded by the tracking region limits. This is useful for cameras with slow download times, allowing them to be used more effectively for guiding. This feature applies to both calibration and guiding. During initial looping without a selected star, the full frame is downloaded, but once a star is selected, only this small subframe is downloaded.   If you are using subframes but want to see the full frame to select a different star, just shift-click anywhere in the image display window or shift-click on the 'Auto-select star' button. Using subframes eliminates the option for multi-star guiding, only a single star can be used with the subframe option.
- Cooler controls - a few guide cameras support sensor cooling. These controls let you specify whether the cooler is on and what the cooler set-point should be.

Note that some of the controls in this list will be disabled if the camera isn't connected to PHD2 or if the camera driver doesn't support the feature.

Guiding Tab



The guiding tab shows the parameters used for calibration, star-tracking, and guiding behavior shared by all of the guide algorithms..

Guide Star Tracking

- 'Search region' - specifies the size of the "tracking rectangle", in units of pixels. You may need to increase this value if your mount does not perform well or, more commonly, if it's not well-aligned on the celestial pole. You may also want to increase it temporarily while using the Guiding Assistant so that backlash measurement can be done without losing the guide star. Just remember that an overly large search region also increases the likelihood that multiple stars will live within its boundaries, which could lead to guiding problems. The value is actually a "radius" amount, so a search region of 15 pixels translates to a square of 30x30 pixels.
- 'Star mass detection' - tells *PHD2* to monitor the brightness and size of the guide star compared to the sky background. This feature has been deprecated and can generally be left un-checked (default value) for most configurations.
- 'Star mass tolerance' - if the 'Enable' box is checked, *PHD2* will trigger a 'lost star' error if the measured brightness and size vary by more than this percentage. This might be useful if you have two stars inside the tracking rectangle and you want to be sure *PHD2* doesn't mistakenly switch stars. It can also prevent errors caused by thin clouds, high camera noise, or alpha particle artifacts; but it may be unreliable if you are guiding on a faint star. If you are getting too many 'lost star - mass change" errors when the star is plainly visible on the display, try increasing the value of this setting or disable it entirely. .
- 'Minimum star HFD' - specifies the minimum half-flux-diameter (roughly the 'size') of a suitable guide star. This is probably the best way to prevent PHD2 from mis-identifying clumps of hot pixels as usable guide stars. You can determine a suitable value for your system by manually selecting some small stars that you know are not just hot pixels, then use the star-profile tool to see the HFD values of those stars. You'll want to specify a minimum HFD value that allows selection of legitimate faint stars but not hot pixels. The default value of 1.5px should work for most configurations but you can adjust it if needed - for example, if the guide camera pixels are large and too many candidate guide stars are being rejected because of their apparent small sizes.
- 'Minimum star SNR for AutoFind': specifies the minimum SNR value that will be accepted by the auto-select function for non-saturated stars. This should only be adjusted by experts because a value that is too large can result in no stars being selected. It can be used in situations where you would rather use a saturated star instead of a faint star that you know from experience will prove to be unusable. However, many of these situations can be avoided by getting better guide camera focus, refreshing the dark library, or slightly increasing the exposure times.
- 'Use multiple stars' - determines whether PHD2 will use more than one star for guiding. See Multi-star Guiding for details.
- 'Auto-selection frame downsample' - can be used in unusual situations where PHD2 guide star auto-selection is not recognizing misshapen stars. If this happens, you can try values greater than 1 to improve the chances of recognizing such stars. For most users, this property should be left at its default value of 'Auto'.
- 'Beep on lost star' - specifies whether PHD2 will produce an audible 'beep' sound when the guide star is lost during guiding.

Calibration

- 'Focal length' - the focal length of the guide scope (millimeters). This provides one of two parameters needed by *PHD2* to compute the image scale and thus report guiding performance in units of arc-seconds. If the focal length value is wrong, some of the default guiding parameters will not be set correctly, and we won't be able to help you assess performance and resolve problems. You should use the new-profile-wizard to specify focal length as part of defining your equiipment configuration.

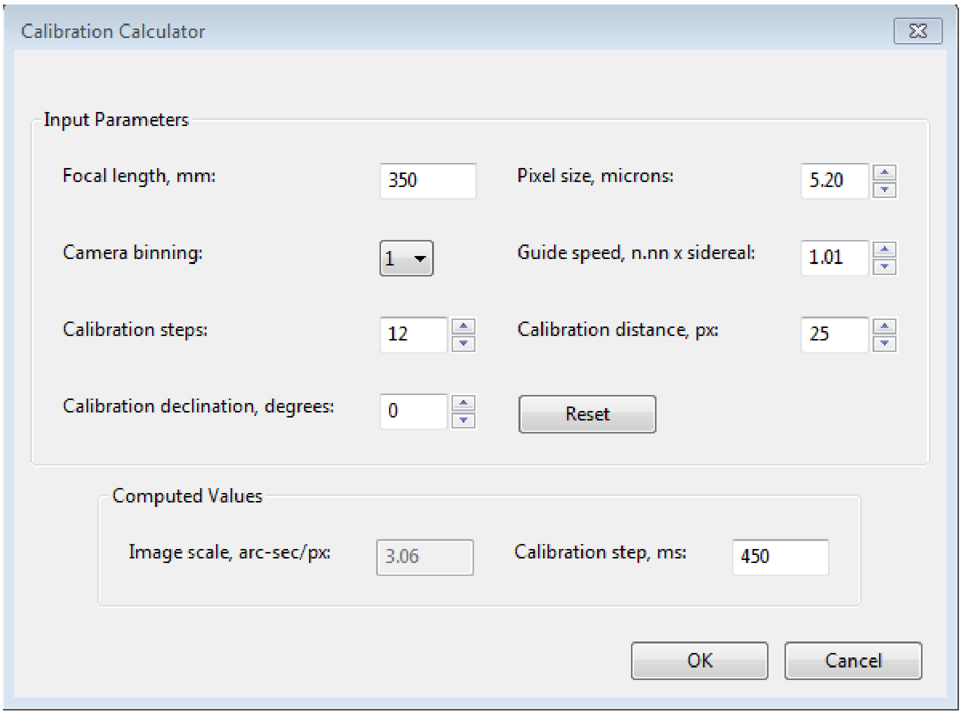
- 'Calibration step-size' - specifies the duration of the guide pulse that *PHD2* will use during calibration. Its use is described in the 'Auto Calibration' section of the 'Basic Use' help page. You can adjust the value depending on whether the guide star is moving too quickly or too slowly during calibration. As a general guideline, it is best to calibrate within about 20 degrees of the celestial equator (declination = 0), well above the east and west horizons; and to use a calibration step size that will result in 8-14 steps in each direction. The 'Advanced...' button to the right of this control will launch a calculator dialog that can help you compute an appropriate value (see figure below) . As with other parameters, this value is computed for you as part of running the new-profile-wizard so there is usually no need to adjust it.
- 'Auto restore calibration' - tells *PHD2* to automatically reload the most recent calibration data as soon as the equipment is connected. If you're using an ASCOM (or Indi) mount connection or have an 'aux-mount' connection, you probably want to set this option. Conversely, if PHD2 has no scope pointing information available, this option should be reset. The new-profile wizard will ask you how you want to set this option. Note that auto-restore is remembered for each separate equipment profile, and it only has an effect when you load the profile and connect to the equipment. If you want to force a recalibration before an individual guiding session begins, there are multiple ways to do that - doing a Shift-Click on the PHD2/guiding 'Guide' button is the easiest. **If you have set the auto-restore option, you must be sure that the guide camera is not rotated with respect to the guide scope or the sky.**
- 'Assume Dec orthogonal to RA' - Normally, the calibration process independently computes the camera angles for both right ascension and declination. There is no need for great precision on these values, and the default behavior normally works well. However, if your mount has very high periodic error, very large Dec backlash, or you are dealing with very bad seeing conditions, you may want to force the RA and Declination angles to be perpendicular. If you choose that option, PHD2 will compute the camera angle for RA, then assert a declination angle that is orthogonal to it.
- 'Clear mount calibration' - tells *PHD2* you want to clear the calibration data currently being used for the mount and re-calibrate before guiding is restarted. You might do this for a variety of reasons - rotating the guide camera or seeing that guiding results are substantially worse than normal, for example. You can accomplish the same result by doing a Shift-Click on the PHD2 guiding icon on the main page, which will force a re-calibration.
- 'Use Declination Compensation' - if PHD2 can get pointing information from the mount via an ASCOM/Indi connection ('Mount' or 'Aux'), it will automatically adjust the RA guide rate based on the current declination. This box should be left checked except in very unusual cases where the mount controller is making the adjustment. Don't confuse this option with 'Declination backlash compensation', which is an entirely different feature.

Shared Guiding Parameters

- 'Fast re-center after calibration or dither' - during calibration or dithering, the mount may be moved a significant distance from the initial "lock" position. If you click this checkbox, PHD2 will move the mount back to the lock position as quickly as possible, using the largest guide commands permitted by the 'Max Duration' settings of your guide algorithms and by the size of your tracking region. This is only a way to speed up the calibration process, the use of this checkbox is completely optional. If you find that calibration often fails because the star is lost during the fast re-center, you should disable this option. That sort of problem may indicate that you have a large polar alignment error or excessive periodic error in RA. You can run the Guiding Assistant to help see what's causing the problem.
- 'Reverse Dec output after meridian flip' - tells *PHD2* how to adjust the calibration data after a meridian flip. Some newer mounts track their 'side of pier' state and automatically reverse the direction of the declination motor after a meridian flip. Older mounts do not do this. In either case, *PHD2* needs to know if the mount will automatically change its behavior based on side-of-pier. You may have difficulty finding information about how your mount behaves in this respect, so PHD2 provides the Meridian flip calibration tool to determine the correct setting automatically. It's also easy to figure out the setting manually with this quick experiment:
    - With the checkbox disabled, calibrate on one side of the pier, then move the mount to the other side.
    - If you are guiding via ASCOM or Indi or are using an 'aux mount' connection, just start guiding.
    - If you're guiding only via ST-4 and PHD2 has no scope pointing information, first select 'Flip Calibration' under the 'Tools' menu, and then start guiding.
    - In either case, if the guiding works normally, leave the box un-checked; but
    - if you see guiding run-away ***in declination***, check the box and repeat the entire procedure, including calibration. You **must repeat the procedure**, simply checking the box doesn't "fix" anything.

  Note: **this procedure must be following in its entirety until you determine the correct setting**. Changing the 'Reverse Dec' setting only determines what will happen **in the future**, at the next calibration.
- 'Enable mount guide output' - this is normally checked because it tells *PHD2* to send guide commands to the mount. There are some circumstances where you might want to disable this, usually because you want to observe the uncorrected behavior of the mount. In most cases, you will be better off running the Guiding Assistant for these purposes, which automatically handles this setting for you.
- 'Stop guiding when mount slews' - prevents PHD2 from trying to continue guiding when the mount is being slewed, often by an imaging automation app. It should normally be left checked. Note: this option is only displayed if you have an ASCOM or INDI mount connection.

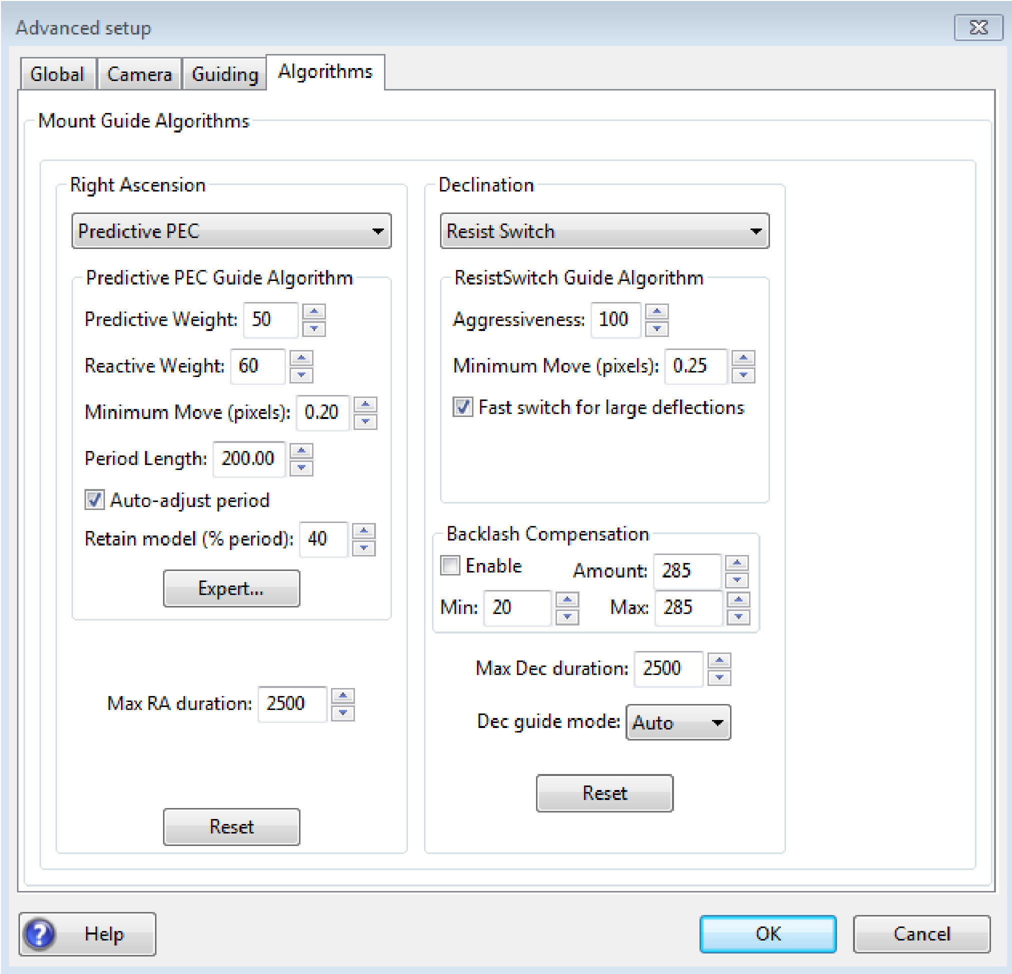
Advanced Calibration Calculator



To review or change calibration parameters, be sure the topmost four edit controls are correctly filled in. If you have already specified the focal length and the camera pixel size via the new-profile-wizard, those fields will already be populated in this form. If you are using an ASCOM connection to your mount, the fields for "Guide speed" and "Calibration declination" will usually show the correct values unless the driver doesn't report them correctly. Otherwise, you'll need to supply them yourself. The guide speed is specified as a multiple of sidereal speed - most mounts will use something like 1X or 0.5X sidereal, but you can choose something else. **Note: changing the guide speed setting here never changes the guide speed setting in the mount - that can only be done via the mount driver or the hand-controller. If this field is already filled in, changing it will have no effect.** You can leave the 'calibration steps' field at the default value of 12, which is likely to result in a good calibration. Use of a significantly smaller value raises the likelihood that seeing errors or small mount errors will cause calibration errors . You should be careful about increasing this value above 12 because "bigger" is not always "better". With larger values, uncorrected periodic error in RA or large drift in Dec will degrade the accuracy of the calibration. As you change the values in these fields, *PHD2* will recalculate the value for the calibration step-size. If you then click on 'Ok', that value will be inserted into the calibration step-size field of the 'Guiding' dialog and will be used for the next calibration. Clicking 'Ok' will also populate the focal length and camera pixel size fields in the 'Guiding' and 'Camera' tabs, so any changes you made in the calculator will be reflected there as well. Don't do this if you are just using the calculator to experiment or check settings for someone else's system. Clicking on the 'Cancel' button will close the calculator without changing any of the values in the curren profile. Again, PHD2 never changes the guide speed setting in your mount regardless of what may be entered in the 'Guide Speed' field.

If you've used the new-profile-wizard to build your equipment profile, there's rarely any reason to use the 'Advanced" button and the Calibration Calculator dialog.

Algorithms Tab



The algorithms tab can be used to select the guiding algorithms you want and fine-tune the parameters associated with them. The parameters displayed will change significantly if you change the algorithm selections. For that reason, all the parameters related to guide algorithms will be treated together, in a separate section.

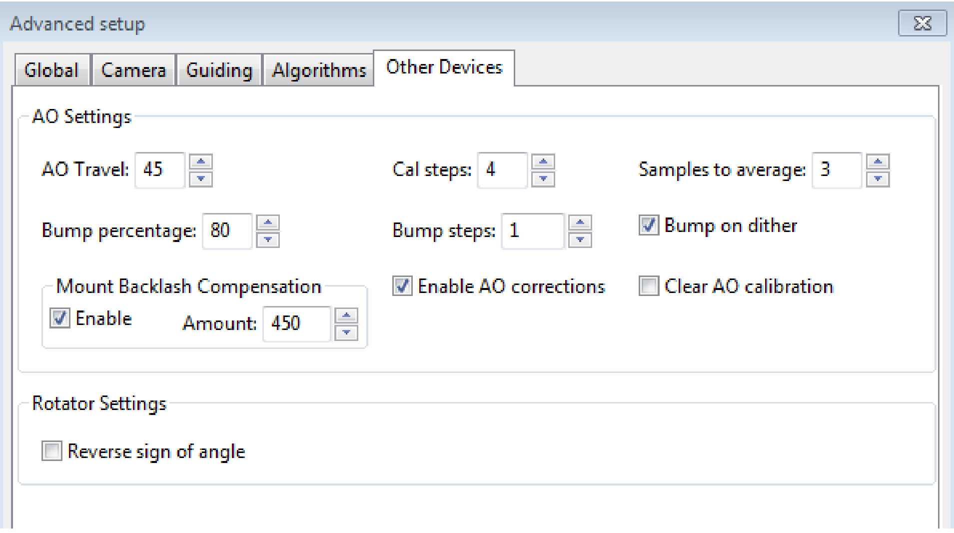
The remaining controls, the ones that are independent of the guiding algorithm selections, are described below.

- 'Max RA duration' - specifies the maximum allowed guide pulse duration for right ascension. You might reduce this below the default value if you want to avoid chasing a large deflection that could be caused by a spurious event (e.g. wind gust, hot pixel, etc.) .' However, there is rarely any reason for changing it if you have protected yourself against hot pixels (Minimum star HFD).
- 'Enable' PHD2 Backlash Compensation - this controls whether PHD2 will apply a compensation factor when the direction of declination guiding needs to be reversed. **See section below**.
- 'Max Dec. duration' - specifies the maximum allowed guide pulse duration for declination (same as above but for declination).
- 'Declination guide mode' - gives you additional control over declination guiding. Declination guiding is not like RA guiding because the tracking errors are not caused by imperfections in your mount's drive system - the Dec motor is idle during normal sidereal tracking, running only in response to short Dec guide commands. Instead, tracking errors in declination are caused by polar alignment error, mechanical flexure, wind, binding or dragging of cables, or unwanted movement of the guiding assembly. Absent these mechanical problems, declination tracking should be smooth and mostly uni-directional assuming there is no over-shoot from an earlier correction. The default value of 'auto' tells *PHD2* that some reversals in direction are acceptable, subject to the behavior of the various guiding algorithms. However, if your mount has severe declination backlash, you may want to prevent direction reversal altogether. You could then select either 'north' or 'south' to restrict corrections to only that direction (uni-directional Dec guiding). Keep in mind, however, that an over-shoot in correction with one of these modes might leave the star positioned off-target for an extended period of time. So you'll probably want to use conservative aggressiveness values for either 'North' or 'South' modes and you may want to intentionally degrade the polar alignment to help keep the drift rate larger than the deflections caused by seeing. Finally, a choice of 'off" here disables declination guiding altogether, an appropriate choice for simple tracking mounts that don't support Dec guiding.
- 'Reset' - resets the guiding parameters for the selected RA or Dec algorithm to their default values. Min-move settings will be set using the same algorithm employed in the new-profile-wizard. If you previously used the Guiding Assistant to adjust the min-move settings, you should repeat that procedure.

Declination Backlash Compensation

Most commonly-used mounts have some backlash in declination. You can find a brief discussion of backlash mechanics here: Dec Backlash Backlash causes a delay whenever there is a change in direction of the Dec guide commands. During this interval, the declination gears aren't fully engaged and the axis doesn't move in response to the guide commands. Many mounts have settings for backlash compensation but these should not be used for guiding - they are typically intended for visual use only. Because the actual amount of compensation needed at any given time depends on the pointing position and the mechanical load on the system, a fixed value will usually result in oscillations that never stabilize. Reasons for the positional dependency include uneven gear wear or significant imbalance of the scope in declination. The backlash compensation implemented by PHD2 is adaptive, meaning that the compensation amount is adjusted up or down depending on the measured results. Before enabling this feature, you should run the Guiding Assistant and measure the declination backlash - the time delay required to fully reverse direction in declination. Keep in mind, the higher the guide speed setting in the mount (e.g. 0.9x sidereal), the smaller this delay will be. If the measured amount is 3 seconds or less, the Guiding Assistant will recommend trying backlash compensation. If you apply that recommendation, the backlash compensation settings will be handled for you automatically. The UI controls for backlash compensation include settings for 'minimum' and 'maximum' compensation amounts. These effectively limit the range of the adjustments that are made to the starting compensation value. If you're experienced with your mount's behavior, you can adjust these settings manually to be sure the compensation stays within a range that you know works well. Otherwise, you should just leave these at their default values. The backlash compensation algorithm will generally work well if the backlash is less than a few seconds and the mount doesn't have other significant mechanical problems. You should expect a short period of instability when guiding starts because the initial state of the Dec gear system is unknown - just let it stabilize before you actually start imaging. If you see recurring periods of Dec oscillation or the axis won't settle down, disable the compensation feature and submit your debug log file to the PHD2 support forum.

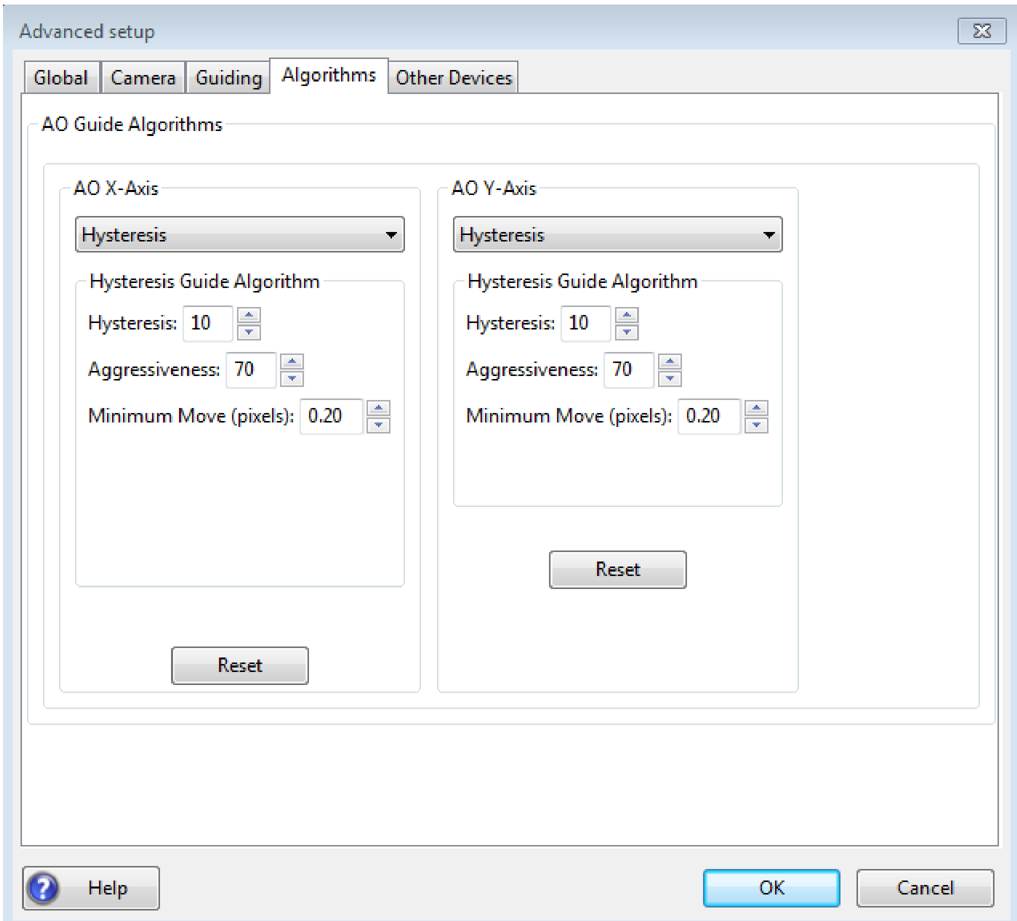
Other Devices Tab



If you are using either an adaptive optics or rotator device, the "Other Devices" tab will be shown. A general discussion of using an AO for guiding can be found here: [AO Guiding](#) The upper section deals with the AO device if one is being used. You can use these parameters to control the calibration process and the manner in which 'bump' operations are done. The 'calibration step' field tells *PHD2* the amount to move the tip/tilt element in each of the up/down/left/right directions, in units of AO steps, during calibration. The guide star position is measured at the beginning and end of each leg of the calibration, and the 'samples to average' parameter tells *PHD2* how many samples to take at each of these points. Averaging images is important because the seeing will always cause the guide star to "bounce around" a bit. As discussed elsewhere, the AO unit can make corrections only within a limited range of guide star movement. You will want to initiate mount 'bump' corrections before these limits are actually reached, and the 'bump percentage' field is used for that purpose. To move the mount, the full bump correction is accomplished in steps - the 'bump step' field controls the size of these increments. If the bump operation has begun and the guide star remains outside the "bump percentage" area, *PHD2* will increase the bump size until the guide star is back within that range. Additional movement from that point to the center position will continue at the specified "bump step size". This complexity is required in order to maintain good guiding, with no elongated stars, even as the mount is being bumped. During the bump operation, the AO is continuing to make corrections, so the long "mount bump" is continuously offset by adjustments in the AO. The 'AO Travel' field specifies the number of steps the AO can make on each axis. The default value works well for most SX AO devices but in some cases it may be too large. If you encounter problems during AO calibration where the AO hits its limits, you can adjust the 'AO Travel' amount downward.

The 'Bump on dither' option tells PHD2 to bump the mount when a dither command is received and thus move the guide star back closer to the center position of the AO. The option to enable or disable AO guide commands operates independently from the 'Enable mount guide output' checkbox in the Guiding tab. So you can independently enable/disable either the guide commands to the tip/tilt device or the 'bump' guide commands to the mount. The same principle holds for the 'Clear AO calibration' option - that will force a recalibration of the AO without affecting calibration of the mount. The 'Mount Backlash Compensation' controls let you apply PHD2 Dec backlash compensation when mount bumps are done. This can help speed up large dither operations, but it's only appropriate if the mount has a limited amount of Dec backlash. You should use the Guiding Assistant to measure your Dec backlash and see what it recommends with regard to using Dec backlash compensation. The backlash compensation value cannot be adjusted automatically when the AO is being used so it is a good idea to specify a value that is perhaps 1/2 the value suggested by the Guiding Assistant.

When an AO is in use, the 'Algorithms' tab will only show choices for controlling the tip/tilt optical element in the AO device itself.



Since the AO is not trying to move a heavy piece of equipment, you can afford to be more aggressive in your guide algorithm choices. The default algorithms for an AO are 'Hysteresis", which provides an easy way to control damping and aggressiveness. If you use a different algorithm, you should probably start with a high level of aggressiveness there as well. The other, shared guiding parameters normally displayed on the 'Algorithms' tab will not be shown for the AO because they aren't used to control the device.

The rotator device has only one parameter which lets you match the behavior of the device to the ASCOM notion of positive and negative angles. The "Reversed" checkbox can be used for optical systems that reverse the image, usually because they have an odd number of mirrors. The direction and amount of rotation is used to adjust the calibration data, so PHD2 follows the ASCOM standard: "the rotator position is expressed as an angle from 0 up to but not including 360 degrees, counter-clockwise against the sky." Experimentation is likely to be the quickest way to determine if the box should be checked.

Guide Algorithms

[Guiding Theory](#)
[Guide Algorithm Parameters](#)

Guiding Theory

The default guiding algorithms in *PHD2* are well-established and should work well for most users. Unless you already have experience with guiding and understand its principles, you should be somewhat cautious about changing algorithms. However, the Advanced Settings dialog in *PHD2* makes it easy to do that. Each algorithm has a set of parameters that control how observed changes in guide star position (star deflections) are translated into guiding corrections that will be sent to the mount.

Before discussing the details of these parameters, it is worth reviewing a little guiding theory and looking at what these algorithms are trying to accomplish. Setting aside adaptive optics devices, which are considerably different, conventional guiding faces substantial challenges. The problem at hand is how to move machinery that weighs tens or even hundreds of pounds with a level of precision that will not cause streaked or oblong stars. Even though many guide cameras are sensitive to guide star deflections of only a few microns on the sensor (e.g. 0.0002 inches, 0.005 millimeters), we still expect the mount and the guiding software to move the camera across the sky for hours with this level of precision. Guiding applications like PHD2 are best able to deal with tracking errors that are "slow and steady", not "fast and random." Sources of slow, steady, or predictable (correctable) errors include the following:

- Certain kinds of mechanical imperfections in right ascension gears, including those that cause periodic error.
- Small errors in the sidereal tracking rate of the mount
- Reasonable amounts of declination backlash
- Atmospheric refraction - stars appear to move more slowly as they near the horizon
- Limited kinds of mechanical deflection and flexure - but **not** differential flexure
- Mis-alignment of the right ascension axis on the celestial pole (polar alignment error)

So what isn't included in the above and isn't correctable by conventional guiding? Unfortunately, it's a long list, of which a few are:

- Atmospheric seeing ("turbulence")
- Gear noise, roughness, and vibration
- Binding and high static resistance in the axis drive systems from over-tightening or other mechanical problems
- Gross imbalance of the scope on the mount axes
- Differential flexure - relative movement between the imaging scope and the guide scope
- Wind gusts, cable snags, grit in the drive gears
- And lots more...

The common denominator shared by the guide algorithms is the need to react to the slow, steady, or predictable deflections while ignoring the rest. This is a difficult problem at best because any given guide star deflection is likely to have contributions from multiple sources. And if that isn't hard enough, remember that real-world mounts are never perfect - so the correction you ask for will not be exactly the correction you get. Usually, the most important requirement for any algorithm is to avoid over-correcting, wherein the mount is being pushed back and forth and the guiding never stabilizes. A typical approach in these algorithms is to ignore deflections that are most likely caused by seeing and to apply "inertia" or "impedance" to the guiding corrections that are sent to the mount. That usually means making corrections that follow a pattern of movement and are generally consistent with corrections that have been made before; while being reluctant to make corrections that require a big change in direction or amplitude. Resistance to changes in direction is particularly important in declination, where backlash is a common problem. Hopefully, this background will give you enough insight into the basics of guiding so that the various guiding parameters used in *PHD2* will make sense.

Guide Algorithm Parameters

In *PHD2*, the various guide algorithms can be applied to either the right ascension or declination axes. Most of these algorithms include a **minimum move** parameter. This is used to avoid making guide corrections that are overly small, are unlikely to have any effect on star shape, and are mostly due to transient seeing effects. These values are entered in units of pixels, so you need to think about them in the context of your image scale and the typical size of your guide stars. If you have used the new-profile-wizard to configure your system, the min-move parameters will be set to values that are likely to work well for the image scale you're using. The Guiding Assistant can also adjust these values based on its measurement of high-frequency seeing disturbances. If you are seeing a high rate of declination guider corrections and lots of direction reversals, you may be "chasing the seeing" and adjusting the min-move values upward can be a simple way to reduce that. **Of all the detailed guiding parameters discussed here, the two min-move values are the most likely ones to warrant adjustment on a nightly basis based on seeing conditions.**

The **hysteresis** algorithms keep a history of the guiding corrections that have been made in the recent past, and these are used to help compute the next guide correction. The **hysteresis** parameter, expressed as a percentage, specifies the "weight" that should be given to this history as opposed to looking only at the star deflection in the latest guide frame. Consider an example where the hysteresis parameter is 10%. In that case, the next guiding correction will be 90% influenced by the star movement seen in the current guide frame and 10% by the corrections that have been made in the recent past. Increasing the hysteresis value will smooth out the corrections at the risk of being too slow to react to a legitimate change in direction. The hysteresis algorithms also include an **aggressiveness** parameter, again expressed as a percentage, that is used to reduce over-correcting. On each frame, *PHD2* computes how far and in what direction the mount should be moved. The aggressiveness parameter scales this. For example, take a case where the star deflection has been evaluated and a corrective move of 0.5 pixels is warranted. If the aggressiveness is set to 100%, a guider command will be issued to move the mount the full 0.5 pixels. But if the aggressiveness is set to 60%, the mount will be asked to move only 60% of that amount, or 0.3 pixels. If you've done a reasonable job of setting Min-Move values, there is generally no need to modify these parameters, and any modifications you attempt should be based on a careful analysis of long guiding sessions using the PHD2 LogViewer tool.

The **ResistSwitch** algorithm behaves much as its name implies. Like the hysteresis algorithms, it also maintains a history of past guide corrections, and any change of direction must be "compelling" in order to issue a reversing guide command. This is appropriate for declination guiding, where reversals in direction are both suspect and likely to trigger backlash in the gears. For that reason, ResistSwitch is the default algorithm for declination but not for right ascension, where valid direction reversals are expected. Two parameters are available fur controlling the ResistSwitch algorithm. The first is "aggressiveness", a percentage amount that behaves like the hysteresis aggressiveness described above. The second parameter is a checkbox labeled "Fast switch for large deflections." If this is checked, PHD2 will react immediately to a large change of direction rather than waiting for three consecutive deflections in the new direction, which is the normal behavior. This can help to more quickly recover from large excursions in Dec, perhaps caused by wind, cable snags, or other mechanical shifts The definition of a "large deflection" is 3x the minimum-move value. So if PHD2 is over-reacting to direction changes, you can tune the behavior with the min-move parameter or disable the "fast switch" option altogether. It is worth remembering that "less is usually better" when it comes to Dec guiding, so don't try to over-tune these parameters.

The **LowPass** algorithm also employs a history of recent guiding corrections in order to compute the next correction. The starting point for the computed move is the median value of the guide star deflections that have occurred in recent history. This means that the star deflection seen in the current guide frame has relatively little impact on calculating the next move and the algorithm is resistant to quick changes. But the history accumulation also includes a calculation to determine if deflections are trending in a consistent direction. The **slope weight** parameter, expressed as a percentage, determines how much influence this should have in calculating the actual guider movement - it is there to keep the algorithm from being overly sluggish. If you set a slope weight of zero, the guide pulse will always be just the median value of the recent history. If you set a non-zero slope weight, that median value will be adjusted either upward or downward based on the recent trend of guide star movements. Because the low-pass algorithm is so resistant to quick changes, it is probably most applicable to declination guiding or to mounts with absolute encoders. Use of this algorithm has been deprecated in favor of the LowPass2 algorithm.

The **LowPass2** algorithm is a variation of the original LowPass algorithm with somewhat different behavior. It also maintains a history of guiding corrections, but the next correction is simply a linear extension of the commands that have come before it (i.e. a slope calculation). This continues until a significant change in direction is seen, at which point the history is cleared. The algorithm has two adjustable properties: minimum-move and aggressiveness. Minimum-move has the same effect as it does in the other guide algorithms, and aggressiveness (percentage) is a way of further dampening the size of the guide corrections. LowPass2 is a very conservative, high-impedance algorithm that is a good choice for users with good seeing conditions and well-behaved mounts with little or no declination backlash. It is the recommended algorithm for mounts that have high-precision encoders.

The **Z-filter** algorithm is a variation on the LowPass algorithms but operates in the discrete frequency or "Z" domain. In terms of guiding it applies full correction to the low frequency components caused by mount periodic error. Higher frequencies are corrected with aggression progressively reducing down to zero.

The Z-filter algorithm allows you to use shorter guide camera exposure times (e.g. 1s or 0.5s) without chasing the high frequency seeing. The advantages of shorter guide exposure time are reduced lag time for applying corrections and smaller corrections.

The Z-filter algorithm offers just two adjustments: Exposure Factor (XFac) and Minimum Movement (MinMo). The virtual guide exposure time is given by the actual exposure time multiplied by the Exposure Factor. A given virtual exposure time will perform similarly to an unfiltered algorithm using the same actual guide exposure time. For example, an exposure time of 1s with Exposure Factor of 4 gives a virtual exposure time of 4s (4 x 1s) and performs similarly to Hysteresis with Aggressiveness 100% and Hysteresis 0.0 using an exposure time of 4s. An exposure time of 2s with an Exposure Factor of 2 also has a virtual exxpsoure time of 4s (2 x 2s) and thus performs much the same. The main difference is that the shorter actual exposures allow the corrections to be applied sooner and more frequently so they are smaller.

This feature lets you adjust the guide exposure time to optimise the guide star SNR and guide latency. You can then adjust the Exposure factor to get the desired guiding response. A virtual exposure time of 2s to 4s per the usual recommendation is a good starting point for the RA axis. On the Dec axis, longer virtual exposures can be used and can help minimise reversals that can result in backlash.

Note that when using short exposures the movement from seeing will be more visible on the guiding graph. This does not mean the guiding is worse. Other algorithms rely on guide exposure time to filter out the movement from seeing. The Z-filter Exposure Factor performs the same function.

The Z-filter also has a MinMo setting. The value should be chosen to match the ability of the mount to accurately make small corrections. With other algorithms MinMo is sometimes recommended to provide some filtering e.g. to prevent reversals of the Dec axis. With the Z-filter the recommended approach is to increase the Exposure factor. The Z-filter algorithm is more complex and harder to understand and is unlikely to produce results better than LowPass2 with most mounts, so it is not generally recommended.

PHD2 Predictive PEC Guide Algorithm (PPEC)

Overview

The PPEC algorithm is different from the others in PHD2 because of its modeling and predictive capabilities. The algorithm analyzes the tracking performance of the mount in real-time and once the analysis is complete, it will compute guiding corrections even before a repetitive error is actually seen. Issuing proactive guiding corrections reduces the time delay inherent in traditional guiding and can significantly improve performance. With the other algorithms, which are completely reactive, guide corrections are issued only after the error has been seen on the camera sensor.

Once guiding has begun, the algorithm analyzes the performance of the mount and looks for tracking errors that are repetitive and thus, predictable. The algorithm employs a sophisticated Gaussian process model developed by a research team at the Max Planck Institute in Germany. The mathematical details can be found in a paper referenced here:

http://ieeexplore.ieee.org/document/7105398/?reload=true

The PPEC algorithm will normally be used for RA, where residual periodic error and other gear-related errors often reduce tracking accuracy. The algorithm uses separate time-scales for characterizing the behavior of the system:

- Short-term: for high-frequency errors such as those caused by gear roughness or seeing
- Medium-term: for residual periodic errors, typically occurring at intervals less than or equal to the worm period
- Longer-term: for steady drift and for lower frequency (longer time interval) harmonics that can be caused by the interaction of multiple gears in the drive train

The short-term behavior is used to identify the unpredictable noise in the system, which is essentially filtered out in order to identify components that are predictable. For most mounts, the medium-term component will be the most important. If you're following best practices, you will have programmed periodic error correction in your mount (assuming that feature is available to you). Doing this reduces the amount of work that needs to be done by PHD2, and the PEC correction in the mount is normally saved permanently. This approach is preferable to having to measure and infer the periodic error behavior every time you set up your equipment. That said, PEC in the mount is never perfect, and you will often see residual repetitive errors even when PEC is active. These often arise when the tracking errors occur with a frequency that is not a harmonic (integer fraction) of the mount's worm period – most PEC implementations can't deal with those. You can also get residual periodic errors if they are dependent on the mechanical loading of the mount or if the mount's behavior has changed since the PEC was programmed. The PPEC algorithm can be quite effective at identifying and reducing these errors because it doesn't depend on the worm period and is always doing a fresh analysis of the mount's current behavior.

The PPEC algorithm will also detect and proactively correct for drift errors. Although drift is typically handled well by any of the guide algorithms, the corrections will always lag the error by some amount. For some use cases – perhaps spectroscopy, photometry or comet-tracking – this might be a problem, in which case PPEC may deliver better results.

Since PPEC employs a learning process, it will usually take about 2 worm periods to model the mount and become fully effective. During this training period, the algorithm will behave more like the 'hysteresis' algorithm, so you won't normally see a performance penalty while the internal model is being built. Instead, you're likely to see a steady improvement in tracking as the model is refined and the algorithm shifts seamlessly from hysteresis to predictive-mode. This improvement can usually be seen even before the medium-term mount behavior is fully modeled.

Since the PPEC model is implicitly tied to the state of the gear train, it must be re-learned if the mount is slewed by a substantial distance. For the same reason, it can't be retained across different guiding sessions, which is why conventional PEC is important. However, the PPEC model will remain intact during dither operations and while guiding is paused (via automation) for activities like focusing. For the most common use-case, namely imaging the same target for multiple hours with periodic dithering, the PPEC model will remain valid. In any case, the learning process and transition from one mode to the other is handled automatically, so you won't need to pay it any attention.

Algorithm Details

Once the training period is completed, the PPEC algorithm computes the guide correction using two factors. One is reactive, based on the displacement of the guide star in the most recent exposure. The second is predictive, based on the output from the Gaussian process model constructed during the training period. Each of these terms includes a separate gain or aggressiveness factor, so the final guide pulse amount is a sum:

Guide-correction = (predicted amount * predictive gain) + (recent displacement * reactive gain)

The '**predictive gain**' and '**reactive gain**' parameters are exposed in the Advanced Settings dialog, and their default values for these parameters should work well for most mounts. You should be conservative about changing them because bad choices for these parameters can definitely make your guiding worse. Note that the two components in the calculation of the guide-correction are vector quantities - they may have opposite east/west polarities. For that reason, there is no restriction that the sum of the two gain values must be less than 100% - but be careful to avoid over-correcting.

During the training period, the algorithm needs to identify periodic errors in the observed guide star movement. For initial trials, you can use the worm period of your mount as the starting point for the '**period length**'. This gives the algorithm a good starting point, but you should initially leave the 'auto-adjust period' option checked until you have a clear view of your mount's periodic error curve. This tells the algorithm to adjust the period as needed to better control whatever periodic errors it finds. Once you have run the algorithm multiple times and are happy with the results, you can typically un-check the 'auto-adjust period' option to be sure the PPEC algorithm remains focused on the most important frequency. Similarly, if you have a mount with a recurring tracking error that occurs on a non-harmonic frequency, un-checking the option is probably a good idea as well. Obviously, knowing this requires an FFT analysis of your native tracking performance, a capability that's part of the PHD LogViewer tool.

The '**Retain model (% period)**' parameter specifies how long the mount can track unguided before the PPEC algorithm will be reset. This is computed as a percentage of the current period length. This is useful in situations such as auto-focusing where the mount is continuing to track at the sidereal rate but guiding isn't being done. It also applies to westward changes in the RA pointing position from slewing. Care must be taken if the default setting of 40% is adjusted upward. Running for extended periods of time unguided causes the PPEC model to lose accuracy, in which case a reset would be the best course of action. The point where that occurs is specific to the mount and the current seeing conditions, so you may need to experiment if you want to adjust this parameter.

The '**min-move**' parameter affects only the reactive component of the algorithm. If the measured star displacement is less than this amount, the reactive component will be set to zero. However, the predictive component of the algorithm will still be computed and applied.

Tools and Utilities

Polar Alignment Tools

PHD2 offers three different polar alignment tools. The three approaches share the same basic objective: to help you physically align the RA axis of your mount to the celestial pole. These polar alignment tools are different from the "two-star" or "three-star" alignment procedures that are part of many popular go-to mounts. The mount software routines are generally focused on optimizing go-to operations by adjusting the slewing/pointing operations to compensate for various errors in the mount, including polar alignment error. They generally don't involve physical adjustment of the mount's azimuth and altitude controls, which is what is necessary for successful imaging and guiding.

The three polar alignment tools have different requirements and behaviors, as summarized in the table below. The accuracy and speed columns show values in the range of 1-3, where 1 is lowest and 3 is highest.

Method	Accuracy	Speed	Sky View	Other
Traditional drift alignment	3	1	East or west horizon Meridian/celestial equator	Most slewing Axes measured/adjusted separately
Static polar alignment	1	3	Polar region	Requires identification of polar region stars Minimal slewing
Polar drift alignment	2	2	Polar region	Minimal slewing

The original polar alignment routine, drift alignment, is still considered by most to be the "gold standard" for accuracy. Partly, this is because it directly measures the thing you're interested in: the amount of drift that will be caused by mis-alignment of the RA axis on the celestial pole. The drift alignment tool requires use of only one visible star at a time, and identification of the star is unnecessary. But the procedure can be time-consuming, especially for beginners, because each mount axis must be adjusted separately and the telescope will need to slew over a fairly wide area. Also, it works best if you have clear views of the celestial equator/meridian intersection and an area around 30 degrees above either the eastern or western horizon (azimuth 90 or 270 degrees). For imagers who are rushing to set up each night or have a limited view of the sky, these requirements may be unappealing.

The second alignment option, static polar alignment, addresses these concerns by taking a different approach. It specifically trades off some accuracy to optimize the speed of the process. It requires only a clear view of the northern or southern polar region, and it facilitates adjustment of both mount axes at the same time. It is therefore a bit more intuitive and quite likely to be quicker to complete. It does require visibility and identification of several stars near the pole, but the tool makes that reasonably easy assuming your sky conditions are good enough to see the stars.

The third alignment option, polar drift alignment, is probably the simplest one to perform at the expense of a bit of accuracy and speed. It requires a clear view of the northern or southern polar region, and it facilitates adjustment of both mount axes at the same time. Minimal user input is needed so it is very simple to use.

The three techniques are described in detail in the following sections. Imagers should probably experiment with them and choose the one that best suits their needs. The importance of alignment accuracy is often over-emphasized, so users need to keep things in perspective. Most declination drift can be well-managed by PHD2 guiding assuming the mount behaves well and doesn't have a lot of declination backlash. However, at some point, the amount of polar alignment error can create field rotation in the images, something that can't be corrected. The larger the imaging sensor and the closer to the pole the target is, the more field rotation can be an issue. You can compute the expected field rotation using an online calculator such as this one:

http://celestialwonders.com/tools/rotationMaxErrorCalc.html

The calculator can help you decide how much accuracy is "good enough" for your situation. It's also important to remember that any of the procedures can be limited by the precision of the adjustment mechanisms on the mount and your ability to tighten them sufficiently to keep things from moving around as you slew to various parts of the sky.

Drift Alignment Tutorial

Static Polar Alignment Tutorial

Polar Drift Alignment Tutorial

Auto-Select Stars

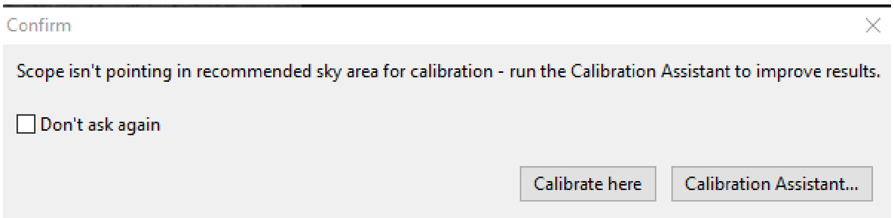
Automatic guide star selection can be accomplished in several ways. The simplest way is to click on the 'Auto-Select Stars' icon in the main window, next to the 'Guide' icon. Auto-selection can also be triggered by using the keyboard shortcut of <Alt>S or by clicking on the 'Auto-select stars' item under the 'Tools' menu. Taking any of these actions tells *PHD2* to scan the current guide image and identify stars most suitable for guiding. PHD2 will try to select stars of sufficient brightness that are not saturated, have sufficient size, and are not too near other stars nor too close to the edge of the frame. The selected stars may appear fairly dim on the screen, but that's not important - just adjust the gamma slider on the main window if you feel the need to see them. The auto-select function will nearly always do a better job than you can by just looking at the display, and it is the only way to invoke multi-star guiding. In many cases, a star you choose interactively is at or near saturation and will produce sub-par results. You can use the Star Profile tool to examine the properties of the primary (brightest) selected star, however it was chosen. To get the best results from Auto-Select, you should use either a bad-pixel map or dark library and specify a Min-HFD value (Advanced Settings/Guiding tab) to reduce the likelihood of PHD2 mistakenly choosing a hot pixel. It also works better if you set the option to measure saturation by Max-ADU value (Advanced Settings/Camera tab), assuming you know or can determine the maximum ADU value of your camera. For example, a 16-bit guide camera will have maximum ADU values approaching 65000, an 8-bit camera will saturate near 255. Camera images are always delivered as either 8 or 16-bit quantities by the camera drivers, regardless of the internal electronics of the camera (e.g. 12 or 14-bit ADCs).

To de-select the star and continue looping exposures, just shift-click on the 'Auto-Select Star' icon or shift-click anywhere in the image display window. This can be useful if you're using sub-frames and want to return to a full-frame view of the guider images.

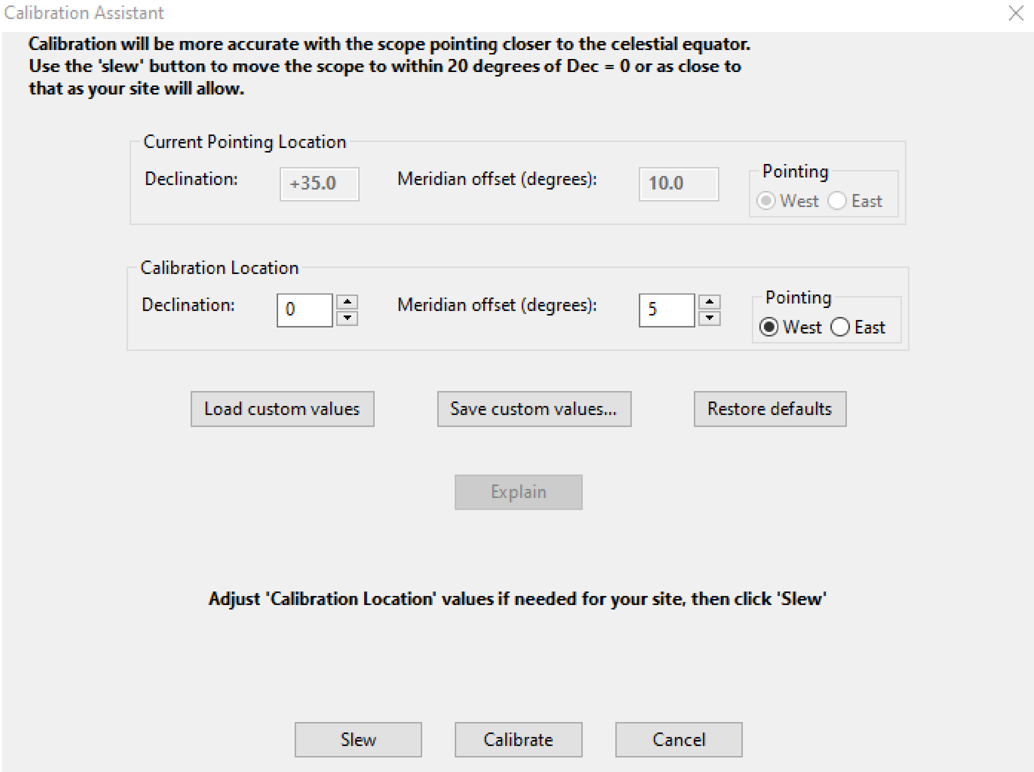
Calibration Assistant

The Calibration Assistant (CA) provides the best means for completing an accurate calibration. It does this by helping you avoid operational problems that can interfere with the calibration process. This is particularly important for beginners who often struggle with both operational and mount-related problems and then can't understand what went wrong. The CA is also useful to experienced imagers who want to complete a calibration as quickly as possible without having to think about the procedural details. There are three basic phases of a calibration assistant session: 1) slewing the telescope to an optimum sky position and pre-clearing any Dec backlash,, 2) starting the calibration and waiting for its completion, and 3) evaluating the results and providing an overall quality assessment. If the quality is judged to be less than "good", additional explanations are offered that are specific to whatever problems arose. In order to use the CA, you need to be using a 'mount' or 'aux-mount' connection that can provide pointing information to PHD2 - typically an ASCOM or INDI driver but possibly the "Ask for coordinates" tool for very basic mounts. If the mount can't be slewed through one of these connections, you can still use the CA as a guide for how to point the telescope and then let it start the calibration and assess the results.

The CA is only usable in interactive mode, it doesn't come into play when guiding is being controlled by a separate imaging application. The CA can be explicitly started using the 'Calibration Assistant...' entry under the 'Tools' menu. The CA will handle any necessary steps of starting/stopping camera exposures and doing an auto-find for guide stars so you can start it whenever you want. If calibration is started by doing a shift-click on the guiding icon, you may see a new dialog if the scope isn't pointing in a suitable area of the sky:



This dialog shows the button to start the Calibration Assistant, the option you should generally choose. If you click, instead, on 'Calibrate here', the CA will not run and calibration will proceed as it has in the past. Once the CA is active, you will see a non-modal dialog window like this:



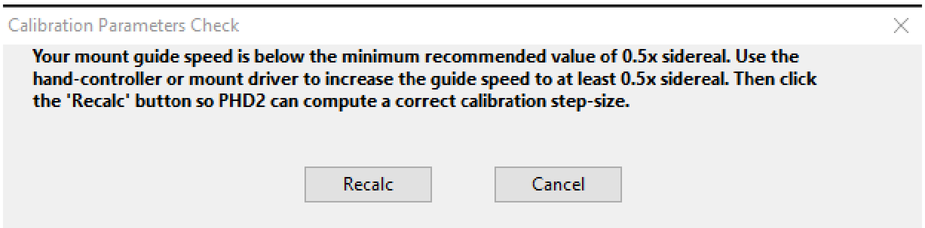
The explanatory text at the top of the window will change depending on where the scope is currently pointed.

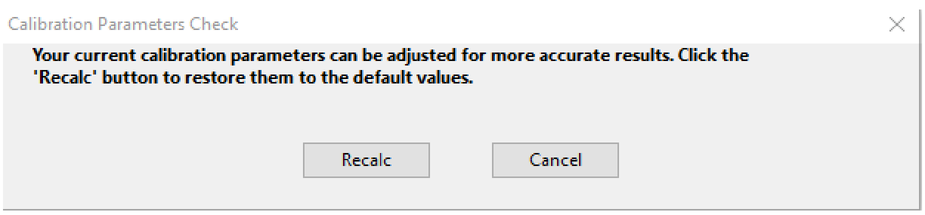
Slewing Operations

The CA will always propose to slew the telescope to a location near Dec=0 (the celestial equator) and 5 degrees east or west of the central meridian. The choice of 'east' or 'west' is based on where the mount is currently pointing in order to avoid triggering a meridian flip. Users of fork mounts aren't affected by meridian flips, and any flip-related messages in the user interface can be ignored. If you are like most users, the recommended calibration location will be the best choice and you should simply click on the 'Slew' button to move the telescope to that location. Obviously, you must insure that the scope can perform the slew safely. If you have obstructed views of the sky at your site, you can adjust the calibration location by changing the values in the 'Calibration Location' group of controls. You should be conservative about doing this or you will defeat the purpose of using the CA. If you regularly have the same visibility limitations, you can save your modifications using the 'Save custom values...' button and then re-use those values on other nights by clicking on the 'Load custom values' button. Clicking on the 'Slew' button will result in two successive slews of the scope: the first to roughly position it slightly south of the calibration location, and the second to move it north by one degree in order to clear any Dec backlash. This action, alone, will eliminate the most common source of problems that people have with calibration. When the slewing is completed, the existing calibration is still valid - it won't be cleared until you click on the 'Calibrate' button. This means the CA can also be used as a convenient means for slewing the telescope to a location that works best for Guiding Assistant diagnostics or for measuring the performance of your mount. The CA dialog will remain open until you click on the 'Cancel' button so its functions can be used iteratively.

Calibration

When you click on the 'Calibrate' button, the CA will first sanity-check settings such as mount guide speed and the calibration step-size value. If these values don't look right, you will see another dialog warning you of the specific problem. If the calibration step-size is wrong, the CA will offer to recalculate ('Recalc') it for you. If the mount guide speed is too low, it will advise you to increase it to at least 0.5x sidereal. This isn't done through PHD2; you will need to adjust it in the mount driver or via the mount hand-controller. The CA sanity-checking dialogs look this this:





As with the other CA messages, you are strongly encouraged to follow the recommendations.

After this sanity-checking is complete, the CA will trigger the normal calibration process. You can move the CA window out of the way if you want to watch how the calibration proceeds. When the calibration completes, the CA will use various metrics to judge the results and will display an overall assessment of 'poor', 'acceptable', or 'good'. In some situations with poor site visibility or mechanical problems with the mount, it may not be feasbible to achieve a 'good' result. 'Acceptable' results are just that - good enough to continue guiding, not something to obsess over, but something to keep in mind if you want to later improve your guiding results. 'Poor' results can still be used in most cases but you should expect that guiding results will never be very good. If the calibration fails altogether - too little movement, lost stars, etc - you should remedy the problem and repeat the calibration.

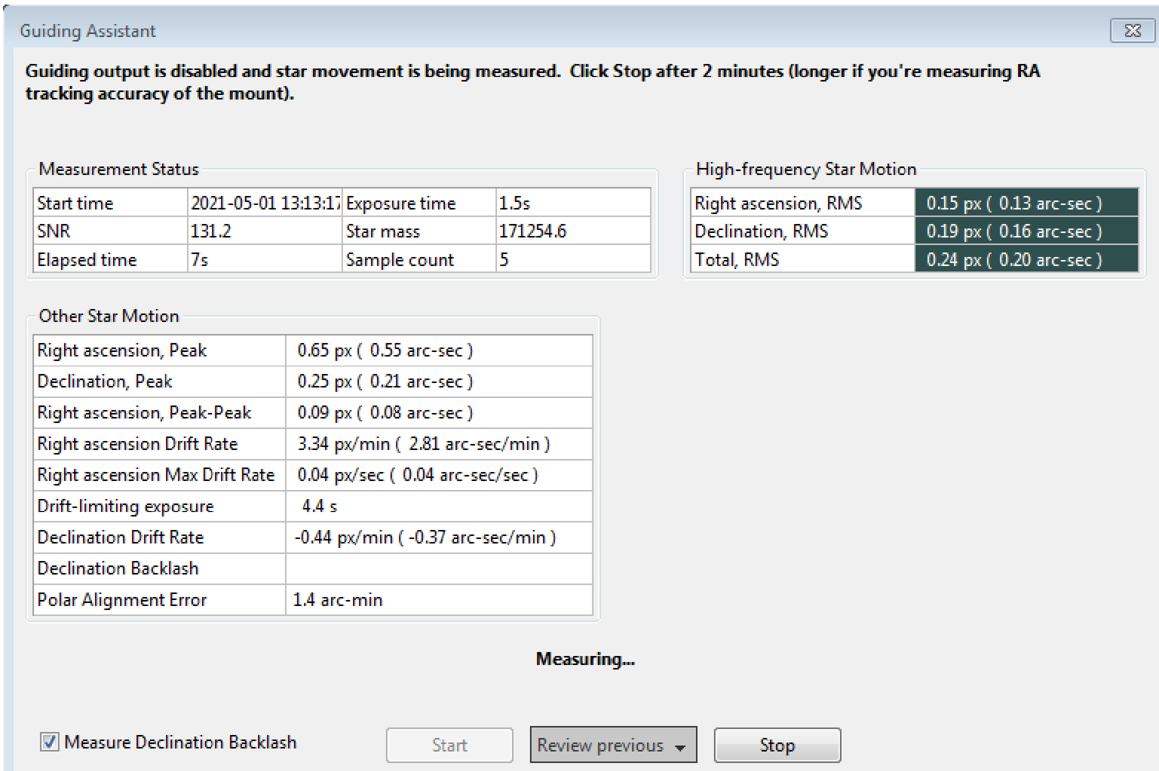
If the calibration result is less than 'good', you can click on the 'Explain' button to see a description of what problems were present and what things you can do to get a better result. If you have followed all the CA instructions, the explanations are likely to help you better understand issues like 'orthogonality error', 'unexpected rates', and other situations that trigger calibration alerts.

Clicking on the 'Cancel' button only closes the CA window, it doesn't cancel or stop any operations that are happening in the PHD2 main window.

Guiding Assistant

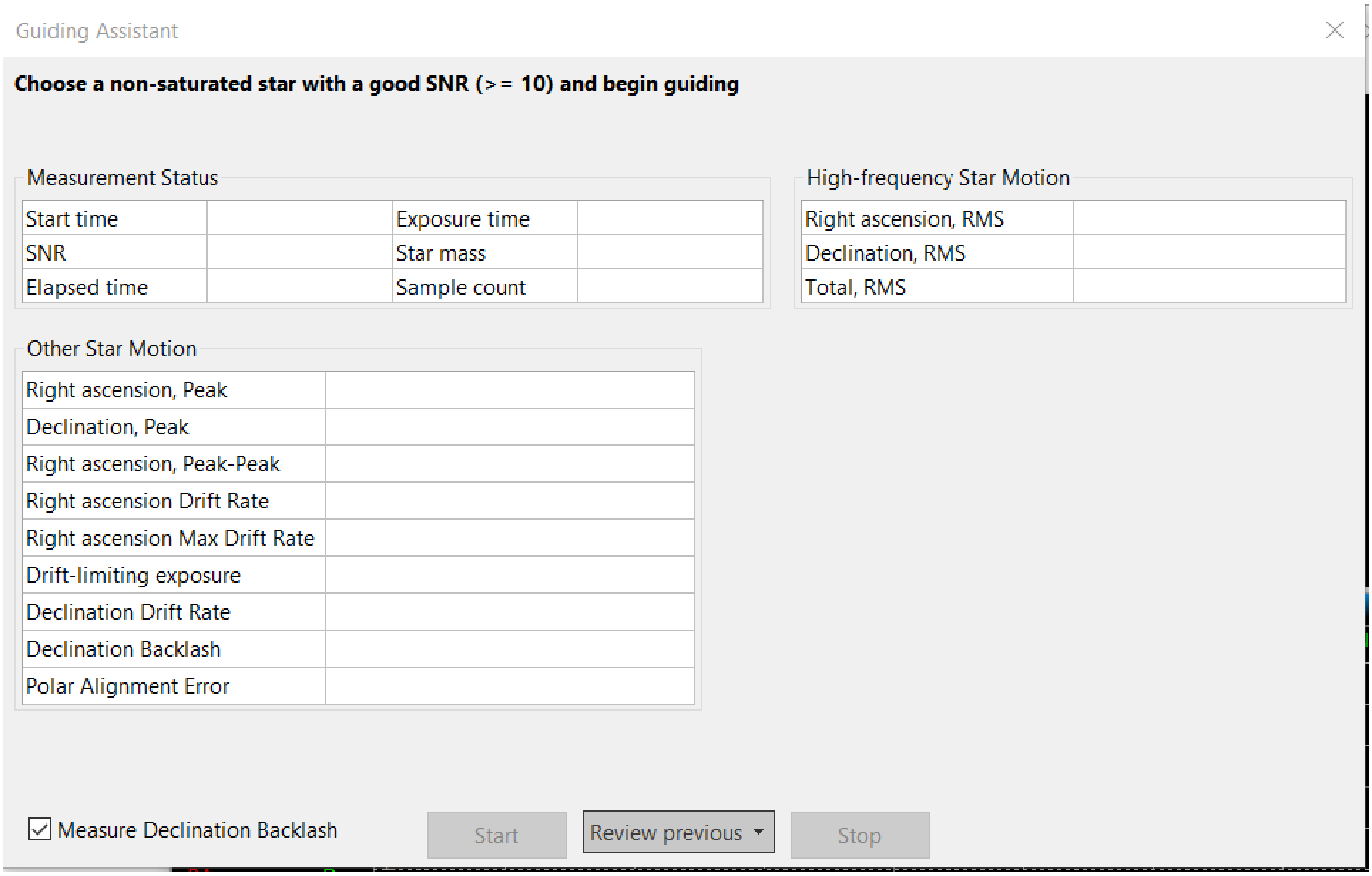
The Guiding Assistant (GA) is an instructional tool to help you measure current seeing conditions and the general behavior of your mount and guiding subsystem. When it's run, it temporarily disables guiding output and measures the ensuing motion of the guide star. This can help you see the high-frequency motions caused by seeing (atmospheric) conditions. These cannot be corrected by conventional guiding because they occur at a much higher frequency than you can measure. Trying to correct for them with conventional guiding is often called "chasing the seeing" and usually leads to poor results. Avoiding it is best accomplished by setting a minimum-move level that will cause PHD2 to ignore most of this high-frequency behavior. The GA can also show you other behavior of your system such as overall drift rates in right ascension and declination as well as peak-to-peak and maximum-rate-of-change measurements in right ascension,. While these things can usually be "guided out", measuring them can be helpful if you want to improve the underlying performance of the mount - for example, by applying periodic error correction in RA. The GA can also measure the declination backlash in your system if you select that option in the user interface. If you're not familiar with these terms, you can find a short discussion here: Common Mount Problems

When you start the Guiding Assistant, its behavior depends on whether you are already guiding. If guiding is active, the initial screen will look like this (with different data values of course):



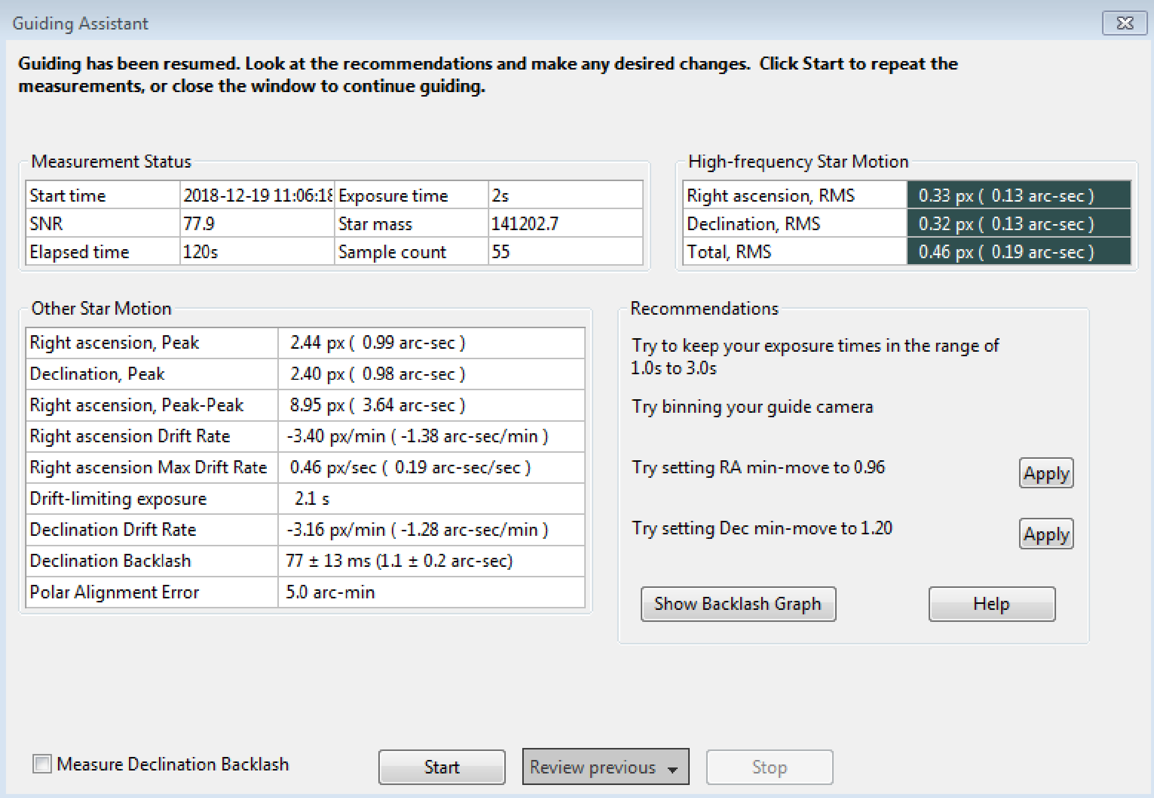
The topmost field in the form always shows what the GA is doing and what action you should take, so you should always look there first if you don't know what's happening. In this case, the measurement process has been started automatically and you should simply let it run for at least two minutes. The text field immediately above the buttons also summarizes what's happening. The three buttons are enabled or disabled based on the operating state of the GA. In this case, 'Start' is disabled because the measurement is already underway.

If you launch the GA when guiding is inactive, the initial form will look different:



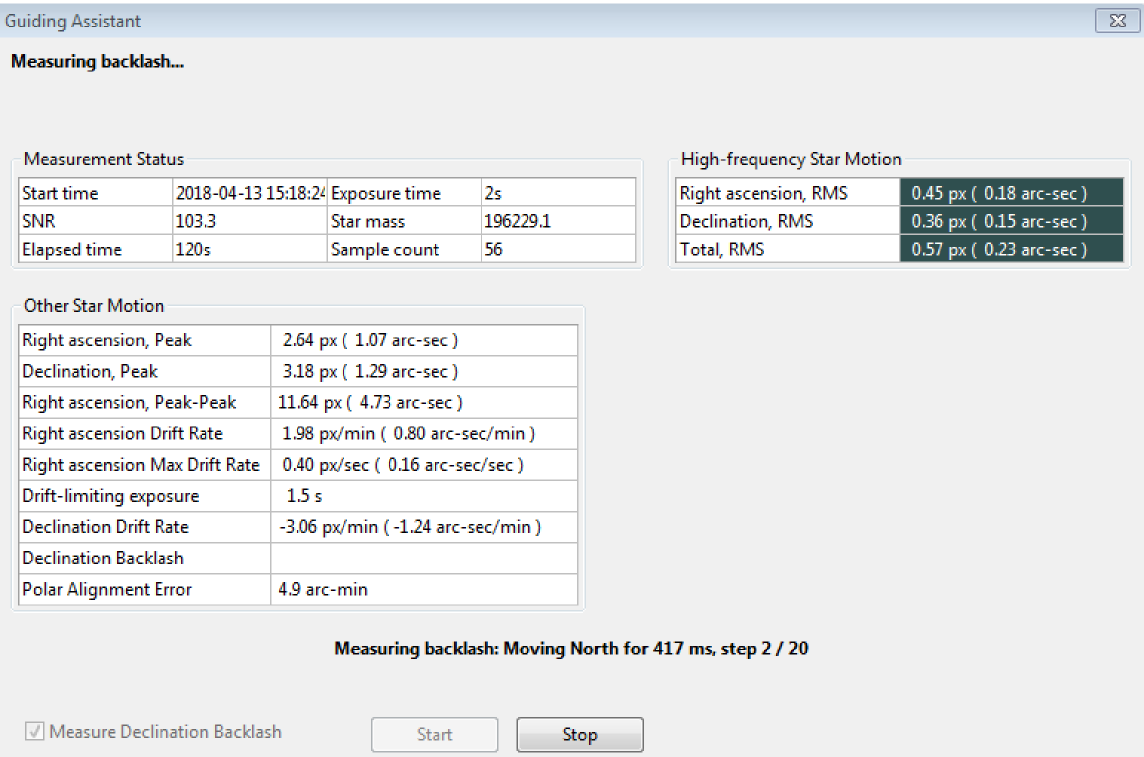
In this case, you'll need to first start guiding in PHD2 - start looping, auto-select a star, and guide. Once that's done, the 'Start' button in the GA will be enabled and you can begin measurement.

When GA measurement is active, guiding commands will be disabled, so the star will appear to wander around on the display - this is entirely normal. As guider images are acquired, statistics are computed and displayed in real-time in the user interface. After about two minutes of data collection, the more volatile measurements like High-frequency Star Motion and Polar Alignemt Error will usually stabilize and you will probably have reasonably accurate measurements. If you want to get a more accurate measure of your polar alignment error and any uncorrected periodic error in RA, you'll need to let the GA run for up to 10 minutes. Also, the computed polar alignment error is sensitive to the current scope declination. To get the most accurate measurement, you should point the scope to within a few degrees of the celestial equator and near the celestial meridian, the same area you should use for calibration.. When you finally click the 'Stop' button, this phase of the measurement process will stop. If you've checked the box to 'Measure Declination Backlash" that process will commence (see below). If not, guiding commands will be re-enabled and the data collection process will end. Other computed results will be displayed in the lower area of the table showing overall drift rates and various other measurements. All of these values are displayed in units of both arc-seconds and pixels. The dialog box will look something like this:

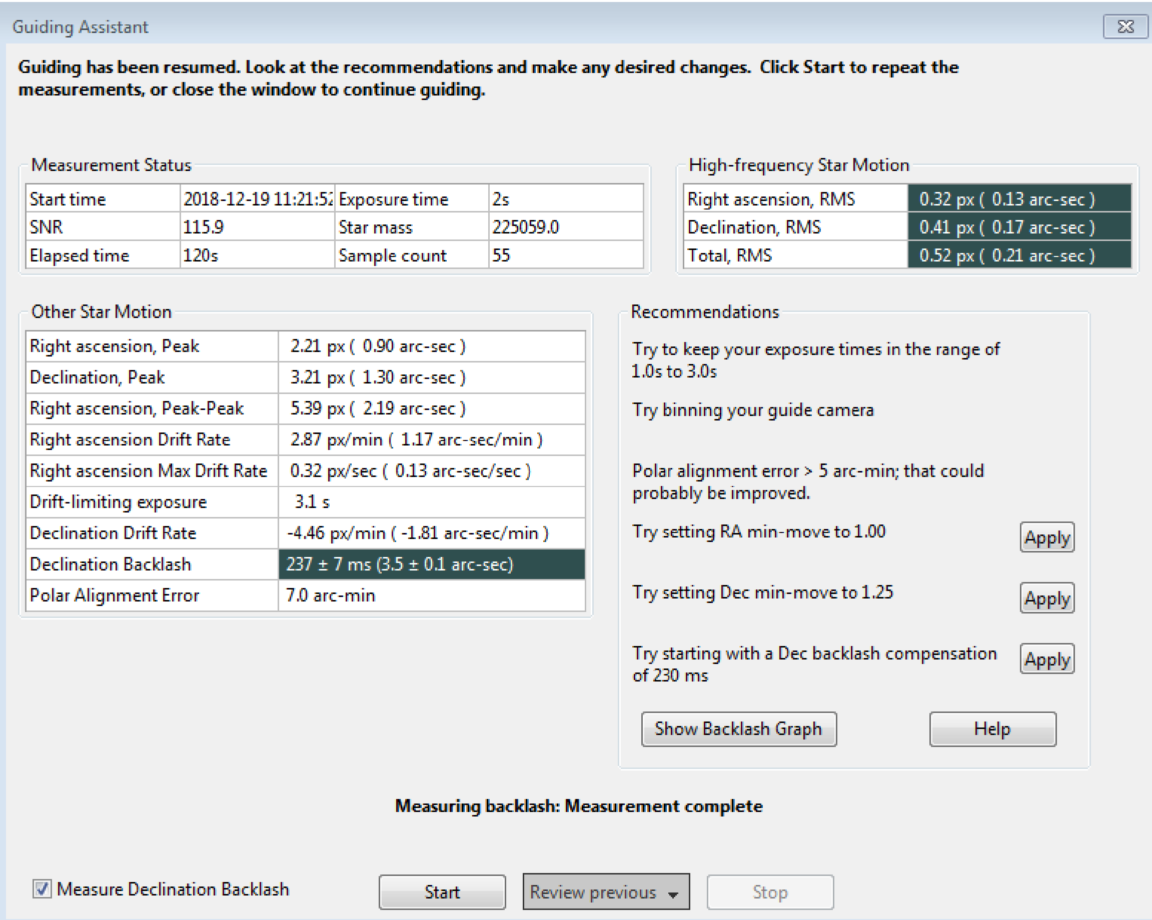


The contents of the 'Recommendations' group on the right side of the window reflect the results of the statistical measurements. Assuming your chosen guide algorithms support a minimum-move property, you have the option of automatically setting those parameters based on the results. You can also elect to re-run the measurements or close the dialog box altogether if you want to proceed with normal guiding operations.

Measuring Declination Backlash (Dec reversal delay)
If you've checked the box to 'Measure Declination Backlash', that process will begin as soon as the baseline measurements are completed. In other words, clicking once on the 'Stop' button halts the baseline measurements and begins the measurement of declination backlash. However, if the initial sampling period was less than 2 minutes, a dialog box will appear and the GA will continue to sample until the 2-minute period has expired. A new group of status messages will be shown immediately above the 'Start' and 'Stop' buttons so you can see what's being done:

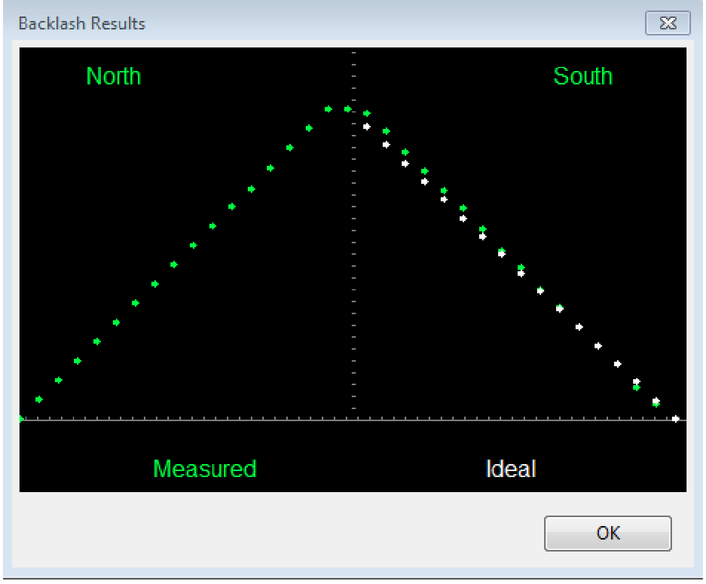


To do backlash measurement, PHD2 will move the star by large amounts, first in the north direction, then back to the south. There is some risk the star will be lost during this process or the star might already be too close to the north edge of the sensor. You should choose a guide star that has plenty of room to move north to get the best accuracy. You may need to manually select a single guide star if the auto-select function keeps choosing a primary star too close to the edge of the frame. If the star is lost because it's been moved outside the search region, you can temporarily increase the size of that region from the 'Guiding' tab of the Advanced Settings dialog. A search region size of 20 pixels should work for most configurations - just be sure you don't have multiple stars inside the search region. The first phase of backlash measurement tries to clear the backlash that is present in the north direction. The GA will continue with these clearing commands until it sees a significant and consistent movement of the guide star in one direction. Once this is done, the GA will issue another sequence of commands to continue moving the star north by a large amount. This will take at least 16 seconds and may take longer depending on the configuration - you can watch the status update to see what's being done. When the north steps are finished, the GA will issue an identical number of steps in the south direction. If there's significant backlash in the mount, it may take a long time for the star to start moving south, but that will usually be handled. Once the south steps are done, the GA will try to compute an accurate estimate of the backlash amount, corrected for Declination drift. This won't be done if the mount never established a consistent rate of south movement that was at least 90% of the measured rate moving north That situation usually indicates binding in the Dec axis or substantial imbalance, in which case a simple estimate of backlash will be inaccurate and probably irrelevant. You can always use the 'Show graph' button to see what happened during the test even if no estimate is produced. When the test is completed, the GA will try to move the star back close to its starting position and will re-enable guiding. Again, there is some risk the star may be lost, but this won't affect the calculations - you can simply stop and resume guiding as you normally would. Unlike the first phase of baseline measurements, you don't need to click on the 'Stop' button once backlash measurement has begun. The measurement process will terminate when all the steps have been completed, and normal guiding will be resumed. However, you can click on the 'Stop' button if something has gone wrong - such as a lost-star condition - and then restart when you're ready. When the backlash tests are finished, you'll see the results displayed as before, with the addition of entries for the amount of declination backlash and the measurement uncertainty (or a status line that says the test failed):

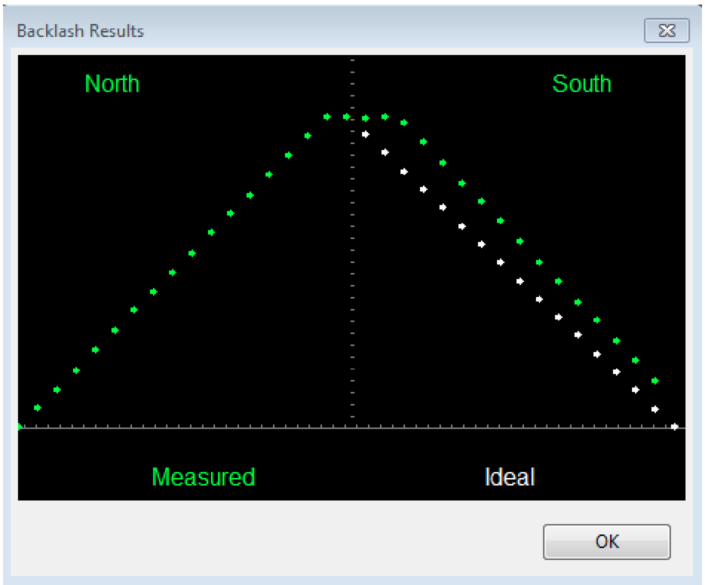


Depending on the amount of backlash, you may see a recommendation for setting a backlash compensation factor - 230 ms in the example shown above. This type of backlash compensation is different from the feature offered in many mount controllers and is described here: PHD2 backlash compensation If the measured amount is less than 100 ms, no recommendation will be made because such a small amount probably doesn't warrant any compensation. If the backlash is very large, over 3 seconds, you'll see a different recommendation to use uni-directional guiding in declination. That's because trying to compensate for such large values probably won't work very well, and the mount will probably not be able to reverse directions quickly enough to support bi-directional guiding. Obviously, you can reach your own conclusions based on your experience with how the mount behaves. Before doing these measurements, be sure to disable any backlash compensation that's previously been enabled in the mount software. If this isn't done, the measurements and any subsequent attempts at compensation by PHD2 will be invalid. If you want to try uni-directional guiding, you can find instructions here: Uni-directional guiding

You can look at a graphical display of the backlash measurement results to get a better understanding of how the mount performed even if the test failed. Just click on the 'Show Graph' button to see a graph that might look something like this:



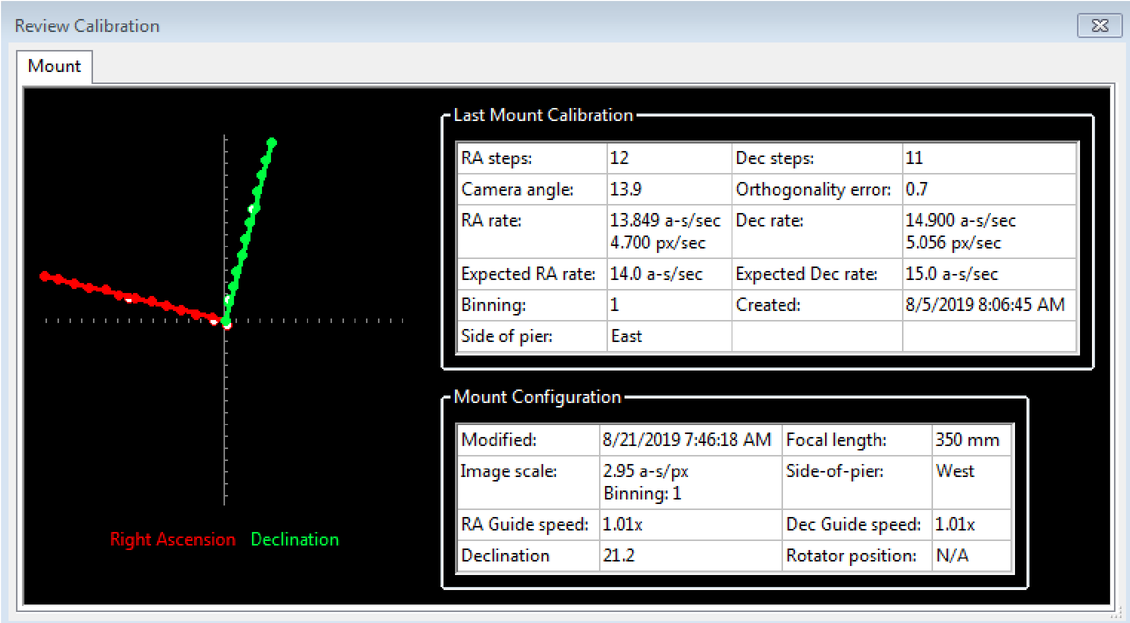
The green points show the measured declination positions, shown left to right, beginning with the north moves and ending with the south (return) moves. The white points show the south-return behavior for a perfect mount with zero backlash. In this example, there is only a small amount of backlash as evidenced by the flattened top of the green points. However, the flattened top will be more pronounced when there is significantly more declination backlash in the mount, as in the following example:



The 'Review Previous' button at the bottom of the window lets you review the previous three GA results. If you've run backlash tests at any time, at least one of the three sessions will include a backlash measurement result. Clicking on the 'Review' button displays a list of timestamps when a GA was run for the current profile, so you can just select the date/time you want. All the grid values and recommendations will be filled with the results from the selected GA run, including active buttons for applying the recommendations.

Calibration Review and Modification

Most of the calibration-related windows, including calibration sanity-checks, will open a window that looks something like this:



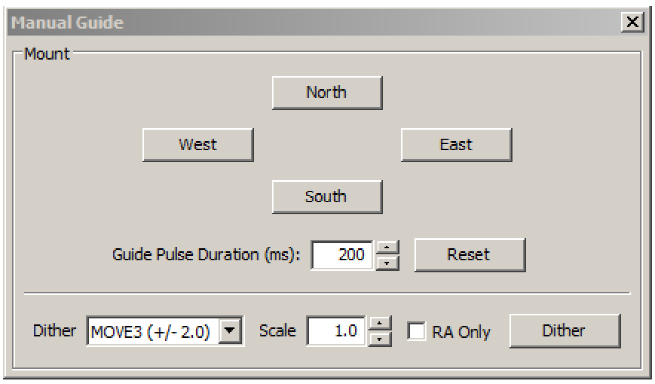
The first thing to look at is the graph to the left, which shows the guide star movements as a result of the guide pulses that PHD2 sent during calibration. The lines show how the RA and Dec mount axes relate to the camera sensor X/Y axes - these lines should be roughly perpendicular but their overall orientation is unimportant. The data points on the lines will never be perfectly spaced or aligned, but they should not have major curves, sharp inflections, or reversals in direction. Particularly with longer focal length scopes, the points will often show scatter around the lines, but this is normal. The solid points (west and north pulses) are used to compute the RA and declination rates, while the hollow points show the "return" paths of the east and south moves. These can help you see how much fluctuation occurred due to seeing and also whether there is a significant amount of backlash. If you are using the "fast-recenter" option in the Advanced Settings, there will be many fewer points shown in the east and south paths. The tabular information to the right shows what was known about the pointing position of the scope and the various ASCOM settings that relate to guiding. If you are not using an ASCOM mount and don't have an "Aux mount" specified, some of this information will be missing. The table will also show the expected guiding rates for a "perfect" calibration using the same sky position and guide speed settings you used. You will almost never achieve these ideal values, but you shouldn't worry about them unless you see alert messages warning of suspicious values. If you didn't see any alert messages when the calibration completed, your results are probably good enough. If you want to re-use a calibration for an extended time, it is probably worth a few extra minutes to check this information and confirm that the calibration went reasonably well and produced sensible results. Bad calibrations can occur even for experienced imagers and high-end mounts, so it is good to check.

If you are having consistent problems getting alert-free calibrations, you should review the material in the Trouble-shooting section .

Other Calibration-Related Menu Options

Calibration data are saved automatically each time a calibration sequence completes successfully. The use of the calibration data has been described elsewhere (Using PHD Guiding), including options for restoring calibration data from an earlier time or "flipping" it after a meridian flip. You access these functions using the 'Modify Calibration' sub-menu under the 'Tools' menu. Two other calibration-related items are shown there, namely the options to clear the current data or to enter calibration data manually. The "clear" option accomplishes the same thing as the 'Clear mount calibration' checkbox in the Advanced Settings dialog - it will force a recalibration whenever guiding is resumed. The 'Enter calibration data' option is intended for development work or for use by experts, and is mostly there for completeness.

Manual Guide

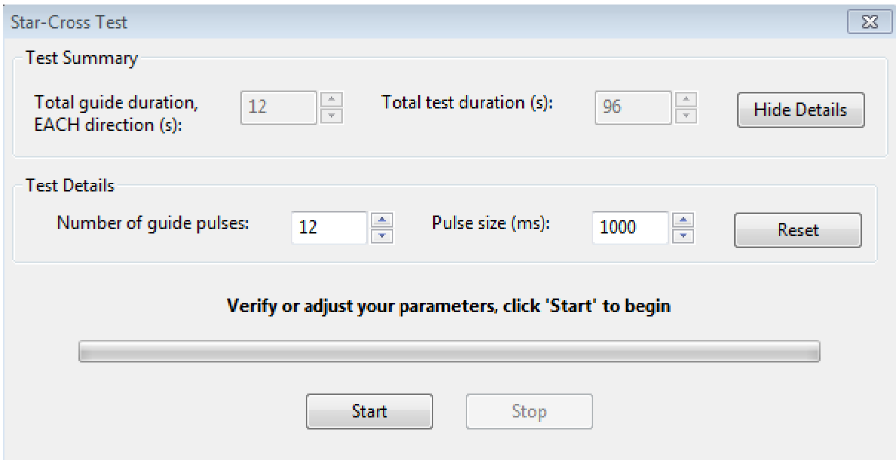


If you are encountering calibration problems, you should be sure that *PHD2*'s commands are getting to the mount and the mount is responding accordingly. Or you may want to nudge the mount or experiment with manual dithering. In the 'Tools' menu, click on 'Manual Guide' and a dialog will appear to let you move the mount **at guide speed** in any direction. If you have an adaptive optics device attached, you'll see separate move buttons for both the AO and the secondary mount. Each time you click the button, a pulse of the duration specified in the 'Guide Pulse Duration' field will be sent. Holding a button down has no effect and you need to give the mount time to respond (at least the full duration of the guide pulse) between button-clicks. The default value is the 'calibration step-size' set in the Advanced Settings dialog. If you are debugging mount/calibration problems in the daytime, listen to (rather than watch) your mount to determine if it is getting the commands from *PHD2*. The idea here is just to determine if the mount is responding to *PHD2*'s guide commands. You won't be able to see the mount move (it's moving at guide speed) but you may be able to hear the motors. Other options include watching the motors and gears or attaching a laser pointer to your scope and aiming it at something fairly far away (to amplify your motions). A better approach for nighttime testing is to run the "star-cross" test described here. Beginners often make the mistake of confusing the slewing-type operations done by planetarium and imaging applications with the completely different guiding operations done by PHD2. Knowing that an imaging app can slew your telescope correctly doesn't tell you anything useful about whether the mount is guidable.

Dithering is used primarily with image capture or automation applications using the PHD2 server interface. However, you can do manual dithering or experiment with dither settings using the controls at the bottom of the dialog. The 'dither' amount field at the left controls the amount the mount will be moved, in units of pixels. You can scale this amount - i.e. multiply it by a constant - by using the 'scale' spin control to the right. These two controls establish a maximum amount of movement that will be used for dithering - the product of 'scale' x 'dither'. When you click on the 'Dither' button, PHD2 will move the mount by a random amount that is less than or equal to the limit you have set, in one of the north/south/east/west directions. The 'RA Only' checkbox will constrain the dither adjustments to only east or west. Obviously, if you are doing a manual dither in this way, you'll want to be sure your imaging camera is not in the middle of an exposure.

Star-Cross Tool

The Star-Cross tool can help you test the mount's response to guide commands as described in this Trouble-shooting section. Although the test is easy to perform manually, you may prefer to use this tool. The star-cross tool will show the following dialog:



This test presumes you're using the main image camera to expose the image, and PHD2 doesn't know what image scale is being used for that. You need to be sure the settings are large enough to show a distinct pattern on the main camera image but not so large that all the stars will move out of the field of view. The default settings should work well for most set-ups but you can adjust them as needed. The important thing is to get a clear record of the movement of the stars in the main camera image and to save that image in a raw, uncompressed format (eg. FITs or uncompressed TIF). During this test, looping will be active but no guide star will be selected, and it doesn't matter if individual stars move out of the guide camera frame. Looping is activated just so you get some quick visual feedback on whether the mount is moving.

Meridian flip calibration Tool

The meridian flip calibration tool (wizard) is used to automatically determine the correct value for the setting Reverse Dec output after meridian flip. Running the wizard involves two calibrations -- one with the telescope on the East side of the pier, and one on the West. You will be instructed to slew (meridian flip) the telescope when needed. This only needs to be done once for each type of mount you use. You **must carefully follow all the instructions** shown in the wizard's dialogs - failing to do so or taking short-cuts will invalidate the results and will siimply waste time.

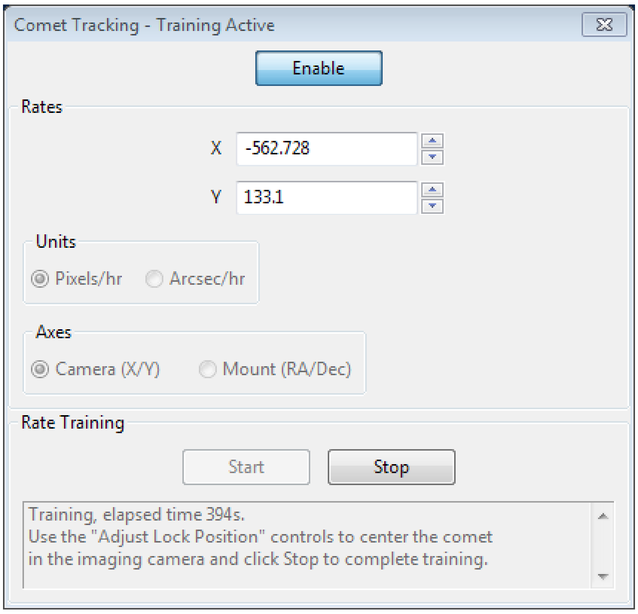
Comet Tracking

One way to image a comet is to have PHD2 use the head of the comet as the guide "star", but this approach may not always work. For example, the head of the comet may not present a star-like center suitable for guiding. Or, when using an off-axis guider, the comet may not even be visible in the guide camera.

PHD2 provides a Comet Tracking tool for use when guiding on the comet itself is not feasible. The idea is to guide on an ordinary star, but to gradually shift the lock position to match the comet's motion, or *tracking rate*.

There are a three different ways to provide the comet tracking rate to PHD2.

- Some planetarium applications, especially Cartes du Ciel, can send the rate directly to PHD2;
- You can enter the tracking rate manually, or,
- You can train the rate in PHD2 by following the comet for a period of time in the imaging camera.



To enter the rates manually, you would select "Arcsec/hr" for units and "RA/Dec" for axes, then enter the rates from the comet's ephemeris. If you are getting the rates from the MinorPlanetCenter web site, you should choose the option for 'Separate RA and Declination coordinate motions'. PHD2 will automatically adjust the rates to compute the apparent motions in the sky.

Comet rate training works like this:

First, center the comet in your imaging camera. If your imaging application has some kind of reticle display, you should use that to note the precise position of the comet on the imaging sensor. Once this is ready, select a guide star in PHD2 and start guiding. Next click "Start" in the Comet Tracking tool to begin training.

Take a continuous series of short exposures in your imaging camera using your imaging application's Frame and Focus feature. Over time, the comet will drift away from the starting location. Use PHD2's "Adjust Lock Position" controls to move the comet back to the starting location. You may have to experiment a bit to determine which way the comet moves on the imaging camera sensor in response to the Up/Down/Left/Right controls in PHD2. You may find it useful to enable the "Always on top" button in the Adjust Lock Position window so the controls stay visible on top of your imaging application.

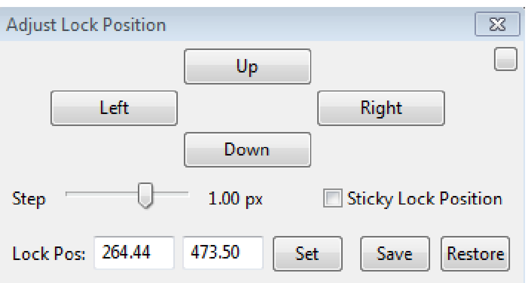
PHD2 will quickly learn the comet tracking rate as you re-center the comet. Once you are satisfied that PHD2 is tracking the comet, you can click Stop to end the training. PHD2 will continue shifting the lock position to track the comet until you disable comet tracking by toggling the Enable/Disable button.

You can practice the comet training technique using the built-in camera simulator. Check the "Comet" option in the Camera Settings dialog, and the simulator will display a comet. Use a bookmark to mark the comet's starting location, and use the Adjust Lock Position controls to move the comet back to the bookmark location.

Lock Positions

PHD2 normally sets a 'lock position' where the guide star is located at the end of a calibration. Depending on the details of the calibration sequence, this may not be exactly where the star was located at the start of calibration - it could be off by a few pixels. If you are trying to precisely center your target after calibration, you may want to use a '**sticky lock position.**' You do this by clicking on your guide star *before calibration*, then clicking on 'Sticky Lock Position' under the 'Tools' menu. After calibration is complete, *PHD2* will continue to move the mount until the star is located at the sticky lock position. So you may see an additional delay after the calibration while *PHD2* repositions the scope at guide speed. The sticky lock position will continue to be used even as guiding is stopped and subsequently resumed unless you change the lock point through actions such as dithering. Again, this insures a rigorous positioning of the guide star (and presumably your image target) at the expense of delays needed for *PHD2* to reposition the mount.

If you need to fine-tune the position of the guide star on the camera sensor after guiding has begun, you can use the 'Adjust Lock Position' function under the Tools menu:



You can nudge the guide star in small increments (at guide speed) or you can move it by a larger amount by typing in a new lock position and clicking 'Set'. Clicking on the up/down/left/right buttons will cause the lock position to be shifted in the corresponding direction by the amount shown in 'Step', and the revised lock position will be displayed   If you type in a new lock position, you run the risk of losing the guide star if the new position falls outside the current search region. This tool is useful if you need to achieve precise positioning of either the guide star or the imaging target, for example with spectroscopy - but it is unnecessary for most users.

PHD2 Server Interface

PHD2 supports third-party imaging and automation applications that need to control guiding operations. In recent years, many new automation applications have become available and nearly all of them use the PHD2 server interface. By using this API, these applications can control all the typical activities relating to PHD2 guiding: starting/stopping, pausing/resuming, dithering/settling, calibrating, profile-loading, and many others. To use automation applications of this type, you should be sure the PHD2 'Enable Server' option under the 'Tools' menu is enabled. With the option enabled, the operating system firewall must be configured to let PHD2 use network connections, something that is typically done as part of the PHD2 installation. Documentation for the server API is available on the PHD2 Wiki.

Trouble-shooting and Analysis

General Guide to Resolving Problems

The field experience with PHD2 since its initial release in 2013, involving thousands of users worldwide, has shown that 99% of what people think of as "guiding problems" are not really that at all. Instead, they usually come from two sources:
1) Operational errors made by the user
2) Mechanical problems with the mount or the physical equipment riding on the mount

It's important to remember this when you encounter difficulties and can't get the results you want. Operational mistakes can be avoided by carefully studying the documentation on the PHD2 web site (or in this built-in Help), following the steps described in the "Best Practices" document, and using the 'search' tools on the PHD2 support forum. YouTube videos, unless done by someone close to the PHD2 project, have wildly variable quality, often reflecting misunderstandings and sometimes producing a witches' brew of good and bad advice - so be careful what you watch. One of the most common mistakes is to wildly change the PHD2 guiding parameters in a futile attempt to correct for mechanical problems that exist in your setup. This only makes things worse. The default guiding parameters calculated by PHD2 reflect the parameters you entered in the new-profile-wizard, so they are already adjusted for your setup. You should be able to get reasonable results out-of-the-box if the equipment behaves and if you don't, you are probably dealing with operational mistakes or mechanical problems. Although it is frustrating to be confronted with mechanical problems, it is important to isolate, identify, and understand them before trying to fix them or mitigate their effects. Mechanical problems won't simply go away. Even if they temporarily subside, they will inevitably come back to bite you. And something that worked fine just last week or even last night may no longer work - that is the nature of hardware.

PHD2 or any guiding software is often the messenger of bad news because of the incredible level of accuracy required for guiding. Modern guide cameras are capable of measuring movement on scales of just a few microns - as a comparison, a human hair is about 50 microns thick. Until you have tried guiding, your equipment setup has probably never been tested or measured at this level of accuracy even by the manufacturers. Beginners are often in denial about mechanical problems because the scope and mount apparently slew well enough, they seem to track the sky reasonably well, various planetarium applications can move them without complaint, and they look and feel well-made. Even worse, they were expensive! But none of this matters when you're trying to get the full assembly of equipment to track the sky, hour after hour, horizon to horizon, with sub-arc-second accuracy. Fortunately, most mechanical problems can be eliminated or reduced fairly easily or at least without great financial expense. Most vendors are willing to help with the problems so long as they have been carefully documented and demonstrated - and PHD2 is an excellent tool for doing that. For most people, the cost of eliminating problems comes from time spent doing trouble-shooting, lost imaging opportunities, and general frustration; but these problems are part of the hobby and most successful imagers have learned how to work through them.

If you're unfamiliar with the kinds of mechanical problems commonly found with telescope mounts, you can get a quick introduction here: Common Mount Problems Also, many problems can arise from the way the imaging-related gear is attached to the main scope and mount - guide scopes, camera attachments, cable routing schemes, etc. When these components sag, drag, or move around on their own, they create unwanted guide star movements that masquerade as tracking problems in the mount. If you're unhappy with your overall guiding results, you should proceed in a careful and systematic way to identify the sources - flailing around in the dark is a recipe for failure. Here is a quick blueprint for trouble-shooting:

1. Be sure the parameters you entered in the new-profile-wizard were accurate - guide scope focal length, mount guide speed, and the camera pixel size if you had to enter it manually. If you find mistakes, don't try to fix them manually - just re-run the new-profile-wizard.
2. Be sure you have reliable camera operations that deliver consistent, reasonable-looking images of the sky. If you have problems in this area, follow the procedures in the Camera Timeout and Connection Problems.
3. Be sure the guide camera is well-focused and you aren't getting frequent lost-star messages when using 2-second guide camera exposures. Tips for getting a good focus are discussed here: Star Profile Tool . If you're using imaging and guide cameras from the same manufacturere, be sure PHD2 is connected to the right one.
4. Get a reasonable mechanical polar alignment, one that is within about 10 arc-min of the celestial pole. Doing this requires mechanical adjustments of your mount or wedge - you will be loosening fasteners and cranking knobs to get this done, it can't be done by software alone. You can use a polar alignment scope, a high-powered eyepiece, another app that assists with polar alignment, or one of the polar alignment tools in PHD2. Great precision isn't required, "close enough" is "good enough".
5. Concentrate on getting a usable calibration in PHD2, one that doesn't generate error messages or "alert" warnings. If site conditions allow it, calibrate with the scope pointing in a declination range of -20 to +20 degrees and a right ascension (hour angle) that keeps the scope pointing well above the east and west horizons. If you have visibility restrictions at your site, come as close as you can to the above goals. If you get error messages (failed calibrations) or you see alert messages at the top of the display, follow the advice shown here: Calibration Problems. It's important to get workable results in this step because the calibration is fundamental to all the guiding activity that will follow.
6. Use the Guiding Assistant tool to examine how your mount tracks and behaves working on its own, without guiding. Use the GA to measure the declination backlash and once the measurement session has finished, apply the recommendations you'll be given. If you see large, abrupt guide star excursions or other inexplicable results during the GA session, resolve those problems first.
7. Perform a series of 15-20 minute guiding sessions, still in the same region of the sky. Do **NOT** modify any of the guiding parameters attempting to make things better.
8. Use the PHD2 LogViewer tool to analyze your results and develop a strategy for fixing the problems that have been revealed. You can get help doing this on the PHD2 support forum.

Large/Abrupt Guide Star Deflections

Most users eventually encounter situations where the guide star appears to make a large, abrupt excursion away from the lock-point. The great majority of these problems arise from neither the mount nor PHD2's guide commands. Instead, they usually come from unwanted mechanical movement in the gear that is riding on top of the mount, especially the guide camera/guide scope assembly. This is especially true if the large deflections occur in declination because the Dec motor is normally idle except for executing the very short, relatively infrequent guide commands it receives. The unwanted mechanical movement usually comes from several sources:

1. Tiny movements of the various components in the guiding assembly as a result of the changing gravitational forces while the mount tracks the target object
2. Dragging, binding, or snagging of cables, especially those that are connected to the guide camera
3. Wind gusts or less commonly, effects from camera filter changes, auto-focusing, or mirror movement
4. Use of mount features for backlash compensation - these should not be used with PHD2 guiding

Before rejecting these things as likely sources of problems, think again about the tiny measurement scales and tolerances described in the previous section. With many guiding set-ups, a movement of only 5 microns can create an apparent tracking error (guide star deflection) of over 6 arc-sec, the equivalent of many star diameters. Every mechanical interface, every set-screw, every movable element has the potential to shift or move on its own by these tiny amounts. Even when cables have been routed in a purposeful way, they may bind or pull in certain sky positions or after a meridian flip. Cable ties or ribbed plastic cable guides hare small protrusions that can briefly catch on stationary parts of the mount. For large Dec deflections, it's easy to determine if these things are coming into play. Just use the PHDLogViewer tool to zoom in on the time of interest and see if the deflection was immediately preceded by a correspondingly large guide command in the direction of movement. In most cases, you will find this didn't happen. It can sometimes happen at the beginning of a guide session if you're using PHD2 Dec backlash compensation, but those events should disappear quickly. If the abrupt deflections occur in RA, the analysis is less straightforward because the RA motor runs continuously. But even then, unusually large, randomly space deflections are more likely to arise from the sorts of mechanical problems described here than from errors in the RA drive system.

Camera Timeout and Download Problems

In some cases, you may experience problems where guider images aren't downloaded or displayed. In extreme cases, this may even cause *PHD2* or other camera-related applications to be non-responsive (i.e. to "hang"). This is nearly always due to hardware, camera driver, or connectivity issues, with one of the most common culprits being a faulty USB cable or device. It is highly unlikely to be caused by an application like *PHD2*, so you should begin your investigation at the lower levels of the system.

To help detect these problems and avoid "hangs", PHD2 uses a camera timeout/retry mechanism. This timeout value is set in the Camera tab of Advanced Settings and uses a default value of 15 seconds. This means that PHD2 will wait up to 15 seconds *after the expected completion of the exposure* to receive the image from the camera. This is a very generous amount of time and should work well for most cameras. When the timeout occurs, PHD2 will automatically disconnect the camera and try to re-connect. An alert message at the top of the screen will advise you of the timeout event and whether the reconnection attempt was successful. Regardless of whether the reconnection succeeded, you have a hardware problem of some kind that needs attention.

Here is an approach you can use to reproduce and then identify the problem:

1. Make sure you are running the latest version of PHD2 – often a development version – and the latest versions of the camera drivers. Some of the camera vendors issue frequent software changes that must be matched by corresponding changes in the software libraries used by PHD2. When these updates aren't backward compatible, you have no choice but to run the latest versions of everything.

2. Confirm that the guide camera is basically functional - try using a short, direct cable from the camera to the computer and taking exposures with the native or test application that came with the camera.

3. Repeat step 2 but use PHD2 as the application. You can do this in the daytime by just connecting to the camera and looping 1-2 second exposures for a reasonably long time. The PHD2 display will often be all-white in daytime operation, but as long as the looping continues with no error messages, things are going ok. If you see problems in this step, it doesn't mean it's a PHD2 problem – it isn't. The difference is that PHD2 is using the camera in single-exposure mode whereas most other apps use it in video streaming mode. The single-exposure mode involves more back-and-forth data traffic with the camera and can expose timing problems in the drivers.

4. If you can't trigger a failure in step 3, add the imaging camera into the mix. Use your imaging application to loop exposures in parallel with what PHD2 is doing. This will help expose traffic and bandwidth problems in the USB system.

5. If no problems occur in step 4 over extended time periods, use the same USB cables and host computer that you were using when you first encountered problems. If you're already doing this, you need to consider other possibilities:

   - The problem may be temperature-related – perhaps it occurs in colder nighttime conditions but not during the daytime.
   - The OS may be suspending one or more of the USB ports for power-conservation. This has become a more common problem with Windows 10 and later releases. Use the Windows device manager and find all the entries that refer to a USB "hub" or a USB controller. For each of these entries, open their properties dialog and click on the 'power management' tab. Disable any permissions that allow the OS to suspend the device for power management reasons.
   - Make sure the power source on your test computer matches that of the computer you use for imaging. Both should be running on A/C power at this point.
   - The problem may be triggered by loose cable connections on either end – the cables should not lose connectivity if the cable is

moved around as it will be during imaging.

When you can replicate the timeout problem, the first place to look is the USB cable followed by the other USB components on your system. Sources of USB-related problems include the following:

- Low-quality or slightly damaged USB cables - in recent years, some of the camera vendors have started shipping low-quality USB cables with their cameras so you shouldn't assume the one you got with the camera will work. It's also important to remember that we work in a hostile environment while imaging, and many of the components we use were not designed for cold, outdoor conditions. If you regularly tear down and reassemble your gear, the flexing of the cables can damage low-quality conductors. So something that worked just last week or last month may no longer be reliable. High-quality USB cables with 24AWG conductors and lengths no greater than 15 feet are recommended.
- USB-2 cameras and cables plugged in to USB-3 ports - those combinations are supposed to be backward-compatible but that's only at the hardware level, the driver implementations can be adversely affected.
- USB port suspension by the OS (step 5b above)
- Marginal power delivery to the guide camera - your main imaging camera probably has its own power supply but other devices like the guide camera are typically powered via the USB cable. Particularly with laptops and inexpensive computers, you may want to try using a powered USB hub to deliver power to the camera. This approach may also be required when operating in cold conditions or when using cables of maximum length.

If you can't isolate the problem at this point, there are a few other places to look:

- Use a Microsoft tool (USB View) for mapping the tree structure of USB ports and USB controllers.
- Try choosing ports that will keep your imaging and guide cameras on separate USB buses.
- Try using a different camera driver. Many vendors supply both an ASCOM and a native driver, so try the one you haven't been using. It's not uncommon for some of the ASCOM drivers to lag the native drivers in terms of bug fixes and compatibility
- See if the problem is related to overall USB bandwidth and try to reduce the total USB usage:

  a. Throttle the USB usage limit of the imaging camera if possible – many of the drivers allow that.
  b. Bin the guiding camera unless that will result in an image scale greater than 6 arc-sec/px.
  c. Use sub-frames in PHD2 if the camera driver supports that.
  d. Don't run other processor-intensive applications while imaging and don't allow any of the planetarium applications to poll devices and other applications at high rates.

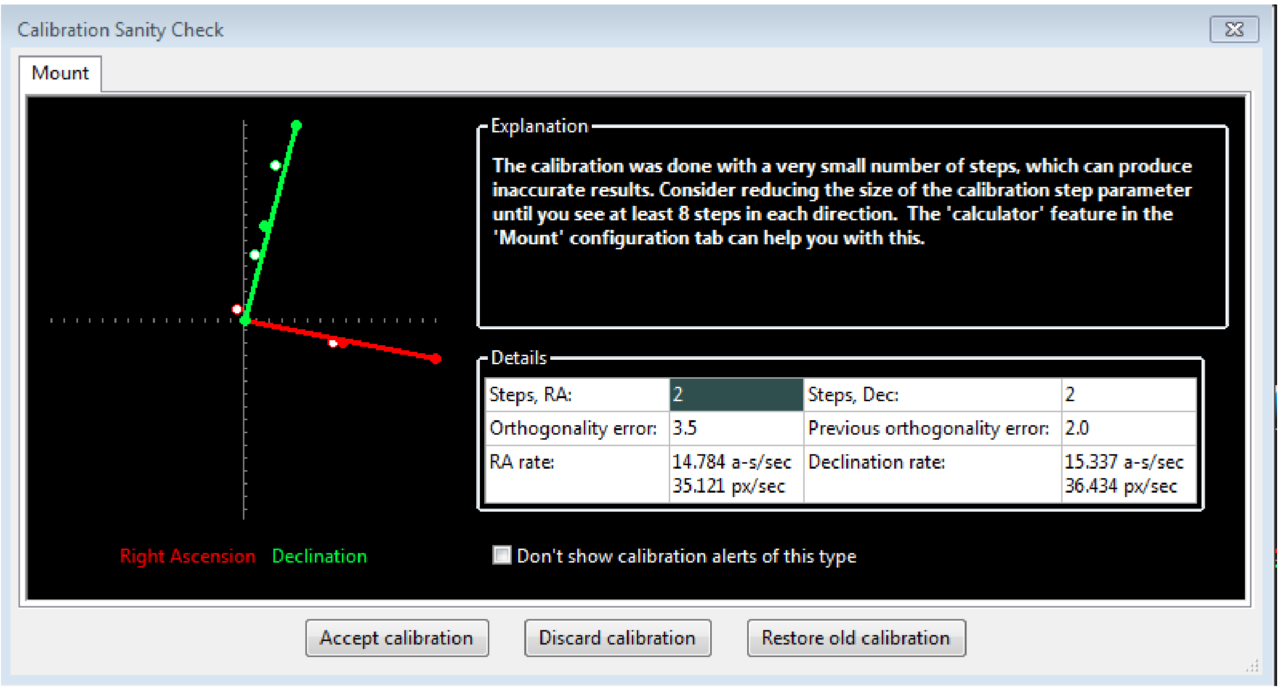
Calibration and Mount Control Problems

If you are just starting to use *PHD2* or are connecting to new equipment for the first time, you may have trouble getting calibration done. **The best way to minimize this risk is to use the Calibration Assistant, and beginners are strongly urged to do that**. Calibration problems generally take one of two forms: 1) outright failures of the calibration because the mount didn't move far enough in RA and Declination or 2) cases where calibration completes but the results are suspect. Both types of results are shown by Alert messages at the top of the PHD2 window. For the situation where the calibration fails, there are, again, two likely reasons:

1. **Mount/connectivity problems or operational mistakes:** These are the most common sources of the problem. The best tools for trouble-shooting them are the 'Manual Guide' dialog or the Star-Cross test, both under the 'Tools' menu and described in the Tools section of this help document. Simply use the directional controls in the 'Manual Guide' window to send commands directly to the mount while watching a star in the image display window. Use fairly large guide pulse amounts - at least several seconds - so you can clearly see if the mount is moving. Try to move the mount in all four directions and verify the target star is moving by roughly equal amounts. If the mount does not respond, you know you have either hardware or connectivity problems to resolve - nothing to do with *PHD2*. Operationally, you cannot complete a calibration if you're pointing close to the celestial pole or if the mount isn't properly initialized, un-parked, and tracking at the sidereal rate. If you're using a Shoestring device to connect to the mount, watch its indicator lights to see if the commands are reaching it. Similarly, your ST-4 compatible guide camera may have indicator lights to show when guide commands are being received. If you're using an ASCOM connection to the mount, be sure the COM port assignments are correct and you've selected the correct ASCOM mount driver for your equipment. You can use some of the ASCOM-supplied tools like POTH to be sure the ASCOM driver is communicating correctly with the mount. It is best to use the latest version of the ASCOM driver for your mount to insure pulse-guiding support is complete.
2. **Incorrect calibration step-size:** If you've used the new-profile wizard and have provided correct values for focal length, camera pixel-size, and mount guide speed, the "step-size" used in calibration should already be correct. You should confirm this, however, because beginners frequently enter incorrect values for these parameters. If you've defined or modified your profile by hand (a bad idea) or have changed guide speed settings in the mount, you may need to adjust the 'calibration step-size' parameter in the 'Guiding' tab of Advanced Settings. The help content there describes how this parameter is used, and you should be able to resolve the problem quickly. But if you've used the new profile wizard carefully and are seeing problems with too little or no guide star movement, the problem probably lies elsewhere.

Calibration Sanity-Checks and Alerts

It is also possible that the calibration process will complete but PHD2 will post a calibration alert message saying that some of the results are questionable. Again, the likelihood of getting these alerts will be minimized by using the Calibration Assistant (CA). Even if alerts are triggered while using the CA, you will get a more specific explanation of what problems occurred during the calibration. In any case, the alert messages **do not** mean that the calibration failed or is unusable, but they are warning you that some of the results don't look quite right. Such a "sanity check" dialog will show an explanation of the issue and some details of the calibration results:



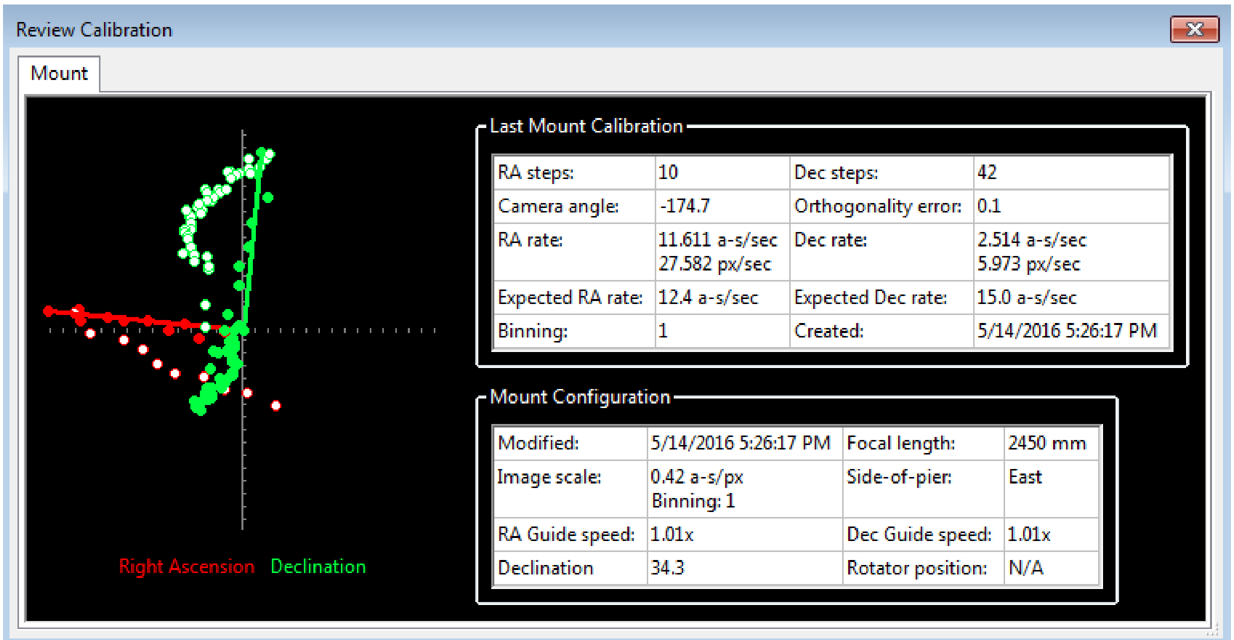
There are currently 4 things checked by PHD2 as part of calibration:

- **Too few steps** (shown above) - resolving this issue can be easy assuming the mount is actually working correctly. Just adjust the calibration step-size downward until you get at least 8 steps in both the west and north calibrations. If you used the new profile wizard to set up your configuration, a good starting value for calibration step-size will already be set. In that case, the alert suggests you entered parameters incorrectly in the new-profile-wizard or the mount guide speed has changed. You should check these things and make sure they're right. If you find that the number of steps in RA and Declination are substantially different, you are probably seeing evidence of declination backlash unless you are using different guide speed settings on the two axes.
- **Orthogonality error** - the camera axes are normally computed independently even though they *should* be perpendicular. The angle calculations do not require great precision, but if they are significantly non-orthogonal, you should repeat the calibration. If you see repetitive alerts of this type and the axes are significantly non-orthogonal, you need to identify the problem and fix it. Common causes are bad polar alignment, large declination backlash, or large periodic error in RA. Any of these problems can cause the guide star to move significantly on one axis while PHD2 is trying to measure its motion on the other axis. If you suspect these problems, go ahead and accept the calibration, then run the Guiding Assistant to measure your polar alignment error, declination backlash, and RA tracking error. In other cases, the mount may not be moving at all, and the measured displacements of the star are just caused by seeing effects. This sort of problem should be obvious in the calibration graph at the left of the dialog. If the axis error is relatively small and you are convinced the hardware is working properly, you can avoid further alerts of this type by setting the option to 'Assume Dec orthogonal to RA' in the 'Guiding' tab of the Advanced Settings dialog. But you should do this only if the error is fairly small - otherwise, you are simply ignoring a serious problem.
- **Questionable RA and Dec rates** - assuming the guide speeds reported by the mount are accurate, the measured guide rate for right ascension should be related to the declination guide rate by approximately a factor of cosine (Declination). In other words, the apparent RA rate gets smaller as you move the scope closer to the pole. PHD2 won't try to identify which rate is incorrect - it is simply alerting you that something looks wrong with the rates. You can sanity check these rates yourself quite simply. If you are guiding at 1X sidereal rate, your declination guide rate should be approximately 15 arc-sec/sec; with a guide rate of 0.5X sidereal, the declination rate would be 7.5 arc-sec/sec, etc. **A declination rate that is significantly smaller than the RA rate is often an indication of substantial declination backlash**. Using a calibration that triggered this alert can lead to over-shooting in Dec guiding because the actual guide rate is probably larger than the measured one. To work around this problem, you should manually clear the Dec backlash before starting calibration. You can do this in either of two ways: 1) make sure the mount's last slew direction was **north** or 2) use the hand controller to manually move the mount **north** ('up' arrow) at guide speed for 10-20 seconds.
- **Inconsistent results** - if the calibration results are significantly different from your last-used calibration, an alert message will be generated. This may happen because you've made a change in your configuration. That doesn't imply a real problem, but you should probably consider creating a separate profile for the new configuration. By doing so, PHD2 will remember settings for each of your profiles, letting you switch between them easily. If you haven't made a configuration change, you should determine why the results are so different.

With any of these alerts, the relevant data field will be highlighted based on the type of message. You can choose to ignore the warning ('Accept calibration'), re-run the calibration ('Discard calibration'), or restore your last good calibration ('Restore old calibration'). With the third option, you can defer calibration until later and start guiding with your last good calibration data. If you see repeated alerts on the same topic and are convinced there really isn't a problem, you can use the 'don't show' checkbox to block future alerts of that type. But you should be aware that the sanity-checking used by PHD2 works well for a wide range of equipment, and most users don't see these calibration alerts at all.

Declination Backlash

The most common source of calibration problems is declination backlash, which is present to some degree in most geared mounts. Backlash can occur when the direction of motion on the axis is reversed. The telescope may not immediately start moving in the reverse direction, even though the motor is turning. The usual cause is loose meshing of the gears in the drive train. With many less-expensive mounts, it may take several seconds for the axis to start moving in the correct direction and this can lead to poor calibration and guiding results. Consider the following example of a calibration review dialog:



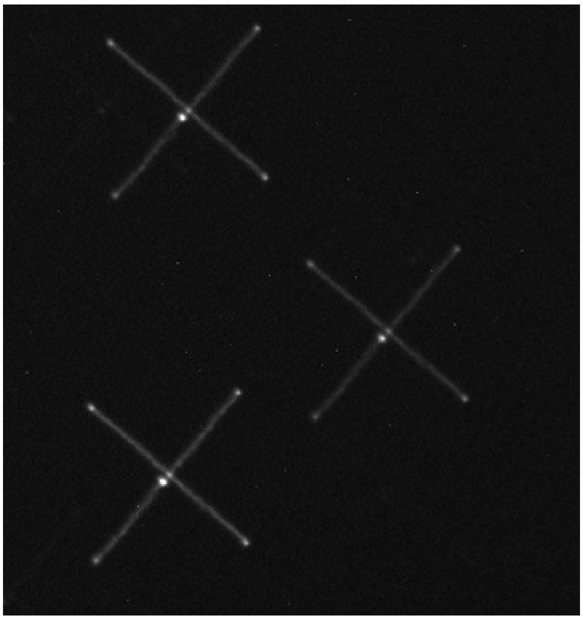
The first clue to the problem is found by comparing the number of steps required for calibration on the two axes - 10 for RA but 42 for Dec. This shows the mount was not moving consistently in declination, probably because the backlash had not been cleared. This also explains the "wandering" behavior of the declination points (light green) when the guide commands were reversed from north to south. Finally, the computed declination rate is much smaller than the RA rate even though the guide speed settings on the two axes were identical. In fact, this would have triggered a calibration alert dialog. There are actually two problems to be addressed here. First, the calibration result is poor and should be repeated in order to get a more accurate measure of the declination guide rate. Second, the mount is likely to behave badly during direction reversals in declination even if the dec guide rate is correct. **The calibration can be improved by taking these steps:**

Start looping guide camera exposures on a field with usable stars, preferably near Dec=0 and within 15 degrees of the celestial meridian
Using the hand-controller, move the mount north ('up' arrow) until you see the stars in the display moving
Start the calibration

Once this is done, most of the declination backlash in your mount should have been cleared and you will probably get better results from the calibration. The underlying backlash problem generally requires some mechanical adjustment to the mount. If the mount isn't using a guide speed close to 1x sidereal, you can probably get an immediate improvement by increasing the mount guide speed. You can also try using a PHD2 backlash compensation setting, but this is not likely to work well if the backlash is large - more than 3 seconds, for example. If you can't correct the backlash or reduce it to manageable levels, you should consider choosing uni-directional guiding for declination. To do this, you determine which way the mount drifts due to polar alignment error and tell PHD2 to guide only in the opposite direction (see Uni-directional guiding). This is controlled by the 'Dec guide mode' control on the'Algorithms' tab of the Advanced Settings dialog. For example, if the mount tends to drift north overall, restrict guide commands to south-only. This is not an ideal solution, obviously, but you can still use reasonably long exposures and achieve good guiding results - many imagers choose to use this approach.

Validating Basic Mount Control - the Star-Cross Test

If you are having repeated problems getting calibration to complete without alert messages, you should run a very simple test to see if the mount is responding to guide commands. This test basically mimics what is done during calibration, but it is more direct and can give you a better feel for what's going on. We'll call it the "star-cross" test. The idea is to open the shutter on the main imaging camera, then send guide commands that should cause the stars in the field to trace out a distinctive cross pattern. In other words, you want to get an image that looks something like this:



The angular orientation doesn't matter, that's just a function of how you have the guide camera rotated. What is important is that the lines in the cross are perpendicular and have roughly equal lengths in each of the four directions relative to the starting point in the center. If the image you get doesn't have this approximate appearance, guiding will either be impaired or perhaps impossible. For example, consider the following poor result:

You can see the star has moved along only one axis - only in right ascension in this example. The declination guide commands sent to the mount did nothing at all. Until this is fixed in the mount, you won't be able to guide in declination at all and will have to disable declination guiding to even complete a calibration. There are many other permutations of bad results, each suggesting a particular problem in the mount, the guide cable, or much less likely, the ASCOM driver for the mount. You can safely assume it has nothing to do with PHD2.

Here are the steps for running the test manually:

1. Set the mount guide speed to 1X sidereal. Bring up the 'Manual Guide' tool in PHD2 and choose an initial value for 'Guide Pulse Duration' - start with, for example, 5 seconds.
2. Start a 60 second exposure on the main camera.
3. Send a 5-second pulse west, then two 5-second pulses east, then a final 5-second pulse west. This should return the star to its approximate starting position. You should wait about 5 seconds after sending each guide pulse to give the command time to complete before sending the next pulse.
4. Now send a 5 second pulse north, then two 5-second pulses south, then a final 5-second pulse north. This should again return the star to its starting position.
5. Wait for the main camera image to download and see what you get.

You can use different pulse lengths if you want, perhaps using smaller values to confirm the mount will respond to them. Just be sure the total exposure time on the main imaging camera is longer than the total of guide durations plus a margin for error. On most mounts, the star will not return to its exact center because of some declination backlash - you can see that in the first example image. But it should be fairly close or you'll need to look more carefully at how much declination backlash you have in the mount. PHD2 also has a Star-cross Tool that will automate these steps for you.

One benefit to using this test is that it reduces things to the absolute basics: will the mount move as directed or not. It has nothing to do with PHD2 guide settings because they aren't involved in the test. You may find it helpful to use the test results to communicate with the mount manufacturer or other users who understand your type of mount and its typical problems.

Measuring the Mount's Behavior
If you're having trouble getting decent guiding results, your first instinct will probably be to try making wild changes to the guiding parameters in the hope of finding a magic solution. This almost never works, and you're more likely to just make things worse. If the default parameters from the new-profile-wizard aren't producing reasonable results, the fault is probably with the hardware and you'll need to determine the underlying cause. Once you understand the cause, you can probably improve your guiding results even if no actual repairs can be made - but understanding the underlying problem is important. To understand what the mount is doing, perform the following steps:

1. Use the new-profile-wizard to create a new equipment profile for the test, being sure the *guide scope* focal length and camera pixel size are correct. Don't guess at them, look them up if you aren't sure.
2. Use an ASCOM connection to the mount if one is available and set the mount guide speed to 0.5x - 1x sidereal. Disable any backlash compensation you have in the mount.
3. Use 2-second exposures and let PHD2 auto-select a guide star near Dec=0 with the scope pointing at least 45 degrees above the east and west horizons to minimize seeing effects.
4. Run the Guiding Assistant for 10-15 minutes and apply whatever recommendations it makes, particularly with respect to min-move values. Let it measure your declination backlash. You may need to use a large tracking region to avoid losing the guide star during this part of the process - just be sure there aren't multiple stars in the tracking rectangle. The backlash test will move the star a long distance north, so choose a guide star that is nearer the southern edge of your camera frame to give yourself plenty of room.
5. Watch how things are going during the GA session. If you bump the mount or something really unusual happens, stop the test and then restart it. The goal is to measure the performance when things are running normally.
6. Do not change any of the guide parameters beyond what is recommended by the Guiding Assistant.
7. Take a careful look at the results shown in the Guiding Assistant table. Each entry in the table can tell you something useful about the mount's performance. These results are also written to the guiding log, so they are available for later analysis.
8. If you got calibration alert messages in step 3, you should probably remedy those problems before proceeding. Guiding with a bad calibration is not likely to produce good results. Also, if your polar alignment error is 10 arc-min or more, you should improve on that and then repeat the above steps.
9. Let PHD2 guide for another 10-15 minutes, just letting it run as long as there aren't gross errors from wind or other "mistakes." **Do NOT** change any of the guiding parameters while this is being done.

If you want to analyze the results yourself, use the PHDLogView tool and the tutorial on "Analyzing PHD2 Guiding Results". You should also consult the document on PHD2 Best Practices. All of these references are available on the OpenPHDGuiding.org web site under the 'News' tab. If you'd like some help understanding the results, post both the guiding and debug log files on the OpenPHD2 Google forum and we'll be glad to help you out.

Lost-Star Events

When PHD2 can't locate the primary guide star in a camera frame, several things happen:

1. The screen will flash and a "beep" tone will sound. The sound can be disabled if you wish (Advanced Settings/Guide tab) but the screen will always flash
2. No guide commands will be issued and the next guide camera exposure will be started
3. Lost-star event messages will be sent to any imaging applications that are connected to PHD2
4. Lost-star messages will be displayed in the status bar including the reason for the loss - low SNR, low HFD, low-mass, or mass-change

Lost-star events occur when the object in the search region no longer meets the criteria for identification as a star. It may no longer be bright enough, meaning that its SNR or its total brightness ("mass") are too low. Or it may look too much like camera sensor noise, meaning that its size (HFD) is lower than your setting for Min-HFD. If you are using "star-mass-detection" as a way to discriminate between mutliple similar stars in the search region, a lost-star event will be triggered if the star mass value changes by more than the allowed amount. This feature is generally unnecessary for current versions of PHD2 and can be disabled. In any case, the first steps in trouble-shooting will be to understand the reason for the lost-star events and whether they happened because of degraded sky conditions, mechanical tracking errors, or inappropriate star selection parameters. For beginners, a common cause of lost-star events is poor focus of the guide camera, and you should insure that your guide camera remains well-focused using the procedures described in the Star Profile tool section. Star Profile Tool

PHD2 doesn't invoke any sort of extended guide star recovery process - it simply keeps taking exposures and looking to see if the guide star reappears within the current search region. This works well for brief or intermittent problems like clouds, wind gusts, or sporadic mechanical problems but it assumes that the tracking accuracy of the mount is sufficient to keep a guide star within the search region for a reasonable length of time. As the elapsed time of the lost-star events grows, the mount will slowly drift off-target and a star that re-appears in the search region at a much later time is probably a different star. In this case, PHD2 will resume guiding but the original astronomical target will no longer be centered and may not even be in the field of view. Recovery from extended lost-star periods is the responsibility of the end-user or the imaging automation application, not PHD2. Doing the recovery properly requires re-slewing the scope to its original sky pointing position, a procedure that PHD2 is not equipped to do.

Alert Messages

PHD2 will sometimes display alert messages at the top of the main display window. These generally show error or diagnostic information that warrant your attention. During normal operation, you probably won't see any of these, but if you do, this section can help you decide what to do about them.

Dark-library and Bad-pixel Map Alerts

"Use a Dark Library or a Bad-pixel Map" - using a dark library or bad-pixel map reduces the likelihood that PHD2 will mistakenly identify hot pixels or other sensor noise as a star. If you choose to ignore this message, you'll be vulnerable to situations where PHD2 inadvertently switches from the guide star to a hot pixel and no longer guides correctly.

Format/geometry mismatches - dark frames and bad-pixel maps must match the format of the sensor in the camera being used. If you've changed the camera in an existing profile, the existing dark/bpm files will not be usable and you'll see this alert message. To avoid seeing the message, you should instead create a new profile when you change cameras. You'll still need to shoot new darks or bpms, but you can keep the old files for use with the original camera. You might also see a format-incompatibility alert message if you have mistakenly connected PHD2 to the wrong camera - this is a particular risk when your guiding and imaging cameras come from the same vendor. You can completely specify the camera you are using for guiding in the Connection Dialog Specifying camera ids . Unless you're connected to the wrong camera,, you should rebuild the dark library or bad-pixel map from scratch - more information can be found here: Dark Frames and Bad-pixel Maps

ASCOM Alerts
When you first connect to a mount, camera, or other ASCOM-controlled device, you may see an alert message saying that a required capability is not supported by the driver. One example would be lack of support for pulse-guiding by an ASCOM telescope/mount driver, something that can occur with outdated drivers. In these situations, your only recourse is to update the ASCOM driver. These drivers are generally available from the ASCOM web site or, in some cases, from the device manufacturer. As a rule, the best practice is to use the latest versions of these drivers so you don't encounter problems that have already been fixed.

You might also see other alert messages associated with the ASCOM driver for the mount:

1. "PulseGuide command to mount has failed - guiding is likely to be ineffective." This is usually caused by a bug or timing sensitivity in the ASCOM mount driver, and there is generally no way to know if the guide command was executed properly or not. If you rarely see the alert and your guiding results are acceptable, you can probably ignore it. Despite the alert condition, PHD2 will continue to issue guide commands, so you don't need to take any immediate action. If you see the alert frequently, you should send us your debug log so we can help you communicate the problem to the author of the ASCOM driver.
2. "Guiding stopped: the scope started slewing." This is pretty self-explanatory, but the determination that the scope was slewing is something reported to PHD2 by the ASCOM mount driver. Whether it was actually slewing isn't known to PHD2. Assuming you didn't mistakenly slew the scope with guiding active, there is probably a timing problem in the driver. If you want to sidestep the problem temporarily, you can disable the logic to check for slewing - go into the 'Guiding' tab of the Advanced Settings dialog, and un-check the box that says "Stop guiding when mount slews." This will let you continue guiding, but the results might be suspect. The debug log should provide the details needed to describe the problem to the author of the ASCOM driver.
3. "Mount is reporting invalid guide speeds." Some new drivers don't follow the standards and report nonsense guide speeds, often because they aren't using the correct units of degrees/sec. When this occurs, PHD2 will treat the reported guide speeds as "unknown" and will ignore them. This degrades the accuracy of the PHD2 PPEC guide algorithm and otherwise reduces the effectiveness of calibration review and other diagnostic tools. This is not a PHD2 problem, it must be fixed by the author of the driver.

Camera Timeout Alerts
Alert messages associated with camera timing/timeout problems are discussed above: **Camera Timeouts**

Calibration Alerts
A number of alerts may appear during the mount calibration process. These are described here: Calibration Alerts

Maximum-Duration Limit Alerts
During normal guiding, you may see an alert message saying that your settings for maximum-duration limits in RA or Dec are preventing PHD2 from keeping the guide star locked. If you've decreased these parameters from their default values, you should restore them. However, if the limits are well above one second, this alert probably indicates you've encountered a mechanical problem that needs to be corrected. In the simplest cases, you may have suffered a cable snag, wind gust, mount bump, or other external event that caused the guide star to move by a large amount. In such cases, you simply need to correct the problem if you can and proceed with guiding. But in other cases, the alert may be triggered by a steadily growing guide star displacement that is not being corrected at all. For example, if PHD2 can't move the mount correctly in either the north or south directions, the cumulative uncorrected error will eventually reach a point that triggers the alert. Or you may be encountering "runaway" Dec guiding because the setting for 'reverse Dec output after meridian flip' (Advanced Settings/Guiding tab) is incorrect. These sorts of problems will require some diagnosis and simply increasing the maximum-duration limits will not help.

Display Window Problems

New users often complain that the image displayed in the main window is extremely noisy or is almost all-white or all-black. Assuming the camera is functioning and actually downloading images, the display issues are often caused by the absence of any usable stars in the frame. For example, trying to test the camera indoors or in daylight will almost always create these conditions. The appearance of the image display window in these situations provides no useful information and should be discounted. PHD2 uses an automatic screen-stretching function that is intended to help you see real stars under a nighttime sky. When no stars are present, the display will be stretched to show the range of minimum-to-maximum brightness values of whatever is in the frame - which is often nothing at all. This is usually what causes the noisy/all-white/all-black display results. You may also encounter display problems if the guider is not well-focused. Focusing the guider can be a tedious process but it's critical to getting good guiding results. A good technique is to start with a bright *but unsaturated* star and try to reach focus with that. Then move to successively fainter stars to fine-tune the focus position using the PHD2 Star Profile tool to measure the size of the guide star. Good results can also be obtained using a Bahtinov focusing mask or focusing tools in other applications. It doesn't matter what you use, but just trying to judge focus by looking at the display is not likely to produce a good result.

Hot-pixel and Star-Selection Problems

With most guide cameras, you can encounter problems where clumps of hot pixels are mistaken by PHD2 as guide stars. This can be especially troublesome if you're using automation tools and the 'auto-select' guide star selection is mistakenly choosing hot pixels. For many cameras, a simple dark frame will suffice for reducing or eliminating hot-pixel problems, and dark frames should always be used as a starting-point. But for other cameras, you will need to build a bad-pixel map and update it as necessary when you see changes in the locations and sizes of defective pixels. Camera sensors change over time and may react to changing temperatures, so bad-pixel map maintenance is a small task you should be willing to perform. Step-by-step instructions can be found in the Bad-pixel map chapter of this document. These problems are different from transient hot pixels, which can be caused by cosmic ray strikes on the sensor. Although cosmic ray hits can disrupt guiding, there's really little you can do about them.

Since the recommended practice is to let PHD2 choose the guide star ("auto-select"), you should use the available UI controls to help PHD2 do the best possible job. The Minimum-HFD property on the Guiding tab of the Advanced Settings dialog is probably the most effective tool for avoiding hot-pixel selection. You should set its value to allow use of the smallest and faintest real stars your setup can produce. You should use the Star Profile tool to measure a reasonable sample of legitimate guide stars for your system. Then set the Minimum-HFD value to accept those stars while rejecting smaller bright spots that are really just sensor defects. At the other end of the scale, you should also specify the brightest pixel value your system will deliver - the ADU value that represents saturation. By doing this, you will prevent PHD2 from rejecting stars that have a flattened profile but aren't really saturated. The saturation control resides on the Camera tab of the Advanced Settings dialog and is part of a control group labeled 'Star Saturation Detection'. Choose the option for 'Saturation by Max-ADU value', then set the value for your system. If you have an 8-bit camera, saturation will be around 255, while a 16-bit camera will saturate around 65000 ADUs. If you don't know the correct value, you can just point the scope at a bright star, use a multi-second guide camera exposure, and again look at the Star Profile window. One of the things you'll see in that window is the 'Peak Value' - that's the ADU value for the brightest pixel and will tell you whether your images are 8-bit or 16-bit.. Using both of these controls is likely to produce much better results for PHD2 guide star selection.

Restoring a Working Baseline

Despite advice to the contrary, you may have made rapid, uninformed changes to your guiding parameters only to find the performance stayed the same or even got worse. Before proceeding, you should restore the settings to their default values. If you used the new-profile-wizard to build your profiles, the parameters will have been set based on the specifics of your configuration, and they are likely to be pretty close. If you encounter significant guiding problems using those settings, you are probably having issues with the mount or other hardware. Blindly changing guiding parameters almost never solves these problems and quite often makes things worse. You have several options for restoring the settings to their default values:

1. On the 'Algorithm' tab of the Advanced Settings dialog, you can individually reset parameters by looking at the tool-tip for each field. Hover your mouse cursor over the field and the default value will be displayed. Note that this is not accurate for the min-move settings, which depend on your image scale. This approach is best when you want to restore only a few settings.
2. Click the 'reset' buttons on the 'Algorithm' tab for the selected RA and Dec guide algorithms. This is the recommended approach for resetting all the guiding parameters. The min-move settings will be reset to the values originally calculated by the new-profile-wizard. If you subsequently adjusted those settings by running the Guiding Assistant, you should repeat that process.
3. Run the new-profile-wizard, accessed by clicking on the 'Manage Profiles' button in the 'Connection' dialog. Use the same camera and mount choices you already have and give the profile a new name. If you want to re-use the dark library and bad-pixel map from the old profile, connect to the new profile and use the 'Darks' menu to import those files from the old profile. Once you are satisfied with the new profile settings, you can delete the old one.

Poor Guiding Performance

Once you've gotten everything running, you will probably get reasonably good guiding results almost immediately. You will have to decide what "good enough" means, and everyone's standard is likely to be different. But if you find your imaging results are not acceptable because the stars are streaked or elongated, you'll need to take a systematic approach to correcting the problems. It is often tempting to just start blindly adjusting the various guide parameters in an effort to make things better. There is nothing wrong with adjusting the parameters - that's why they're there - but it should be done carefully based on an understanding of what they do and what problem you're trying to solve. The PHD2 default settings are carefully chosen to produce reasonable results for most amateur equipment and locations. Optimal settings are entirely dependent on the image scale, seeing conditions, and behavior of your specific mount. In other words, they are unique to your situation - there is no magic "red book" of correct guiding parameters, and settings you get from other users may be completely irrelevant to your situation. If you got started by using the new-profile-wizard, the default settings will already be tuned fairly well to match your image scale. By using the Guiding Assistant, you can get more specifics about your situation - how the seeing conditions look and how you might adjust the minimum-move settings to avoid chasing the seeing. You can also use either the Guiding Assistant or the Manual Guiding tool to see how much backlash is present in your mount, something that can be important to understanding your declination guiding results.

Log Analysis

Any sort of problem isolation or tuning will invariably require use of the PHD2 log files. Both are formatted for straightforward interpretation by a human reader, and the guide log is constructed to enable easy import into other applications. As mentioned in the 'Tools' section, applications such as PHDLogViewer or Excel can be used to visualize overall performance, compute performance statistics, and examine time periods when guiding was problematic. With Excel or similar applications, simply specify that the guide log uses a comma as a column separator. That said, PHDLogViewer is strongly recommended for log analysis and is the tool used by the developers to provide support on the PHD2 Google forum.

Guiding Log Contents

The contents of the guiding log will continue to evolve as new capabilities are added. But the basic content is stable, and considerable care is taken to not "break" applications that parse it. If you wish to analyze the log yourself, the following information will be helpful.

The PHD2 guide log will contain zero or more sequences of calibration and zero or more sequences of guiding. Each of these sections has a header that provides most of the information about the guiding algorithms being used and the internal parameters used by PHD2 for guiding. At the start of either a calibration run or a guiding sequence, the last line of the header information defines a set of column headings. The meanings of those columns are shown below:

Calibration columns:

- dx, dy are offsets from the starting position, in pixels, in the camera coordinate system
- x, y are the camera x/y coordinates of the guide star at the end of each calibration step
- Dist is the total distance moved in the camera coordinate system (dist = sqrt(dx*dx + dy*dy). This is the value used by PHD2 to compute the calibration parameters

Guiding columns:

- dx, dy are the same as for calibration - offsets from the "lock position" of the guide star in the camera coordinate system
- RARawDistance and DECRawDistance - these are the transforms of dx and dy into the mount coordinates - in other words, they use the arbitrary angle of the guide camera to map from X/Y on the camera to RA/Dec on the mount
- RAGuideDistance and DECGuideDistance - these are the outputs from the various guiding algorithms. The guide algorithms operate on the "raw" distances and decide how far, if any, the telescope position should be adjusted in each axis. For example, with a "minimum move" parameter set, the "guide" distances can be zero even when the "raw" distances are non-zero.
- RADuration, RADirection, DECDuration, DECDirection - these are the values determined by the two "guide" distances above. The "durations" are the lengths of the guide pulses, in milliseconds, needed to move the mount by the distances specified by RAGuideDistance and DECGuideDistance
- XStep, YStep - step-adjustment durations for the adaptive optics device if one is being used
- StarMass - a brightness measure of the guide star image
- SNR - an internal "star-detection ratio" used by PHD2 - essentially a measure of how well the star can be distinguished from the sky background
- ErrorCode - an integer value representing the quality of the guide star measurement:
  - 0 - no error
  - 1 - star is saturated
  - 2 - star has low SNR
  - 3 - star mass is too low for accurate measurement
  - 4 - star HFD is below Min-HFD value
  - 5 - star HFD is above Max-HFD value
  - 6 - star has drifted too near the edge of the frame
  - 7 - star mass has changed beyond the specified amount (only if mass-checking is enabled)
  - 8 - unexpected error

All distance values are in units of pixels. The header for the guiding section will show the image scale as it is known by PHD2, and that can be used to scale the pixel distance values into units of arc-seconds if desired.

Problem Reporting

If you encounter application problems that are specific to *PHD2*, you are encouraged to report them to the open-phd-guiding Google group: OpenPHDGuiding Group You need to first establish a membership in the group in order to get help. Obviously, the more information you can provide about your problem, the more likely we will be able to resolve it. Using the following guidelines will help in that regard:

1. Try to reproduce the problem - if we have a clear set of steps to follow, we are more likely to find a solution quickly. If you can reproduce it, try to reduce things to the minimum number of steps. Remember, we won't have your hardware or computer environment when we try to reproduce it ourselves.
2. Try to be complete about describing your configuration - operating system, equipment types, *PHD2* version, etc.
3. Upload the *PHD2* log files from the session in which you encountered the problem - this is a critical step. Use the 'Upload log files' function on the 'Help' menu to do this -- it gives you an easy way to select the relevant log files and then uploads them to our server without constraints on file size. Attaching log files to forum messages is discouraged and will often not work at all because of the file sizes. If you can't reproduce the problem, try to estimate the time of day when you first saw it - this could help us find evidence in the debug log without having to sift through hundreds of lines of output. If you request help on the forum without uploading your log files, you will usually be asked to do so, thus adding an unnecessary delay in getting help.

Supplemental Information

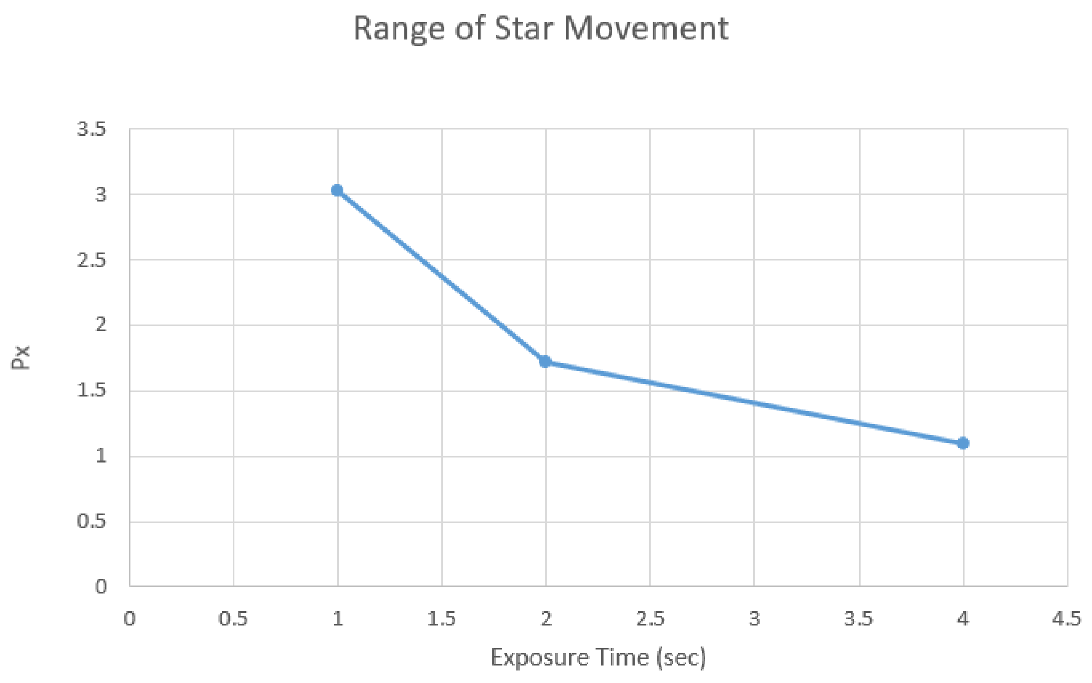
Astronomical Seeing and Guiding

It's difficult to get far in imaging and guiding without coming to grips with astronomical seeing. This is a complex subject so only the bare minimum can be covered here. "Seeing" is the term given to the positional jitter and sudden brightness changes of stars we see (or photograph) through a telescope. With the naked eye, we see this as "twinkling" because our eye can't resolve the tiny positional movements of the star. It is atmospheric turbulence, caused by the movement of thermal cells at various levels in the Earth's atmosphere. Light is refracted as it passes through each atmospheric cell, so when you look at a star, you're really looking up through a column of air that is behaving like a column of little lenses. The refraction of the light by each cell depends on its temperature, and the cells generally have different temperatures. And because the atmosphere is very dynamic, these elements are all moving around at various speeds, coming into and then leaving the column of air you're looking through. Particularly with longer focal lengths, this atmospheric seeing is the single biggest source of the guide star movement we see with a properly working mount, and it can't be "guided out". The movement of the atmospheric cells means the guide star position is changing at rates of 10's to 1000's of times per second, and amateur-grade equipment, even adaptive optics devices, can't react quickly enough to correct for it. Professional observatories are able to do it to a large extent by employing very expensive measurement devices, artificial stars, and mechanisms that can both deform the mirror and shift the image at very high frequencies. For these observatories, most of the seeing disturbances originate in the upper layers of the atmosphere and those are the layers that are used for seeing models and most seeing forecasts. For amateurs and especially for those who image from urban or backyard locations, seeing problems also arise from sources close to the telescope. Heat convection from hard ground surfaces or neighboring rooftops create lower frequency "boiling" behavior that degrade guiding and imaging performance. Ground-level heat can also create tube currents and uneven layers of hot air inside the telescope tube - these also can masquerade as low-frequency seeing effects. Users should do what they can to avoid or mitigate these situations and, when working in locations with high daytime temperatures, should expect it will take many hours after sunset for the equipment temperatures to equilibrate.

From a guiding perspective, we are always "under-sampling" the seeing behavior. By the time we've taken an exposure, downloaded the image, computed the location of the guide stars, and then transmitted a guide command, the star position on the sensor has moved – probably 100's of times. As the exposure time decreases, these measurement errors become even larger, a phenomenon known as "aliasing". You're exposed to aliasing any time you watch a TV show or a film that has rapidly spinning objects like automobile wheels. Over the years, you've been conditioned to ignore it but, really, are those car wheels actually spinning backwards during the chase scene? This aliasing effect happens because the exposure rate of the film equipment - e.g. 60 frames/sec - is too slow to accurately meaure the movement of the spinning objects. Getting back to auto-guiding, we're always dealing with outdated information about the actual guide star position – and that doesn't even take into account whatever shortcomings the mount has in precisely executing the guide commands it receives. The star movements we *can* correct for - drift, periodic error, atmospheric refraction, mechanical deflections, etc - are hiding in a sea of noise created by the seeing conditions. One of the major objectives of the PHD2 guide algorithms is to identify and react to the tracking errors that can be corrected while ignoring the spurious effects of seeing that can't be corrected. Your choice of guide camera exposure times can make this job easier.

Seeing and Exposure Times

The high-frequency, seeing-induced star motion seen by the guide camera is strongly affected by the length of your guide exposure. Look at the following plot to see how the observed range of guide star motion decreases as the exposure time is increased:



Essentially, the camera sensor is averaging the changing light pattern of the star and smoothing the result. Measurement uncertainty is still present because of under-sampling, but the longer exposures make it easier for PHD2 to isolate and identify the lower frequency errors that really can be improved through guiding. Obviously, there is a practical upper limit to the exposure time. Typically, it will be limited by the length of time your mount can run on its own without needing a correction. Small errors from periodic error, drift, flexure and other sources need to be corrected before they become large enough to ruin an image. Finding the right balance will always depend on both the seeing conditions and the quality of the equipment. As a starting point in PHD2, we typically recommend using exposure times of around 2 seconds and lower exposures of at least 0.5 sec only if the mount requires it and then only if guiding is active on multiple stars.

Use of Binning

Many of the guide cameras available in PHD2 support hardware-level binning, which may be helpful in situations where you are guiding at long focal lengths or have a guide camera with very small pixels. These scenarios often result in having to use faint guide stars, and the guider images may be substantially over-sampled. Over-sampling provides no real benefit, and the projection of a faint star disk onto many small pixels can result in a low signal-to-noise ratio (SNR). By binning the image, you can reduce the impact of camera read noise and thus improve the SNR; and if you are over-sampled, you won't degrade the accuracy of computing the guide star location. Choosing a binning factor greater than one will have the following effects:

1. Star images will have a higher SNR and will be easier to detect above the background noise level. This is especially helpful if you are limited to using faint stars (i.e. with SNR values below about 10).
2. The amount of data downloaded from the camera will be reduced by the square of the binning factor. This can be helpful if you are using a camera that makes heavy use of USB resources even if star brightness and SNR are already reasonable with un-binned images. Of course, using sub-frames can achieve the same result once a star has been selected.
3. The resolution (image scale) of your guider image will be reduced by the binning factor. This is not likely to be a problem if the un-binned image scale is below 1 arc-sec/pixel, but your guiding results may suffer if the un-binned image scale is above 2.5 arc-sec/pixel. You may need to experiment because the results will also depend on the image scale of your main camera system.

Each binning level requires its own dark frames and bad-pixel map - they are not interchangeable, nor can a transform be done automatically. If you want the flexibility of switching back and forth between binning settings, you should create separate profiles for each binning value. Then build a dark library and a bad-pixel map for each of those profiles. When you want to change binning factors, just switch to the profile that has the setting you want, and a dark library and/or bad-pixel map will be available. If you want to check that the camera is binning correctly, you can use the Stats window to confirm the frame size and current on-camera bin settings. Even if you've made a firm decision to change the binning, you should create a new profile using the new-profile-wizard - that will automatically adjust all of the guiding parameters that depend on image scale. From a guiding perspective, a change in binning is essentially the same as switching to a different camera.

Dithering

In order to reduce fixed-pattern noise and hot pixels, imagers often move the telescope by very small amounts between exposures – this is called dithering. Dithering is always controlled by the imaging app because it is the only one that can suspend exposures with the main camera while the pointing position is being shifted. PHD2's only role in this is to issue guide commands that will accomplish the requested shift in position – it is simply doing that it's told. The small shift in pointing position is accomplished by PHD2 in two steps:

1. Change the lock-point of the primary guide star by the amount requested by the imaging app.

2. Use the normal guiding routines to move the primary guide star to the new lock-point

The size of the dither is controlled by the imaging app, at least indirectly. The app may let you specify the maximum size of a dither, typically in units of pixels. In that case, PHD2 interprets this as the upper range of random values between zero and this limit. The randomizing process is done to insure that dithering doesn't follow a simplistic back-and-forth pattern or shift the frame back to a location where it has previously been. For some applications that do PHD2 dithering, you can't specify the maximum amount directly - you are perhaps limited to choices like small/medium/large and the max dither amounts will have preset values. For that reason, PHD2 has a dither scaling parameter in the 'Global' tab of the Advanced Settings dialog. It is basically a multiplier term that lets you adjust the range of dither amounts that are possible. So a scale factor of 1 doesn't change the preset value at all, a value of 10 multiplies it by 10X, etc. If you're using an app that lets you specify the maximum amount directly (e.g. PHD_Dither), you should leave the dither scale set to 1.0. Otherwise, you can adjust the scale factor if you aren't happy with the overall range of dithering you're getting with one of the small/medium/large choices..

It's up to the imaging app to determine when the guiding has settled down and it's time to start the next exposure with the main camera. To make this easier for authors of the imaging apps, PHD2 provides some extra measurement information on how the settling process is proceeding. This information doesn't need to be used by the imaging app, it is entirely optional. In order to take advantage of this help, the imaging app specifies what level of stability it wants to see in order to decide that the dithering activity has settled down. There are three settling parameters for doing this:

1. The maximum amount of guide star position error that is considered acceptable – call that position tolerance, **PT**

2. The length of time that must elapse during which the guide star position error stays below the position tolerance – call that the evaluation time, **ET**

3. The maximum amount of time that can be tolerated before the measurement process is terminated and the dither is declared to be "done" regardless of the guiding stability – call that the time-out period, **TO**

To state this in a sentence, the settling process is "done" when the guiding error is <= **PT** for **ET** seconds or, if that condition is never satisfied, after **TO** seconds have expired. When this evaluation process is complete, PHD2 sends a message to the imaging app saying settling is done. This is all just extra credit for PHD2, normal guiding is being done from the time the lock-point is moved.

Of course, the specification of these parameters, **PT**, **ET**, and **TO**, is up to you and the values have to be chosen intelligently. Your imaging app may not expose all of these parameters in its user interface or it may give them different names. If you're dithering by large amounts with a low-performance mount, you have to expect it will take a long time to settle down. If you specify a **PT** value that is too large or an **ET** value that is too small (overly lax parameters), the imaging app may start the next exposure too soon and you could get streaked stars in the image. The same problem could occur if you specify a **TO** value that is too short. Conversely, if you specify a **PT** value that is too small or an **ET** value that is too long (overly demanding parameters), then all of your dithers will incur a delay of **TO** seconds and settling will "fail" – you are asking too much from your mount. A sensible approach is to look at your past performance to see how well your mount responds under typical seeing conditions with the size of dithering you want to use. If your mount has a lot of Dec backlash, you should see how long it takes for guiding to settle down when the direction of the Dec guide command is reversed. The **ET** and **PT** values should reflect the guiding performance you normally get with your setup with a little bit of slack to avoid wasting time.

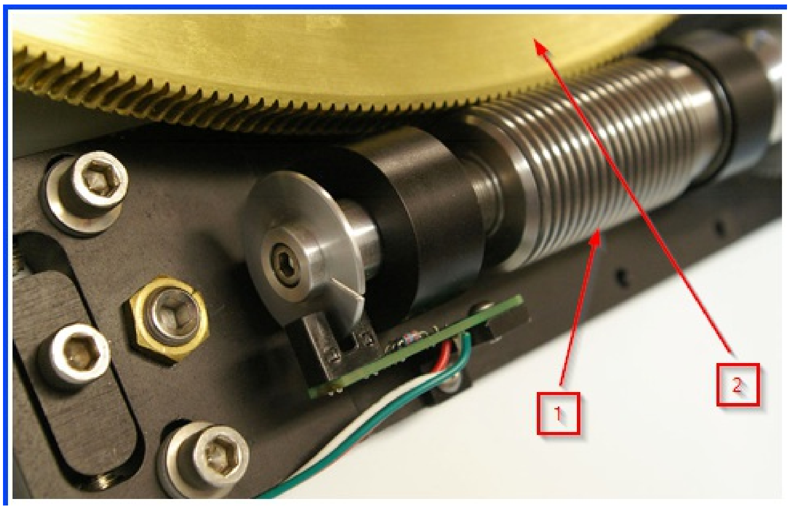
PHD2 also supports different choices for how the star is moved in RA and Dec. With the default settings, the mount will be shifted in RA and Dec by different random amounts as described earlier. If you choose "spiral mode", the guide star will be moved in a pattern that eventually produces a spiral pattern around the original lock-point. This automatically reduces the number of Dec reversals and can be a good choice if your mount has substantial backlash. In this mode, there is no randomizing process involved, each dither has the size specified by the imaging app. Alternatively, you can choose the RA-only option and eliminate Dec reversals altogether, but this may not be a good choice if your imaging camera has a lot of fixed-pattern noise.

If your mount has a substantial amount of declination backlash in the mount, you may be guiding in only the north or south Dec direction. If PHD2 receives a command to dither in declination while you're operating in this mode, it will temporarily allow guiding in both Dec directions until the dither and settling are completed. It will then revert to the original north/south-only guiding mode. If you don't want this behavior, you should restrict dithering to 'RA-only'. All of the PHD2 dither controls are contained on the 'Global' tab of the Advanced Settings dialog.

Common Mount Mechanical Problems

Periodic Error in Right Ascension (PE)

Periodic error is most often caused by very small machining errors in the various components of the RA drive system. One part of a typical drive system is shown here:



Credit: Mathis Instruments

A high-precision worm gear (arrow 1) is used to drive the much larger worm wheel (arrow 2). The latter is attached to the RA shaft and when the mount is tracking at the sidereal rate, the worm wheel will complete a rotation in one sidereal day (23.934 hours). In order for this tracking to be perfect, all the following conditions must be met:

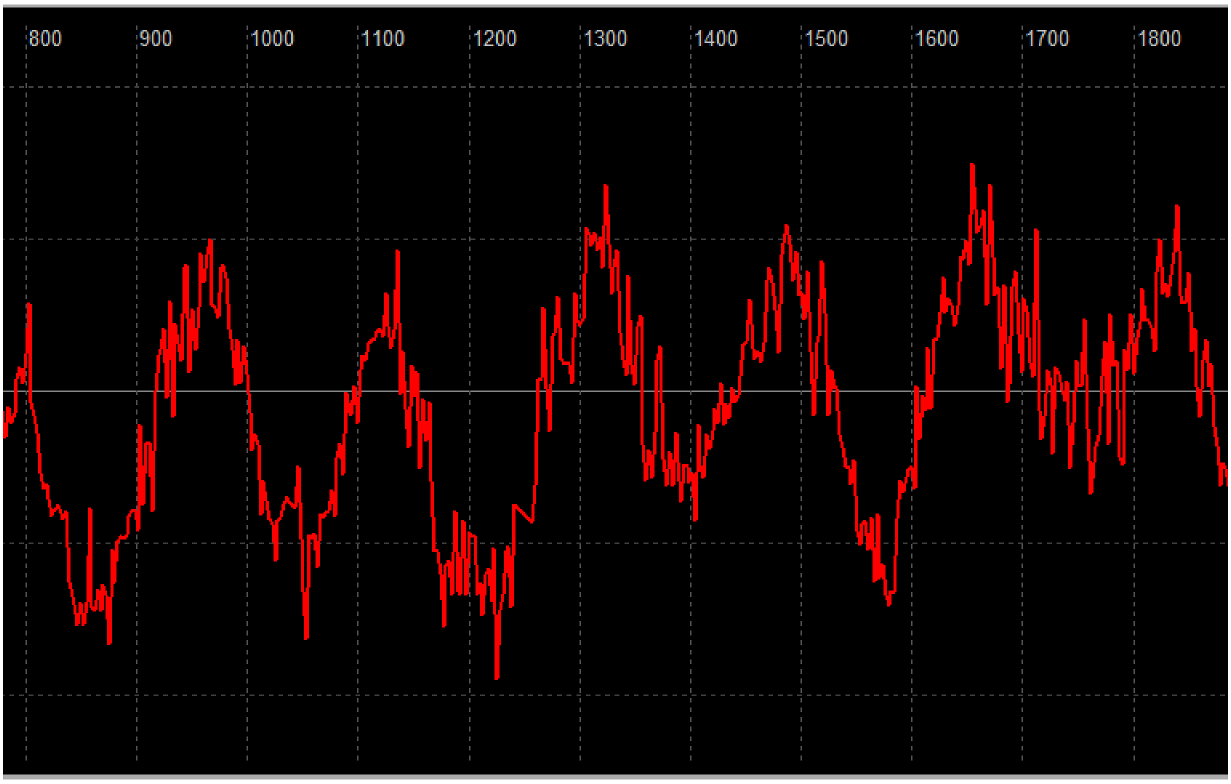
Identical pitch and spacing for every thread in the worm gear

Rigid attachment of the worm gear to the mounting plate with no flexure or movement of the gear or the mounting blocks

Identical shape and spacing of every tooth in the worm wheel

Worm wheel perfectly round and perfectly centered on its axis of rotation

These are actually just a few of the necessary conditions, but it's obvious that this level of precision is not likely to be present in most amateur mounts. The machining of the worm gear is usually the biggest challenge so tracking errors often originate there. The worm gear turns at a constant rate during sidereal tracking and the time it takes to make one full revolution is called the "worm period". Worm periods vary among different mounts but generally fall in the range of 4 to 10 minutes. A machining inaccuracy on one of the worm threads will therefore make its presence known once in every worm period. Of course, many of the worm gear threads are likely to have some inaccuracies and each will make its own contribution to tracking error once during the worm period. When the tracking error is graphed over a single worm period, the result is usually a curve that is roughly sinusoidal with varying slopes, peaks, and valleys – this is what is known as periodic error. Here's an example:



Notice the high-frequency movements caused by seeing that are not part of the mechanical periodic error.

There are other gears in the RA system, often a series of gears that lie between the motor and the worm gear. These are required to convert from the native speed of the motor to the slower rotation speed of the worm gear and also to generate the torque needed to drive the worm gear. Each of these components will have machining inaccuracies of its own and will contribute to cumulative tracking errors of the mount. Many of these components will introduce errors on shorter time periods than the worm period. Some mounts use drive belts to sidestep some of these "upstream" gear inaccuracies but those can introduce errors of their own – incorrect tensioning, lateral movement of the belt on spindles, etc.

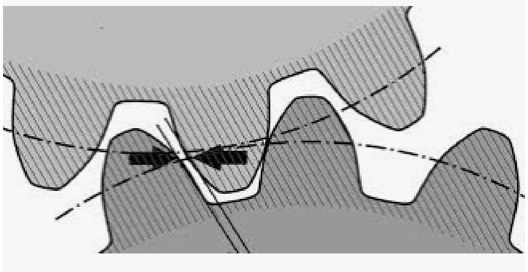
RA Periodic Error Correction

Periodic error correction (PEC) in the mount firmware is beneficial to auto-guiding if the feature is implemented correctly. Unfortunately, this isn't always the case. But when done correctly, periodic error correction handles some tracking errors before they are seen in the guide camera image. These corrections are predictive, based on a model of the mount's PE, as opposed to being reactive like normal auto-guiding. The net result is that PHD2 has less work to do to keep the RA axis on-target. Even when the implementation in the mount is done well, calculation of a high-quality PEC curve must be done carefully using an application specific to the purpose. During the measurement process, the app must filter out seeing-induced guide star movements to produce a smooth correction curve that represents samples across multiple worm periods. It must also be aware of the worm period and the various harmonics in the mount drive system in order to apply corrections only for those tracking errors that are harmonic - i.e. errors with frequencies that are integer multiples of the worm frequency. If the PE correction curve is poorly constructed, the RA tracking can be worse than using no PEC at all.

If PEC isn't available for your mount or is badly implemented, you can use the PPEC guide algorithm in PHD2. PHD2 Predictive PEC

Declination Backlash and Stiction

Backlash can occur when the direction of motion on an axis is reversed. The telescope may not immediately start moving in the reverse direction even though the motor is turning. The usual cause is loose meshing of the gears in the drive train. For auto-guiding, this problem doesn't affect guiding in RA because the RA drive system is continuously moving the axis west as it tracks the sky - it never reverses direction because of guiding. But it is a common source of trouble for Declination because the Dec axis is mostly idle during guiding, running only in short bursts in response to guide commands to move the scope north or south.. A simple picture of what causes backlash is shown here:



The backlash gap between mating teeth ...
researchgate.net

This diagram shows two spur gears, but the basic principle also applies to worm gear and worm wheel pairs. In the diagram above, assume the bottom gear is the *drive* gear currently rotating counter-clockwise. The teeth on the drive gear are in contact with the teeth on the *driven* gear above it and the latter is being driven clockwise. But the arrows show that the surface on the trailing edge of the drive gear tooth is not touching the matching tooth on the driven gear - there is a small gap. So when the drive gear reverses direction, there will be a short period of time before the gears are fully meshed and the driven gear starts turning in the opposite direction. The "reversal delay" in this case is caused by simple backlash. Some amount of gap is generally required to avoid binding in the gear system and to allow room for lubricant and thermal expansion. When the mesh is too tight, the axis may exhibit stiction (static friction), a situation where the axis will not move smoothly and freely or is difficult to get moving from a stationary state. Stiction on the Dec axis can result in a pattern of an initial reversal delay that looks like backlash followed by a large over-shoot once the axis finally starts moving. Other than mistakenly having backlash compensation enabled in the mount software, stiction is the most common cause of oscillations in Dec guiding.

The Guiding Assistant will measure how the Dec axis behaves when it is forced to reverse direction. It is only capable of measuring the "reversal delay", the amount of time it takes to change direction and get the axis rotating at the expected rate. It isn't always possible to distinguish whether the problem is backlash, stiction, or both; but the graph produced by the GA can often provide clues. This behavior can also be seen during normal guiding sessions that don't employ the large guide pulses used by the GA. If the reversal delay is large, say above 3 seconds, it's probably best to try adjusting the Dec drive system. If the delay is less than that, the PHD2 Dec Backlash Compensation feature will probably be able to handle Dec reversals fairly well. Note that the amount of delay is inversely proportional to the guide speed in the mount - as the guide speed is increased, the reversal delay decreases. This is one of the reasons we recommend using guide speeds of at least 0.5x sidereal.

The reversal delay is usually not a constant value for the mount. Instead, it often depends on the pointing position of the scope and the balance of the scope on the Dec axis. As mounts age, the gears wear and for Dec, the wear will be greatest where the scope spends most of its time during imaging. For northern observers, that is probably in the Dec range of 0 to 40 degrees. With older mounts especially, the reversal delay can be quite different in those pointing positions than, for example, regions closer to the pole. This is another reason why the PHD2 Backlash Compensation feature is a better choice than any fixed-size compensation that is programmed in the mount controller.

Uni-directional Declination Guiding

As discussed above, some mounts may have too much reveral delay in Dec to support guiding in both north and south directions. This situation can be mitigated by configuring PHD2 to guide in only one direction, what we call uni-directional Dec guiding. This is a viable option because declination guiding is only intended to correct for slow drift - errors caused by polar misalignment and to a lesser extent, mechanical flexure. Ironically, you might want to de-tune your polar alignment a bit to make it easier to see the drift direction and to reduce the likelihood that seeing will interfere with uni-directional guiding. Remember that polar mis-alignment, within reason, doesn't usually degrade guiding performance. Instead, it may introduce field rotation if you're imaging near the pole and have a large camera sensor. A good first step would be to polar align to within 5-10 arc-min of the pole before setting up for uni-directional guiding. You can always go back later and check for field rotation. Just take a sample image with your main camera at the highest declination you would expect for imaging - perhaps 70 degrees north. If you don't see field rotation there, you can leave the polar alignment where it is. With any amount of polar mis-alignment, the direction of Dec corrections will change at some point in the sky. (Technically, it will reverse directions at two points in the sky but one of those is usually below the horizon.) The sky location for the reversal depends on how you are mis-aligned on the pole - the relative amounts of azimuth and altitude alignment errors. If most of the polar alignment error is in altitude, the point of direction reversal should be near the celestial meridian, about the time a meridian flip is required.

To set up for uni-directional guiding, you can follow these steps:

1. Move to a field with a good guide star and run the Guiding Assistant for several minutes. Look at the guiding graph and note whether the guide star is drifting north or south. Once you see this, reset the Dec guide mode to issue corrections in the **opposite** direction. For example, if the star is drifting north, set the Guide mode to 'south.'
2. Try using the 'LowPass2' guiding algorithm for declination and start with a fairly low aggressiveness factor, say 50%. If the aggressiveness is too high, the correction may push the star to the "wrong" side of the lock position, where it will remain until the slow drift rate moves it back. It's better to issue a few small corrections rather than one larger one in order to minimize this type of over-shoot.
3. Watch the guiding graph to be sure the corrections are being issued in the right direction and the star isn't just steadily drifting off-target. Over the course of minutes or hours, you may notice the amount of drift is decreasing. This means you are slowly approaching the point of declination reversal and you should be prepared to change the Dec guide mode accordingly.
4. If you are dithering, you may want to set the dithering parameters to "RA-only" to avoid disrupting the Dec guiding.

If dithering is being done through the PHD2 server interface, uni-directional Dec guiding will be temporarily switched to 'Auto' in order to execute dithers. This may result in extended settling times but it allows the kind of dithering that is required for cameras with fixed-pattern noise. Once settling is completed, the Dec guide mode will be restored to its original setting. This only works via the server interface, dithering done using the 'Manual Guide' tool will not suspend uni-directional guiding in this way..

High-precision Mounts and Variable-delay Guiding

Mounts with very accurate absolute encoders and detailed pointing models often allow imaging without any guiding at all. But there are limitations to how long this can be done without needing some guiding corrections. The goal in this scenario is to provide a "backup" guiding mechanism that won't conflict with the inputs from encoders and pointing models and will still improve the overall result. The recommended strategy for accomplishing this is as follows:

1. Keep the frequency of guide commands as low as possible. These mounts can actually be quite "busy" with corrections coming from encoders and fine-grained pointing models, none of which are visible to ASCOM applications. A slow guiding frequency will minimze the potential for creating instabilities in these functions from external guide commands.

2. Be especially carefully to avoid chasing the seeing – this is most easily done by using moderate-length or long guide camera exposures and generous min-move settings.

In previous PHD2 releases, users have been able to approximate this approach by using exposures in the 4-8 second range, coupled with a non-zero "time lapse" delay. The latter simply imposes a fixed delay between the completion of the last guide command and the start of the next guide camera exposure. The downside of this approach is that operations other than steady-state guiding – things like looping, star selection, calibrating, dithering and settling, etc. – are unnecessarily slowed by the time-lapse value. The "variable delay" feature eliminates this problem by letting the user specify two different delay values:

1. A "short" delay that will be used for any activity other than steady-state guiding. This might be zero but at least for some mounts, it should be non-zero to allow time for the encoders to finish their corrections. Values above 1 second are probably unnecessary.

2. A "long" delay that will be used for the normal frame-frame guiding that is typical of steady-state, long-exposure imaging. This is the value, in addition to the camera exposure time, that controls the "cadence" of the guiding.

To give an example, you might use camera exposures of 4 seconds, a "short" delay of 1 second, and a "long" delay of 4 seconds. The 4-second exposure time will provide good suppression of seeing-related effects and the sum of (4+4) seconds results in a steady 8-second guiding cadence for most of the imaging session. At the same time, the dither settling times will benefit from the short (4+1) second delays between camera exposures.

Differential Flexure

Any telescope/camera combination is going to flex and sag in various ways as it tracks an object in the sky – that's just a consequence of gravity and physics. In fact, each individual component is going to exhibit its own unique behavior in this regard depending on its mass and how it's attached to its neighboring components. Especially with larger scopes and heavier cameras, the amount of flexure can be significant, keeping in mind that guiding is dealing in units of a small number of microns. Since we aren't generally familiar with dimensions this small, it's useful to remember that a human hair is roughly 50 microns thick, roughly 10x larger than most guiding corrections.

When a separate guide scope is being used in addition to the imaging scope, each unit will flex and shift independently – this is called differential flexure. If PHD2 is using the separate guide scope, it will only see and correct for the movements of the guide scope/camera, the differential movements of the imaging scope/camera are invisible. This can lead to a fairly common and frustrating problem where the guiding results are excellent but the stars taken through the main camera are elongated.

There will **always** be some amount of differential flexure in a dual-scope system, it's only a question of how large it is and whether it is large enough to degrade your images. For imaging scopes with focal lengths of 1800mm or greater, differential flexure is usually a problem unless the main-camera exposures are kept fairly short. There's no way to predict this because there are simply too many mechanical interface points that can move around – movable SCT mirrors, all the connectors between the cameras and their focusers, the focusers themselves, all the thumb-screw fasteners in the system, the mounting ring arrangement for the guide scope, etc. The typical solution is to eliminate the dual-scope setup and use an off-axis-guider (OAG) on the imaging scope. This allows PHD2 to "see" all the movements, mechanical or otherwise, that will affect the main-camera images. In the early days, OAGs were often difficult to use because their fields of view were small and usable guide stars were hard to find. With the current generation of guide cameras and their large, highly sensitive sensors, most of these problems are a thing of the past.

If you have a situation where you frequently have elongated stars but the guiding results show reasonably similar results for both Dec and RA, you should suspect differential flexure. You can usually verify this fairly easily with a simple test. Using the main camera, with guiding active, find the largest exposure time that still has acceptably round stars. Then capture a sequence of perhaps 10-20 images at that exposure time. Using an app that is capable of displaying that image set, "blink" through the images in the order they were captured. You will usually see a consistent offset of the stars in each image relative to the previous image – the stars will appear to "march" in a particular direction as you cycle through the image set. Alternatively, you can simply stack all the images without first aligning them to see the star elongation emerge.

Adaptive/Active Optics Devices

Generally speaking, amateur-grade adaptive/active optics (AO) devices can only deal with some of the problems that create imperfect guiding. AO's can usually mask or at least improve the behavior of an under-performing mount because most of the guiding adjustments are accomplished by moving a small tip-tilt optical element – not 70 pounds of telescope gear. Basically, the mount is rarely asked to do anything beyond basic sidereal tracking. Problems with backlash, stiction, and periodic error are mostly masked with AO use. In addition, because an AO is inherently an off-axis-guider, it also eliminates differential flexure problems. These are significant benefits and explain why many serious imagers use AO's.

What an AO can't eliminate is guide star movement due to seeing, at least not under normal conditions. Guide star movement due to upper atmosphere seeing occurs at frequencies of at least 100s/sec and it isn't usually practical to find guide stars that can be measured that rapidly. If you attempt to run the AO at such high rates you will have two problems: 1) Any available guide stars will probably have low SNR values, and the calculation of their positions will degrade proportionately; and 2) you will under-sample the seeing deflections. The latter situation results in "aliasing", resulting in guide commands that are invariably incorrect and likely to make things even worse. For these reasons, AO users are still advised to use exposure times of no less than 0.5 second to avoid chasing the seeing. The goal with AO guiding is really to make the mount "look" better than it really is in terms of tracking accuracy and responsiveness. If your imaging isn't limited by mount performance, an AO is not likely to provide much benefit.

AO guiding usually involves guide commands being directed, at times, to both the AO and the mount. The commands are sent only to the AO so long as the guide corrections don't exceed the physical limits of the tip-tilt element. As this limit is approached, "bump" guide commands are sent to the mount to help restore the primary guide star to a more central position of the tip-tilt element. This can happen to correct for polar alignment drift, large guiding excursions arising from external problems (e.g. cable snags) or for large dithers. An explanation of how these guide commands are "blended" is provided in the Advanced Settings/AO Parameters section of the manual. AO Parameters

Logging and Debug Output

PHD2 automatically creates two types of log files: a debug log and a guiding log. Both are very useful for different reasons. The guide log is intentionally formatted to allow easy interpretation by either a human reader or an external application. For example, the PHDLogView application (not part of the PHD2 release) can produce a variety of graphs and summary statistics based on data in the PHD2 guide log. But the log can also be easily imported into Excel or other applications for analysis and graphing. When importing into Excel, just specify a comma as a column separator. The debug log has a complete record of everything that was done in the *PHD2* session, so it is very helpful in isolating any problems you have. It also employs a human-friendly (albeit verbose) text format, so it's not difficult to examine the debug log to see what happened. If you need to report a problem with the software, you will almost certainly be asked to provide both log files. If you have neither log file available, you are unlikely to get any help. Note that log files are always created when PHD2 is run, regardless of what was done (or not done) during the time that PHD2 was running so you **will** have log files to support a request for help.

The location for the files is controlled by the 'Log File Location' field in the 'Global' tab of the 'Advanced Settings' dialog. By default, log files are stored in the OS-specific default directory for user documents. In Windows, for example, the files will be stored in a '*PHD2*' sub-folder in the "Documents" directory. This may not be a convenient location, so you can specify a different folder using this edit field. In order to prevent excessive accumulation of log files, PHD2 automatically removes debug logs that are more than 30 days old and guide logs that are more than 60 days old. If you want to retain the files for longer periods, you should move or copy them to a different folder location, one not used by PHD2.

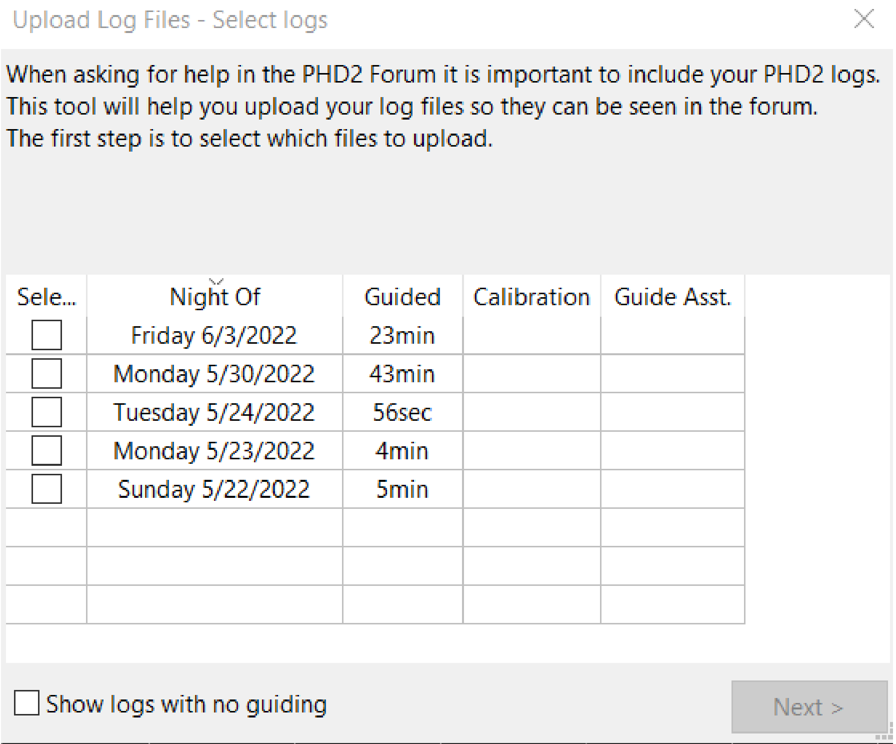
To simplify the automatic log upload process (see below), log data is grouped by "imaging day", defined to be a 24-hour period beginning at 09:00

am local time. This means that all the PHD2 executions on the same imaging day will write guiding and debug log data into the two log files for that imaging day.

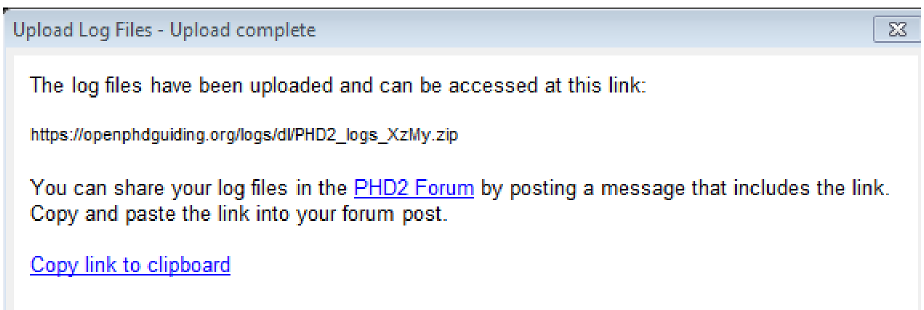
In some unusual cases, you may need to capture guide camera images, usually to support debugging and problem resolution. This can be done by using the 'Enable diagnostic image logging' controls on the 'Global' tab of Advanced Settings. The resultant image files will be stored in the same location as the other log files and will be written in the 'Fits' format for maximum fidelity. If you want to capture a single guide camera frame, you can simply use the File/Save Image... menu item.

Automatic Log File Upload

If you need help using PHD2 or improving your guiding results, you can post a request on the Open-PHD-Guiding forum (https://groups.google.com/forum/#!forum/open-phd-guiding). Your question should be accompanied by the PHD log files associated with the guiding session you're talking about. The debug log files are usually very large so you can't post them as attachments - you should use the Upload tool described below. Please do not edit, trim, or rename the log files. To make uploading easier, PHD2 has a built-in function to select, compress, and automatically upload the relevant log files. That function is located on the 'Help' menu. You'll see a dialog box that shows all the available log files, including their timestamps and duration:



Just select the files you want and start the upload process by clicking on 'Next'. Please be careful to look at the 'Night Of' column to be sure the log covers the time period you're interested in. PHD2 creates guide and debug log files every time it's run, so some of the log files will be nearly empty - don't upload those. Be selective about the files you choose - just the files for the session you were having trouble with. When the upload process is complete, you'll see another window that gives you a link to the files:



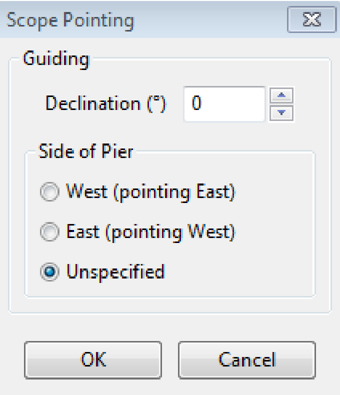
You need to capture or record that link so it can be included with the question you'll post on the forum. Log files will be automatically removed on the server after a reasonable amount of time has elapsed, so you won't need to worry about that. When you post your request for support, please include a full description of what you were doing, whatever problem you saw, and roughly what time period you want us to focus on.

Managing Equipment Profiles

Equipment profiles were introduced in the section on Basic Use where they are used as part of the 'Connect Equipment' dialog. If you want to manage multiple profiles, you should use the 'Manage Profiles' button in the 'Connect Equipment' dialog. Using the menu items there, you can create a new profile or edit/rename/delete an existing one. The most important option and the one you are most likely to use is to launch the New-Profile-Wizard, described in the Basic Use section of the manual. This is the function that will configure the PHD2 settings that are specific to your equipment configuration. Each profile holds all the settings that were active at the time the profile was last used except for the dark and bad-pixel map files. To edit the settings in an existing profile, you first select it in the equipment profile drop-down list, then click on 'Settings' under the 'Manage Profiles' pull-down. This will take you to the Advanced Settings dialog, where you can make whatever changes you want. Remember that profiles are automatically updated anytime settings are changed during a *PHD2* session. Finally, you can import and export profiles for purposes of debugging, backup, or exchange between computers.

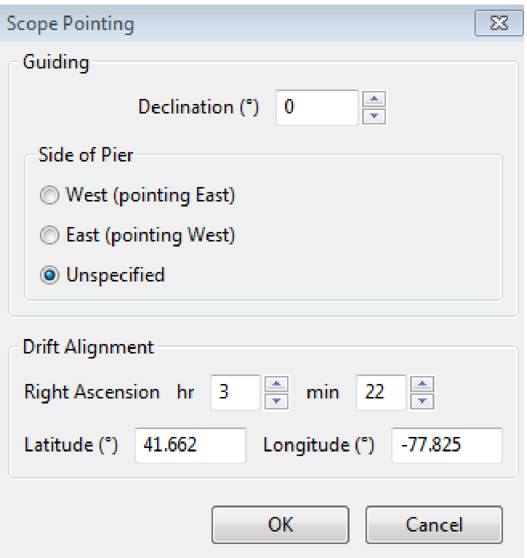
Aux-Mount Connection using "Ask for coordinates"

If you can't connect to your mount using either ASCOM or INDI drivers, you still have a better-than-nothing alternative by using the "Ask for coordinates" aux-mount connection. With this option, you'll be asked to enter or confirm the scope position each time guiding is going to begin::



If you enter your scope's current declination and east/west pointing position, PHD2 will automatically adjust the calibration to match that sky location. You don't need to be precise, a Declination value that's within a few degrees will work. This means you won't need to recalibrate as you slew to different targets so long as you update these values each time. For example, you can do a calibration near Declination=0 then enter new position values when you've slewed to a high declination imaging target. This is likely to produce a better result than trying to calibrate at a near-pole position. This dialog will not be displayed if the start of guiding is the result of a dither operation or a server command from an imaging application. In order for the calibration adjustment to work correctly, your previous calibration **must** have been completed with correct positioning data available.

If you're using this option with the Drift Alignment tool, the dialog will look a bit different:

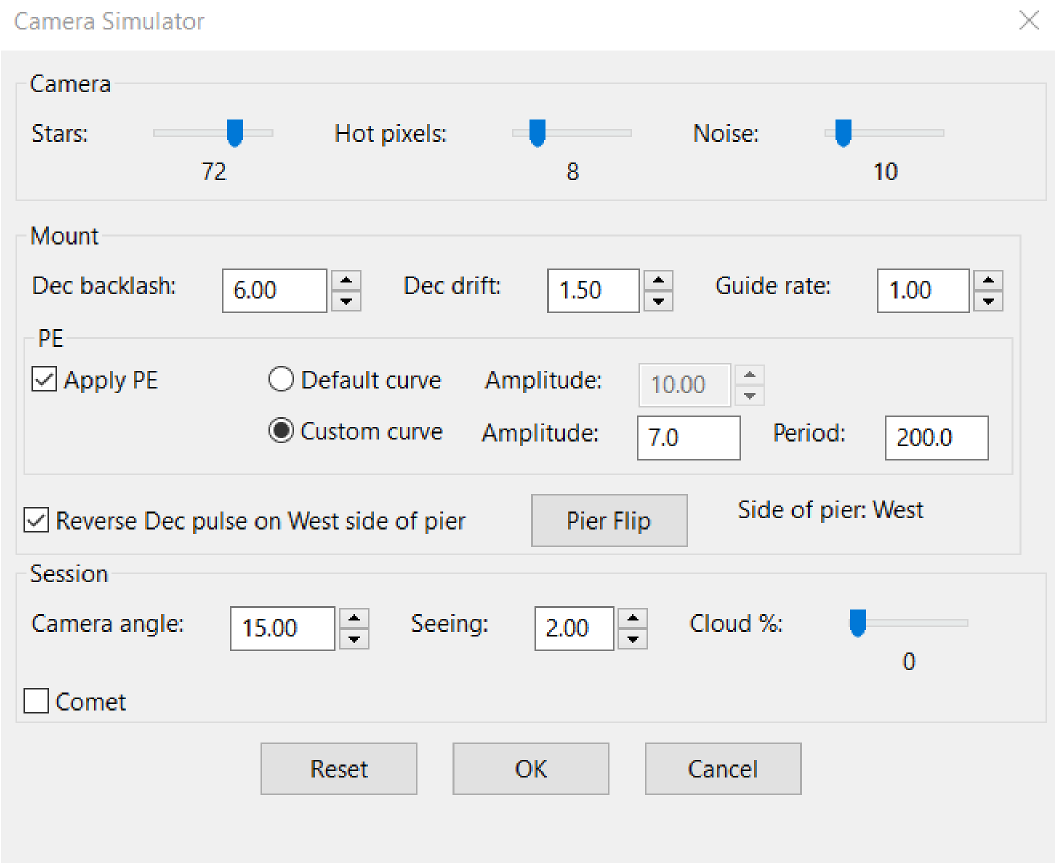


If you enter the additional information for Right Ascension, latitude, and longitude, the Drift Alignment tool can more accurately adjust its magenta target circle. Otherwise, the circle will show only an upper-bound estimate of the pointing error during the 'adjustment' phases.

You can connect or disconnect the "Ask for coordinates" aux-mount without affecting the camera or mount connections. So you might decide to use the option for drift alignment or for an initial slew to your imaging target, then disconnect from it in order to avoid the repetitive dialog displays. Regardless of how you choose to use it, you're responsible for having the correct values in place, and you should remember that significantly wrong values can result in poor guiding results.

Advanced Settings for the Simulators

The device simulators were introduced in the Basic Use section as useful tools for experimenting with *PHD2* and becoming familiar with its features. Remember that you must choose 'Simulator' as the camera type and 'On-camera' as the mount type in order to do useful simulation. As you become more interested in the details of the simulation, you can use the 'Camera Settings' button on the main display to adjust the simulation parameters:



You can adjust simulated mount behaviors for declination backlash, drift due to polar mis-alignment, and periodic error. You can also adjust the 'seeing' level, which will create fairly realistic guide star deflections that look like seeing effects. If you adjust these parameters one-by-one, you'll see how they affect star deflections and how the different guide algorithms react to those movements. Of course, you're dealing with a "nearly perfect" mount in these scenarios (except for backlash), so the simulation can't be entirely realistic. The simulation dialog is primarily used for development purposes so UI controls may change without corresponding changes to tool tips or documentation.

Multiple Program Executions

In some situations, you may want to run multiple instances of PHD2 at the same time. To start the second instance of PHD2, you need to supply a command-line parameter of -i 2; the third instance would be started with -i 3, etc. You can accomplish this in Windows by running PHD2 from a command line using the Windows cmd.exe utility. Or you can create a Windows desktop shortcut by doing the following:

Right-click on your desktop
Select: New/Shortcut
Enter the following string to identify the location of the program: "C:\Program File (x86)\PHDBuiding2\PHD2.exe" -i2
Click Next
Enter a name for the shortcut, e.g. PHD2 #2
Click Finish

Note the quotes around the name in the 3rd line are required by Windows because there are blanks embedded in the directory name.

Keyboard Shortcuts

Keyboard shortcuts are available for many of the more commonly used tools and functions in PHD2. These are enumerated in the Keyboard Shortcuts section.

Software Update

One of the most common responses to a request for support in the PHD2 Forum is: please upgrade to the latest version and see if the problem still exists. If you are seeing an issue in an older version of PHD2 it is quite likely that you are not the first person to encounter it, and it has already been discovered and fixed in a newer version of PHD2. For this reason, the developers of PHD2 feel that it is important to be running the most up-to-date version of the program.

Updating a program that you rely on for unattended imaging can sometimes be perceived as a risky proposition. The developers of PHD2 recognize this sentiment--we are imagers too! There is a necessary trade-off between maintaining a stable software installation and staying current with the latest bug fixes and other improvements. In some cases, camera vendors will issue "breaking" changes to their software drivers and SDKs, often because they have introduced a new camera model. This poses a problem for us because we are forced to update the camera SDK in order to support the new camera. But this also means that current users may encounter problems with a camera and drivers that have been working well, something that can only be corrected by upgrading to the latest camera drivers and the latest version of PHD2.

PHD2 achieves a balance between these two opposing needs by publishing two series of software releases. The development releases contain the latest ongoing bug fixes and feature improvements and are tested by the developers--usually during actual imaging time--before being released. Users who choose to run the development releases will get the latest bug fixes and newest features. Development releases have names like "2.6.3dev6" indicating, for example, the 6th development release after the 2.6.3 major release.

Periodically, after a development release has received more test time, it will be published as a major release. For example, 2.6.3dev6 could be published as major release 2.6.4.

Checking for updates

PHD2 has an option to automatically check for software updates. We recommend enabling this option to help keep your version of PHD2 up to date. When the automatic check option is enabled, PHD2 will check for updates in the background when PHD2 starts. If new updates are available, PHD2 will give you the option to install the new version. Enabling the automatic check for updates will not interfere with the ordinary operation of PHD2, including automated operation. It is also safe to leave the option enabled if you are imaging in the field without internet connectivity. If PHD2 cannot check for updates, it will wait until the next time it is started before trying to check again.

Regardless of whether you allow PHD2 to automatically check for updates at startup, you can always manually check for updates by clicking "Check for updates" from the Help menu.

PHD2 Drift Alignment Tool

The drift align tool in PHD2 can be used to quickly obtain a precise polar alignment of your equatorial mount. The process takes a little bit of practice, but after doing it a few times, you should be able to obtain an accurate polar alignment in minutes. You can use either a separate guide scope or the main scope for doing the alignment, whichever is more convenient.

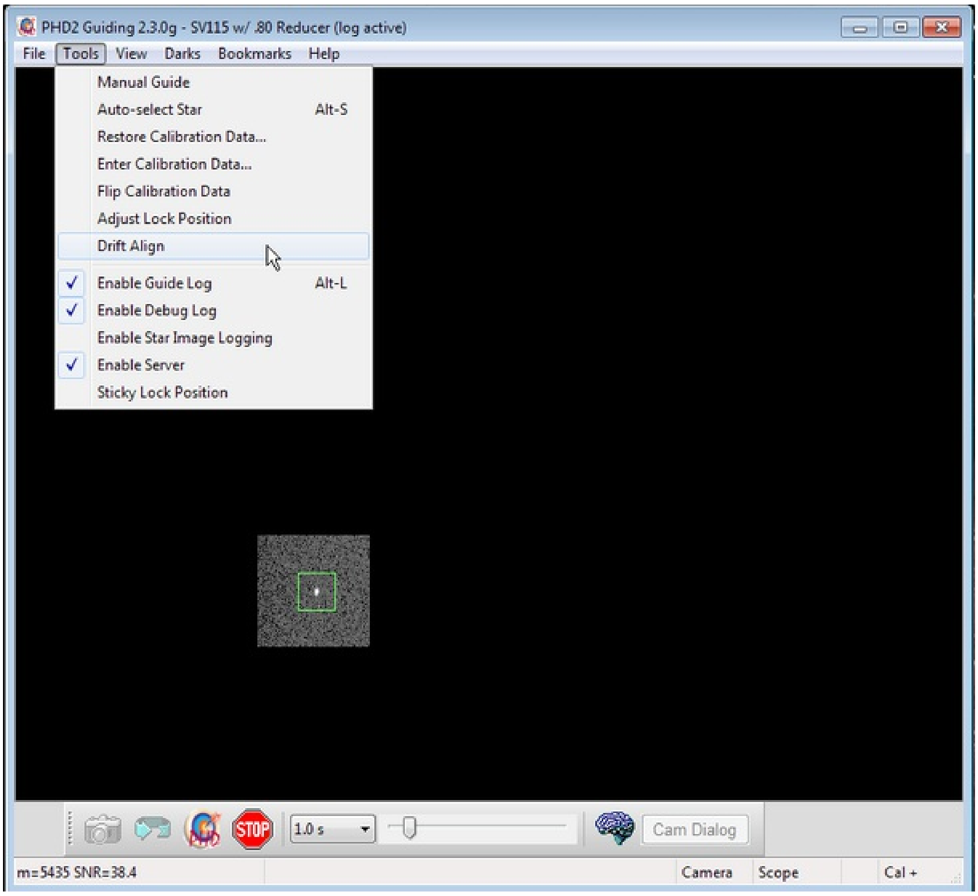
Preparation

- Make sure your mount is reasonably level.
- Make sure your scope is balanced and ready for guiding.
- Try to get your mount's polar axis roughly aligned by using your mount's polar alignment scope if it has one. Otherwise, make sure the mount's polar axis is pointing towards the pole, and the altitude setting corresponds to your local latitude.
- Make sure you can see your computer screen when you are standing at the mount.
- Start PHD2 and connect your equipment.
- You should be using an up-to-date version of PHD2..
- These instructions assume you have an ASCOM connection to your mount so PHD2 knows where your scope is pointing. You can still drift align without an ASCOM connection, see Note about ASCOM.
- Calibrate on any convenient guide star, preferably at a declination within 20 degrees of Dec=0, or reload an accurate calibration if you have an ASCOM or Indi mount connection. Be sure the calibration is correct for the side-of-pier where you plan to do the alignment. If you're using an 'on-camera' guiding interface, do a fresh calibration from the side-of-pier where you plan to do the alignment. If the calibration is not correct for the current side-of-pier, the direction of drift will change and any direction-related notes you made previously won't be correct.
- Make sure your PHD2 settings have the correct values for your guide scope focal length and your guide camera pixel size. (Brain => Global tab for focal length, Camera tab for pixel size)

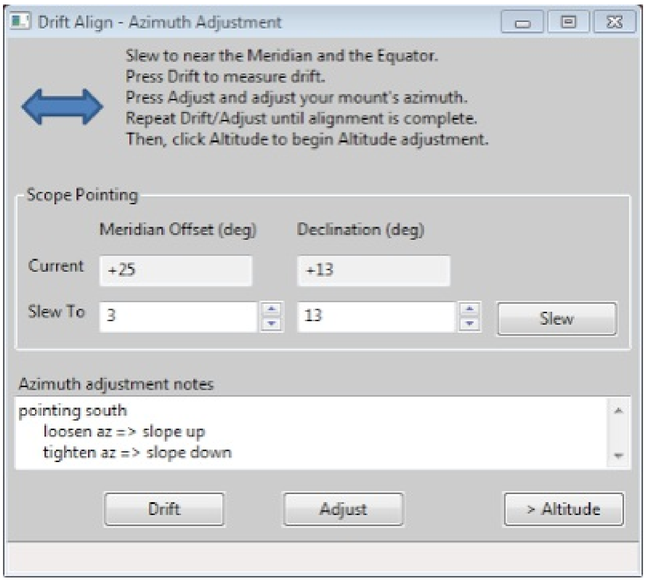
Now you are ready for drift aligning.

Azimuth Alignment

Open the Drift Align Tool:

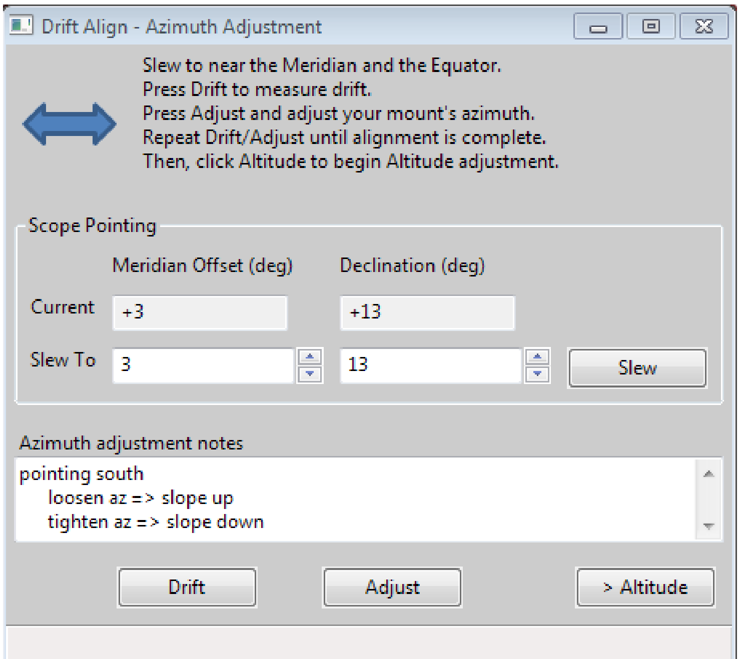


You will see a window like this:



Position your scope for the Azimuth axis adjustment. Point near the Meridian and the celestial equator. You can either click the 'Slew' button, or move the mount manually. Your scope should now be pointing something like this:

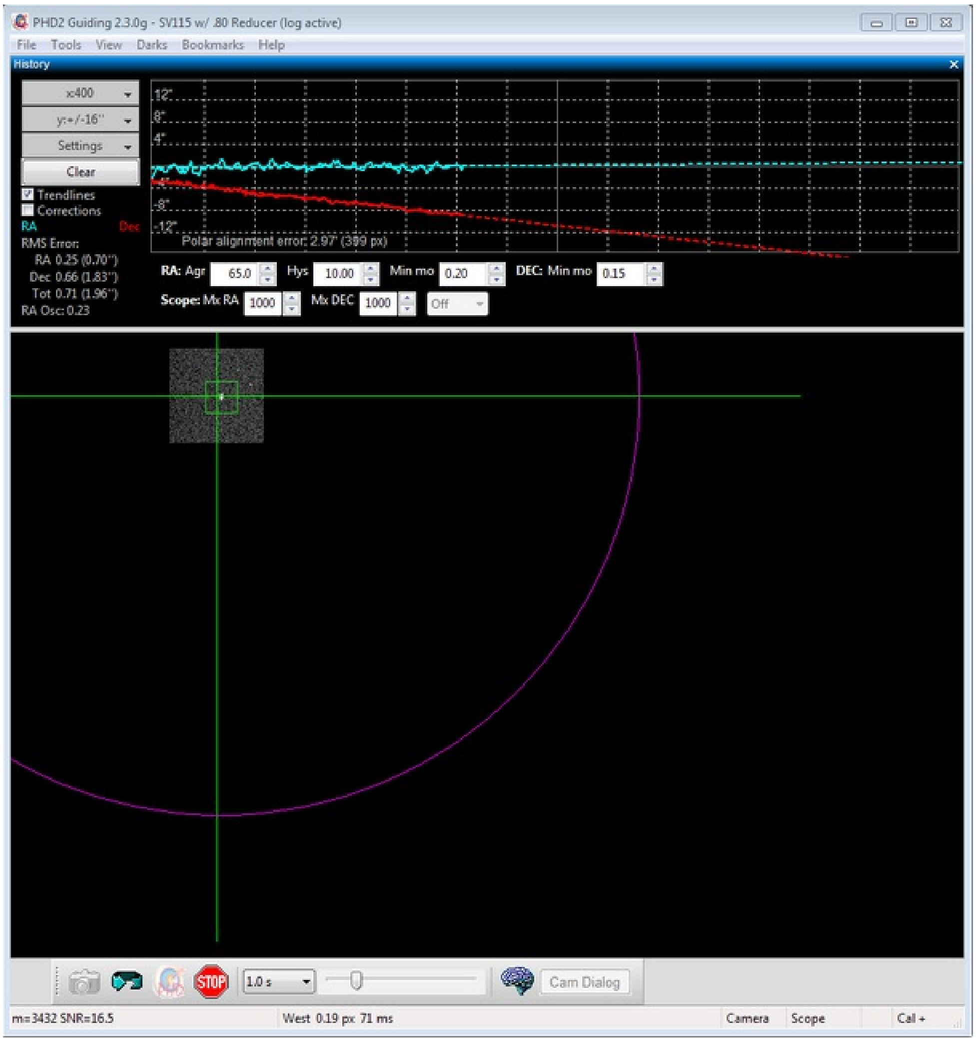
And the Drift Align window will look like this:



Notice we are only a few degrees off the meridian ("Meridian offset"), and close to the equator (small value of Declination.)

You are going to alternate between measuring the error ('Drift'), and adjusting the mount ('Adjust'). The rate of declination drift tells us the amount of alignment error. Each adjustment will reduce the error, and you repeat the process as many times as you need to get the error close to zero.

Click 'Drift' to start measuring the declination drift. PHD2 will select a guide star and start guiding. After a few moments you should see something like this:

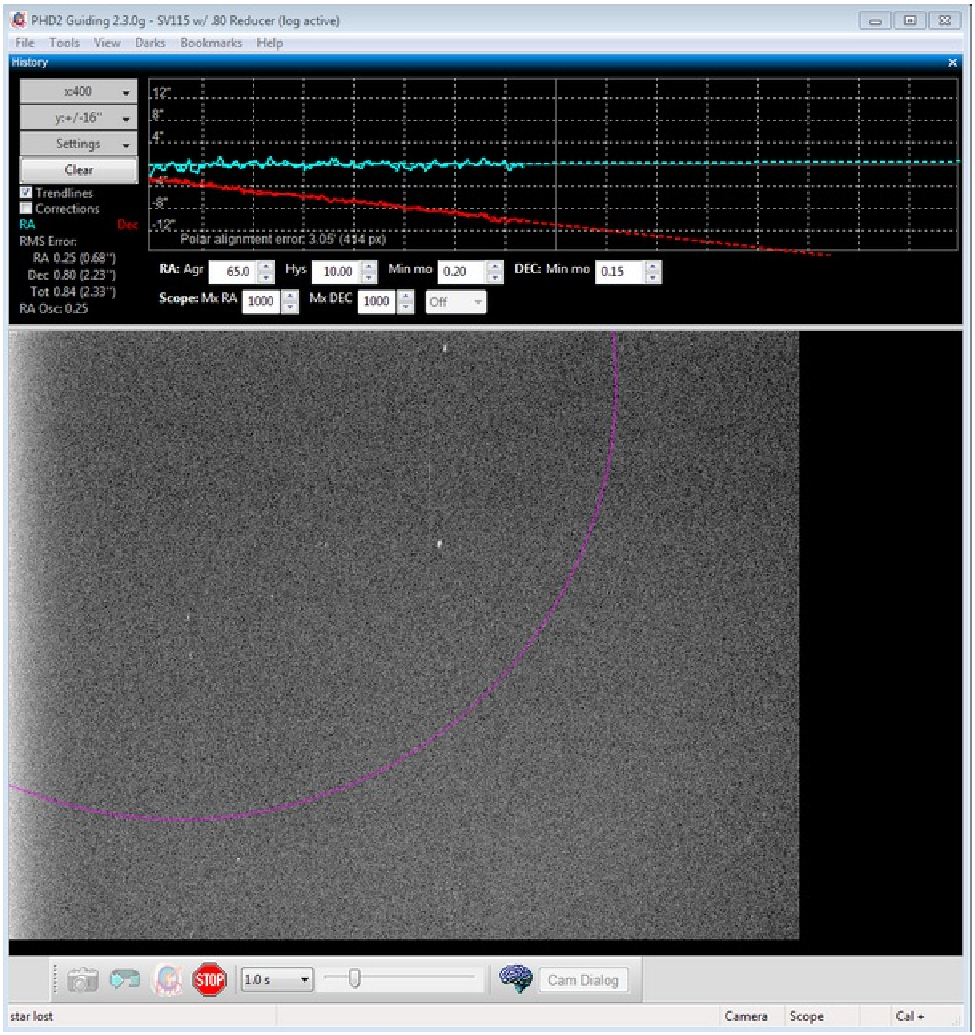


Pay particular attention to the Declination trend line (Red). At first the Dec trend line will be jumping up and down, but soon the noise should "average out" and the slope of the line will become somewhat stable. When that happens you are ready to adjust the mount's Azimuth.

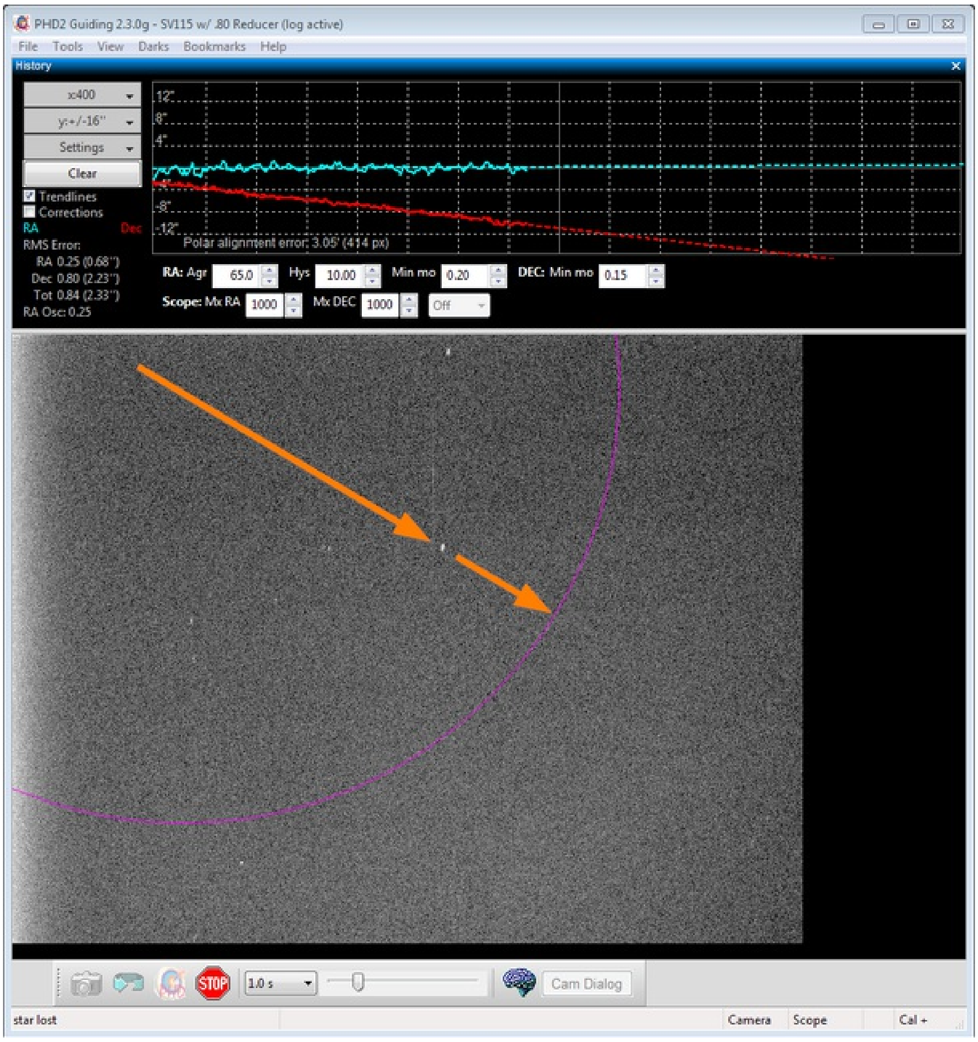
Our goal is to make the Dec trend line "flat" -- neither trending up nor down over time. By adjusting the mount's azimuth, you will change the slope of the Dec trend line.

If this is your first time adjusting Azimuth, you will not know which way to go--East or West? PHD2 does not know either, so you just have to guess, and you have a 50-50 chance of getting it right. If you choose correctly, the new drift line will be flatter (less steep, closer to horizontal) If you choose incorrectly, the drift rate will increase (more steeply downward in the example above.)

Click the 'Adjust' button. PHD2 will stop guiding, and you can make your adjustment. You'll see something like this:



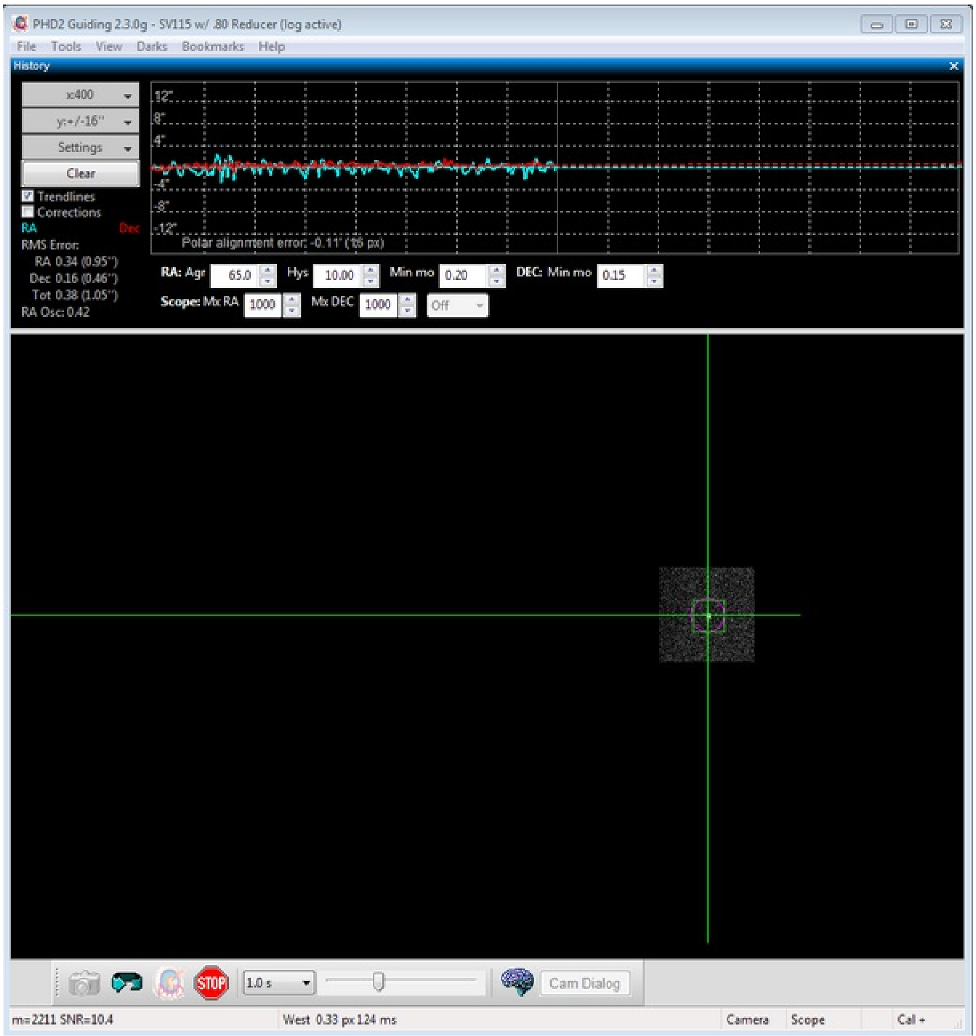
Slowly turn your mount's Azimuth adjustment, watching the screen and moving the guide star towards the magenta circle. The magenta circle shows how far the guide star needs to move. The magenta circle is larger when the Dec slope is steeper, and it may initially be so large that it is not visible on the screen. That's to be expected; if it is not visible, just move the guide star approximately the width of the screen. If you do see the magenta circle, you should move the guide star to the circle, like this:



After moving the guide star, click 'Drift' to make another measurement. Before you click 'Drift', it's OK to nudge the mount to re-center the star, or to find a different star, or to get back closer to the meridian. Also, you can choose your own guide star by clicking on it, or just let PHD2 choose.

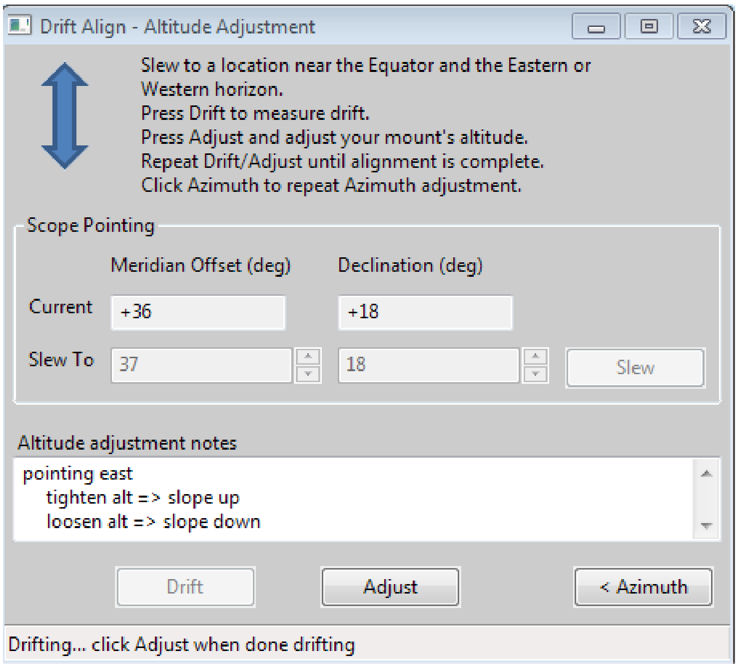
After a short time drifting, you will have another Dec trend line. Did it get better (closer to horizontal) or worse (away from horizontal)? Make a note to yourself in the "Azimuth adjustment notes" area, recording how you adjusted azimuth and which direction the Dec slope moved. You can use this information next time you drift align so you do not have to guess which way to make the azimuth adjustment. For example, with my setup, turning the azimuth knob clockwise makes the slope go down. Having the note there reminds me that I need to turn the azimuth knob counter-clockwise to make the slope go up.

Repeat the measurement and adjustment of the mount until you achieve a good flat horizontal dec trend line, like this:



Altitude Alignment

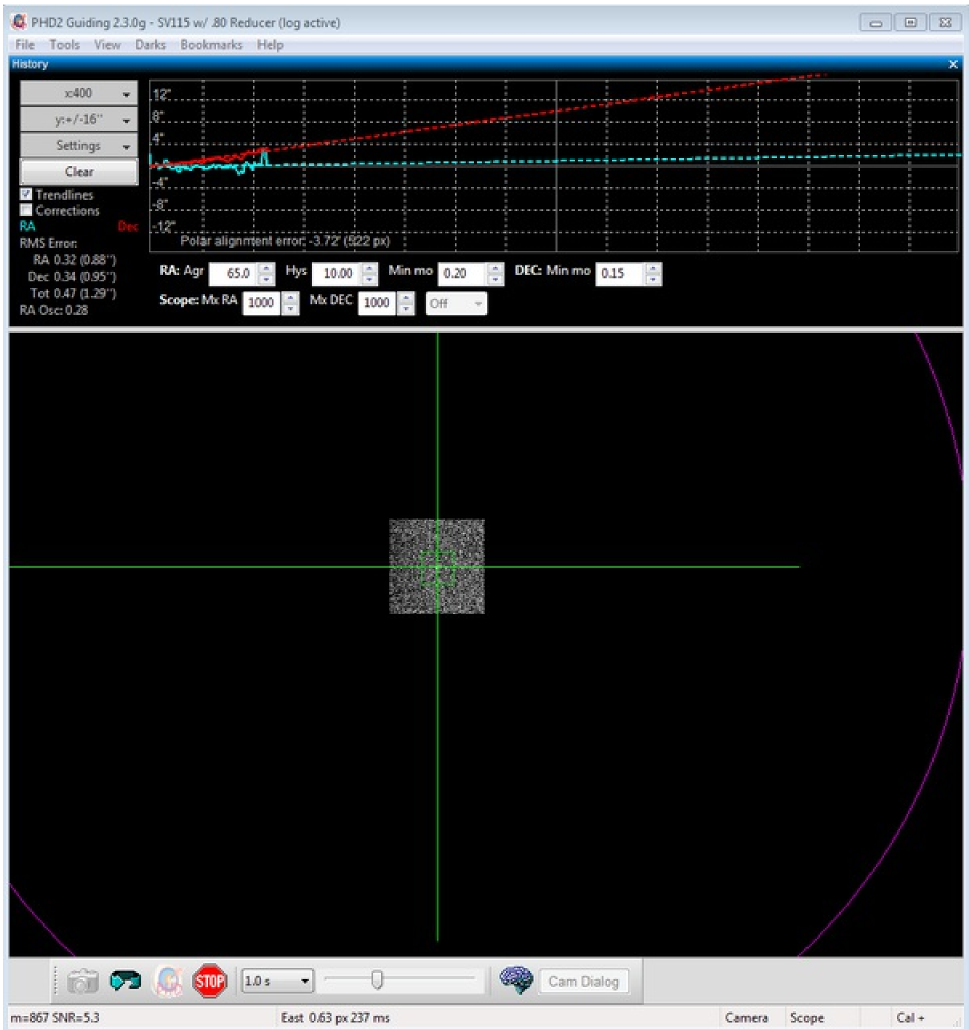
Now, you will need to repeat the process for the mount's Altitude adjustment. Click the Altitude button; the Drift tool will now look like this:



Click 'Slew' or manually slew your mount toward the horizon (east or west):

The exact position is not important, but 23-35 degrees above the horizon works well.

Click 'Drift' to start drifting.



Drift until you have a stable Dec slope. Click Adjust, then turn the mount's Altitude adjustment knob. Use your notes recorded in the "Altitude adjustment notes" area from a previous session to determine which way to turn the knob to move the slope in the desired direction. For example, with my setup I turn the altitude knob clockwise to make the slope go "down".

Just as with the Azimuth adjustment, repeat cycles of Drift and Adjust making the measurements and moving the guide star to the magenta circle. Again, the goal is to get the dec drift line to be horizontal.

Using Bookmarks

Until you are experienced with drift aligning your particular mount, the 'adjustment' part of the process can be a bit tedious. At first, you'll have to determine how to adjust a knob on the mount to achieve the desired effect: "how much" and "what direction." To help with this, the *PHD2* drift align tool supports "bookmarks". These are a handy way to record the positions of the guide star before and after you've made an adjustment. Bookmarks are accessed using the Bookmarks menu, or keyboard shortcuts, as follows:

- b : toggle/show bookmarks
- Shift-b : set a bookmark at the current guide star position (the "lock position")
- Ctrl-b : clear all bookmarks
- Ctrl-click somewhere on the image: set a bookmark at that position, or remove the bookmark that's already there

By setting a bookmark before you make a mount adjustment, you can get a clear view of how the adjustment has moved the star on the guide frame.

Notes about ASCOM

The instructions and screenshots above correspond to what you see in PHD2 with an ASCOM or INDI connection to the mount. There are a couple of differences if you do not have one of those connections.

- Scope position data and slewing functions will not be available - you'll have to slew the scope yourself. Keep in mind, the target altitude/azimuth positions are only approximate - you don't need to be particularly concerned about accuracy - just get reasonably close with a good guide star available in the field of view.
- The solid magenta circle becomes a dashed-line magenta circle. The dashed magenta circle represents a limit to how far the guide star needs to move, not the exact distance. We only know that the star should not move past the circle. Rather than moving the star all the way to the circle, you may want to only move it half-way or so as an initial guess. You can use Bookmarks to keep track of where the guide star was in each Drift/Adjust iteration.

PHD2 Static Polar Alignment (SPA) Tool

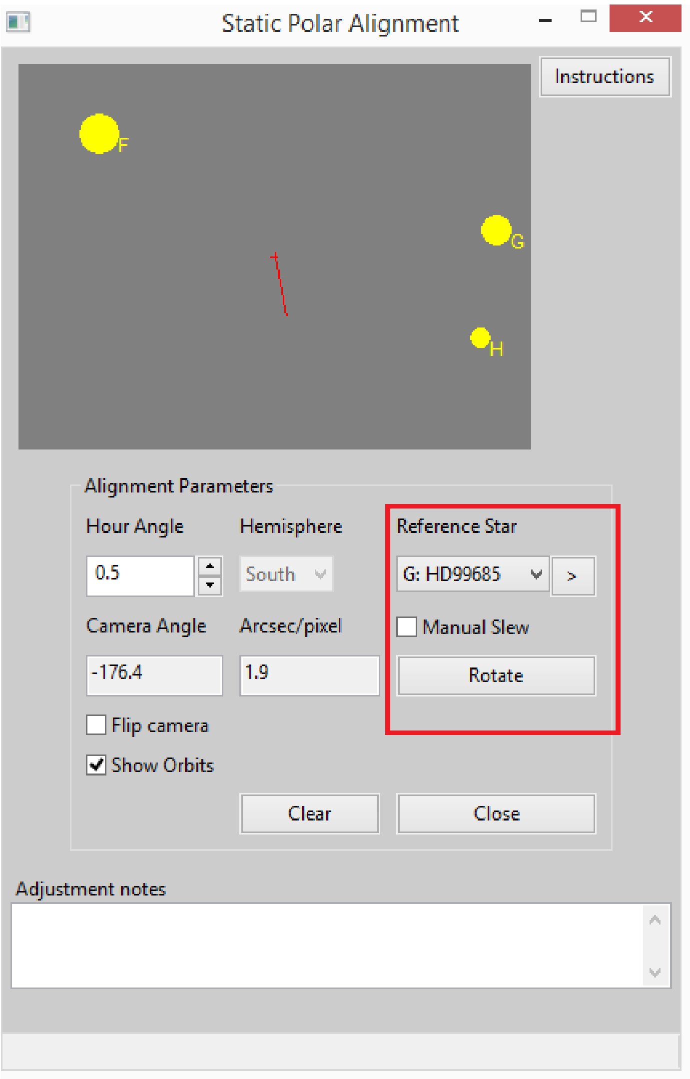
The Static Polar Alignment tool provides two modes of operation. Automated mode requires a mount that can slew under computer control and report its position. Otherwise manual mode is available for ST-4 type guiding ('On camera', GPUSB, etc) or for mounts that are manually controlled. The SPA tool selects the most appropriate mode according to your mount's capabilities.

Automated Mode

In the automated mode, PHD2 will slew the telescope as needed to perform the alignment procedure. To do this, PHD2 must be connected to the mount through either an ASCOM or INDI interface, and the mount must be initialized and ready to perform go-to (slewing) operations. To get started, perform the following steps:

- Connect PHD2 to your camera and to your ASCOM or INDI mount driver
- Be sure that PHD2 has already done calibration for this set-up
- Manually adjust the mount’s RA axis to point within 5 degrees of the apparent pole, then slew the telescope to point to Dec = +90 or -90. On a German equatorial mount, it’s best to start with the mount in the counterweight-down orientation, pointing at the pole. Use star alignment or plate solving to get as close as practical to Dec = +90 or -90 degrees.
- During the alignment process the mount will slew 10 degrees west, so make sure there is nothing to obstruct the view or interfere with the scope’s rotation.

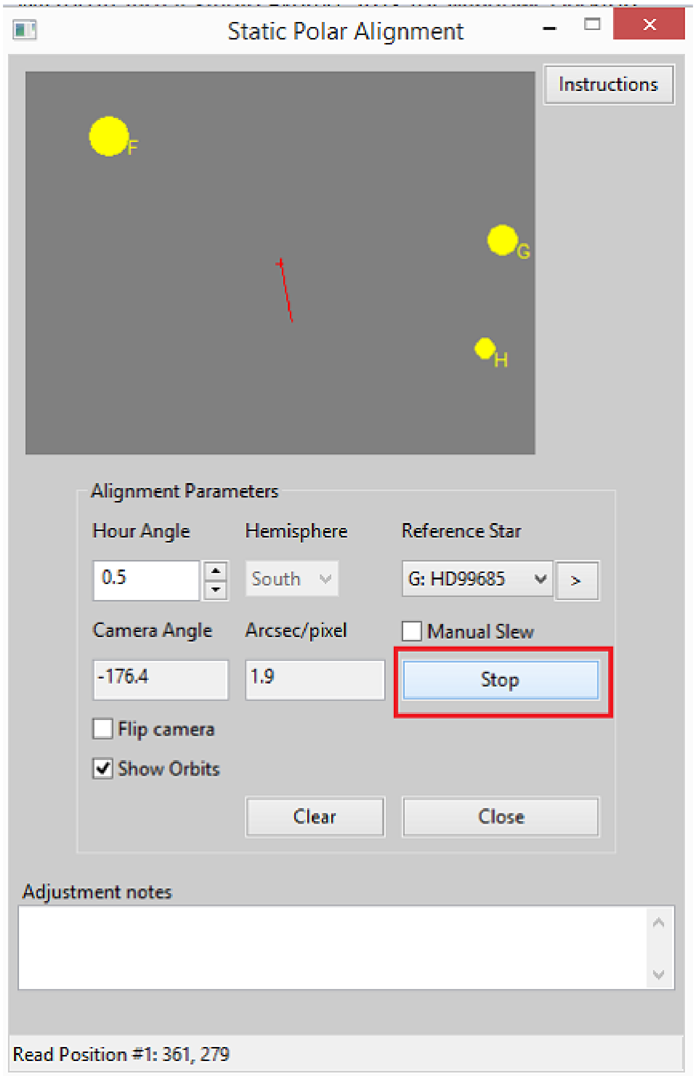
Now open the SPA tool via 'Tools'/'Static Polar Alignment', and the first window will open:

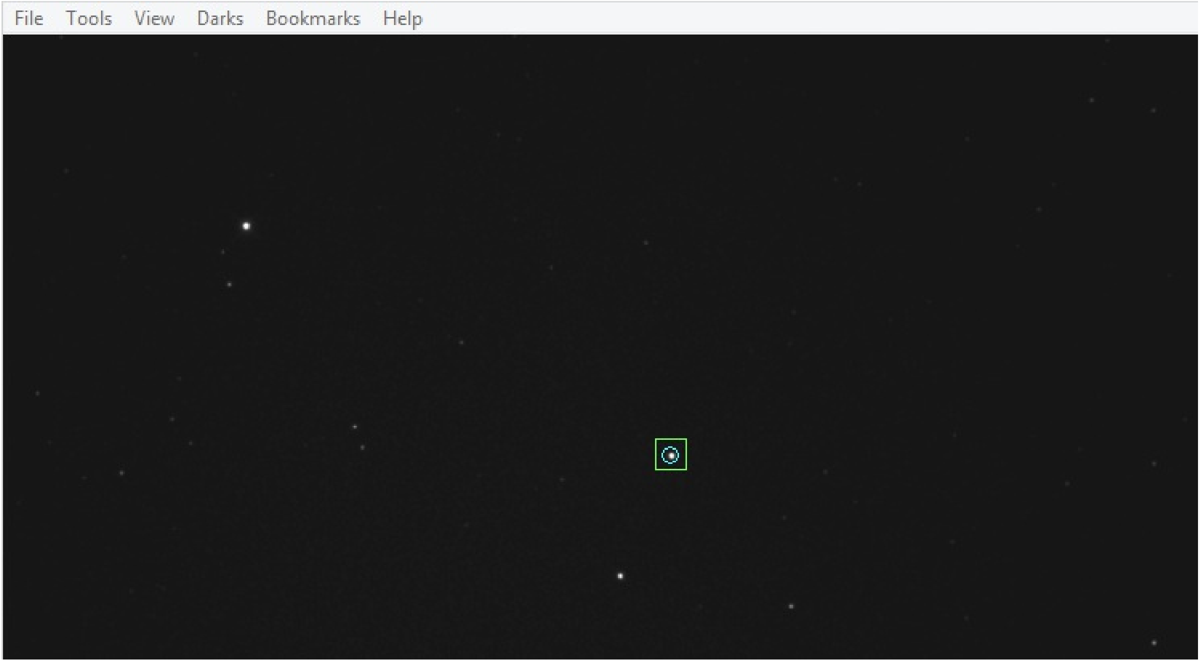


The PHD2 main display would look like this (southern pole example):

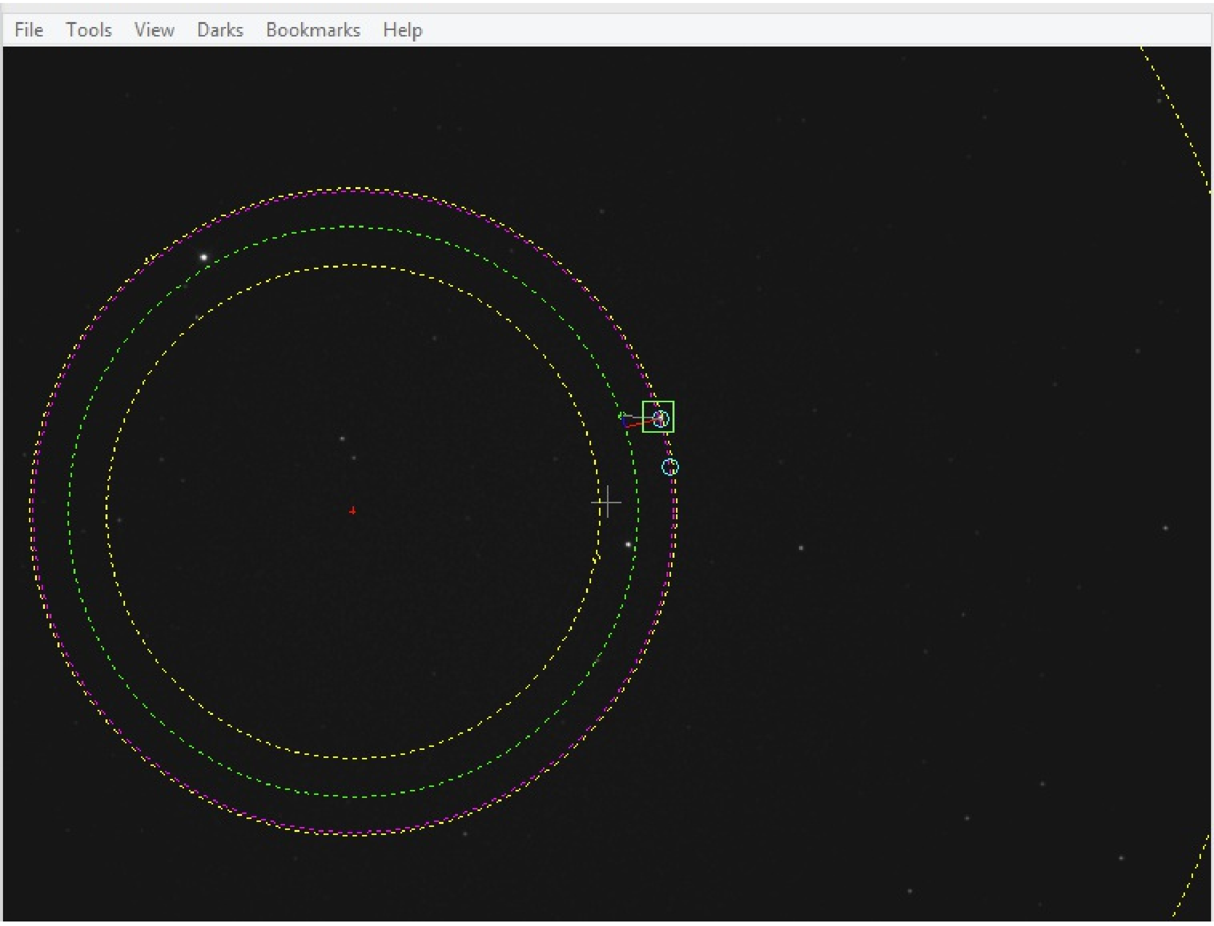
The star map at the top of the SPA window shows the approximate position of the polar stars oriented according to your PHD2 calibration and mount position. You can adjust the 'Hour Angle' control or use the 'Flip Camera' option to orient the star map to the main display. To pan the star

map you can double click the point you want at the center; or click the '>' button to center the selected reference star.
The button to the right of the star map lets you toggle between displaying the star map or instructions for using the SPA tool.
You have the option to use manual control by ticking the 'Manual Slew' checkbox. Refer to the instructions below for manual-mode alignment.
Use the star map to select a 'Reference Star' on the main PHD2 display. Identify which star you selected with the drop-down list. Don't worry if you don't get it right; it can be corrected later.
When you are ready to start aligning, click 'Rotate'. The current position is indicated with a small blue circle on the main display, and the coordinates are displayed in the status bar. Note that the 'Rotate' button has changed to a 'Stop' button. If you want to quit or stop the mount slewing, click the 'Stop' button.





After you click 'Rotate', the mount will slew west in RA in small steps as indicated in the status bar. Once two points have been recorded, the alignment graphic is overlaid on the PHD2 main display.



If you made a mistake identifying your 'Reference Star', select the correct one in the drop-down list.
Now follow the instructions under **Using the Polar Alignment Overlay** to adjust your mount's polar alignment.

Manual Mode

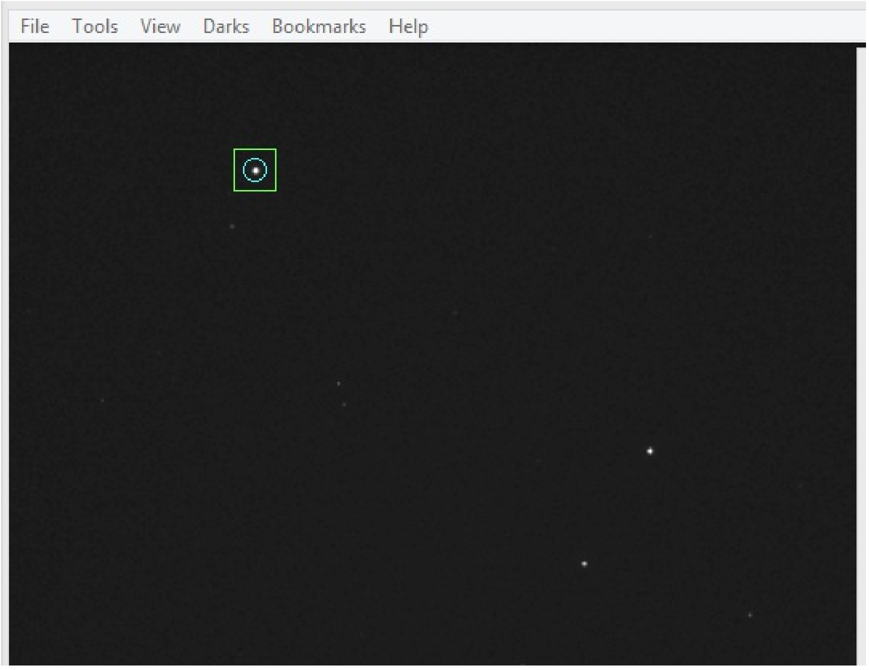
If you don't have a mount driver that supports go-to's or you want to retain manual control of scope slewing, you can use the manual mode of operation. To get started, perform the following steps:

- Connect PHD2 to your camera and to your mount's guider interface (e.g. ST-4)
- Be sure that PHD2 has already done calibration for this set-up
- Manually adjust the RA axis to point within 5 degrees of the apparent pole, then manually slew the telescope to point to Dec = +90 or -90. On a German equatorial mount, it's best to start with the mount in the counterweight-down orientation, pointing at the pole. Use star alignment or plate solving to get as close as practical to Dec = +90 or -90 degrees.
- During the alignment process you'll need to slew the mount up to 15 degrees west, so make sure there is nothing to obstruct the view or interfere with the scope's rotation.

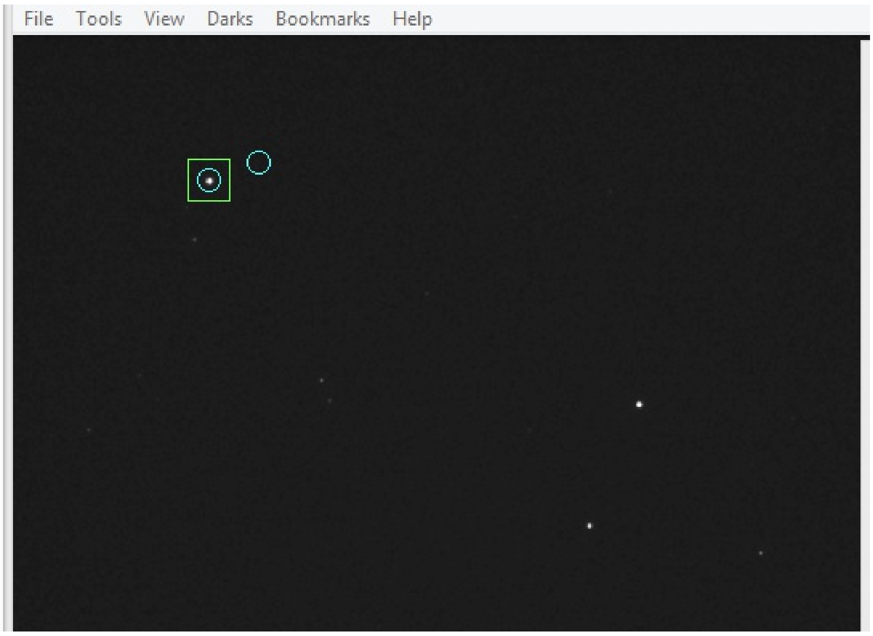
Now open the SPA tool via 'Tools'/'Static Polar Alignment', and the first window will open:

The star map at the top of the SPA window shows the approximate position of the polar stars oriented according to your PHD2 calibration and mount position. You can adjust the 'Hour Angle' control or use the 'Flip Camera' option to orient the star map to the main display. To pan the star map you can double click the point you want at the center; or click the '>' button to center the selected reference star.
The button to the right of the star map lets you toggle between displaying the star map or instructions for using the SPA tool.
You have the option to use manual control by ticking the 'Manual Slew' checkbox. Refer to the instructions below for manual-mode alignment.
Use the star map to select a 'Reference Star' on the main PHD2 display. Identify which star you selected with the drop-down list. Don't worry if you don't get it right, it can be corrected later.

When ready, click 'Get first position'. The current position is indicated with a small blue circle on the main display, and the coordinates are displayed in the status bar.



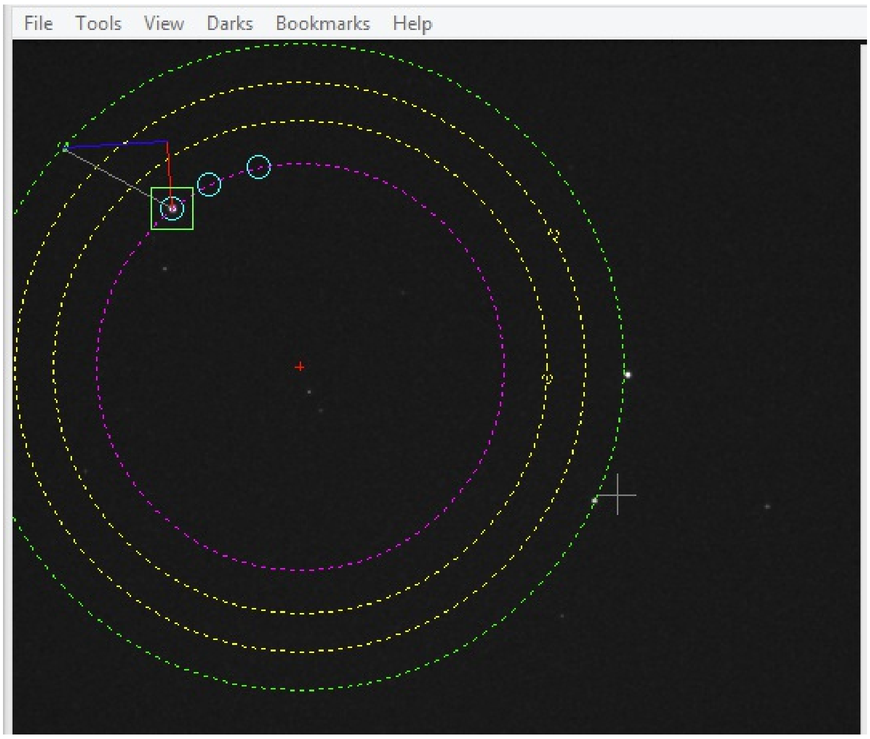
Slew the mount at least 20 minutes west in RA (RA decreases as you slew west).
Select the same reference star on the main display.
Click 'Get second position'. The position is marked with another small blue circle and the coordinates are displayed in the status bar.



Slew west another 20+ minutes in RA and select the same star again.
Click 'Get third position'.

After a few moments the alignment graphic is overlaid on the main display. If you made a mistake, select the correct 'Reference Star' in the drop down list. Similarly, if any of your alignment points are suspect, slew the mount to the bad point and click the appropriate button to replace its coordinates. If you had to slew eastwards then it's best to overshoot and make your final slew westwards to clear any backlash. Alternatively, slew westwards to a new position and replace the bad point. The points do not have to be in order.

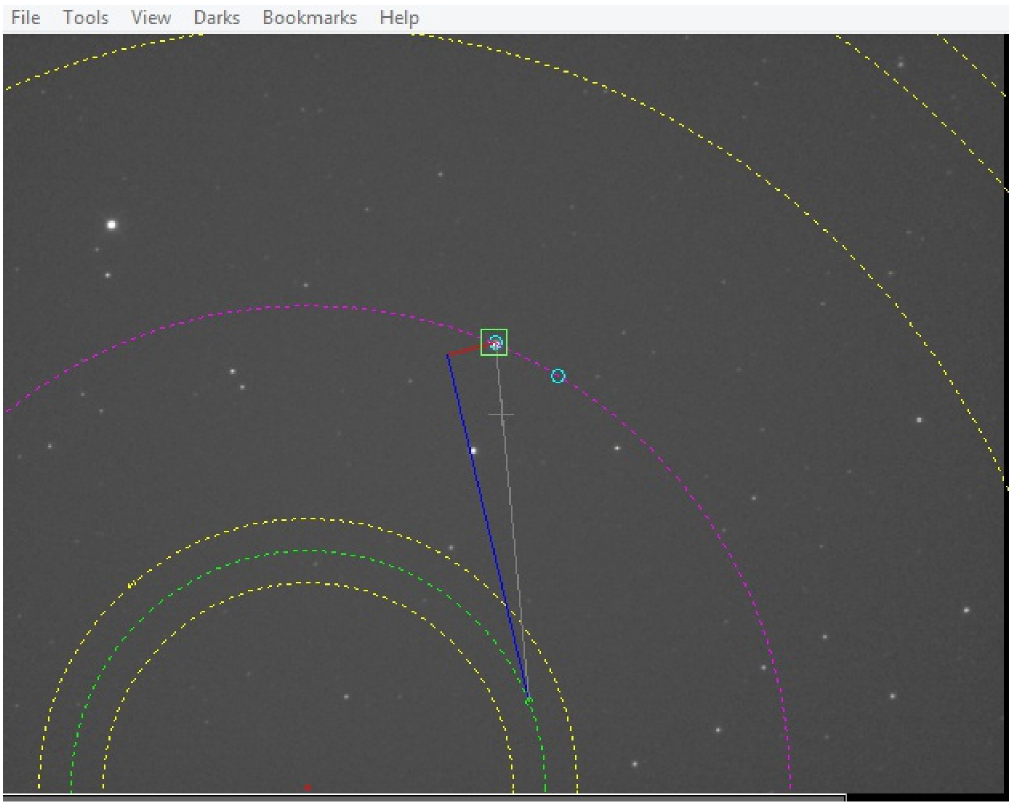
The corrected alignment graphic updates automatically.



Follow the instructions in the next section to adjust your mount's polar alignment.

Using the Polar Alignment Overlay

The polar alignment overlay is placed on the main display once enough alignment points have been collected.



- The center of the display is indicated with a grey +.
- The Center of Rotation is indicated with a red +.
- A magenta circle shows the orbit traced by your reference star.
- A green circle shows the desired orbit of your reference star when the polar alignment is accurate.
- Yellow circles show the orbits of the other reference stars.

Within each of the green and yellow orbits, a small circle indicates where the star should be located. A grey line connects your reference star to its target circle on the green orbit. These positions are dependent on the guide star being correctly identified.
A blue line shows the azimuth correction needed to move the reference star and a red line shows the altitude correction required.

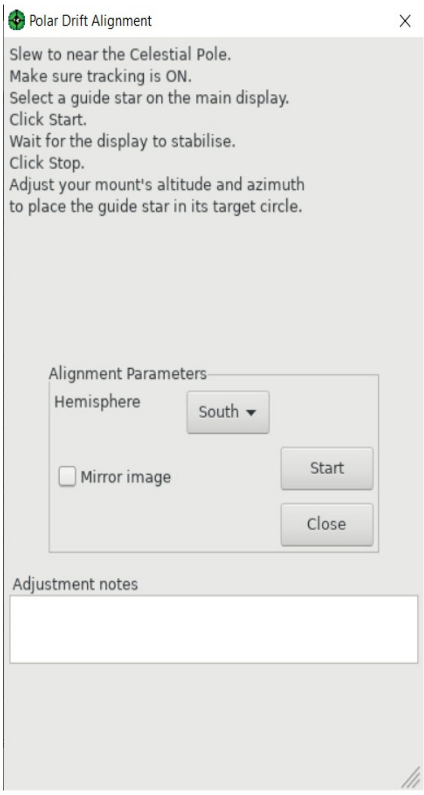
To make the adjustment lines easier to see, the orbits can be shown or hidden with the ‘Show Orbits’ option.
Adjust your altitude and azimuth knobs to move your reference star to its target circle. Adjusting in altitude moves the reference star along the red line. Adjusting in azimuth moves the reference star along the blue line. As an alternative, you can position three reference stars on their respective orbits. This is important when using manual mode.
To get the most accurate alignment, adjust the ‘Hour Angle’ till the stars on the main display are all offset by the same amount and direction from their target circles. Then make your adjustments.
To confirm, you can redo the process. You may need to adjust your declination to keep the polar region centered if you had to make large adjustments. You may also want to return the mount to the start position if you have limited visibility. When finished, click ‘Close’. If you made large adjustments you may want to re-calibrate.

PHD2 Polar Drift Alignment Tool

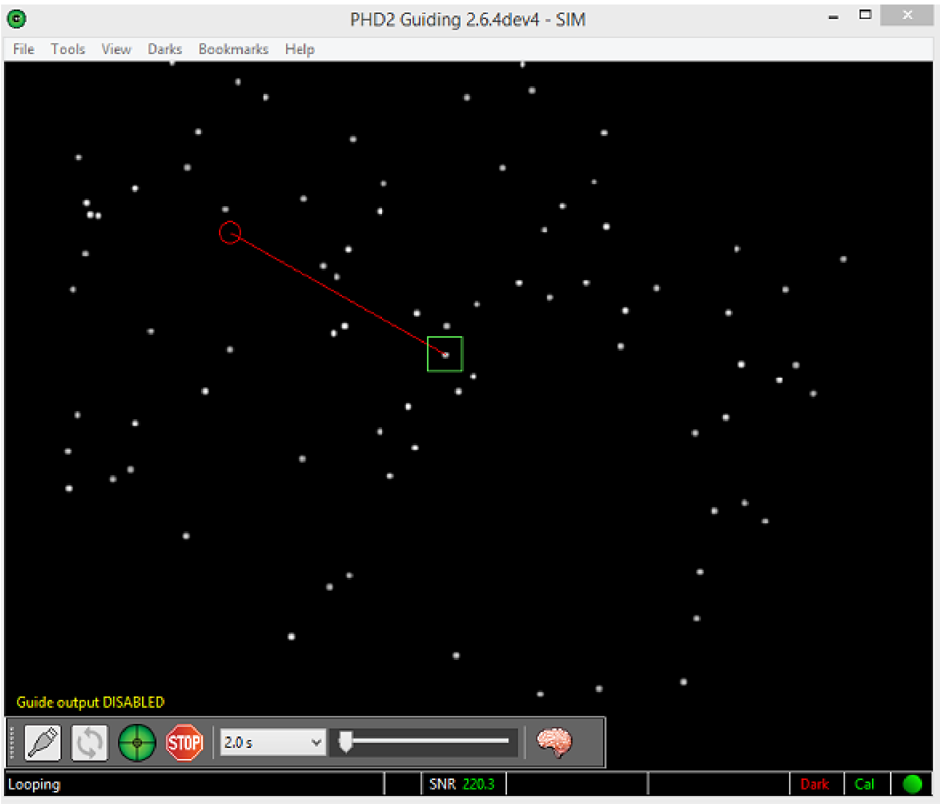
The Polar Drift Alignment tool operates on a similar principle to the original Drift Alignment tool. The difference is that the drift is measured near the celestial pole to calculate the adjustments needed in both Azimuth and Altitude at the same time. However, it becomes less accurate as the distance of the drift star from the pole increases. Also, it may take some time for the adjustment to settle so Static Polar Alignment can be faster.
The main advantages of Polar Drift Alignment are that any star can be chosen, the tool only needs to know which hemisphere you're in and it does not need PHD2 to be calibrated first.
To get started, perform the following steps:

- Connect PHD2 to your camera
- Manually adjust the mount’s RA axis to point within 5 degrees of the apparent pole, then slew the telescope to point to Dec = +90 or -90. On a German equatorial mount, it’s best to start with the mount in the counterweight-down orientation, pointing at the pole.
- Check that your hemisphere is correctly identified and adjust if necessary
- If your camera image is mirrored e.g guide camera on an OAG, tick Mirror image
- Select a suitable guide star on the main display

Click the ‘Start’ button to start the drift.



You will soon see a red line appear on the main display. This shows the adjustment needed on the guide star to minimise the drift. At first it will move around a lot until it settles onto a stable adjustment.
When it has settled, click the ‘Stop’ button. The adjustment will remain on the main display.
Adjust the altitude and azimuth knobs to move the guide star into the red circle at the end of the red line.


PHD2 Guiding 2.6.4dev4 - SIM
File Tools View Darks Bookmarks Help
Guide output DISABLED
STOP
2.0 s
Looping
SNR 220.3
Dark
Cal