

# **PHD2 v2.5.0dev7**

## **User Guide**

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# 1. Introduction

*PHD2* is the second generation of Craig Stark's original *PHD* application. *PHD* has become 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:

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

In order to extend *PHD* to more platforms and further expand its capabilities, Craig released his program to the open-source community, and *PHD2* is the direct result of that generosity. It has been substantially restructured to make it more extensible and supportable going forward. Moreover, the initial release of *PHD2* already includes a substantial number of new features and refinements while retaining all the core strengths of the original. Users of the new *PHD2* can be confident it will remain committed to the three objectives that made the original application so successful.

## 2. 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 your guide camera and mount
2. Start a sequence of guide exposures to see what stars are available in the field of view
3. Choose a guide star and calibrate the guider
4. Continue guiding on the target star 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 star field from your guide camera. The display is automatically adjusted for size, brightness, and contrast so you can have a clear view of 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 is also used to select a guide star by simply clicking on it.

## 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:

1. The USB connector icon - used to connect to your camera and mount devices
2. The Loop icon - used to start a sequence of repeated exposures with the guide camera ("looping"), with each resultant image (guide frame) being displayed in the main window. If guiding is subsequently started, clicking on the 'loop' icon again will pause guiding while continuing to take guide exposures.
3. The PHD2/Guide icon - used to start calibration, if needed, and then to start guiding on the selected star.
4. The Stop icon - used to stop both guiding and looping

To the right of the stop icon is a pull-down list of exposure durations (0.01s - 15s). You use this control to quickly 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 desired exposure time, *PHD2* will automatically acquire images for one second and stack them on the fly to create a composite image for guiding.

The next control to the right is a slider for adjusting screen stretch and contrast, essentially a "gamma" adjustment. *PHD2* automatically adjusts the display accounting for the darkest and brightest pixels in the image, and the slider is used to fine-tune the display to better see the stars in the field of view. 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.

Next to the gamma slider is the "brain button." This button brings up an [Advanced Dialog](#) for making detailed adjustments to *PHD2*'s guiding operations. An important design goal of the program is to minimize your need to change these parameters, but "the brain" is nothing to be feared - there are adjustments available here that can significantly improve your guiding results and make your life easier. Over a period of time, you should take a look at this dialog and learn what it can do for you.

The rightmost control in this row is a "camera properties" button. This may be disabled (grayed out) depending on the type of guide camera you have selected. If it is enabled, you can click on it to set various parameters that are unique to that type of camera - binning and specialized gain settings are examples of such parameters, but there could be others depending on 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 [Visualization](#) 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. For example, the rightmost three panels on the status bar will show you whether the camera and mount are connected and whether the guider has been successfully calibrated.

## 3. Using *PHD2* Guiding

There are five basic steps to start guiding.

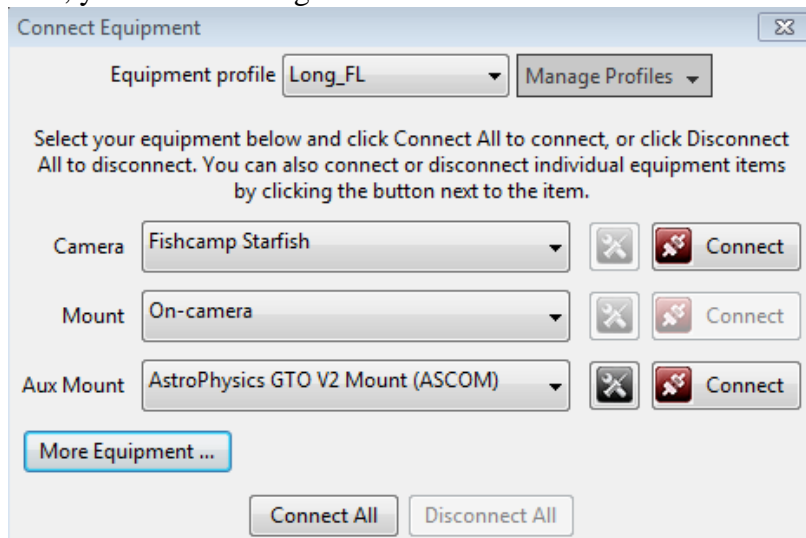
1. Press the USB-icon button and connect to your guide camera and mount.
2. Pick an exposure duration from the drop-down list.
3. Hit the loop button and look at the available stars, adjusting focus if necessary. Move the mount or adjust the exposure duration as needed to find a suitable guide star.
4. Click on a non-saturated star that's not very near an edge for use as the guide star.
5. Press the *PHD2* Guide button.

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

- [Equipment Connection](#)
- [Exposure Time and Star Selection](#)
- [Automatic 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, or a rotator. When you click on the camera icon, you'll see a dialog that looks like this:



## Camera Selection

The Camera drop-down list shows all the camera types currently supported by *PHD2*. With the exception of ASCOM-compatible cameras, the camera drivers are bundled with *PHD2* and will reside on your system after the *PHD2* installation. ASCOM-compatible camera drivers are available from the ASCOM web site or from the camera manufacturer, and the drop-down list will show only those ASCOM cameras that are already installed on your system, if any.

The list of supported cameras at the time of writing is shown below - but you can contact the [open-phd-guiding forum](#) to inquire about your specific camera or mount.

Supported cameras, December 2014:

Windows:

- ASCOM v5/6 compliant cameras
- 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
- 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
- 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

## 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. At the time of this writing (October 2015), the only imaging application that does this is Sequence Guider 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.

## 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 telescope driver that sends guide commands to the mount over a serial cable (or more commonly, a USB/Serial connection)
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. 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 mount, especially the declination and side-of-pier, which can be used as factors in guider calibration.

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:

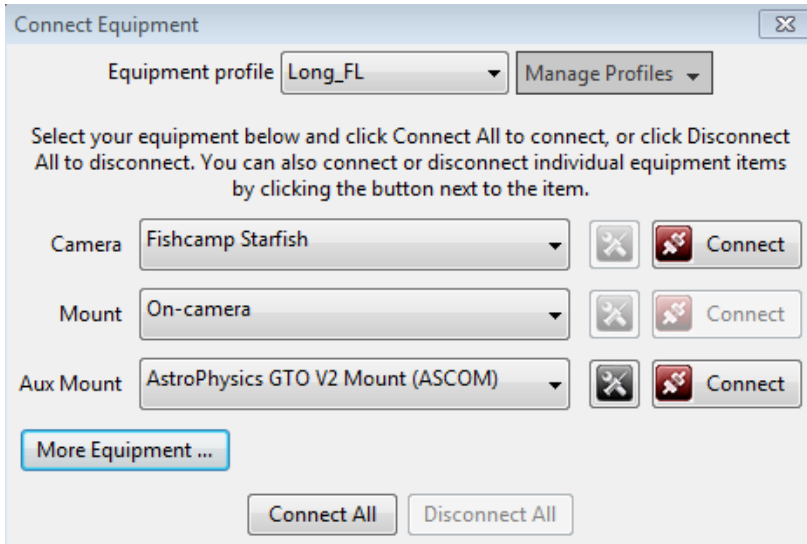
1. Any of the guide cameras which have an ST-4 compatible "on-camera" guider interface. Use the 'on camera' mount choice for these setups.
2. Any of the Shoestring GP-xxx devices
3. A supported AO device with a guide port interface

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 have selected an ST-4 style of guiding in the 'mount' section, that interface cannot be used to query the pointing position of the telescope. As a consequence, guider calibration won't be automatically adjusted for declination, nor will it be automatically flipped when the side-of-pier

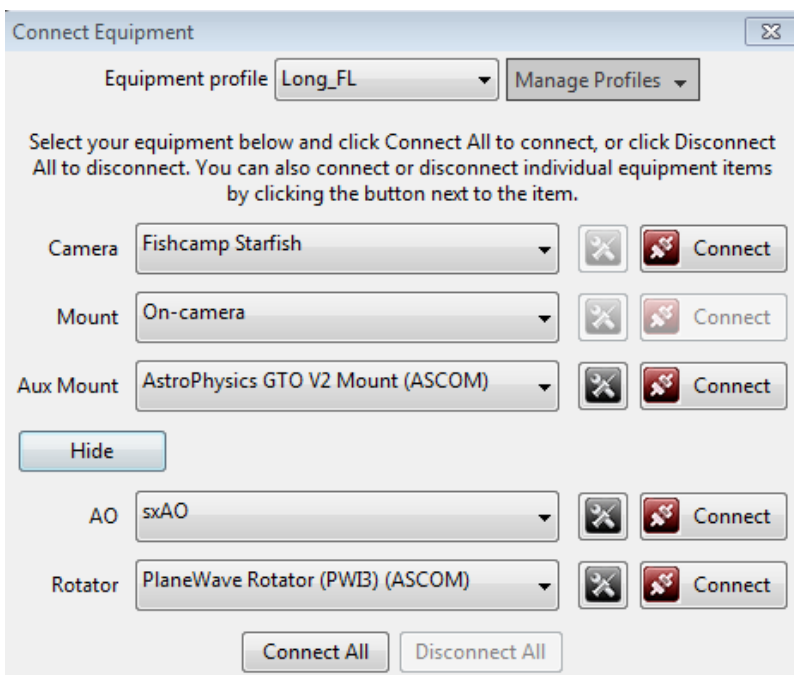
changes. You can restore these features by specifying an "aux" mount connection that will be used only to get the telescope pointing information. An example is shown below:



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.

### Adaptive Optics and Rotator Selections

With *PHD2*, you now have the option of controlling the Starlight Xpress adaptive optics unit and/or any of several ASCOM-compatible camera rotators. 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. PHD2 does not control a rotator, but it will read the current angle setting from the rotator and adjust the guiding calibration if needed.

## Simulators

All of the *PHD2* devices - camera, mount, AO - include built-in simulators. You can use these simulators to explore how *PHD2* works and to decide how you want to use the program. There's no reason to waste valuable dark-sky time learning to use *PHD2*! Virtually all of *PHD2*'s features, including full calibration and all the graphical display options, will work properly when device simulators are used. You will even see fairly realistic guiding performance to give you some idea of what to expect in the field. To get started using the simulators, choose 'Simulator' for the camera type and 'On-camera' for the Mount type.

That said, the simulators are **not** useful for trouble-shooting any problems you encounter with your real mount. 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.

## Equipment Profile

At the top of the 'Connect Equipment' dialog are some additional controls for managing equipment profiles. All of the guider settings in *PHD2*, default or otherwise, are automatically stored as part of an equipment profile. If you have only one guiding setup - you use the same camera and guide scope combination each time - you will only need one profile; and you can just use the default 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 are likely to be different, so you would want to 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.

The recommended way to create a new profile is to use the "Wizard" capability. The wizard takes you through a sequence of dialogs that explain the various settings and help you decide how to set them. It will also calculate a recommended set of guiding algorithm settings that are likely to get reasonable results right away. 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'. 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.

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 'Camera' button and *PHD2* will automatically re-connect to your hardware.

## Exposure Time and Star Selection

The guide star can be selected (clicked on) while "looping" is active - in fact, this is the recommended method. It can also be selected after looping has been stopped, but this opens the possibility that the star might have moved since the last exposure. No great precision is required in clicking on the star - *PHD2* will find the star nearest to the cursor. After you do this, a green box will appear to frame the star. If you pick a star that is too bright, a message box will tell you the star is saturated, and you should either use a different star or decrease the exposure duration. 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 benefit from 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 4-6 seconds, the effects of seeing are smoothed out. The camera is essentially averaging out the larger, high-frequency seeing movements, so the guide algorithms have less difficulty distinguishing "seeing jitter" from actual guide star displacements that need to be corrected.

As a starting point, try using exposure durations in the range of one to five seconds. Rather than choosing the star yourself with a mouse-click, you can let *PHD2* [Auto-select](#) the guide star by using the Alt-S keyboard shortcut after stars are visible in the main display.

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 constant signal-to-noise ratio (SNR) value. 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 can be especially beneficial for AO users who want to minimize exposure time without losing the guide star. The settings to control Auto-exposure are on the [Global Tab](#) of the Advanced Dialog.

## Automatic Calibration

### Conventional Mounts

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

1. The angle of the camera relative to the telescope axes
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 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* 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.

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 angle. 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. Starting with the 2.5 release, *PHD2* takes a more aggressive approach to clearing this backlash, watching for a clear pattern of movement in a single direction with no reversals. Even so, these pulses may still not clear all the declination backlash in your mount, particularly if you are guiding at a long focal length. In that case, the computed declination rate may be too low, a situation that is discussed further in the [Tools and Utilities](#) section. 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.

In most cases, calibration will complete automatically without any user involvement. Obviously, this assumes that the mount and all the cable connections are working correctly. If they are not, the calibration is likely to fail with a message that the "star did not move enough"; and you'll need to do some trouble-shooting. If the star has basically not moved at all in one or more directions, you should look first at the cable connections and mount behavior. The "manual guide" function under the 'Tools' menu can help with this as can the [trouble-shooting](#) section of this document. But if the star has moved by some amount in each direction, you may need to adjust a calibration setting called the calibration step-size. *PHD2* uses this parameter during calibration as a fixed-size duration of movement. The default value has been chosen to cover a wide range of typical guide scope set-ups, but you may need to adjust it for your situation. For example, an off-axis-guider on a long focal length scope will probably need a setting that's different from the default value. To adjust it, go into the "brain dialog" ([Advanced Settings](#)) and click on the 'Mount' tab. On that tab, you'll find a setting for 'Calibration step (ms)', and that's where you change the value. There's even a 'Calculate' button that will help you choose an optimal value for the parameter. Once you've set this value, it will be remembered as part of your equipment profile and you probably won't have to adjust it again.

You may also see a calibration failure if you're using a star too close to the celestial pole. In those locations, fixed-length movements in right ascension often move the star only a very small distance. In that case, move to a star location closer to the equator, ideally somewhere in the range of -30 to +30 degrees declination, and re-run the calibration. But if this is not feasible, you can adjust the calibration step-size upward until calibration succeeds. 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.

Like all other guide settings, the calibration data is automatically saved as part of your current equipment profile. If nothing has changed in your configuration from one session to the next - even over an extended time period - you can restore the previous calibration data and start guiding immediately. This function is located under the 'Tools/Modify Calibration' menu and is labelled 'Restore Calibration Data.' Remember, the data are saved whenever a full calibration is completed or

when you use the 'flip calibration data' command under the 'Tools/Modify Calibration' menu (see below). If you're using a German equatorial mount and the ASCOM interface or you have an 'aux' mount connected, the saved calibration data will include the side of pier where you were last guiding; so *PHD2* will adjust automatically for your current pointing position. But if you are not using mount interfaces that can return pointing information, you'll need to remember which side of the pier was being used the last time you were guiding. Clicking on 'Restore Calibration Data' will open a window that shows the results from your last calibration, essentially identical to what is shown using 'Review Calibration Data.' You can quickly check the information in this window to be sure the calibration you are restoring is sufficiently accurate and relevant to your current set-up. If it looks good, click on 'Restore' to re-use it.

If you're using an ASCOM mount (or 'aux' mount) connection, *PHD2* will also include the calibration and target declinations as part of its calculations. In that case, guiding moves in right ascension will be automatically adjusted to account for the declination of the current guide star, as opposed to the star you used for calibration. This is really just a refinement and isn't critical in most situations, so absence of pointing information is not a big problem. However, if you are concerned about it and are imaging near the celestial pole, you should consider calibrating using a star that's also at high declination. If you do a calibration at a declination > 60 degrees, *PHD2* will **not** adjust the guide rates if you move to a different location. So calibration at high declination values is really for the purpose of imaging in the same region and should not be used as a baseline calibration for general use. Finally, if you have a rotator configured as part of your equipment profile, *PHD2* will use its angle position property to adjust the calibration for changes in camera angle, thus eliminating another need to re-calibrate.

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 'alert' message at the top of the main window that describes the calibration result that looks questionable. 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 proceed using calibration results that are significantly in error.

## 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 mirror 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, select your star, 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

Obviously, you'll need to identify the source of the problem and fix it. However, it's important to understand that *PHD2* will **not** start moving the telescope around in an attempt to relocate the guide star. It will simply continue to take exposures and look for the guide star to reappear within the bounds of the current tracking rectangle. 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 are likely to 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 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 data" and then resume guiding immediately.

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 'Mount' tab, and clicking the 'Clear 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. But *PHD2* provides many tools for measuring and displaying your performance, as described in the [Visualization](#) 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, you may want to increase the values for these settings or otherwise solve the underlying problem.

## 4. 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 ("stuck") pixels or regions with spurious brightness levels. If there are too many of these defects, you may have trouble identifying and selecting a good guide star - trying to calibrate on a hot pixel is a common problem for beginners. 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:

Build Dark Library

Dark Library

Min Exposure Time: 1.5 s Max Exposure Time: 5.0 s

Frames to take for each exposure time: 5

Options

Existing dark library covers 10 exposure times in the range of 0.5 s to 5 s

Modify/extend existing dark library  Create entirely new dark library

Notes: Simulator, long f-l

Reset Start Cancel

Set your parameters, click 'Start' to begin

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

One 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, so you can see where you are in the overall process. 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.

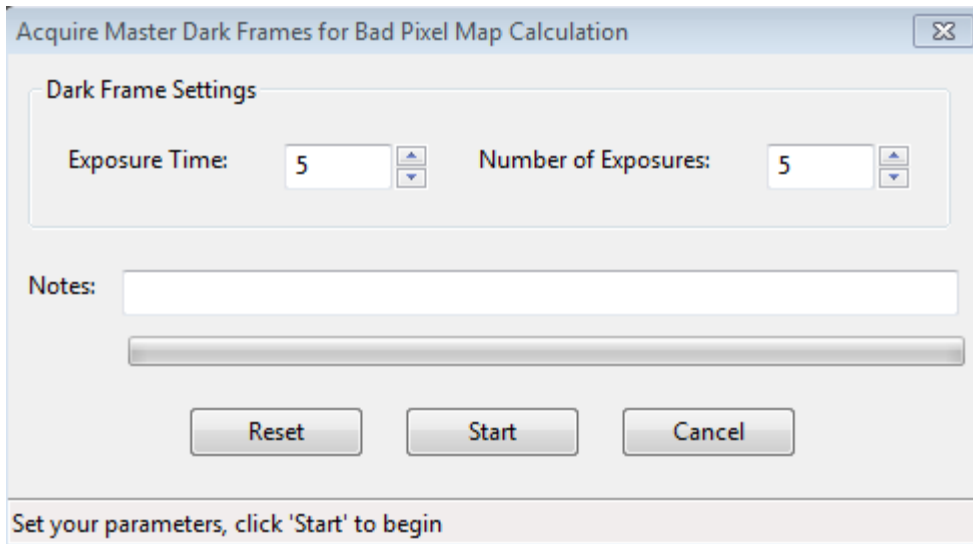
Once your dark library has been built, you control its use by the 'Use Dark Library' item under the 'Darks' menu. The checkbox on the menu item will toggle on or off each time you click on it. The setting of the item is retained across program executions, so if you choose to leave the menu item checked, 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 are encouraged to obtain 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. 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 revert to use of the old camera.

## **Bad-pixel Maps (Defect Maps)**

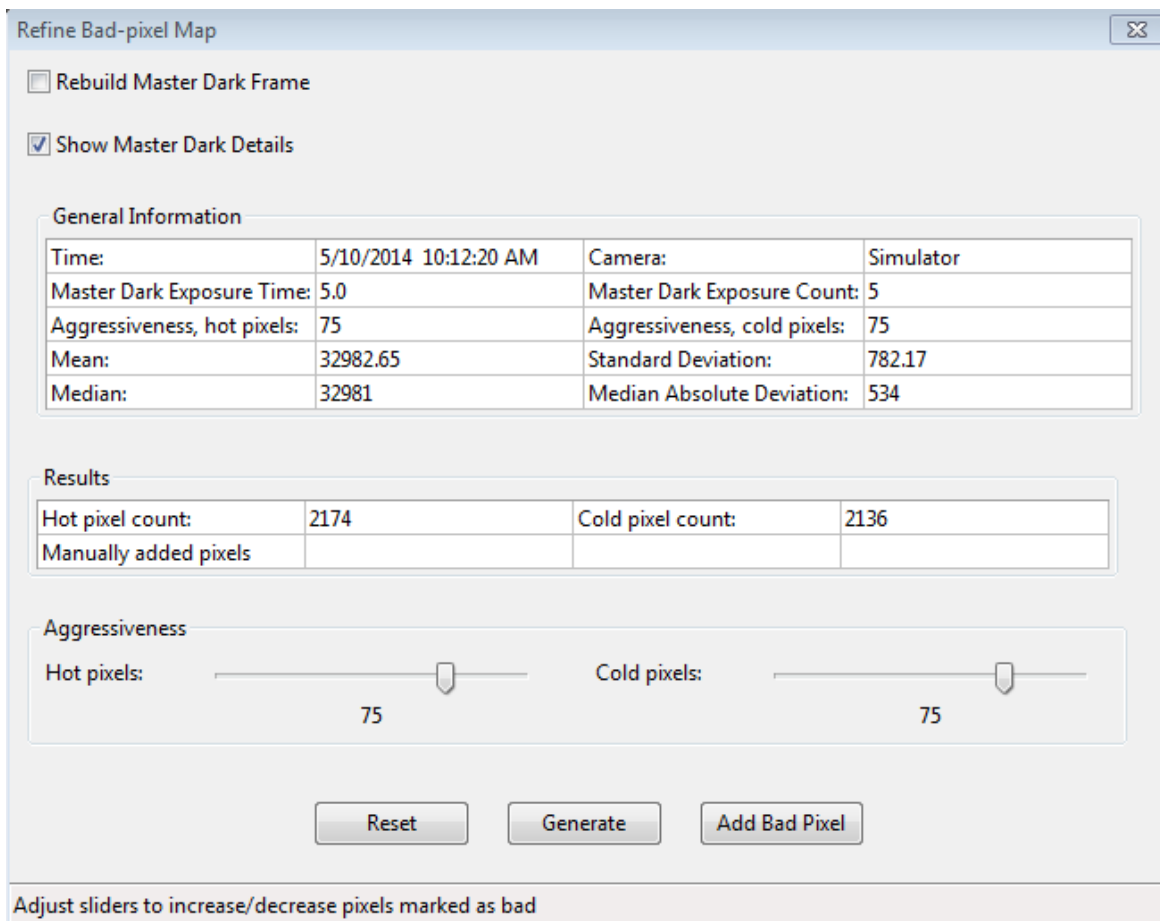
For some guide cameras, dark frames don't do an adequate job of removing the defective pixels that are visible in the guide frame. In those situations, you can probably get better results by building and using a bad-pixel map. This approach directly measures and compensates for specific areas of the 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, and 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 for you 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 that this statistical approach still leaves a few hot pixels that you'd like to eliminate. You can do this quickly and easily by manually adding the bad pixels to the map. Just use the main PHD2 window to take a guide exposure, then click on the hot pixel you want to remove. PHD2 will highlight that area with the green tracking box, at which time you can click on the 'Add Bad Pixel' button in the dialog box shown above. This automatically updates the map with the pixel location you just identified and immediately reloads the map, so you should see the result in the next guide exposure you take. You can continue with this process until you are satisfied with the results. Remember, you don't need "perfect", just "good enough."

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. 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 inside an existing equipment profile, something you shouldn't do unless you have upgraded your guide camera and have no plan to revert to use of the old camera.

## 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. Sometime later, you create a new profile, Profile2, which 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 (size and pixel size). 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.

## 5. Visualization Tools

*PHD2* provides numerous visualization 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

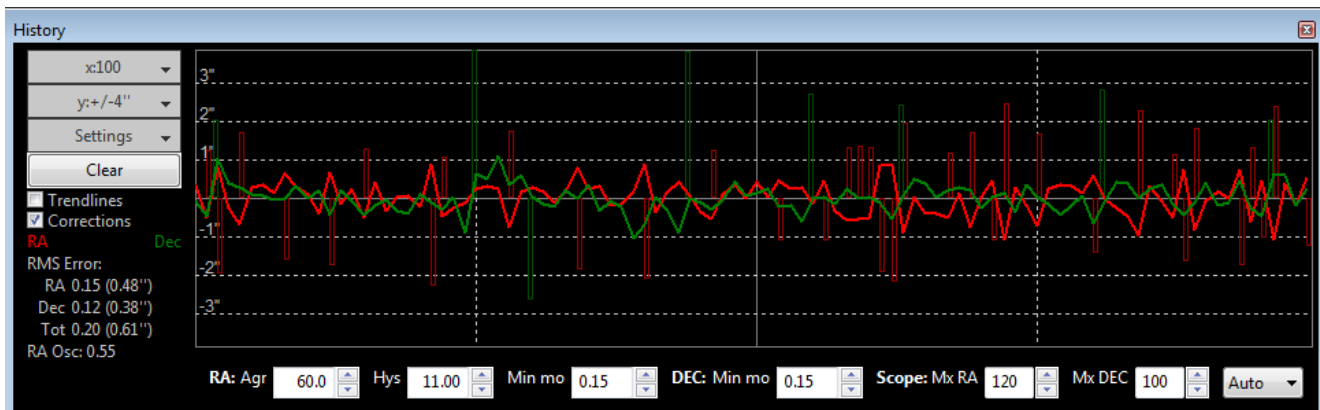
The simplest display tools are grid overlays superimposed over the main guider display window. These are quite straightforward and include the following choices:

- Bullseye target
- Fine grid
- Coarse grid
- RA/Dec - this shows how the telescope axes are aligned relative to the axes of the camera sensor
- 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:



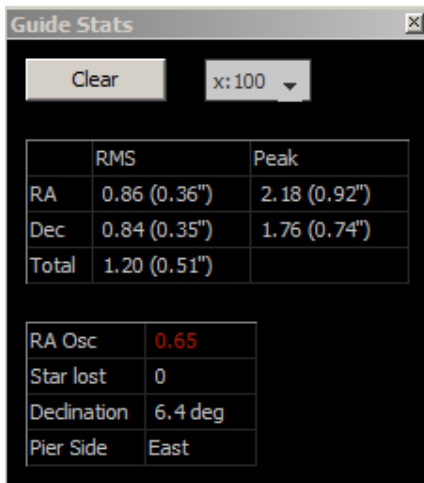
The major portion of the window shows the detailed displacements of the guide star for each guide exposure, plotted left-to-right. Normally, one line shows displacements in right ascension while the second line shows declination displacements. However, you can use the 'Settings' button to the left of the graph to switch to camera (X/Y) axes if you prefer. 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: 100 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 probably 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. If you are too aggressive in your guiding and over-shooting the mark each time, this number will head toward 1.0. If you were perfect and not over- or under-shooting and your mount had no periodic error, the score would be 0.5. Taking periodic error into account, the ideal value would be closer to 0.3. If this score gets very low (e.g. 0.1), you may want to increase the RA aggressiveness or decrease the hysteresis. If it gets quite high (e.g. 0.8), you may want to adjust aggressiveness/hysteresis in the opposite direction. 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. 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. 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 that the star displacements being graphed are being influenced by the dithering operation.

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 and the size of the guide camera pixels. These parameters are set in the 'Brain' dialog, on the 'Global' and 'Camera' tabs, respectively. If they are not specified, *PHD2* will use default values of 1.0, and the guiding performance numbers will effectively be reported in units of pixels.

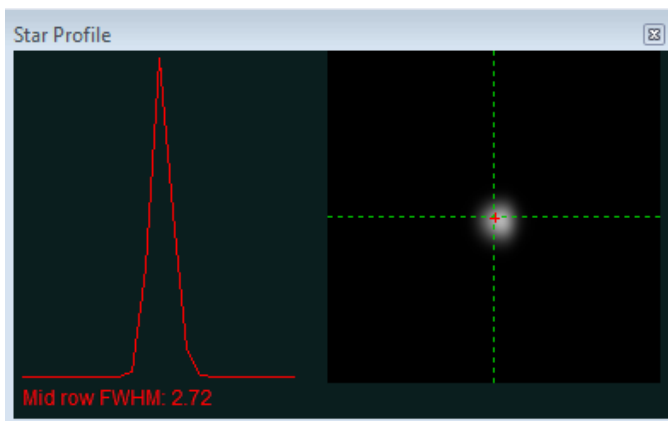
At the bottom of the graph window are active controls for adjusting guiding parameters "on the fly". The guiding algorithm selections you've made will control which controls are shown. These controls have the same effect as those in the 'Brain' dialog, and they eliminate the need to stop guiding and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

## Stats



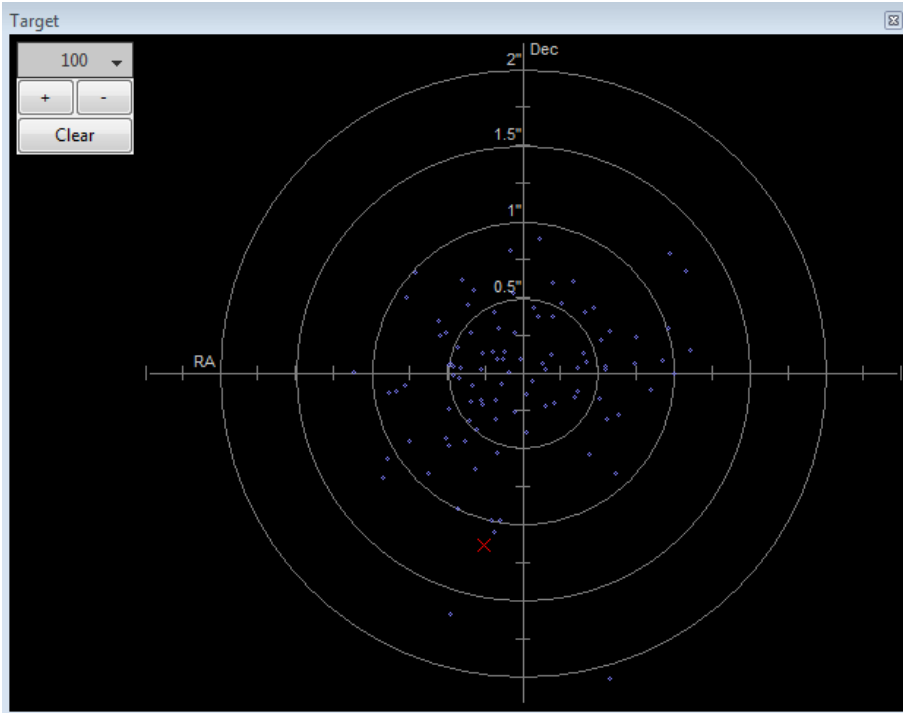
If you want to monitor guiding performance without necessarily having the graph window open, you can click on the "Stats" menu item. That will display the salient statistics with controls for clearing the data or changing the number of guide exposures used to compute the statistics.

## Star Profile and Target Displays



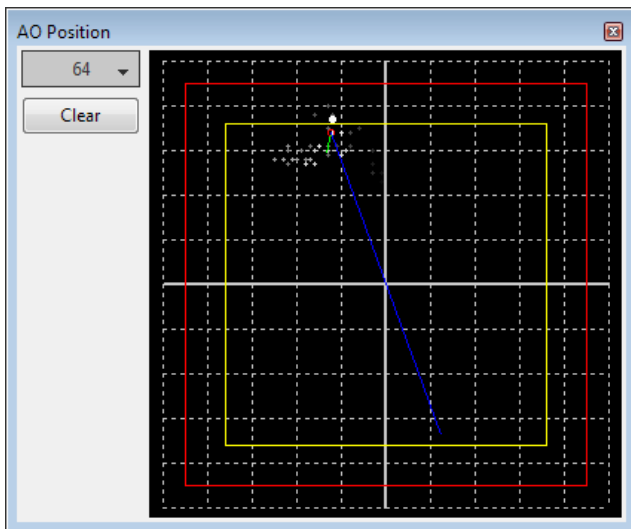
The star profile display shows the cross-section of the guide star along with a measurement of its full-width-half-maximum (FWHM). If you see substantial fluctuations in this parameter, it may be an indication that the star is too faint or the exposure time is too short. This tool can also help with focusing the guide camera, a procedure that can be a bit tedious if you're using an off-axis-guider at a fairly long focal length. An out-of-focus star will not have the sharply pointed profile you want for

guiding. If the profile is flat at the top, the star is over-exposed, so you'll need to find a fainter star or reduce the exposure time to refine the focus.



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.

## 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 left-hand corner of the screen.

## **6. Advanced Settings**

Advanced settings are accessed by clicking on the 'Brain button', a feature well-known to users of the original *PHD*. *PHD2* has a considerably larger set of parameters that can be adjusted to optimize your guiding performance. Although these are called "advanced" settings, they are not particularly difficult to understand, and you shouldn't hesitate to explore 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 many more settings 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](#)

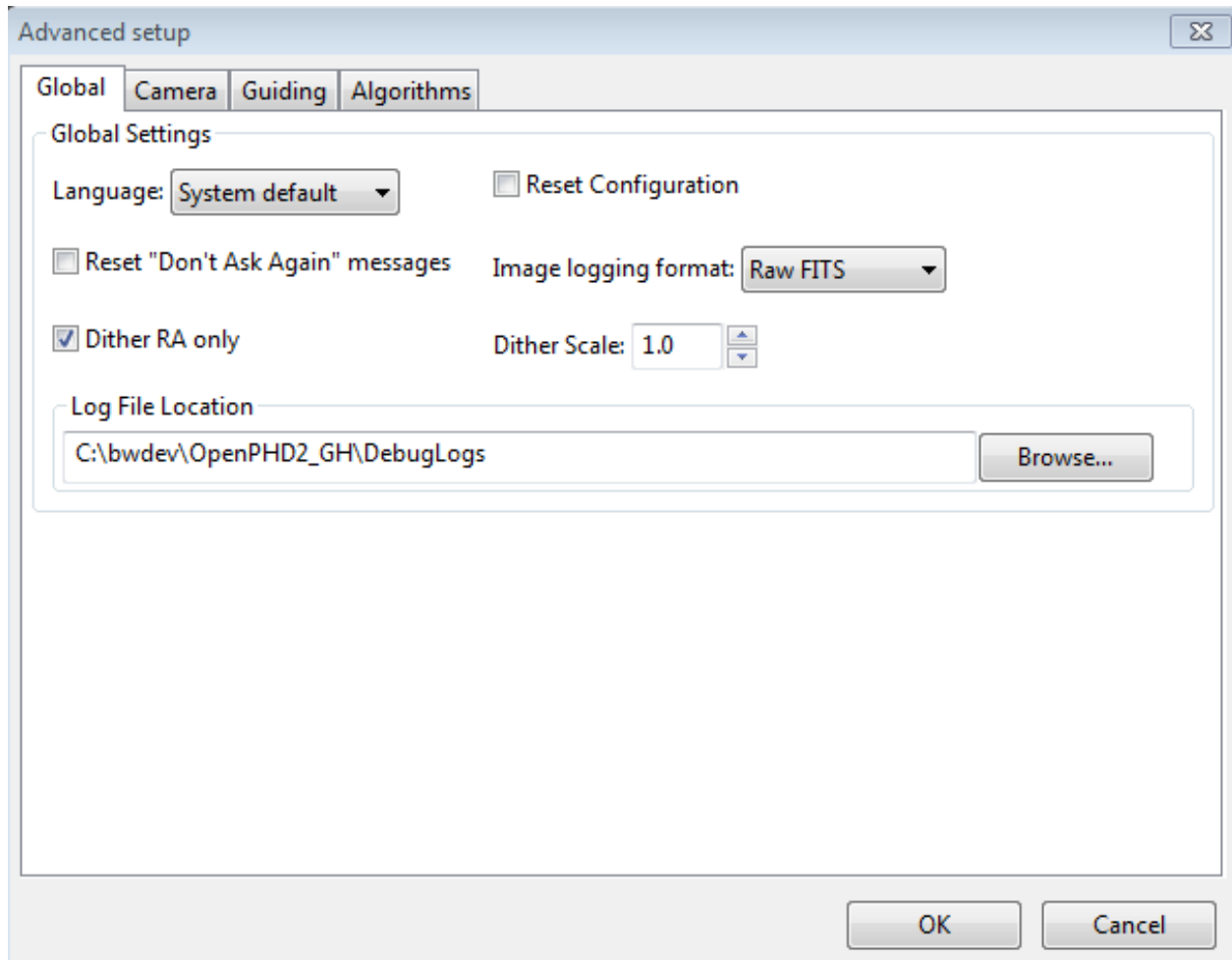
[Camera Tab](#)

[Guiding Tab](#)

[Algorithms Tab](#)

[Other Devices Tab](#)

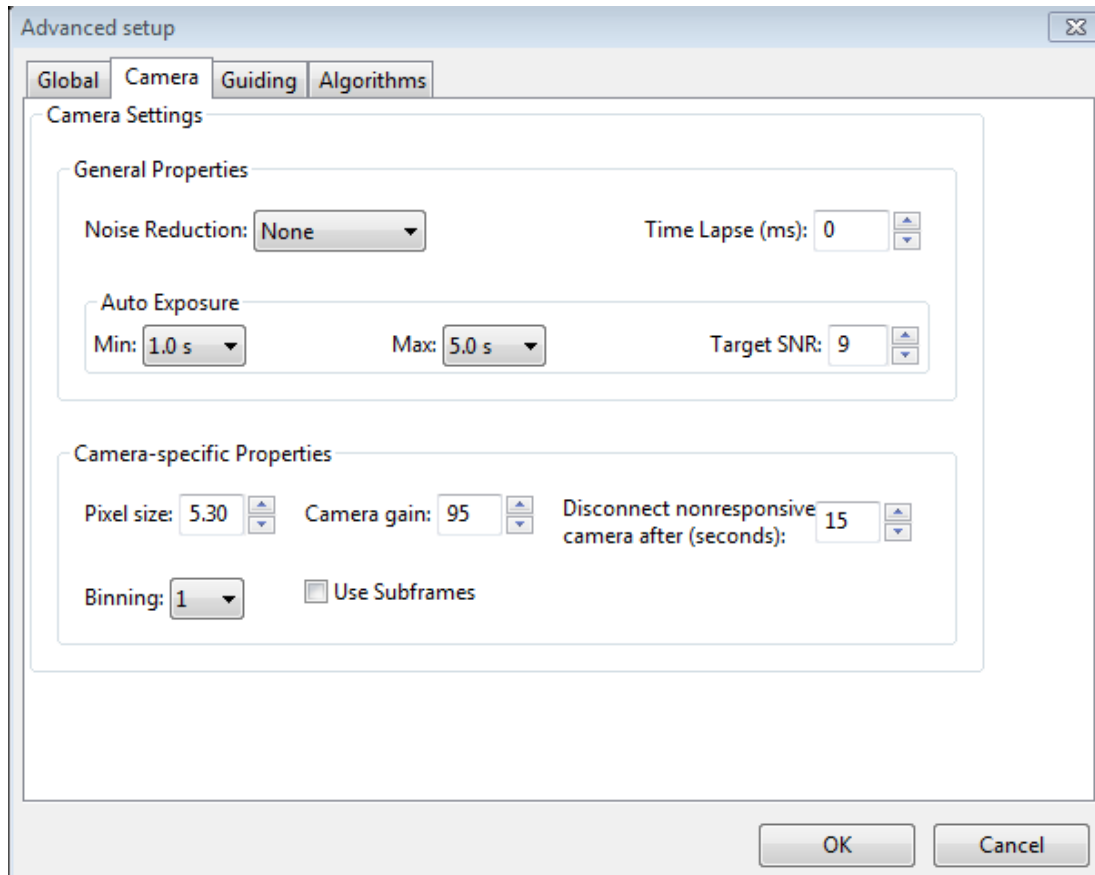
## Global Tab



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 Ask Again messages' - restores the display of alert messages if you have previously chosen to not show them
- 'Image logging format' - specifies the file format if star-image logging is enabled. If you are doing this for the purpose of documenting a problem, use Raw FITS
- 'Dither RA only' - for companion apps that use the *PHD2* server interface, specifies that dithering should be done only on the RA axis
- 'Dither scale' - controls the magnitude of the dithering operation
- 'Log File Location' - specifies a file directory where *PHD2* guide and debug log files will be stored.

## 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.
- 'Auto Exposure' - these are the settings that control Auto exposure time.
  - 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 min exposure time is set too low, you are likely to chase seeing effects and thereby get poor guiding results. Users of AO units will usually set this to a lower value, since rapid small corrections are often desirable with an AO.
  - Max Exposure - the maximum exposure time. Before a guide star is selected, PHD2 will set the exposure time to the maximum value. Once a guide star is selected, PHD2 will then incrementally decrease the exposure time until the desired SNR is reached.
  - Target SNR - this is the average SNR value that PHD2 will attempt to achieve by adjusting the exposure time. SNR can fluctuate 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 reject frames when SNR drops below 3.0. The default value of 6.0 should



provide enough of a cushion to prevent fluctuations from causing the SNR to go below 3.0. As mentioned in the 'Basic Use' section, SNR is similar but not identical to the signal-to-noise ratio used in photometry.

- 'Pixel size' - The guide camera pixel size in microns. This is the second of two parameters needed by *PHD2* to compute the guider image scale and thus report guider statistics in units of arc-seconds. The other parameter required for this is the guide scope focal length, located on the 'Guiding' tab. Refer to your camera documentation to determine the correct value for pixel size.
- 'Camera gain' - Sets the gain level for the many 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.
- '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, and display an alert message in the main window. Since a hardware problem is likely 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 the SBIG driver that is packaged with Sequence Generator Pro. 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. See below for a more detailed discussion.
- 'Use subframes' - For cameras that support this feature, *PHD2* will download only a 100x100 subframe of each guide exposure. This is very 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 click anywhere outside the subframe.

### **Use of Binning**

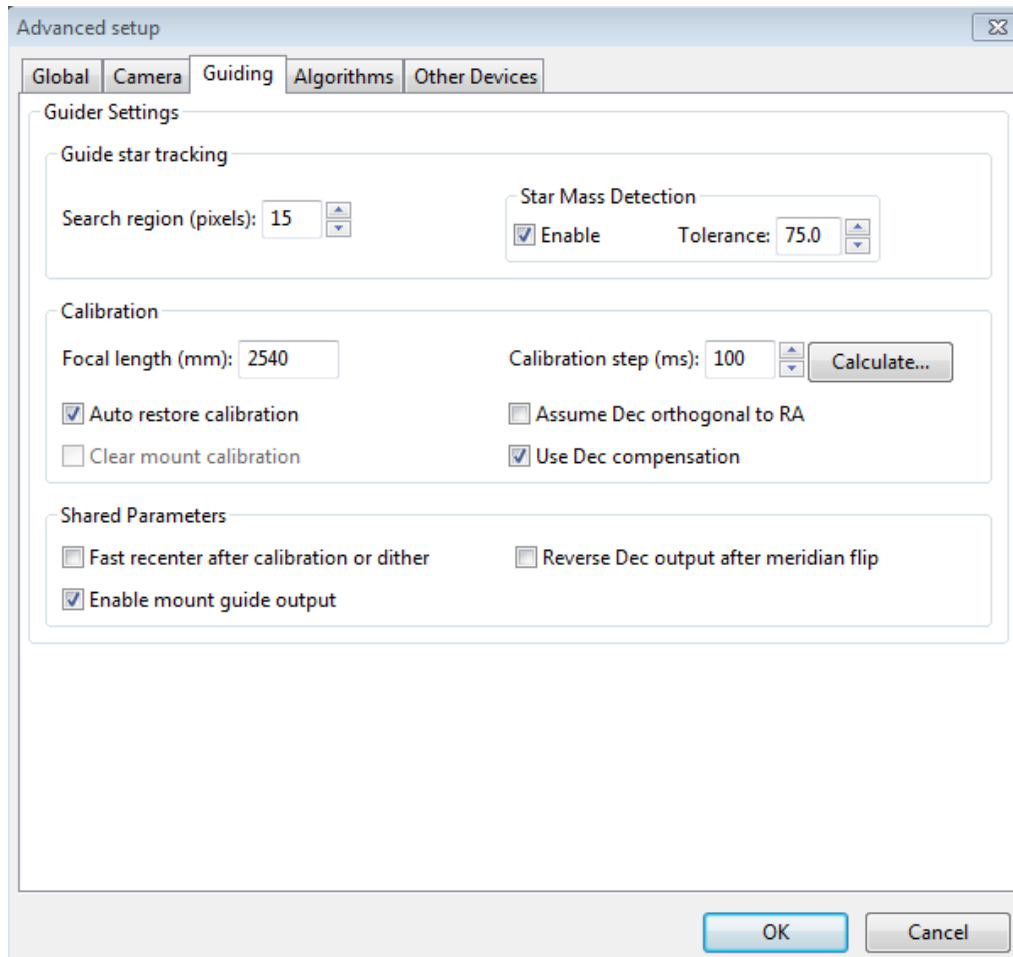
Some of the guide cameras available in *PHD2* support hardware-level binning, and this may be helpful in situations where you are guiding at long focal lengths or have a guide camera with very small pixels. These scenarios often result in having to use faint guide stars, and the guider images may be 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 only beneficial if you are limited to a choice among faint stars (i.e. with SNR values near the threshold of 3).
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 well above 1 arc-sec/pixel. You may need to experiment because the results will also depend on the image scale of your main camera system.
4. 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 foresee the need to switch back and forth between binning settings, you should create separate profiles for each setting. 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.

Most PHD2 users probably won't need to use binning, and you should probably avoid doing so unless you have a clear understanding of the implications and an equally clear idea of what you are trying to accomplish.

## 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.

- 'Star mass detection' - tells *PHD2* to monitor the brightness and size of the guide star compared to the sky background.
- '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' errors when the star is plainly visible on the display, try increasing the value of this setting. Resetting the 'Enable' checkbox or setting the threshold to 100 will disable the warnings entirely.

## 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. The other parameter required for this is the guide camera pixel size, located on the 'Camera' tab.
- '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 good to calibrate within about 30 degrees of the celestial equator (declination = 0), and to use a calibration step size that will result in 8-14 steps in each direction. The 'calculate...' button to the right of this control will launch a dialog that can help you compute an appropriate value (see below)
- 'Auto restore calibration' - tells *PHD2* to automatically reload the most recent calibration data as soon as the equipment is connected. Be sure to read the [Auto calibration](#) section to understand the implications and potential risks of doing this.
- '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 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 - you might have rotated the guide camera or slewed to a target close to the celestial pole, etc. You can also accomplish the same result by doing a Shift-Click on the 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 connection ('Mount' or 'Aux'), it will automatically adjust the RA guide rate based on the current declination. This box should normally be left checked except in very unusual cases. For example, SiTech mount controllers evidently apply a compensation automatically, in which case *PHD2* should not.

## 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. This is only an optimization, so the use of this checkbox is completely optional.
- 'Reverse Dec output after meridian flip' - tells *PHD2* how to adjust the calibration data after a meridian flip. Some mounts track their 'side of pier' state and automatically reverse the direction of guide commands in declination. Other 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 it's probably easiest to just run a quick experiment. With the checkbox disabled, calibrate on one side of the pier, then move the mount to the other side. Select 'Flip Calibration' under the 'Tools' menu, and start guiding. If the guiding works normally, leave the box un-checked; but if you see run-away in declination, check the box and repeat the entire procedure, including calibration.
- 'Enable mount guide output' - this is normally checked because it tells *PHD2* to send guide commands to the mount. But there are some circumstances where you might want to disable this, usually because you want to observe the uncorrected behavior of the mount. For example, you can disable guider output in order to see the general shape and amplitude of your mount's periodic error or to check the amount of drift from polar mis-alignment.
- 'Stop guiding when mount slews' - if guiding through an ASCOM interface, PHD2 can detect that a slew operation is underway and will stop issuing guide commands.

### Calibration Step Calculator

The screenshot shows a dialog box titled "Calibration Step Calculator". It is divided into two main sections: "Input Parameters" and "Computed Values".

**Input Parameters:**

- Focal length, mm: 350
- Pixel size, microns: 5.30
- Guide speed, n.nn x sidereal: 1.00
- Calibration steps: 12
- Calibration declination, degrees: 0

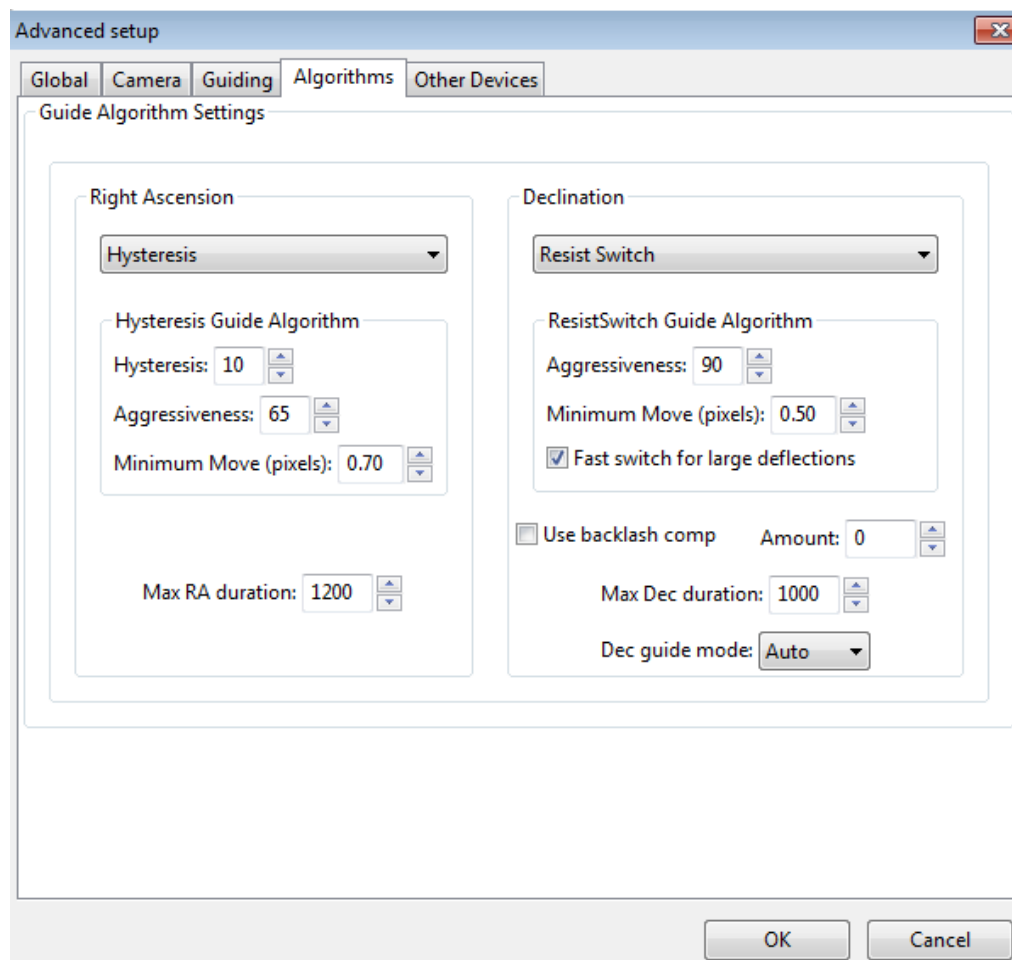
**Computed Values:**

- Image scale, arc-sec/px: 3.12
- Calibration step, ms: 450

At the bottom of the dialog are "OK" and "Cancel" buttons.

To use the calculator, be sure the topmost three edit controls are correctly filled in. If you have already specified the focal length and the camera pixel size in the 'Global' and 'Camera' tabs respectively, 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 also have the correct values. 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. 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. As you change the values in these fields, *PHD2* will recalculate your current image scale and a recommended 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. 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. However, this will not be done if you click on 'Cancel' in the calculator dialog. Note that PHD2 never changes the guide speed setting in your mount regardless of what may be entered in the 'Guide Speed' field.

## Algorithms Tab

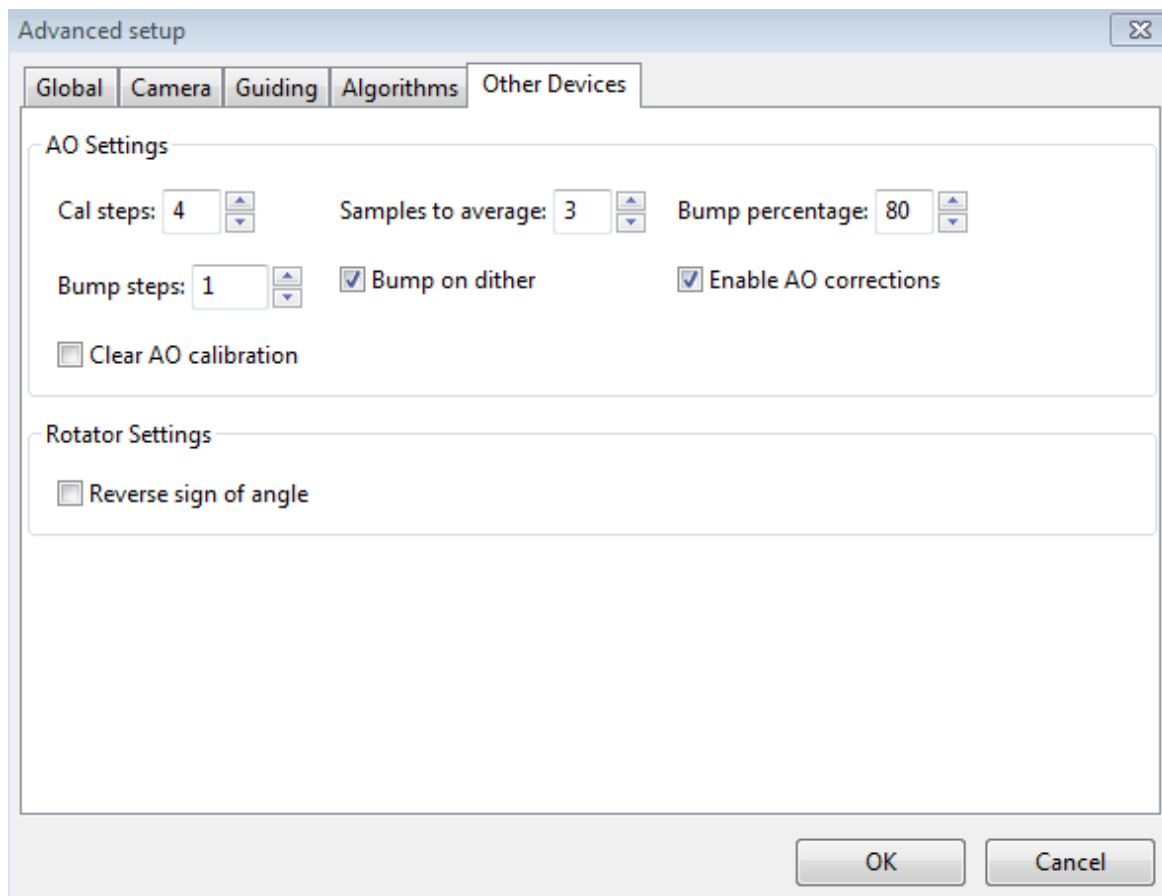


The algorithms tab can be used to select the guiding algorithms you want to use and to fine-tune the parameters associated with them. The parameters displayed will change significantly if you change the algorithm selections. For that reason, all the parameters related to [guide algorithms](#) will be 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.).
- 'Use backlash comp' - this controls whether PHD2 will apply a compensation factor when the direction of declination guiding needs to be reversed. Measurement of backlash and calculation of a good starting value for the compensation factor is done in the Guiding Assistant. The size of the additional guide correction (compensation value) is shown in the 'Amount' field adjacent to the checkbox. This amount may be adjusted downward by PHD2 if necessary to avoid overshooting and oscillation. Since PHD2 has the ability to detect and adapt to over-corrections, the backlash compensation available here should work better than the fixed backlash compensation available in many mount controllers. If you use the PHD2 backlash compensation, you should disable any backlash compensation in the mount. See the help section on the [Guiding Assistant](#) for more details.
- '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 errors are not caused by imperfections in your mount's gears. Instead, deflections in declination are primarily the result of imperfect polar alignment or flexure. The result is an error that 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. If so, you can select either 'north' or 'south' to restrict corrections to only that direction. Keep in mind, however, that an over-shoot in correction with one of these modes will leave the star positioned off-target for an extended period of time. So you'll probably want to use conservative parameters for aggressiveness if you are disallowing direction reversals. Finally, a choice of 'none' here disables declination guiding altogether.

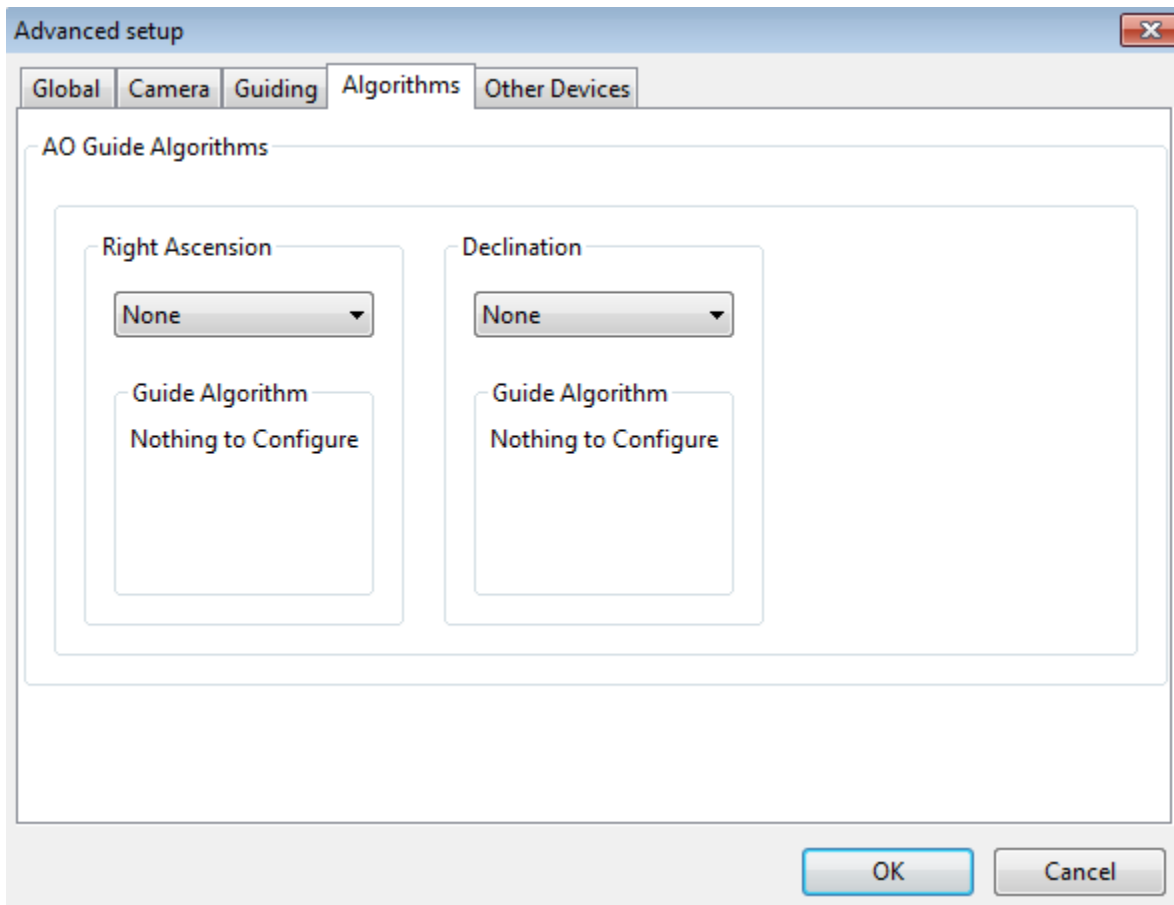
## Other Devices Tab



If you are using either an adaptive optics or rotator device, the "Other Devices" tab will be shown. The upper section deals with the AO device if one is being used. You can use the first four 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 earlier, 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 '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 guiding' 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.

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 'None', which means there will be no damping or history-based calculations applied at all. In that case, each correction will be based only on the most recent guide frame and will make a 100% correction of the most recent deflection. If you use a different algorithm, you should probably start with a high level of aggressiveness there as well, perhaps 100%. 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.



# 7. 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 some experience with guiding and understand the basics, you should probably be cautious about changing algorithms. However, you may have some special circumstances that require changes or you may simply want to experiment with the different algorithm choices. The Advanced Dialog settings in *PHD2* make it easy to do that. Each algorithm has a set of parameters that controls how observed changes in guide star position (star deflections) are translated into guiding commands that are most likely to restore the star to its initial position.

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 entirely different, conventional guiding faces enormous 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. This type of guiding can only hope to deal with tracking errors that are "slow and steady", not "fast and random." Sources of slow and steady (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
- 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

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

- Atmospheric seeing ("turbulence")
- Gear noise, roughness, and vibration
- 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 somehow react to the slow and steady deflections while ignoring the rest. This is a difficult problem at best because any given guide star deflection is likely to have contributions from many of these sources. And if that isn't hard enough, remember that real-world mounts are never perfect - so the move you ask for will not be exactly the move 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 apply "inertia" or "impedance" to the guiding corrections. That means making corrections that follow a pattern 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 gear

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 how large your star images are. The default values work well for short-to-medium focal length systems, but you may need to increase them if you are working at long focal lengths and expect stars to have larger diameters.

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 current 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, which is used to reduce over-correcting. On each frame, *PHD2* computes how far it thinks the mount should move and in what direction(s) it should move. 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 find your mount is always overshooting the star, decrease this value slightly (say, by 10% steps). If you find *PHD2* always seems to be lagging behind the star's motion, increase this by a little bit. A little can go a long way here.

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. Starting with Release 2.4.1, two additional parameters are available for fine-tuning the ResistSwitch algorithm. The first is "aggression", a percentage amount that controls how much of the computed guide correction will be issued. Reducing this parameter can help to avoid over-shooting with mounts that have little or no backlash. 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** algorithms also employ 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 very resistant

to quick changes. But the history accumulation also includes a calculation to determine if deflections are moving in a consistent direction or "getting worse." 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. Because the low-pass algorithm is so resistant to quick changes, it is probably most applicable to declination guiding.

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 may be a good choice for users with good seeing conditions and well-behaved mounts with little or no declination backlash.

## 8. Tools and Utilities

[Manual Guide](#)

[Auto-Select Star](#)

[Calibration Details](#)

[PHD2 Server](#)

[Logging and Debug Output](#)

[Drift Alignment](#)

[Lock Positions](#)

[Comet Tracking](#)

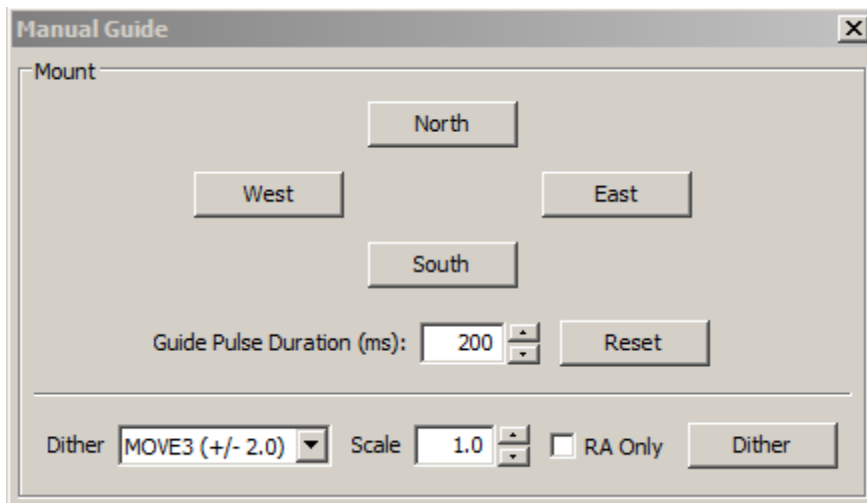
[Guiding Assistant](#)

[Equipment Profiles](#)

[Simulator Parameters](#)

[Keyboard Shortcuts](#)

### Manual Guide



If you are connecting to a new mount and are encountering calibration problems, you will probably want to be sure that *PHD2*'s commands are actually getting to the mount. 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 press the button, a pulse of the duration specified in the 'Guide Pulse Duration' field will be sent. The default value is the 'calibration step-size' set in the Advanced Options 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 figure out if the mount is responding to *PHD2*'s signals. 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](#).

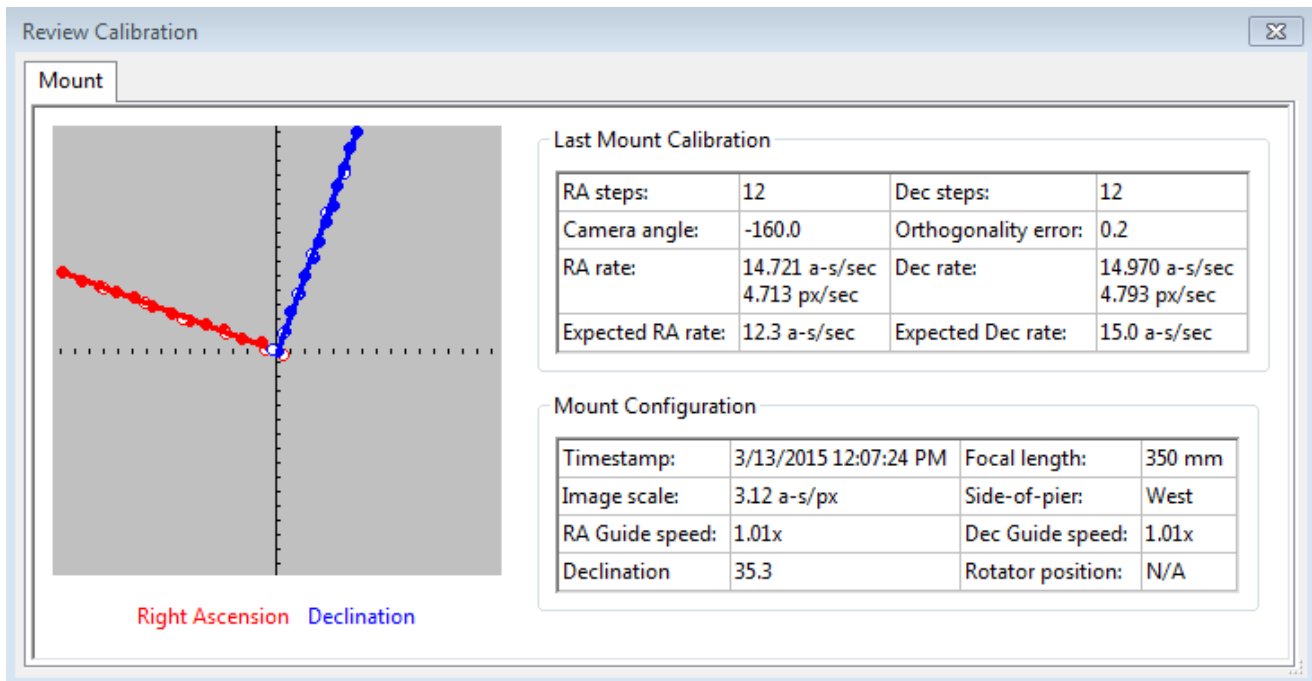
Dithering is used primarily with image capture or automation applications, usually through the *PHD2* server interface. However, you can do manual dithering or experiment with dither settings using the controls at the bottom of the dialog. The 'dither' amount field at the left controls the amount the 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.

## **Auto-Select Star**

Clicking on 'Auto-select Star' under the 'Tools' menu, or using the keyboard shortcut of <Alt>S, tells *PHD2* to scan the current guide image and identify a star suitable for guiding. *PHD2* will try to select a star of sufficient brightness that is not near another star and not too close to the edge of the frame. The selected star may appear overly dim on the screen, but this is usually not a problem. You can use the [Star Profile](#) tool to examine the properties of the selected star - it should be non-saturated with a sharp profile, the same properties you should look for when choosing a guide star manually. The auto-select process is not infallible, so you may need to select a star yourself if you don't like the automated result. If you want to use Auto-Select, you should definitely use either a bad-pixel map or dark library to reduce the likelihood of *PHD2* mistakenly choosing a hot pixel.

## **Calibration Details**

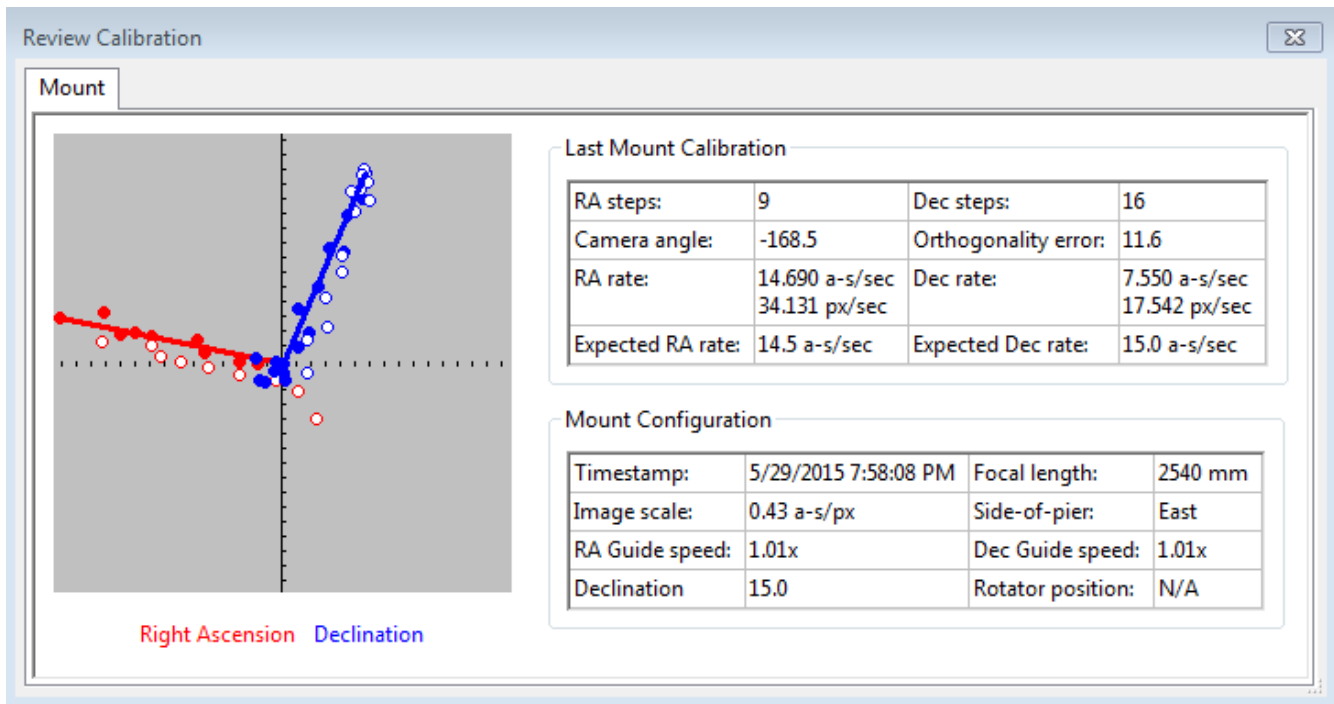
Most of the calibration-related windows, including calibration sanity-checks, will open a window that looks something like this:



The first thing to look at is the graph to the left, which shows what star movements resulted from the guide pulses that PHD2 sent during calibration. The lines represent the RA and Dec guide rates that were computed as a result of the calibration, and these lines should be roughly perpendicular. The data points will never be perfectly 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 considerable 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 may be many fewer points shown in the east and north 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, and you shouldn't worry about them unless your values are very different. If you didn't see an alert message 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 very experienced imagers using high-end mounts, so it is good to check.

### Declination Backlash

A common source of calibration problems is declination backlash, which is present to some degree in most geared mounts. With some mounts, however, the problem can be severe and can lead to poor calibration and guiding results. Consider the following calibration review dialog:



The first clue to the problem is found by comparing the declination and right ascension guide rates. In this case, the declination rate is barely 1/2 of the RA rate, something that should never occur. In fact, this would have triggered a calibration alert dialog. Now look at the graph of the declination points, in blue, and notice the clumping of points near the zero-point of the graph. Although a total of 16 steps were taken in declination, only the last 9 were actually moving the mount in a consistent way - the first 7 basically accomplished nothing because of backlash. 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 first manually moving the mount north at guide speed for 10-20 seconds until consistent star movement is seen in the main window. You can do this with the 'Manual Guide' tool or by using the hand-controller on your mount. Once this is done, most of the declination backlash in your mount should have been overcome. You can then repeat the calibration procedure and probably get a declination guiding rate that is more reasonable. The second problem generally requires some mechanical adjustment to the mount. You can try using a backlash compensation setting, but this is not likely to work well if the backlash is large - more than 2-3 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. 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 decent guiding results - and there are plenty of imagers out there who use this technique.

### 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 calibration' checkbox in the Advanced Dialog - it will force a recalibration whenever guiding is resumed. The 'Enter calibration data' option should be used only under very unusual circumstances and only if you're sure you know

what you're doing; but it is available as a matter of completeness. If you click on the 'Enter calibration data' item, you'll see a dialog box that allows input of relatively low-level calibration data. This data might come from a much earlier session, perhaps extracted from the *PHD2* guiding log file. Keep in mind, if you are using an ASCOM driver for either the 'mount' or 'aux mount' connections, you should have little need for these calibration data controls.

## ***PHD2* Server**

*PHD2* supports third-party imaging and automation applications that need to control the guiding process. Stark Labs' *Nebulosity* program was the first to do this, but other applications have subsequently been produced. By using the *PHD2* server process, image capture programs can control dithering between exposures or suspend guide exposures while the primary imaging camera is downloading data. To use these capabilities with a compatible application, you should click on the 'Enable Server' option under the 'Tools' menu. The server interface has been reworked substantially in *PHD2*, and it's now possible for an application to control most aspects of *PHD2*'s guiding operations. Documentation for the server API is available on the [PHD2 Wiki](#).

## **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 guiding log is similar to the one produced by PHD, but with extended information. The guide log is intentionally formatted to allow easy interpretation by either a human reader or an external application. For example, the very capable 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 that a comma should be used 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 the debug log file. If you have neither log file available, you are unlikely to get any 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 application data files. In Windows7, for example, the files will be stored in a '*PHD2*' sub-folder in the "AppData\Local" location. 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*.

In some unusual cases, you may need to capture guide camera images, usually to support debugging and problem resolution. This can be done by clicking the 'Enable Star Imaging Logging' menu item under the 'Tools' menu. The resultant image files will be stored in the same location as the other log files. The format of these image files is controlled from the 'Global' tab of the 'Advanced Settings' dialog. If you are trying to document a problem you're having, you should choose the 'Raw Fits' format for maximum flexibility.



## Drift Align

Drift alignment is a well-known technique for achieving polar alignment and is considered by many to be the "gold standard". The Drift Alignment tool is a wizard-like sequence of dialogs that can help you work through the drift alignment process and get quantifiable results. Once you've calibrated your guider and have started guiding, click on 'Drift Align' under the 'Tools' menu. The Drift Alignment tool will disable and re-enable declination guiding as necessary, so don't worry about that. It will also keep RA guiding active so uncorrected periodic error in the mount doesn't interfere with the measurements. The first Drift Align dialog will appear to help you adjust the azimuth on your mount. If you are using an ASCOM mount, you'll have the option of slewing to an area near the celestial equator and the celestial meridian. If you're not using an ASCOM mount, you'll need to slew to that location manually. Once the scope is positioned and you have a suitable star in the field of view, click on the 'Drift' button to begin collecting data. You'll see the graph window with a display of star deflections and corrections and, more importantly, two trendlines. When the mount is precisely polar aligned in azimuth, the Declination trend line will be perfectly horizontal. Let the exposures continue until the declination trendline has stabilized and is no longer jumping around with each new exposure. At the bottom of the graph window, you'll see a measurement for the polar alignment error in azimuth. And, in the image window, you will see a magenta circle around the guide star. The circle indicates an upper limit on how far the guide star needs to move when azimuth is adjusted. (Initially, the circle may be too large to be visible on the screen, so you may not see it until your alignment gets closer.)

Now click on the 'Adjust' button to halt guiding, then make a mechanical adjustment in azimuth. Watch the guide star as you make the adjustment, moving the guide star towards the magenta circle, but not beyond it. Once done, click on the 'drift' button again to repeat the measurement. If your adjustment was in the right direction and did not over-shoot, the Declination trendline will be closer to horizontal. Continue iterating in this way until you are satisfied with your azimuth accuracy. You can use the 'notes' field to record which way the drift line moves depending on how you make the adjustment. For example, you might note that a counter-clockwise turn of the mount azimuth knob moves the drift line "up." Since these notes are retained across *PHD2* sessions, subsequent drift alignments will probably go more quickly.

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:

1. **b** : toggle/show bookmarks
2. **Shift-b** : set a bookmark at the current guide star position (the "lock position")
3. **Ctrl-b** : clear all bookmarks
4. **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.

Next, click on the 'Altitude' button. Then slew the scope to a position near the celestial equator and 25-30 degrees above the east or west horizon. If you have obstructions in both directions and can't slew this low, don't worry about it - just get as close as you can. Using higher elevations on the east or west horizon will still work, but it may take a bit longer to converge on your final polar alignment. Click on



the 'drift' button to begin collecting data for the altitude part of the alignment process. As before, you will iterate between making adjustments and measuring your alignment until you are satisfied with the result, keeping notes as you go about how mount adjustments affect the behavior of the declination drift line. If you make substantial adjustments in altitude, you'll need to go back to the 'azimuth' measurement and repeat that procedure. If you work through these procedures systematically, you'll converge on a good polar alignment with a known degree of accuracy. A good polar alignment will help your guiding performance and will avoid field rotation in your images.

The drift alignment tool is easiest to use when you are using an ASCOM connection to your mount (including an 'Aux' connection). Even if you subsequently want to use ST-4 style guiding, you should use the ASCOM connection for drift alignment to make things easier. If you can't do that for some reason, the following features will be impaired:

- 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 magenta circle that identifies the target for moving the star will be inaccurate and will be displayed as a dashed line. This dashed circle will identify only an upper bound to the adjustment, so you will probably want to make smaller adjustments to avoid over-shooting.

A very complete step-by-step tutorial for drift alignment is available on the Openphdguiding web site, and first-time users are strongly encouraged to study it.  
(<https://sites.google.com/site/openphdguiding/phd2-drift-alignment>)

## Lock Positions

*PHD2* normally sets a 'lock position' where the guide star is located at the end of 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, you may want to use a 'sticky lock position.' You do this by clicking on your guide star *before calibration*, then setting the '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. 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.

## Comet Tracking

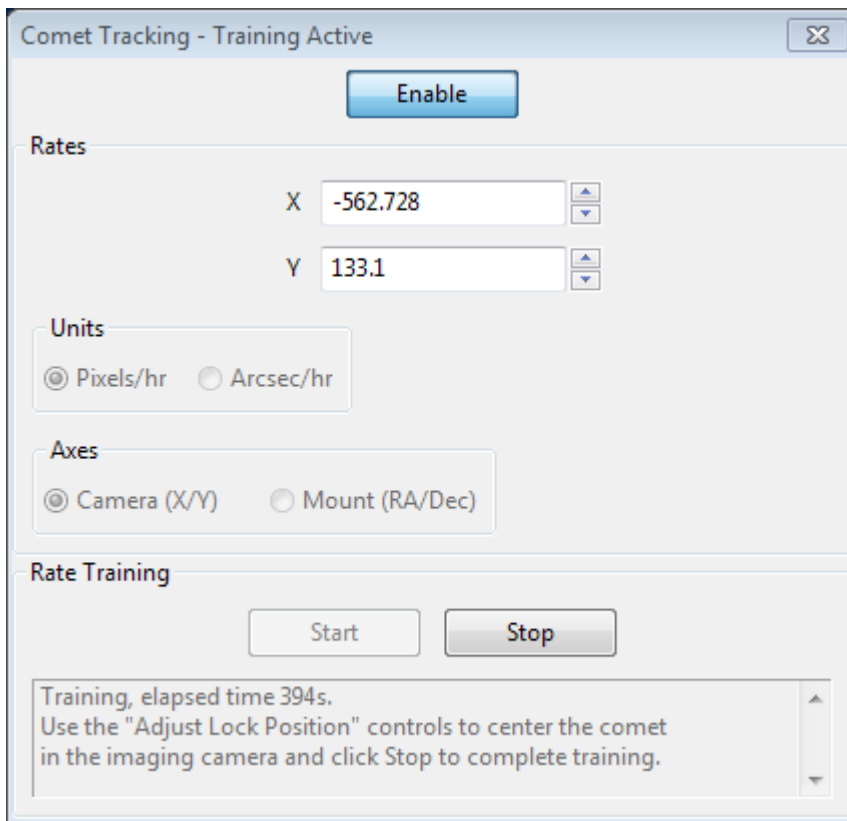
One way to image a comet is to have *PHD2* use the comet as the guide "star", but this approach may not always work. For example, the head of the comet may not present a star-like center suitable for guiding. Or, when using an off-axis guider, the comet may not even be visible in the guide camera.

*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, like 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 rate manually, you would select "Arcsec/hr" for units and "RA/Dec" for axes, then enter the rates from the comet's ephemeris.

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 Cam 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.

## Guiding Assistant

The Guiding Assistant 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 typically even 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 Guiding Assistant 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 improving your polar alignment if the declination drift rate is high. The Guiding Assistant can also measure the declination backlash in your system if you select that option in the user interface.

When the Guiding Assistant is first started, you'll see a dialog box like this:

**Guiding Assistant**

Choose a non-saturated star with a good SNR ( $\geq 8$ ) and begin guiding

Measurement Status

Start time		Exposure time	
SNR		Star mass	
Elapsed time		Sample count	

High-frequency Star Motion

Right ascension, RMS		
Declination, RMS		
Total, RMS		

Other Star Motion

Right ascension, Peak		
Declination, Peak		
Right ascension, Peak-Peak		
Right ascension Drift Rate		
Right ascension Max Drift Rate		
Declination Drift Rate		
Declination Backlash		
Polar Alignment Error		

Dec Backlash

Measure Declination Backlash    Show Graph

Start    Stop

The upper message area in the Guiding Assistant dialog box displays usage instructions, much like a wizard interface. In order for the Guiding Assistant to start measurement, you first need to start guiding in the usual way. This identifies the target star in the frame and enables (but does not start) the underlying data collection mechanism. You then click 'Start' in the Guiding Assistant to begin the measurement process. Once you do this, 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. Of particular interest are the table entries in the "High-frequency Star Motion" section which show ongoing results of the averaging process. After about one minute of data collection, these numbers will usually stabilize and you'll have a reasonable measurement of the high-frequency star movement caused by seeing conditions. You'll also have a reasonable measure of your polar alignment error although the accuracy will generally improve if you let the sampling run for longer periods of time. When you 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:

Guiding Assistant
✕

**Guiding has been resumed. Look at the recommendations and make any desired changes. Click Start to repeat the measurements, or close the window to continue guiding.**

**Measurement Status**

Start time	2015-06-30 11:45:31	Exposure time	2s
SNR	8.6	Star mass	228521.4
Elapsed time	100s	Sample count	49

**High-frequency Star Motion**

Right ascension, RMS	0.31 px	0.13 arc-sec
Declination, RMS	0.26 px	0.11 arc-sec
Total, RMS	0.40 px	0.17 arc-sec

**Other Star Motion**

Right ascension, Peak	2.2 px	0.9 arc-sec
Declination, Peak	2.5 px	0.9 arc-sec
Right ascension, Peak-Peak	11.9 px	5.1 arc-sec
Right ascension Drift Rate	-4.7 px/min	-2.0 arc-sec/min
Right ascension Max Drift Rate	0.4 px/sec	0.2 arc-sec/sec (Max Exp: 0.8s)
Declination Drift Rate	-2.9 px/min	-1.3 arc-sec/min
Declination Backlash		
Polar Alignment Error	4.8 arc-min	

Dec Backlash

Measure Declination Backlash
 Show Graph

Start
Stop

**Recommendations**

Try setting RA min-move to 0.45 Apply

Try setting Dec min-move to 0.45 Apply

The contents of the 'Recommendations' group at the bottom of the window reflect the results of the high-frequency 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 decide to re-run the measurements or close the dialog box altogether if you want to proceed with normal guiding operations.

### Measuring Declination Backlash

If you've checked the box to 'Measure Declination Backlash' that process will begin as soon as the high-frequency measurements are completed. In other words, clicking once on the 'Stop' button halts the high-frequency measurements and begins the measurement of declination backlash. A new group of status messages will be shown immediately above the 'Start' and 'Stop' buttons so you can see what's being done:

**Guiding Assistant**

**Measuring backlash...**

Measurement Status

Start time	2015-06-27 20:23:21	Exposure time	2s
SNR	9.3	Star mass	217193.6
Elapsed time	81s	Sample count	38

High-frequency Star Motion

Right ascension, RMS	0.34 px	0.14 arc-sec
Declination, RMS	0.27 px	0.12 arc-sec
Total, RMS	0.43 px	0.18 arc-sec

Other Star Motion

Right ascension, Peak	2.2 px	0.9 arc-sec
Declination, Peak	2.3 px	0.9 arc-sec
Right ascension, Peak-Peak	8.5 px	3.7 arc-sec
Right ascension Drift Rate	-4.1 px/min	-1.8 arc-sec/min
Right ascension Max Drift Rate	0.3 px/sec	0.1 arc-sec/sec (Max Exp: 1.2s)
Declination Drift Rate	-1.7 px/min	-0.7 arc-sec/min
Declination Backlash		
Polar Alignment Error	2.7 arc-min	

Dec Backlash

Measure Declination Backlash    Show Graph

**Measuring backlash: Moving North for 334 ms, step 3 / 24**

Start    Stop

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. 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 involves an initial attempt to clear whatever backlash is present in the north direction. The Guiding Assistant (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, regardless of how far the star has actually moved, the backlash amount will be computed. However, if the star hasn't moved at all in the south direction, the computed backlash amount will be too small. At that point, you can know your declination backlash exceeds 8 seconds, which is a very large amount. The Guiding Assistant will then try to move the star back 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 process for measuring high-frequency star movement, 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 in units of both pixels and time (ms):

**Guiding Assistant** [Close]

**Guiding has been resumed. Look at the recommendations and make any desired changes. Click Start to repeat the measurements, or close the window to continue guiding.**

**Measurement Status**

Start time	2015-06-27 20:23:21	Exposure time	2s
SNR	9.3	Star mass	217193.6
Elapsed time	81s	Sample count	38

**High-frequency Star Motion**

Right ascension, RMS	0.34 px	0.14 arc-sec
Declination, RMS	0.27 px	0.12 arc-sec
Total, RMS	0.43 px	0.18 arc-sec

**Other Star Motion**

Right ascension, Peak	2.2 px	0.9 arc-sec
Declination, Peak	2.3 px	0.9 arc-sec
Right ascension, Peak-Peak	8.5 px	3.7 arc-sec
Right ascension Drift Rate	-4.1 px/min	-1.8 arc-sec/min
Right ascension Max Drift Rate	0.3 px/sec	0.1 arc-sec/sec (Max Exp: 1.2s)
Declination Drift Rate	-1.7 px/min	-0.7 arc-sec/min
Declination Backlash	17.9 px	529 ms
Polar Alignment Error	2.7 arc-min	

**Dec Backlash**

Measure Declination Backlash

**Recommendations**

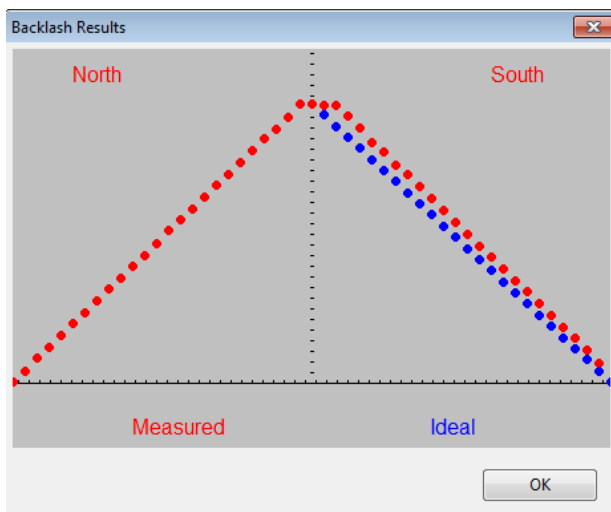
Try setting RA min-move to 0.45

Try setting Dec min-move to 0.45

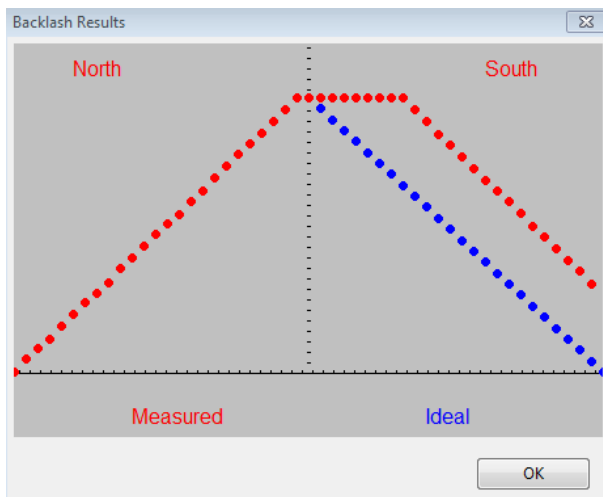
Try setting a Dec backlash value of 529 ms

Depending on the amount of backlash, you may see a recommendation for setting a backlash compensation factor - 529 ms in the example shown above. 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.

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



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



## Declination Backlash Compensation

Starting with the 2.5 release, PHD2 supports a backlash compensation mechanism that may help to improve mount performance when there is a moderate amount of declination backlash. It is different from the backlash compensation that's supported in some mount firmware because the PHD2 implementation is *adaptive*. The greatest risk with backlash compensation is that it will be too large and will drive the mount into unstable oscillations in declination. PHD2 will watch for this behavior and rapidly and automatically adjust the compensation downward until the oscillation disappears. Obviously, backlash compensation is applied only when the direction of declination guiding is reversed. When you first set a backlash compensation parameter with the Guiding Assistant (recommendations section), you should give PHD2 some time to adjust it. Let normal guiding proceed and watch for over-shoots in declination. You can see these pretty easily by watching the guiding graph with the option checked to show guiding corrections. If you see some initial oscillation and instability in declination, let guiding run for a while to see if PHD2 can stabilize the behavior.

The setting for backlash compensation is shown in the '[Algorithms](#)' tab of the Advanced Settings dialog. The value shown there may be smaller than what was computed by the Guiding Assistant if PHD2 had to adjust it downward. You can modify this parameter directly if you want to experiment with it or you can disable backlash compensation altogether using the adjacent checkbox. Once you've measured the backlash a few times with the GA and see a fairly consistent pattern of results, there's probably no need to measure it every time you run the GA. Just uncheck the 'Measure Declination Backlash' option until you want to measure it again.

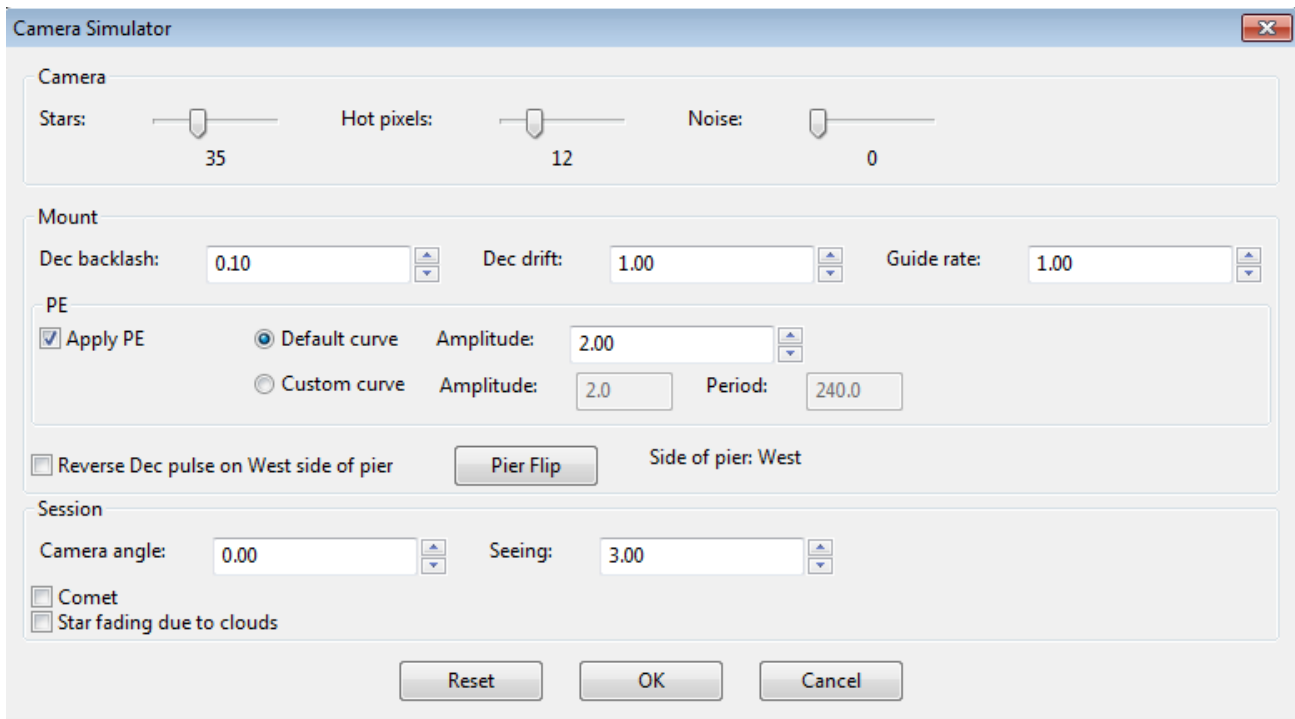
## Managing Equipment Profiles

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 will probably want to 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. Each profile holds all the settings that were active at the time the profile was last used. If you create a new profile, you can import these settings from either the *PHD2* generic defaults or from an existing profile. You can also use the 'Wizard' option to have PHD2 establish settings that are specific to your equipment configuration. 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 'Brain' 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 even exchange with other *PHD2* users.

## Advanced Settings for the Simulators

The device simulators were introduced in the [Basic Use](#) section as useful tools for you to experiment with *PHD2* and become familiar with its features. Remember that you must choose 'Simulator' as the camera type and 'On-camera' as the mount type in order to get the benefits of simulation. As you become more interested in the details of the simulation, you can use the 'Cam Dialog' 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.

## 9. Table of PHD2 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.

<u>Shortcut</u>	<u>Function</u>
F1	Help
Ctrl-C	Open Connect equipment window
Shift-Ctrl-C	Connect all equipment
Ctrl-L	Loop
Alt-S	Auto-select Star
Ctrl-G	Guide
Ctrl-S	Stop
Ctrl-D	Dismiss alert
Alt-C	Review calibration
Ctrl-O	Clear calibration (force re-calibration)
Ctrl-A	Open Advanced settings

B	Toggle Bookmarks shown/hidden
Ctrl-B	Delete all Bookmarks
Shift-B	Bookmark lock position
Alt-L	Toggle Guide Log enabled/disabled
Shift-Ctrl-M	Enter Manual calibration

## 10. Trouble-shooting and Analysis

### Calibration and Mount Control Problems

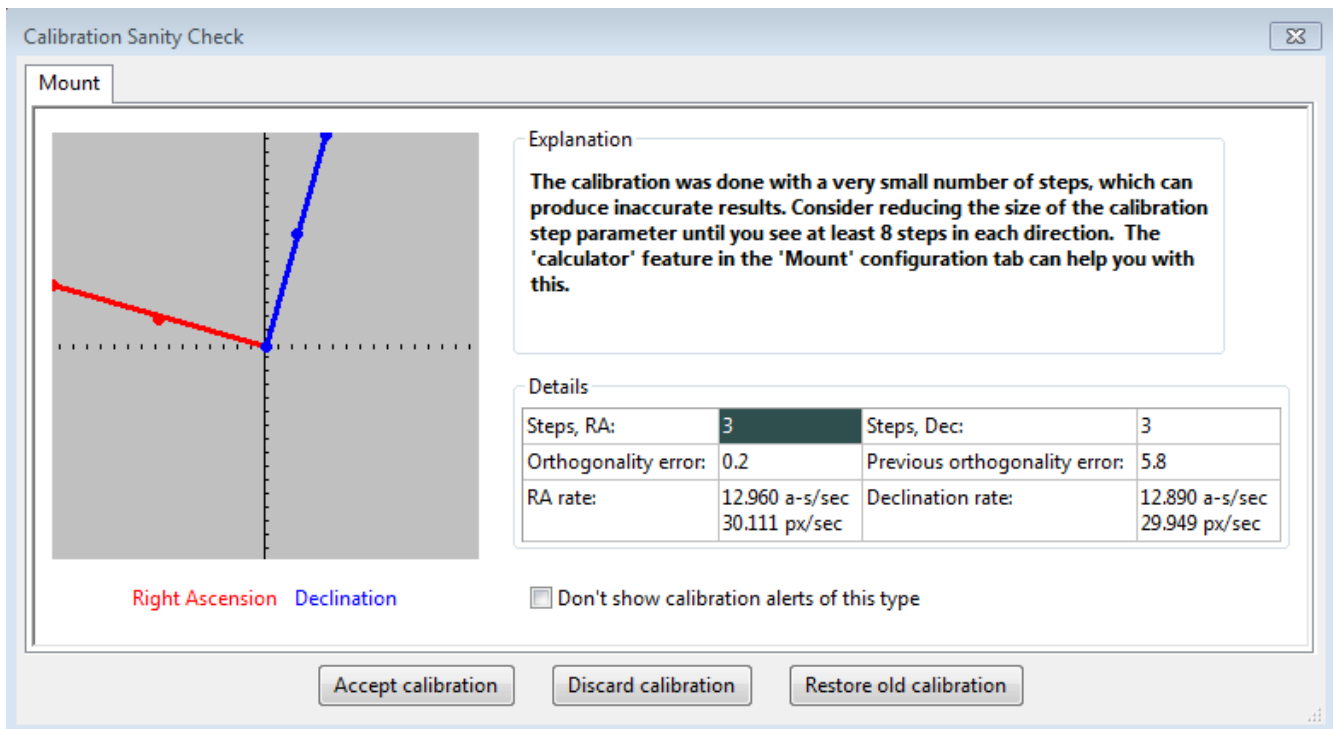
If you are just starting to use *PHD2* or are connecting to new equipment for the first time, you may have trouble getting the guider calibration done. This problem usually takes one of two forms, each requiring different responses:

1. The star moves during calibration but it moves "too far" or "too little." This is usually easy to fix - simply 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.
2. The star doesn't move enough during the calibration phases of moving in RA, clearing declination backlash, or moving in Dec. These problems are announced by **alert messages** at the top of the display window. Often, the small movements in this scenario are often the result of seeing deflections and the mount isn't really moving at all. Dealing with this sort of problem is described next.

In nearly all cases, the "no movement" problem is caused by failures in the hardware or, even more likely, problems in the cabling and connections. The best tool for trouble-shooting this is the 'Manual Guide' option under the 'Tools' menu, as 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 that 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*. 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. You can also 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 because older versions of these drivers often had bugs associated with pulse-guiding.

### 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. This "sanity check" dialog will show an explanation of the issue and some details of the calibration results:



Starting with the 2.4.0 release, there are four things checked by PHD2:

- Too few steps (shown above) - resolving this issue is quite easy. 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. If you find that the number of steps in RA and Declination is substantially different, you may be seeing evidence of a problem with the mount unless you are using different guide speed settings on the two axes.
- Non-orthogonal camera axes - 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, there is something wrong with the mount or the cable connections. You should examine the graph closely to determine what is wrong. In some cases, the mount may not be moving at all, and the measured displacements of the star could be caused only by seeing effects. 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 'Mount' tab of the Advanced Setup dialog. But you should do this only if the error is fairly small - otherwise, you are simply ignoring a serious problem. The graph at the left shows the RA and Dec axis orientation as measured by PHD2.
- Suspicious RA and Dec rates - the guide rate for right ascension should be related to the declination guiding rate by approximately a factor of cosine (Declination). In other words, the RA rate gets smaller as you move the scope further away from the celestial equator (Dec=0). 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.

- 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 will probably want to determine why the results are so different.

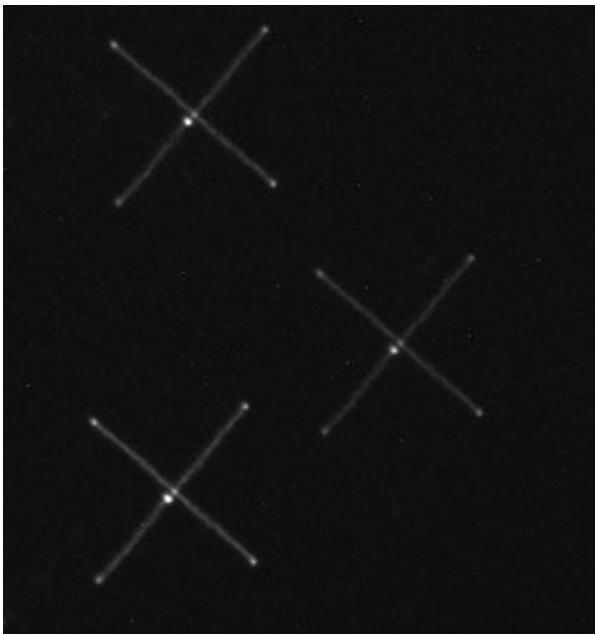
With any of these alerts, the relevant data field will be highlighted based on the type of message. You can choose to ignore the warning ('Accept calibration'), re-run the calibration ('Discard calibration'), or restore your last good calibration ('Restore old calibration'). With the third option, you 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**

One of the more common sources of calibration problems, assuming the guide commands are working at all, is excessive backlash in declination. This is discussed in the [Tools and Utilities](#) section, along with options for either fixing or side-stepping the problem.

### **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:

1. Set the mount guide speed to 1X sidereal. Bring up the 'Manual Guide' tool in PHD2 and choose an initial pulse size - start with, say, 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.

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 that specific mount and its typical problems.

## 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 and frustrating experience 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.

## 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"). Again, this is almost 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. You can start by confirming that the guide camera is working - 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. If the camera is functional, you can start looking at USB hubs and cables, swapping them one at a time to see if you can isolate the problem. It's worth remembering that we work in a hostile environment while doing our imaging, and many of the components we use are not designed for cold, outdoor conditions. So something that worked just last week or last month may no longer be reliable.

Starting with the 2.3 release, PHD2 uses a camera timeout property to protect against hang conditions. This property 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 completion of the exposure* to receive the image from the camera. This is a very generous amount of time and should work well for the majority of cameras. However, some cameras are known to create problems by making large bandwidth or power demands on the USB subsystem. If you are getting timeouts of this sort and are convinced the camera is working properly, you can increase this timeout value. You can even change it to a very high number - even 1000 seconds or more - so that timeout errors are never shown. Doing so leaves you vulnerable to apparent hangs in the user interface and erratic guiding behavior, but it is a choice you can make for yourself. A larger value for the timeout will not create extra delays during normal camera operations - once the image is downloaded from the camera, the timer is cancelled and guiding will proceed immediately.

## 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. 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 somewhat 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.

Achieving the best possible guiding performance can be a complex task and not something that can be covered here. However, you can get help on the web from a variety of sources, with the document by Craig Stark being a very good place to start:

<http://www.cloudynights.com/page/articles/cat/fishing-for-photons/what-to-do-when-phd-guiding-isnt-push-here-dummy-r2677>.

## 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 some other image defect 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 bpm's, but you can keep the old files for use with the original camera. In very unusual circumstances, you may see this message when either the driver or PHD2 code for handling the camera has changed. You might also see a format-incompatibility alert message if you have an old dark library that has somehow accumulated frames with different sensor formats.

In any of these cases, 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 identified and fixed.

## 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 consider increasing 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. These sorts of problems will require careful diagnosis and correction and simply increasing the maximum-duration limits will not help.

## 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.

## 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 ( $\text{dist} = \sqrt{\text{dx}^2 + \text{dy}^2}$ ). 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 indication that some error occurred, typically a "guide star faded" 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: <https://groups.google.com/forum/?fromgroups=#!forum/open-phd-guiding>. Obviously, the more information you can provide, the more likely we will be able to resolve the problem. 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. Attach the *PHD2* debug log from the session in which you encountered the problem. You can find the debug log in the PHD2 folder in your Documents folder. 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.