TPoint Add On

User Guide

A Telescope Pointing Analysis System

Revision 1.45

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Welcome!

Thank you for purchasing the *TPoint Add On* to *TheSkyX Serious Astronomer Edition Software* and *TheSkyX Professional Edition*.

Professional telescopes worldwide benefit from *TPoint's* pointing analysis and correction. With the *TPoint Add On* to *TheSkyX*, you can discover the errors inherent in your telescope, and improve its pointing performance. With less time spent searching for objects, you'll enjoy the increased productivity of your observing sessions.

The combination of *TheSkyX* and the *TPoint* software provides the tools necessary to:

- Analyze and refine the polar alignment your "go to" or robotic telescope.
- Analyze and improve the mount's pointing performance.
- Provide insight into the repeatable errors in your imaging system.
- Automatically correct the mount's pointing errors when used with *TheSkyX*.

As with other components of your imaging system, there is a learning curve with *TPoint*. However, when used in conjunction with *TheSkyX*, you should be able to complete a pointing calibration run on the first night to enjoy the benefits of improved telescope pointing.

What is TPoint?

TPoint is interactive telescope pointing analysis software that can assist with polar alignment and greatly improve your mount's pointing accuracy to make your observing sessions more productive.

A telescope can be calibrated by pointing to a known position (usually a star) and record *the actual* coordinates of the telescope and the star's coordinates. This is called a *pointing sample*. The difference between the star's position and the telescope's position is the *pointing error* (see Figure 1).
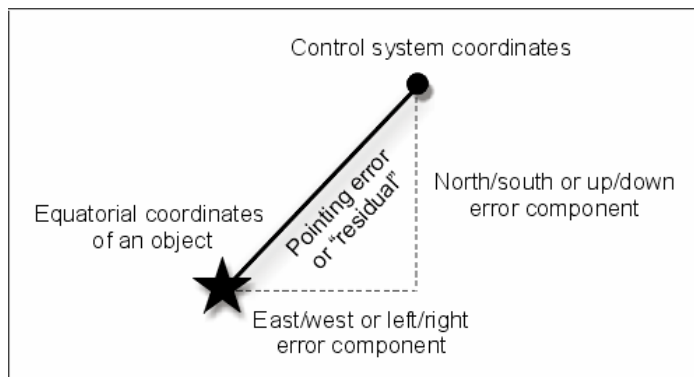
Figure 1: The difference between where the telescope ends up and the actual position of the target is called the pointing or "residual" error.

A minimum of six such pointing samples is required for *TPoint* to generate a *pointing model* that provides information about the geometry of the optical tube assembly and the repeatable errors in the telescope imaging system (which includes the camera, focuser, filter wheel, pier, optical tube assembly, the mount's gears and more). More importantly, *TPoint* uses the pointing model to improve the telescope's pointing accuracy.
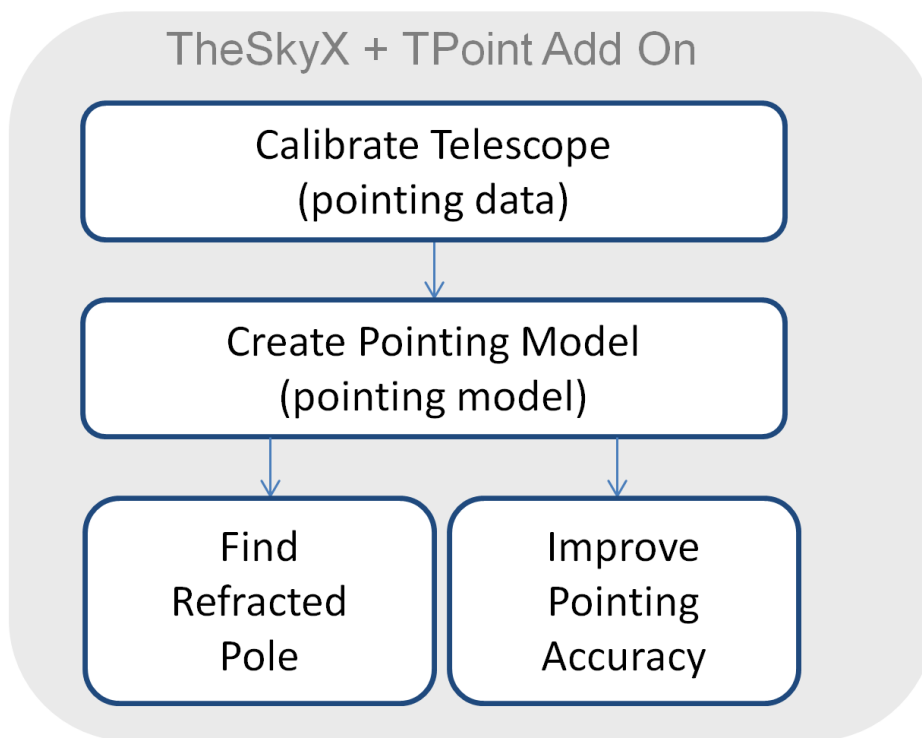
Figure 2: TPoint Add On Flow Chart

Telescope calibration involves pointing the telescope at a series of positions that are distributed more or less evenly across the sky. At each position, the star must be centered in the eyepiece (or on the CCD image), and both the star's coordinates and

the telescope's position are recorded. The two coordinates differ by the *pointing error* or *residual error*.

A collection of pointing samples that are recorded on a single night is called a *calibration run*. At the end of the calibration run (consisting of a minimum of six or up to 500 pointing samples or more, depending on your accuracy requirements), *TPoint* can employ a set of values, called *terms,* that are used to correct the telescope's pointing errors. The collection terms used to correct the telescope's position is called a *pointing model*.

Software Bisque calls to the process of collecting and recording pointing observations as *telescope pointing calibration*.

A set of terms working together to improve telescope performance is called a *model*. Whenever *TheSkyX* commands the telescope to slew (provided there is a minimum of least six pointing samples), the pointing errors are automatically removed.

Taking into account all the residual errors, the sky *root mean square* (RMS) pointing is the statistical measurement whereby the square root of the mean of the squares of the errors is computed. In simpler terms, the computed sky RMS value provides a gauge from which one can estimate, with a high degree of confidence, how well a telescope system will point. TPoint also reports the *population standard deviation* (PSD) A based on the following equation:

$$\sigma = \sqrt{\rho^2 o/(o-n)}$$

Where ρ is the sky RMS, o is the number of active observations and n is the number of floating coefficients in model. PDS gives an indication of how much variance from the average is present in the data.

Once a model is established for a telescope, it is saved and can be used from night to night. The model remains valid as long as no physical changes are made to the telescope system (for example, changing the mount's polar alignment, or switching OTAs). In situations where a telescope must be arbitrarily recalibrated by pointing at a star each session, only a few of the terms must be re-established each night.

The "magic" of *TPoint* is in determining the values of the terms based pointing samples; a process called *fitting* the pointing data. If each term could be dealt with one at a time, the fit might not be difficult. However, when zero-points, polar alignment errors, non-perpendicular axes, gear errors and other repeatable imaging system errors are all mixed together, untangling them becomes a daunting task. *TPoint* handles this task efficiently.

TPoint works in concert with *TheSkyX* to make calibrating and improving the telescope's pointing relatively straightforward.

A Simple TPoint Example

The best way to demonstrate *TPoint's* ability to improve telescope pointing is to look at the before TPoint assisted pointing and after TPoint assisted pointing results.

Figure 3 and Figure 4 show scatter diagrams of calibration data collected using a Paramount ME Robotic Telescope Mount. The blue shaded region represents the sky and the orange squares are calibration points.
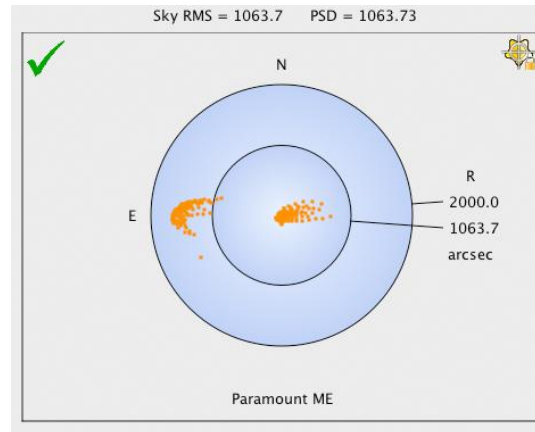
Figure 3: Pointing samples with no TPoint terms.

Before TPoint

Figure 3 shows that, before TPoint corrections are applied, the RMS pointing is about 17 arcminutes. The two "groups" of pointing samples are typical for a German equatorial mount and highlight the significant pointing errors that occur when the optical tube assembly is placed on one side of the pier versus the other.

With this typical system, slewing the telescope to place an object in the center of a 10 x 15 arcminute field of view would be a hit-or-miss proposition.
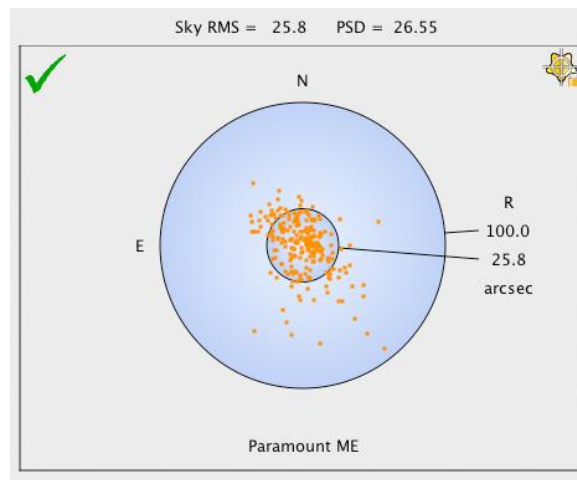
Figure 4: Sample RMS pointing after TPoint model.

Note the difference in scale between the graphs in Figure 3 and Figure 4.

After TPoint

Figure 4 shows the scatter diagram *after* the application of *TPoint*. The RMS pointing is under 30 arcseconds. The telescope will now routinely place objects in the same 10 x 15 arcminute field of view.

Minimum System Requirements

The *TPoint Add On* has the following software and hardware requirements.

Software Requirements

The *TPoint Add On* can be run on any Mac or Windows computer running *TheSkyX Serious Astronomer Edition* or *TheSkyX Professional Edition*.

Hardware Requirements

The *TPoint Add On* requires an *equatorially* mounted go to or robotic telescope with sufficient encoder resolution. The following equatorially mounted; go to telescopes benefit from *TPoint* modeling.

- All control systems that use the LX200/Autostar protocol and have sufficient encoder resolution. This includes virtually all go to telescopes from Meade Instruments Corporation.
- Astro-Physics GTO model mounts.
- Bisque TCS-controlled telescope mounts.
- Losmandy mounts using the Gemini control system.
- Mountain Instruments telescope mounts (using the Astro-Physics control system).
- NexStar GPS Series, CG, CGE, CPC, SLT Series and Advanced GT Series telescopes, or any NexStar-compatible model telescope using firmware version 4.1 or later.
- Parallax GTO telescopes (using the Astro-Physics control system).
- Takahashi Temma mounts.
- Vixen HTTP mounts.

Technical Support

If you need help analyzing your telescope modeling data, or have questions about how to use the *TPoint Add On*, consider posting to the *TPoint* Community Forum on the Software Bisque Support Corner. Software Bisque engineers and knowledgeable *TPoint* users are there to help.

Activating the TPoint Add On

When you purchase *TheSkyX Pro TPoint Add On* from the Software Bisque Store, your *TheSkyX Pro TPoint Add On* serial number is automatically registered to your account.

The *TPoint Add On* serial number is used to activate telescope modeling directly from *TheSkyX Pro*. ***No additional installers, software or software downloads are required.***

To access your serial number and activate the *TPoint Add On*,

1. Sign in to the [Software Bisque web site](#) by clicking the ***Sign In*** link in the upper right corner of the site. After you are signed in, your *Sign In Name* appears in the upper right corner of the site.
2. Navigate to your subscriptions page by clicking your ***Sign In Name***, then click the [Subscriptions](#) link.
3. From *TheSkyX Pro*, click the ***TPoint Add On*** command on the ***Telescope*** menu.
4. On the ***Setup*** tab, click the ***TPoint Add On Settings*** pop-up menu, then select the ***Enter TPoint Add On Serial Number*** command.
5. Enter your ***Name*** and ***Serial Number***.
6. Click ***OK***.

TheSkyX Pro TPoint Add On is now activated and ready to use. You'll need to repeat the above procedure on each computer that is running a licensed copy of *TheSkyX Pro*.

Using the TPoint Add On

Note: The *TPoint* Add On can be run for a 30 day trial period. Visit the Software Bisque Store if you wish to purchase it. *TPoint* is licensed as a non-commercial, single-user product. If you need a site license, contact Software Bisque.

Select the ***TPoint Add On*** command from the ***Telescope*** menu to show the ***TPoint Add On*** window. If you have purchased the *TPoint Add On*, enter your serial number and click ***OK***. Otherwise, click the ***Run Trial Version*** button to proceed.
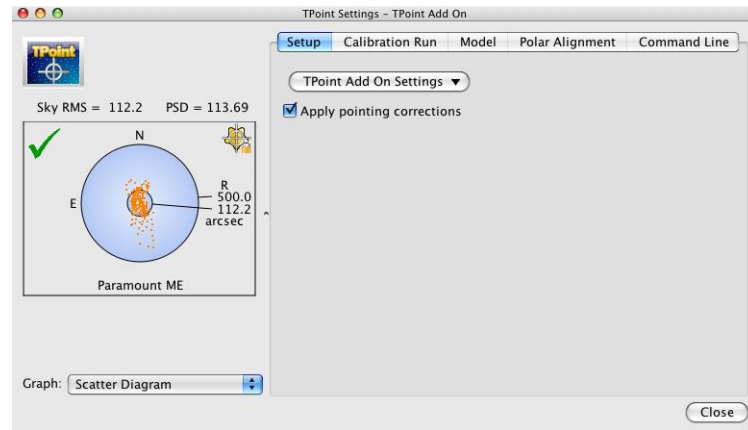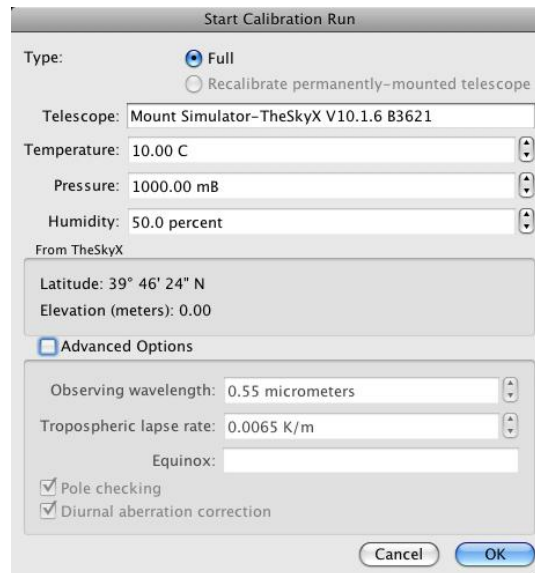
Figure 5: The Setup tab of the TPoint Add On window (Telescope menu).

You can enter your TPoint serial number at any time by selecting the ***Enter TPoint Add On Serial Number*** command from the ***TPoint Add On Settings*** pop-up menu on the ***Setup*** tab.

Quick Start

Follow the steps below if your telescope is setup and are ready to begin. This section assumes that you are familiar with setting up and slewing your telescope from *TheSkyX*.

1. Click ***Telescope > Connect***. Make sure your telescope is properly initialized and synchronized on a star. If your telescope is not available, or you just want to get a feel for the process, choose the ***Telescope Simulator*** from the ***Telescope Setup*** dialog.
2. Click the ***TPoint Add On*** command on the ***Telescope*** menu.
3. On the ***Setup*** tab, turn on the ***Apply Pointing Corrections*** checkbox.
4. On the ***Calibration Run*** tab, click the ***Start*** button to begin a calibration run.

Figure 6: The Start Calibration Run dialog.

5. Click *OK*. If you know the ambient air temperature, enter it now. If not use the default settings for now. They can be refined later if necessary.
6. Slew the telescope to a relatively bright star.
7. On the *Telescope* window (*Display* menu), click the *Add Pointing Sample* button.

Figure 7: Confirm Pointing Sample dialog.

By default, you are asked to confirm whether or not to add this pointing sample to the calibration data. Turn off the *Always Confirm Pointing Samples* check box to bypass this step. This option can also be configured from the *Telescope Setup* dialog on the *Telescope* menu.

8. Repeat steps 6 and 7 for at least six stars or *pointing samples*. After pointing samples have been collected, the scatter diagram of the observations is displayed on the right side of the *TPoint Add On* window.
9. When you are finished collecting pointing samples for this calibration run, click the *Finish* button. Once a model is marked as finished, additional

pointing samples cannot be added to the model. Attempting to add a calibration point will result in a recalibration instead. See "Recalibration" on page 34 for details about the recalibration process.

Once six pointing samples have been added to the calibration run, you should notice a significant improvement in the telescope's pointing accuracy.

Introduction

How can *TPoint* be used to analyze the pointing performance of your telescope?

A reticle eyepiece, low-light video camera, or CCD camera is used to establish a precise and consistent reference point in the focal plane of the telescope. Using this point of reference, a sequence of stars of known coordinates is pointed to and centered on this reference point (with the aid of *TheSkyX* astronomy software). Once a series of observations have been collected, *TPoint* can create a *pointing model* for the telescope based on the *pointing data*. The model is used each time a slew command is issued from *TheSkyX*. *TheSkyX* adjusts the equatorial coordinates to automatically correct for repeatable telescope errors and improve the telescope's pointing.

TPoint calculates the optimum value for each term in the model, such that the overall model is the best possible fit to the pointing data. Using *TPoint's* graphing commands, the remaining pointing errors can be inspected and any remaining obvious repeatable errors can be minimized by adding additional terms to the model.

The final result shows how well the telescope can point, and what coefficients need to be employed to achieve this result. The coefficients that *TPoint* produces (that is, the value of each pointing term) are then saved in the *TPoint Settings* file. The *TPoint* model is then used by *TheSkyX* to adjust the right ascension and declination coordinates issued to the telescope control system, so that the pointing accuracy is improved.

How Accurate Does the Telescope Point?

The pointing accuracy of your go to or robotic telescope is depends on the integrity of your telescope mount, the optical tube assembly, pier, mounting rings, camera mounting and other imaging system components. Even small mechanical errors manifest themselves as pointing errors. If the mechanical errors are repeatable, then *TPoint* will likely be able to determine their magnitude and correct them.

Random errors, such as mirror flop, focusing shift, backlash and others, fall into the category of hysteresis and must be dealt with separately. For example, locking the mirror on an SCT will virtually eliminate the random errors introduced by mirror flop.

Since these errors are random, or somewhat random in nature, a model cannot be created that can correctly predict the size of the errors at all pointing positions. Spending some time at the telescope with a simple video system can expose many of these non-repeatable errors. For example, if the focus is approached from both directions while the telescope is centered on an object, any focus shift (backlash in the focuser or mirror slop) should become apparent.

On most amateur systems, root mean square (RMS) pointing of two arcminutes or better can be achieved without great difficulty. Robust amateur systems can achieve 15-30 *arcsecond* RMS pointing.

TPoint cannot make a silk purse out of a sow's ear. The ultimate results cannot be any better than the resolution of the encoders and any hysteresis effects (for example mirror slop). What *TPoint* will do is get the most accurate pointing possible from your telescope.

The TPoint Approach

The general approach taken by *TPoint* is the telescope model should describe real effects (geometrical misalignments, well understood flexures, etc.), and empirical functions should be used only to "mop up" any remaining systematic errors. There is a school of thought that advocates using empirical functions (for example polynomials or spherical harmonics) for the whole job. However, the *TPoint* approach has many advantages.

Simple geometrical misalignments might require very complicated empirical functions but are simple to deal with analytically. Direct manipulation of certain geometrical terms while the telescope is in operation can be very useful. An important application of this technique on professional telescopes is where a star is switched from one instrument aperture to another simply by changing the collimation parameters. Another example is where the polar axis of a wide field telescope is routinely raised and lowered as a function of declination, to minimize the field rotation effects of differential refraction. The polar axis elevation parameter in the pointing model can simply be changed by the same amount and accurate pointing is maintained.

A realistic model of a telescope frequently exposes mechanical deficiencies, which can then be diagnosed and cured. A realistic model is likely to require fewer terms, and the number of stars observed in a pointing test can be correspondingly smaller. Physically based models are less likely to misbehave when extrapolating outside the area covered by the available test data.

Interaction with TheSkyX

Pointing calibration requires slewing the telescope to a number of known objects (or positions) in the sky. *TPoint* works with *TheSkyX* to provide a set of software tools that make pointing calibration straightforward.

TheSkyX performs the following functions during calibration.

- Oversees telescope control by sending coordinates to the telescope.
- Records the star coordinates and telescope coordinates used by *TPoint*.
- Maintains a visual history of pointing data.
- Once a model is established, it makes adjustments to telescope coordinates so that pointing is improved.

Setting up TPoint for Telescope Use

TheSkyX must be able to control the telescope (issue slew commands) in order to collect *TPoint* pointing data.

How TheSkyX and TPoint Interact

TPoint uses the pointing data to analyze and improve your telescope's pointing. This involves slewing the telescope to a number of different points in the sky, then recording the actual destination and the desired destination of the telescope. *TheSkyX* is a very efficient tool for gathering this data.

After six pointing samples are collected, *TPoint* generates a model of the telescope's pointing. *TheSkyX* uses this model to modify the telescope's destination coordinates each time a slew command is issued.

TPoint works "invisibly" in the background when controlling your telescope with *TheSkyX*. The green check mark on the *TPoint* graph indicates that telescope modeling is enabled.
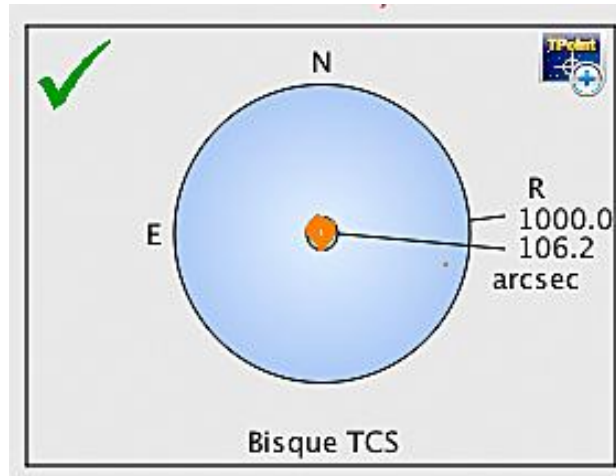
Figure 8: The green checkmark on the TPoint window indicates that telescope modeling is enabled.   The TPoint icon with a plus sign indicates that additional pointing samples can be added to the pointing data.

Collecting Pointing Data

To begin collecting pointing samples, start *TheSkyX* and establish a link with the telescope by clicking the **Connect Telescope** command from the Telescope menu. Next, perform any initialization or synchronization that is required by the telescope's control system.

Once communication is established between *TheSkyX* and the telescope, you are ready to start collecting pointing samples. At *least* six calibration points are needed before *TPoint* can improve the pointing of the telescope. After six pointing samples are collected, you should notice considerable improvement in pointing accuracy.

If you are using a German equatorial mount, continue collecting pointing samples *on one side of the meridian* initially. Polar misalignment and errors due to non-orthogonalities in the mechanical and optical axes can make locating stars "on the other side of the meridian" difficult until a more thorough model is established. See "Using TPoint to Quantify Polar Alignment" on page 30 for more information.

German Equatorial Mounts

In order to collect and record a pointing sample on a German equatorial mount (GEM), *TheSkyX* and *TPoint* must obtain the mount's equatorial coordinates, *and*, unambiguously determine whether or not the optical tube assembly (OTA) end of the declination axis is East or West of the pier.

When the OTA end of the declination axis is East of the pier, the telescope's declination (**Scope Dec** on the **Calibration Run Report**, see page 16*)* is recorded as

180° minus the star declination (**Star Dec**). With this convention, *TPoint* can create an all-sky pointing model from a single set of pointing calibration data.

Astro-physics, Gemini, iOptron and Paramount command protocols provide "side of pier" information so that pointing calibration data is conventionally correct, regardless of the orientation OTA.

The Celestron NexStar and Meade Instruments GEM command protocols do not provide a mechanism to unambiguously determine the side of pier. This means if, when collecting pointing samples, the OTA end of the declination axis is below the counterweight shaft, the recorded **Scope Dec** will not adhere to the coordinate convention. A TPoint model based on this data would be invalid.

Configuring TheSkyX and the TPoint Add On for GEMs

If your NexStar or Meade Instruments mount is a GEM (not an equatorially mounted fork), before collecting pointing calibration data, make sure to turn on the **German Equatorial Mount** option on the **NexStar** or **Meade** windows, respectively. These windows can be turned on from the **Display** menu.
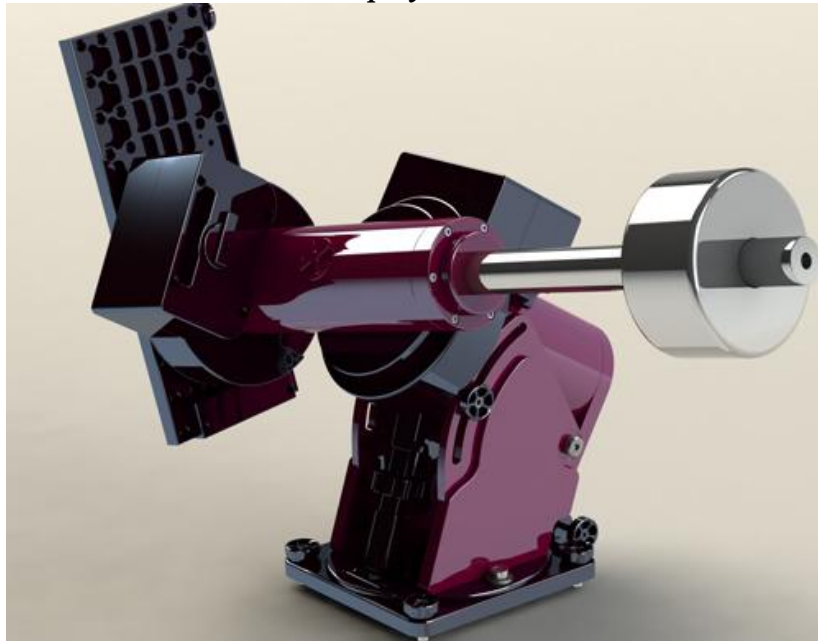
Figure 9: This photo is an example of a GEM in an orientation where the OTA end of the declination axis is below the counterweights. For NexStar and Meade GEMs, collecting a pointing sample when the mount is in this orientation will result in "invalid" pointing data.

For GEMs that *do not* provide side of pier information, you must ensure the OTA end of the declination axis is always above the counterweights when collecting pointing samples. This will ensure that the correct **Scope Dec** will be recorded.

Centering Stars in the Eyepiece or Sensor

There are a number of different methods that can be used to center a star once the telescope control system has been directed at the star's coordinates. Each method (described below) has particular advantages and disadvantages.

A commonly asked question is, *"What focal length should be used?"* Of course, the longer the focal length, the more accurately you will able to center the target. However, using too much magnification can hinder the pointing sample collection process, especially when it is the first time a) the telescope has been calibrated or b) you have used *TPoint*. If the telescope is pointing poorly, locating and centering objects at high magnification becomes an arduous task.

CCD Camera	The goal is to have objects fall on a CCD detector the first slew, so there are obvious advantages to using the CCD camera to perform a calibration run. If the video camera is not centered in the exact same position as the CCD, there will be a consistent pointing error once the video is replaced with the CCD. Of course this offset can be corrected using *TPoint* but this requires an additional step.
Reticle Eyepiece	The simplest method is using a reticle eyepiece. Many eyepieces are available with the reticle lines illuminated, making it much easier to center an object. This method has the benefits of requiring a minimum amount of hardware. However, it does require the user physically views and centers each star – which can be difficult on some telescopes.
Video Camera	A low-light video camera is generally the most efficient method of centering a star at a given location in the focal plane since the gymnastics of placing an eye in the telescope eyepiece is removed. As well, there is no integration and download time associated with each observation as there is with a CCD camera. Be sure to check the focal plane relationship between the video and CCD detector to insure they match satisfactorily.

Overview of Centering Methods

The table below lists some advantages and disadvantages for each centering method.

	Advantages	Disadvantages
Reticle Eyepiece	• Simple; no additional electronics are required.	• Requires manual, visual observations at each pointing sample.
Video Camera	• Efficient, no climbing around the telescope to look into the eyepiece. • No integration and download times when compared to a CCD. • A suitable video camera can be	• Once the pointing model is established, the video camera is normally replaced by a CCD camera for imaging. This will require you recalibrate the model in order to adjust the

	purchased for about the same price as an eyepiece.	model for the new instrument.
CCD Camera and Automated Pointing Calibration	• Use a single instrument for collecting pointing samples and imaging; no additional collimation error adjustments are necessary. • Software collects the data for you.	

Collecting Pointing Data

1. Initialize the telescope (see *TheSkyX*'s documentation for details how to do so.)
2. From *TheSkyX*, click on a star, or use the **Edit > Find** command to show its information. Hint: Choose one that is near the telescope's current position so a long slew is not required. *TheSkyX* uses the equatorial coordinates of the star listed in the Object Information dialog box as the baseline position of the telescope.
3. Click the **Slew** button on the **Telescope** window.
4. Using the **Motion Controls** on the **Telescope** window (or the telescope's hand paddle or joystick), to center the star on the current detector (that is, in the eyepiece, on the video display, or on a CCD image).
5. Once the object is centered on the detector, click the **Add Pointing Sample** button on the Telescope window. *TheSkyX* will issue a warning message if the object's coordinates are more than 30 arcminutes from the telescope's coordinates. When the **Add Pointing Sample** button is clicked (and all else is okay), *TPoint* logs the star's coordinates and the telescope's current coordinates.

Repeat the above steps for each pointing sample. A minimum of six pointing samples are required to compute a *TPoint* model. The maximum number of pointing samples to use in the model depends on how accurate you need the telescope to point.

When you are finished collecting pointing samples, click the **Finish** button on the **Calibration Run** tab of the **TPoint Add On** window. This establishes the set of pointing samples, called the **Pointing Data**, which is used to create a pointing model.

After the **Finish** button is clicked, additional pointing samples *cannot be added* to the **Pointing Data**. If you attempt to do so, the **Start Calibration Run** dialog is show, giving you the option to perform a **Full Calibration Run**, or to **Recalibrate Permanently Mounted Telescope**.

Calibration Run Options

Show Pointing Data

Draw a symbol on the Sky Chart to show the position of each pointing sample.

Show Pointing Data Path

Show the path of the telescope while collecting the pointing data.

Automatically Update Model

Turn this on this checkbox to automatically update the pointing model when new terms are added.

Show Only Bright Stars

Click this button to turn off fainter stars (magnitude 7 and higher) and the planets. Hiding these objects will minimize potential misidentification of calibration stars when collecting pointing data with a video camera or an eyepiece.

Undo Show Only Bright Stars

Click this button to turn on the planets and fainter stars that were turned off using the *Show Only Bright Stars* button.

Pointing Data – How Many Points and Where?

The number and distribution of pointing samples is dependent on the pointing goal for the system and the system itself. Permanently mounted telescopes are better suited for extensive pointing runs (that is, up to hundreds of pointing samples) since the pointing model will probably remain unchanged for a long period of time.

A preliminary assessment of a telescope's improved pointing capabilities can be made using perhaps 20-30 pointing samples. More extensive calibration runs of 50-100 pointing samples (or more) provide *TPoint* with the necessary data to create a robust pointing model. See "Automated Pointing Calibration" on page 36 for more information.

On amateur systems, performing calibration runs of 30 to 100 points usually result in RMS pointing of one to two arcminutes; less than one arcminute and better RMS pointing is possible on higher-end mounts and collecting more pointing samples.

Hint: Avoid collecting pointing samples below 10 degrees altitude or so, where distortion due to atmospheric refraction causes large offsets between the actual position of the object and its observed position. Although *TheSkyX* and *TPoint* make refraction calculations, computing the exact positions of objects "down in the muck" is difficult.

The first six pointing samples should be in the same region of the sky, separated by a few degrees, and on the same side of the meridian. Using the method, the benefits of

the model can be utilized as you migrate away from these stars, making the collecting the remaining pointing samples easier.

Keep an eye on the scatter diagram while collecting pointing samples. If you misidentify a star, the RMS pointing will drastically increase, up to thousands of arcseconds. When this happens, you need to turn off the sample so that it is not used in the model. To do so, either click pointing sample rectangle on the *TPoint Add On* window's scatter diagram, then click the *Ignore Pointing Sample Number N* command. Or turn off the checkmark next to the pointing sample on the *Pointing Data* spreadsheet in the *TPoint Add On* window's *Calibration Run* tab.

Pointing samples and the telescope's path during a calibration run are added to the sky chart as *My Chart Element Reference Points* and *Reference Line* objects. These *horizon-based* objects are a useful visual reference of the pointing sample history.
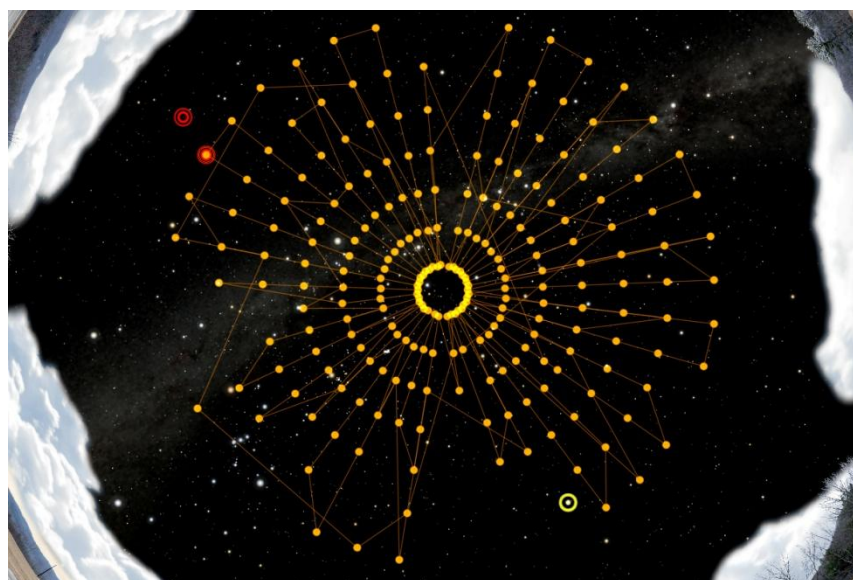
Figure 10: Pointing samples on the Sky Chart. The lines that connect these dots represent the telescope's path.

Turn off the *Show Pointing Data* and *Show Pointing Data Path* checkboxes on the *Calibration Run* tab of the *TPoint Add On* window to hide them. They can be removed permanently by clicking the *Remove All* button on the *My Chart Elements* window from the *Input* menu.

Creating and Using a TPoint Model

In earlier versions of TPoint, a pointing model beyond the six standard equatorial terms had to be constructed manually based on the rules outlined in section "Adding Terms" on page 67.

While the models developed using this technique often achieved very good telescope pointing, the process proved to be somewhat daunting and error prone for many.

A looming question always seemed to remain, "How do I really know that I'm getting the best pointing for my imaging system?"

Introducing the Super Model

The "Super Model" feature automatically determines the best pointing model for your imaging system. Clicking the ***Super Model*** button (Figure 15) performs an extensive statistical analysis of the pointing calibration data and converges on the optimal pointing model using all the processing power of your computer.

The *Super Model* algorithm goes far beyond the iterative approach discussed above and removes the drudgery of creating a pointing model.

Patrick Wallace, the TPoint and Super Model author, comments:

"The modeling has to explore a large multidimensional parameter space, applying strict statistical tests, and despite a myriad of optimizations this inevitably means a large amount of processing time. The application is extremely careful about efficient use of machine resources; the length of time the computations take is purely a reflection of the difficulty of the task."

The length of time required to find the Super Model mainly depends on:

- the number of calibration points in the data set.
- the speed of the computer's CPU.
- when multiple CPU's are available, the more CPUs, the faster (when the ***Use All CPUs*** checkbox is turned on, see page 26).
- The operating system and the operating system's architecture (32- or 64-bit).

Computing a Super Model for 250 calibration points on a single 3.0 GHz CPU on Windows XP 32 takes about 90 seconds. A 4 CPU machine using the same dataset takes about 55 seconds. Large calibration runs (up to 1000 points maximum) on a single CPU can take more than 10 minutes. An 830 calibration point run on an eight-CPU 2.93 GHz Windows 7 64-bit machine using all 8 CPUs takes just over 120 seconds.

Analyzing the Super Model Results

The resulting Super Model will shed light on the integrity of your imaging system. If the TPoint model shows an RMS of about 15 arcseconds or better for a permanently mounted system, you've most likely reached the *"best pointing possible for an amateur telescope"* limit. If the RMS pointing is greater than about 30 arcseconds or so for a permanently mounted system, or greater than one arcminute for a portable

system, and you want to do better, it's time to analyze every single component of your imaging system do determine the source of the pointing errors.

- Is the telescope's mirror fixed? Mirror slop will introduce pointing errors. If possible, fix the mirror in place to minimize this error.
- How is the optical tube assembly attached to the mount? OTA mounting rings provide the most repeatable and reliable pointing. Dovetail mounting introduce flexure and can degrade pointing accuracy.
- How is the mount attached to the pier? Make sure all mounting bolts are tight so that the mount cannot move when the equipment is slewed to different parts of the celestial sphere.
- How is the pier attached to the ground? A solid and rigid mounting to a concrete foundation is critical.
- Are cameras, guiders, focusers, filter wheels and other devices mounted to the OTA bending, flexing or shifting as the mount slews to different areas of the sky?
- How much backlash is in the mount's gears?

The ultimate question you must answer is, "How accurate does my pointing need to be for my imaging system and my observing goals?" No matter what the answer, the *TPoint Add On* will help you achieve your goals.

A Super Model Example

The following example shows the pointing accuracy obtained with a "high quality" imaging system. The pointing calibration data was collected using the Automated Calibration feature (see "Automated Pointing Calibration" on page 36) on a permanently mounted, accurately polar aligned Paramount ME carrying a ring mounted C-14 with the mirror locked in place. The SBIG ST-8 was rigidly attached to an Optec TCS focuser and all cables routed so that there was no drag or sag on the system.

Note that the 831 pointing samples are used for demonstration purposes only. A 300 calibration point run will produce similar pointing accuracy, as well as excellent ProTrack results (on Paramount ME and Paramount MX mounts).
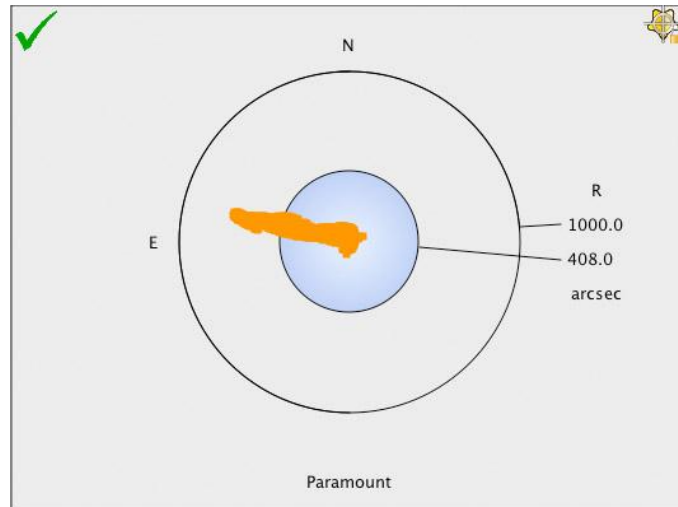
Figure 11: A scatter diagram of an 831 point calibration Run with no terms in the model.

Figure 11 shows a scatter diagram of the system's pointing accuracy with *no terms* in the pointing model. With no *TPoint* modeling, the all sky pointing accuracy is 408 arcseconds (*6.8 arcminutes*). Not great pointing, for sure.

Remember, this high quality system has minimal hysteresis, but the pointing accuracy is degraded by inherent "errors" from the optical and mechanical axis misalignments, gear errors, and so on. In other words, even with a "high end" imaging system, the blind pointing accuracy will not be sufficient to routinely place objects in a relative small field of view.
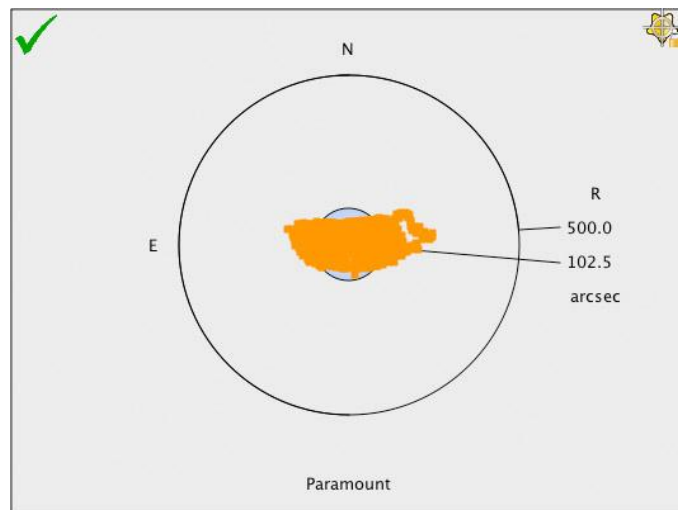
Figure 12: Pointing accuracy using the six standard terms.

Figure 12 shows that the pointing accuracy is improved significantly by adding the six standard terms. With the IH, ID, NP, CH, ME and MA terms, the model's RMS pointing is now 102.5 arcseconds (1.7 arcminutes). Better. But not super, yet.

Bring in the Super Model
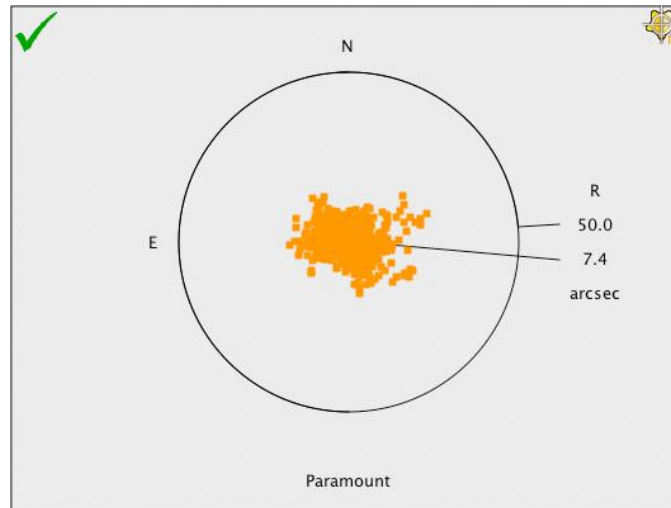
Figure 13: Scatter diagram showing pointing after applying a Super Model.

Figure 13 shows the scatter diagram after applying the terms from the Super Model. The RMS pointing is now *7 arcseconds*. Every object is placed very near the center of a 6 x 10 arcminute field of view.
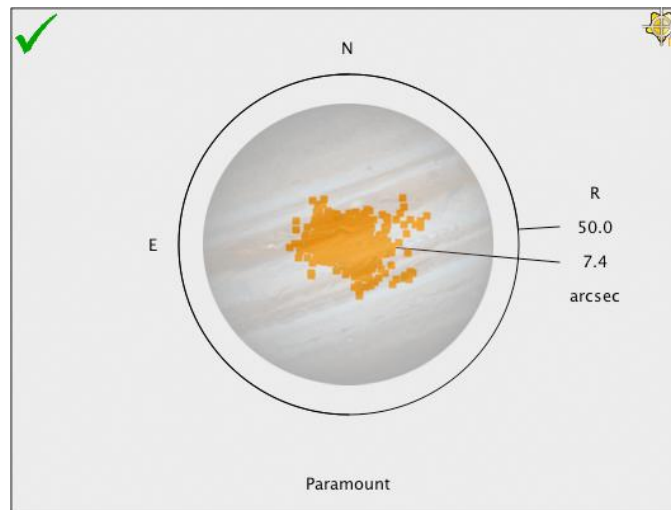
Figure 14: Scatter diagram with the planet Jupiter superimposed for scale.
(Jupiter's apparent size varies from about 30 arcseconds to about 50 arcseconds.)

Figure 14 shows the approximate relative size of the planet Jupiter on the scatter diagram. Now that's super pointing!

Super Model button

Once you have collected approximately 30 calibration points, click the *Super Model* button on the *Model* tab of the *TPoint Add On* window to create the optimal pointing model.
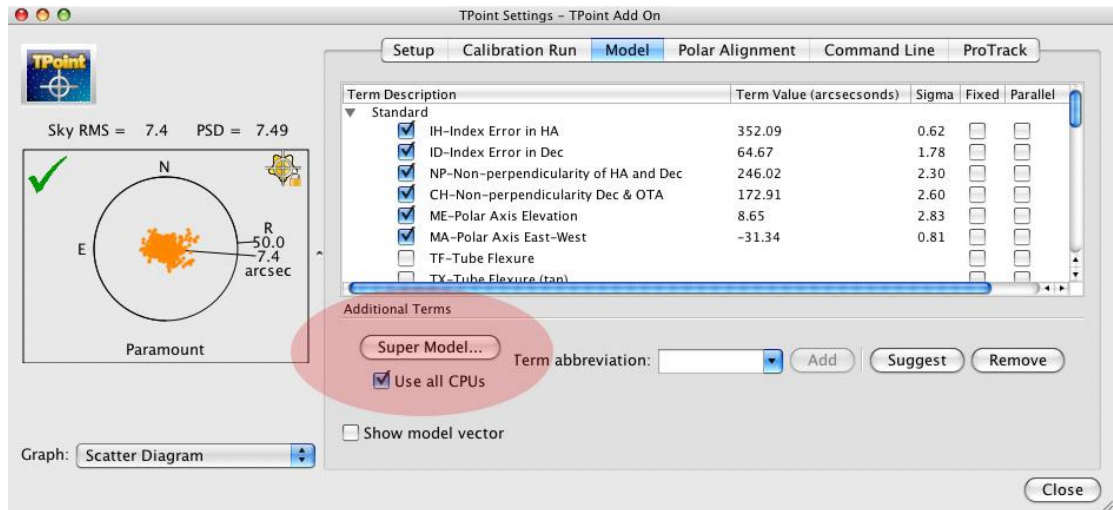
Figure 15: The Super Model button, highlighted in red, is located on the Model tab of the TPoint Add On window.

Use All CPUs

Turn on this check box to use all the available central processing units (CPUs) on your computer when computing the Super Model. Please see "Super Model and Parallel Processing" on page 27 for an in depth discussion on this subject.

The Super Model Status window shows the progress and the total run time in minutes and seconds. Depending on the speed of your computer, computing a super model can take several minutes or more.
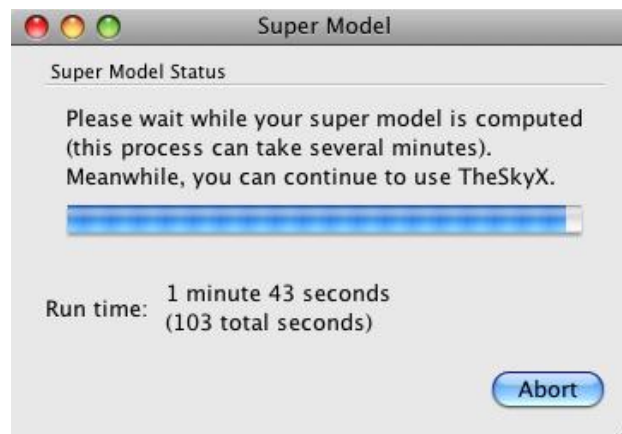
Figure 16: The Super Model Status window.

Abort

Click the Abort button on the Super Model Status window to end the computation process.

The Super Model Window shows the total run time, and Super Model results.
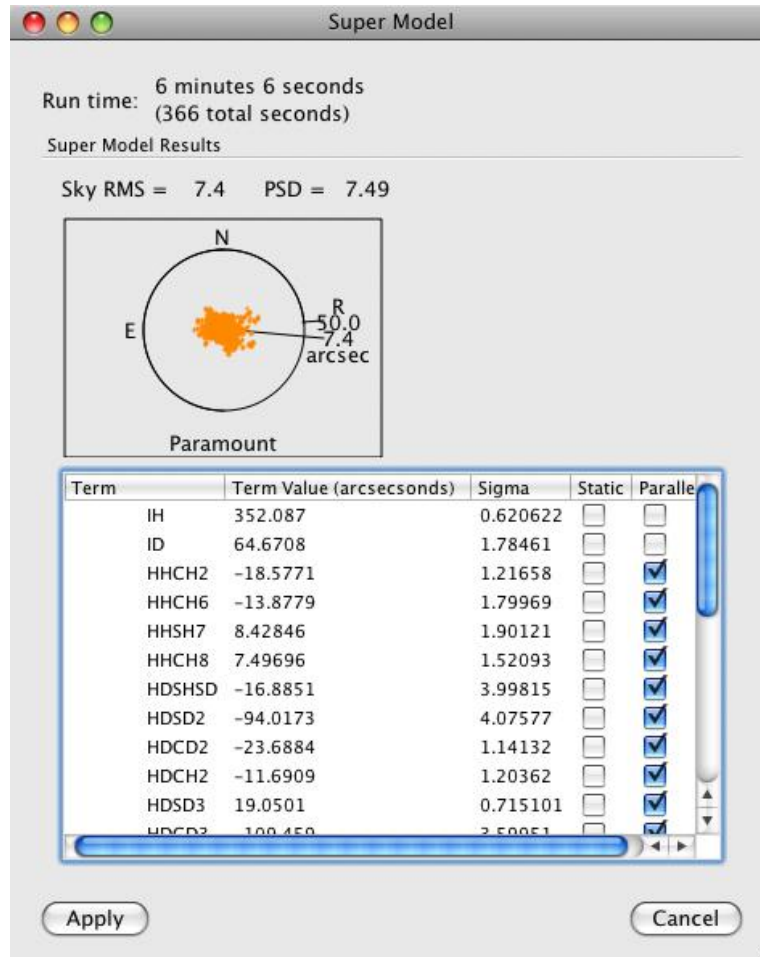
Figure 17: The Super Model window showing the optimal model for your data.

Apply

Click the *Apply* button to update the terms in the TPoint model to use the Super Model.

Super Model and Parallel Processing

Computing a Super Model is an extremely processor intensive process, and the more pointing samples, the more time required to determine the solution. If your computer has multiple processors, turn on the *Use All CPUs* checkbox (page 26) to divide the work across every processor.
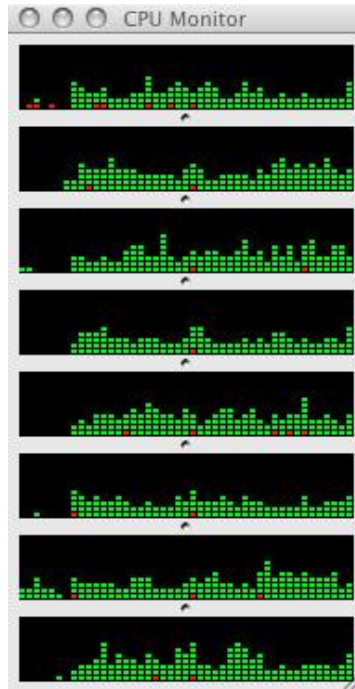
**Figure 18: The Mac CPU Monitor Window showing the CPU usage during a Super
Model run (eight CPU machine).**

Figure 18 shows the Mac's CPU monitor window during a Super Model run. The
graphs of the CPU usage show that, while every processor is being used, not *100
percent* of the processing capability each CPU is utilized. The obvious question is,
"Why not?" The following analogy attempts to explain why optimal parallel
processing isn't always possible for a given task.

Take, for example, the process of shutting down an observatory that has a roll off
roof, where the entire process consists of two tasks (shown in the table below):

Task	Description	Time to Complete (seconds)*
1	Slew the mount to the park position	30
2	Close the roll off roof	30

*For this example, we assume that each task cannot be completed in less time.

Case A	If both tasks can be run simultaneously, the time to shut down the observatory is 30 seconds
Case B	If the roll off roof can strike mount unless the mount is at its park position, both tasks cannot be run simultaneously. Task 2 must follow the completion of Task 1. So, the time required to shut down the observatory in this case is 60 seconds.

Most sophisticated computations like Super Model are analogous to case B. In other words, parallel processing is prohibited because of the nature of the algorithm where tasks and or computations depend on an earlier computations being completed first. *Only when computations are completely independent can they be run in parallel.*

Super Model FAQs

Question: There are terms used in the Super Model that don't seem to apply to my imaging system. Should I remove them?

Answer: For optimal pointing accuracy, the best practice is to use all the terms in the Super Model and not make *any* adjustments. In order to achieve optimal pointing, the Super Model algorithm:

- Removes statistically invalid points
- Adds terms to the model is the specific (optimal) order
- Fixes specific terms in the model
- Adds terms in parallel

Changing, adding or removing terms makes the Super Model less effective.

Question: My computer has eight CPUs, why isn't Super Model eight times faster when the Use All CPUs checkbox is turned on?

Answer: Given the nature of the Super Model algorithm, fewer than 50% of the computations can be performed in parallel (see the observatory shut down analogy above). Therefore, on a given computer, the best possible speed increase is about 50%, or nearly 2 times as fast.

Question: Why don't all my CPUs "peg" when computing a Super Model?

Answer: Given the nature of the Super Model algorithm, fewer than 50% of the computations can be performed in parallel (see the observatory shut down analogy above). Moreover, for this particular task, the parallel computations are short lived and the overall algorithm goes in and out of serial and parallel processing as necessary. Pegged CPUs do not tell the whole story; the Super Model "Total Run Time" when the Use All CPU's checkbox is turned on and off reveals the benefits of parallel processing for this task.

Question: How do you compute how many times faster the Super Model is using all CPUs?

Answer: For a given set pointing calibration data, run the Super Model with the *Use All CPUs* checkbox turned on and off and compare the Run Times (see Figure 17).

Run Time using a single CPU = 100
Run Time using all CPUs = 50
Times Faster = (100-50)/50 = 2

The inverse of this result is the percent faster: ½ = 50% faster.

Using TPoint to Quantify Polar Alignment

Equatorially mounted telescopes need to be aligned with the celestial pole before they can point and track accurately. Although there are many different techniques for aligning a mount with the pole, *TPoint* works best.

The pointing samples you collect can be used by *TPoint* to determine the magnitude (in arcseconds) of polar misalignment in altitude and azimuth. Once the misalignment has been quantified, you can to adjust the mount's azimuth and altitude axes. This process can be repeated until the desired polar alignment is attained.

Once you are familiar with process of telescope calibration, you can begin a calibration run. If the mount's polar alignment is way off, even short "star-hopping" slews will require the destination star to be re-centered in the eyepiece.

Testing Polar Alignment

After synchronizing the telescope on a known star, slew the mount to a second star, two or three degrees away. If the star does not fall near the field of view of a typical eyepiece, the polar alignment is probably way off.

Assessing Polar Alignment

Use *TPoint* to assess the polar alignment of your mount by collecting six to ten pointing samples. Using the bright stars in a constellation (Ursa Major, for example) works well.

After six pointing samples are collected, the telescope's pointing accuracy should improve noticeably.

Procedure for Assessing Telescope Calibration and Polar Alignment

1. Accurately set the computer clock each night. Inaccurate time introduces right ascension offset errors.
2. On the *TPoint Add On* window, click the *New* command from the *TPoint Add On Settings* pop-up menu on the *Setup* tab.
3. On the *Calibration Run* tab, click the *Start* button.
4. Synchronize the telescope on a bright star. When performing a *TPoint* calibration, synchronize the telescope *once* for each run. Synchronizing more than once requires a new *TPoint* model.
5. Click *OK* on the *Start Calibration Run* dialog (page 44).
6. Slew to a nearby star (by identifying the star in *TheSkyX* and clicking the *Slew* button), center the star in the eyepiece, and then click the *Add Pointing Sample* button. The pointing data now has one pointing sample. After collecting six pointing samples, pointing should greatly improve. Now,

you're ready to collect pointing samples over a larger portion of the actual night sky.

7. After collecting about 20 pointing samples, click the **Model** tab and add additional terms to the *TPoint* model so that the RMS value is as small as possible, without increasing the PSD value.

8. Review the suggestions in the polar alignment report by clicking the **Polar Alignment** tab on the *TPoint Add On* window. Adjust the mount's polar axis accordingly.

9. Repeat steps 2-9 until the polar alignment is sufficiently close. The polar alignment report will indicate when no further adjustments are needed.
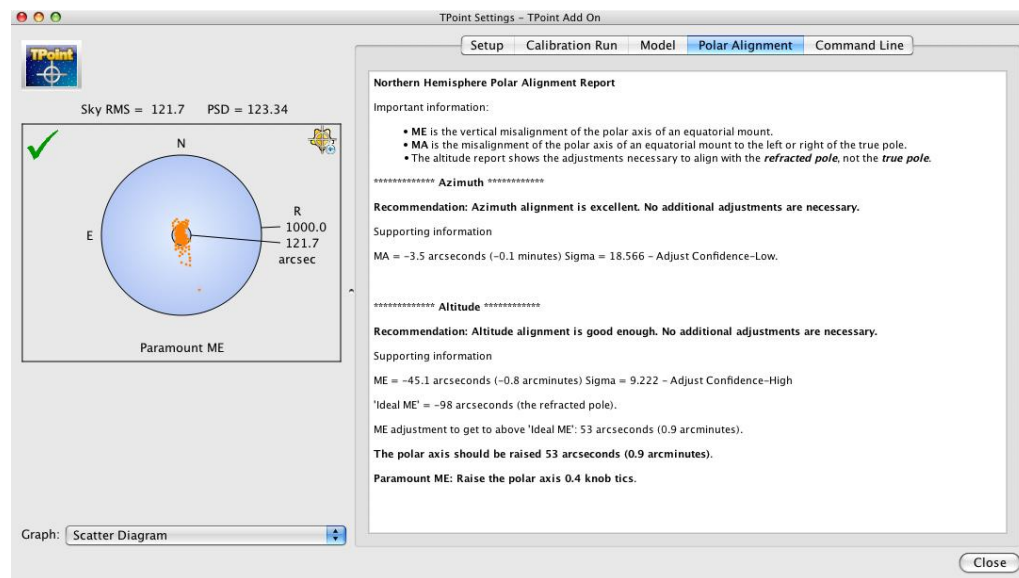
Figure 19: Sample Polar Alignment Report.

Optimum Location of the Polar Axis

The optimum polar axis setting depends on what declination and hour angle you're observing. For observations on the meridian, somewhere between the true and refracted pole is best. Ideally, one should shoot for the refracted pole.

The *TPoint* **Polar Alignment Report** on the **Polar Alignment** tab makes suggestions to align with the refracted pole automatically. For reference, the table below shows the angular distance (in arcseconds) between the refracted and unrefracted poles for different latitudes and elevations for reference.

Angular Distance Between the Refracted and Unrefracted Poles (Latitude vs. Elevation)								
Latitude (deg.)	0m	250m	500m	1000m	1500m	2000m	2500m	3000m
85	5	5	5	4	4	4	4	4
80	10	10	9	9	8	8	8	7
75	15	15	14	14	13	12	12	11
70	20	20	19	18	17	17	16	15
65	26	25	25	24	22	21	20	19
60	32	31	31	29	28	26	25	24
55	39	38	37	35	34	32	30	29

50	47	46	45	42	40	38	36	35
45	56	54	53	50	48	46	43	41
40	66	65	63	60	57	54	52	49
35	80	78	76	72	68	65	62	59
30	96	94	92	87	83	79	75	71
25	119	116	113	108	102	98	93	88
20	152	148	145	138	131	125	118	113
15	205	200	195	185	176	168	160	152
10	305	298	290	276	263	250	238	227

Restoring the Model Each Night

A model remains valid each night if the telescope control system can be synchronized *identically* (to less than one arcsecond) with the celestial sphere *and* an accurate time base is used each night.

Inaccurate time results in a pointing error that is identical to an Index (IH term) error in right ascension. If an accurate local time (within one second of GMT) cannot be achieved, recalibration is required to establish the terms IH, ID, and possibly CH.

A single *TPoint* model can be used night after night, and *does not require* a recalibration for telescopes that use absolute encoders or an absolute positioning system like the Software Bisque Paramount ME. Paramount ME owners are strongly encouraged to carefully read the Paramount ME User Guide regarding night to night startup procedures.

If your "go to" telescope mount does not have absolute encoders, or cannot restore the telescope's position to within one arcsecond when unparking, or must be initialized by synchronizing at least one star, then you will have to *recalibrate* (page 34) each night to reestablish the IH, ID and possibly CH terms.

Using a Model from Night to Night

The nightly setup routine required for optimal TPoint-assisted pointing depends on your observing setup and your hardware.

- For portable mounts, a new calibration run must be performed each time the mount is setup.
- For permanent installations, a single model can be used each night. However, in order to reuse a model, the physical setup of the mount cannot change, precise equatorial coordinates of the mount must be restored from the previous night's observing session and an accurate time base must be used.

Whether or not the telescope's position can be restored each night depends on the capabilities of the telescope.

- If the position of the telescope can be approximately preserved from night to night by parking and unparking the mount, then the model from a previous night's pointing data can be restored using a process called recalibration (page 34). Mounts that provide the ability to park and unpark still require recalibration since the mount's equatorial coordinates are typically not restored with sufficient accuracy to maintain the offset terms (IH, ID, CH).

- If the mount's position can be restored each night to the nearest arcsecond or so, and an accurate time base is maintained, then no recalibration is necessary. The Paramount ME, for example, can restore the mount's position each observing session to with 1/3 of an arcsecond so that the previous night's model can be used.

A limitation of the *TPoint Add On* is that observations *cannot* be accumulated into a single model from night to night. A model can be carried forward to subsequent observing sessions through recalibration, but pointing samples from night to night *cannot* be combined.

Additionally, changing the CCD camera or optical configuration requires the offset terms, IH, ID and CH, to be recomputed. This can be accomplished through *recalibration* (see "Recalibration" on page 34) so that *TPoint* has additional pointing samples to reestablish the model.

Recalibration

After you have established a *TPoint* model that includes *fifty or more pointing samples*, you'll want to use it on subsequent nights to improve your telescope's pointing.

In order to use a TPoint model in future imaging sessions, it must be *recalibrated* each night. Recalibration is a procedure that reestablishes the relationship between the telescope and an existing *TPoint* pointing model. Recalibration is usually performed at the beginning of each observing session on telescope mounts that cannot be homed, or cannot be unparked to an accuracy of one arcsecond, or that do not employ absolute encoders.

For permanent installations, most of the mount's geometrical errors remain constant from night to night. Therefore, the terms in an existing model can remain fixed even when the telescope is "re synchronized". For example, the polar misalignment terms, non-perpendicularity terms and tube flexure terms do not change unless physical adjustments are made to the telescope.

However, the terms representing the Hour Angle offset (IH) and the declination offset (ID) are "polluted" (and become meaningless) when the telescope is synchronized on an arbitrary star. The errors for each term at the synchronization coordinates are unknown. Even if a model exists that more closely estimates the pointing effects at the synchronization position, we do not know the exact magnitude of each term at this position.

Additionally, the axis of the imaging device may change slightly when exchanging the CCD camera with an eyepiece. This will be manifested by a change in the CH term (OTA/Declination axis perpendicularity) when a new model is created. Recalibration allows CH to vary along with IH and ID.

Note: Synchronizing the telescope on a single star with existing model can result in sufficiently accurate all-sky pointing. If the goal for the evening is to slew to and image only a few objects, the recalibration data can include just a single star.

Whereas a calibration run involves fifty or more pointing samples, and all pointing terms are subject to modification, recalibration requires only six pointing samples. These samples are used to establish new values for the offset terms IH and ID and CH *only*. The remaining terms, such as like polar alignment (ME and MA) remain fixed.

A Step-By-Step Guide to Recalibration

Recalibration is required when using a mount that, without *TPoint*, would have to be re-synchronized on a star each night, or whenever the physical mounting of the camera, focuser, filter wheel or other imaging equipment has been altered or changed on a permanently mounted telescope that has an established pointing model. Think of a recalibration as a "six or more pointing sample synchronization" that reestablishes the geometric terms in an existing *TPoint* model.

The following instructions describe the recalibration procedure. Note that a working TPoint model must exist and be marked as "finished" before recalibration can be performed.

1. From *TheSkyX*, click the **Connect** command from the **Telescope** menu.
2. Slew the telescope to a known star, then center the star in the eyepiece.
3. Click the **Add Pointing Sample** button on the **Telescope** window.
4. On the **Start Calibration Run** dialog, click the **Recalibrate Permanently Mounted Telescope** radio button and click **OK**.
5. Click the **Finish** button after six pointing samples have been collected.

Important Recalibration Notes

- Fewer pointing samples *could be* used to recalibrate the pointing model, however, in order to "pin down" the **CH** term, a minimum of *six* pointing samples should be acquired.
- During recalibration, it is very important to point to a star or two at a high declination, say above +80° (in the northern hemisphere or below −80° declination in the southern hemisphere), as well as one or two near the celestial equator. This is so that TPoint can distinguish between the HA sync error, IH, and the OTA/declination non-perpendicularity, CH. Both terms are east–west shifts, and at low declination they mimic one another. CH gives you the same error on the sky wherever you are; IH matters at low declinations, but has a decreasing effect as you approach the pole. It is *essential* to provide TPoint with pointing samples that allow the two effects to be disentangled.

- • The pointing samples collected during recalibration (and displayed on the Sky Chart) will be offset from the actual star position by the amount of the pointing error in that part of the sky. This is expected behavior and is not cause for alarm.

The model's six basic terms have now been reestablished for the current observing session.

What happens during recalibration?

Recalibration establishes the relationship between the telescope and the celestial sphere.

Restarting or synchronizing each night introduces new offset errors in the model; therefore, the offset error terms IH and ID must be reestablished by pointing to at least six stars.

Suppose, using 100 pointing samples for a given model, the non-perpendicularity between the right ascension and declination axis is determined to be 425 arcseconds. This value of term will be "static" or fixed at 425 arcseconds from night to night.

Recalibration does not alter or change the value of static terms. Only the offset terms IH, ID and CH are changed. A new CH term value must be established each session to account for changes to the imaging system, including the use of a different CCD camera, or after rotating a diagonal mirror, or the swapping optical tube assembly.

Modeling the Meade Instruments™ Mounts

Make sure *TPoint's* Pressure and Height are set to zero in the Observing Parameters dialog. This forces *TPoint* to ignore its refraction calculations (the LX200 and Autostar control system performs refraction calculations automatically). See the "Start Calibration Run Dialog" on page 44 for details.

Automated Pointing Calibration

PROFESSIONAL

TheSkyX Professional Edition with the *Camera Add On* and the *TPoint Add On* allow pointing samples to be acquired without human intervention through a process called *automated pointing calibration*. Once the *Camera Add On* has been configured to acquire CCD photos and your telescope and CCD camera's field of view parameters have been determined, the *TPoint Add On* can be used to generate a distribution of optimal azimuth and altitude *targets* that are used to point the telescope.

Figure 20: The yellow circles on the Sky Chart represent each azimuth and altitude target. The yellow line shows the path of the telescope.

During an automated calibration run, at each target, a CCD photo is acquired. Then an astrometric solution is computed (sometimes referred to as a *plate solve*) from the photo by comparing stars in the photo with stars from *TheSkyX's* star catalogs. The difference between the current position reported by the telescope and the actual coordinates computed from the astrometric center of the photo is recorded as a pointing sample (page 16).

This process is repeated for each target in the pointing calibration list.

Minimum Requirements for Automated Calibration

Before getting started, make sure your imaging system meets the following minimum requirements.

- *TheSkyX Professional Edition for Windows or Mac*. See *TheSkyX Professional and Serious Astronomer Edition User Guide* for details about setting up and using your camera. Note that *TheSkyX Serious Astronomer Edition* does not provide a mechanism to acquire CCD photos, so automated calibration is not possible with this Edition.
- A "go to" or robotic telescope mount that is can be controlled by *TheSkyX Professional Edition*.

TheSkyX Professional and Serious Astronomer User Guide describes how to configure *TheSkyX Professional Edition* to acquire photos using either the *Camera Add On* or *CCDSoft for Windows*. Please carefully review this documentation, and make sure that you can take photos with your camera before proceeding.

You also need to determine the *image scale*, in arcseconds per pixel, of your imaging system, as well as the *position angle* of the CCD camera after it has been mounted to your optical tube assembly. See the *Image Link* documentation *TheSkyX Professional and Serious Astronomer User Guide* for details how. Or, click the *Take And Image Link Photo* button on the *Automated Pointing Calibration Run* window to do this step for you.

Once you have configured *TheSkyX Professional Edition* to acquire CCD images and quantified your imaging system, you are ready to perform an automatic pointing calibration run.

Step-by-Step Automated Calibration

Once your imaging system has been setup and tested, performing an automated calibration is relatively straightforward.

Step A
1. Click the *Automated Calibration* button on the *Calibration Run* tab of the *TPoint Add On* dialog.
2. Click the *Setup* tab.
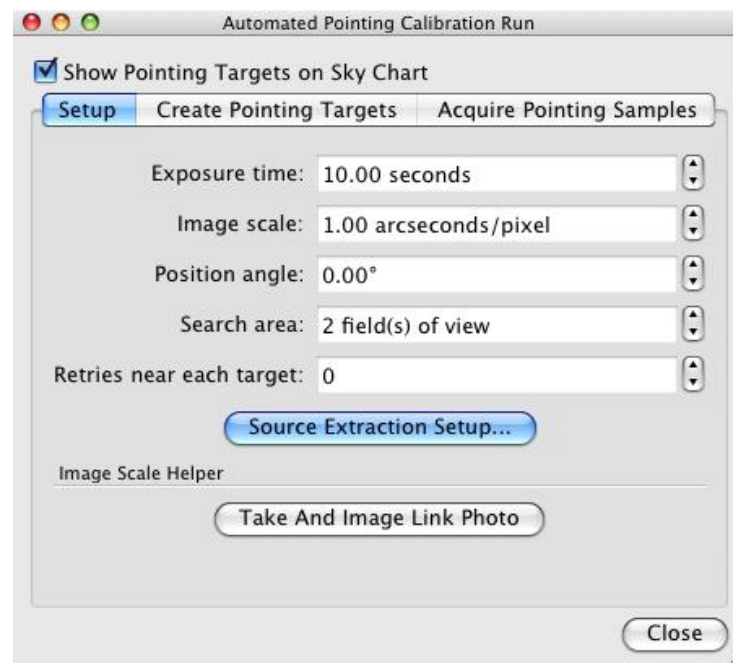
Figure 21: Setup tab on the Automated Pointing Calibration Run dialog.

3. Enter the *Exposure Time*, in seconds, for each pointing sample. You may have to experiment with your imaging system to determine optimal exposure times. For a cooled CCD camera on a typical-sized optical tube assembly, about 1-2 seconds is sufficient. The exposure time needs to be long enough to acquire at least six stars in the photo but short enough to avoid saturation and star "blooming."

4. Enter the ***Position Angle***, in degrees, that a photo acquired from your CCD camera generates (as measured from north to west in the northern hemisphere).
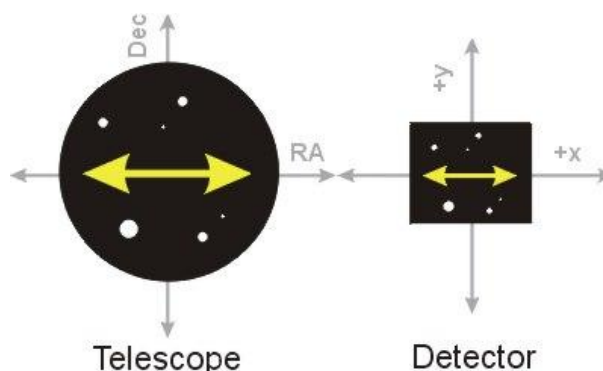
As **Figure 22: Recommended orientation for the CCD detector with respect to the telescope's field of view.**

Figure 22 shows, rotating the camera on the optical tube so that +X and +Y on the CCD photo coincides with RA and Dec, respectively, can be helpful, but is not required.

5. Enter the ***Search Area***, in fields of view, to scan when attempting to overlay the photo on the Sky Chart. Searching a larger area can help minimize the number of failed matches, but may take longer to complete the calibration run.
6. Enter a number for the ***Retries Near Each Target***. If no match for the photo can be can be found on the Sky Chart, the script will offset the position of the telescope and try again.
7. If necessary, click the ***Source Extraction Setup*** button to configure these parameters. See *TheSkyX Professional and Serious Astronomer User Guide* for details about the source extraction setup parameters.
8. If you do not know your imaging system's image scale, click the ***Take Photo*** button to have *TheSkyX* determine it for you.

Other camera settings

*   Optionally specify the ***Bin Mode*** for your camera on the ***Camera*** window. For larger CCD cameras, 2 x 2 binning works well; using an effectively larger pixel means shorter exposure times and the decrease in resolution does not affect the accuracy of the pointing sample.
*   When operating inside an astronomical dome, you may wish to enter a delay between exposures in the ***Exposure Delay*** text box on the ***Camera*** window.

Step B

The next step is to create the azimuth and altitude targets to point the telescope during the calibration process.

1. Click the ***Create Pointing Targets*** tab.
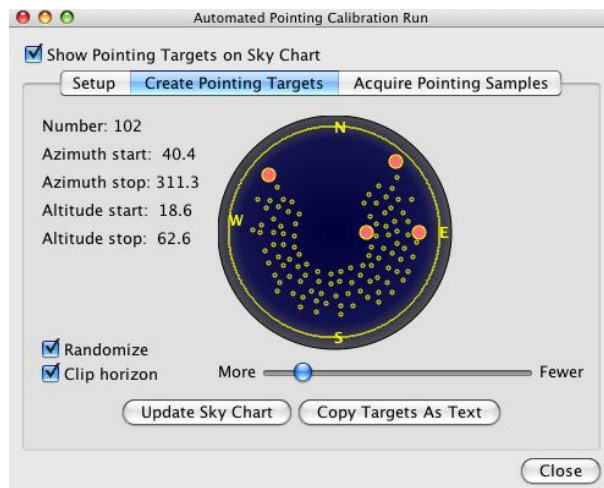
Figure 23: The Create Pointing Targets tab.

2. The blue region on this dialog represents an all-sky Sky Chart with small yellow circles at each target. The four red circles can be used to define *where* in the sky the targets are created. Individually click and drag each to define the region of the sky where the targets appear. The upper two circles adjust the starting and ending azimuth. The lower two circles adjust the starting and ending altitude for the targets.

Clicking the *Update Sky Chart* button shows the new targets on the Sky Chart.

Randomize

Turn on this checkbox to define more or less random positions for the targets. When pointing samples are too evenly spaced (not randomized), the TPoint model can potentially miss repeated pointing errors.

Clip Horizon

Turn on this checkbox to exclude targets that fall below *TheSkyX's* local horizon.

More/Fewer Slider

Use this scroll bar to increase or decrease the number of targets.

Copy Targets As Text

Click this button to copy the list of targets to the Clipboard. It can be used if you want to write your own script to collect pointing samples.

Step C

Once your imaging system has been characterized, and the targets to point the telescope have been defined, the automated calibration process can be started.

1. Click the *Acquire Pointing Samples* tab.
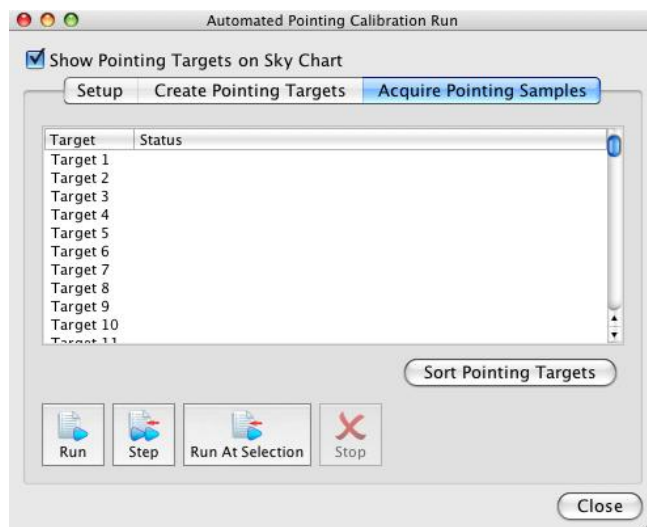
Figure 24: The Acquire Pointing Samples dialog.

2. Click the ***Run*** button to begin the automated process of acquiring pointing samples at each target.

When a pointing target is selected, its number appears next to the target's circle on the Sky Chart.

Figure 25: Sample Sky Chart when Target 1 is selected.

Run

Click this button to start acquiring the pointing samples for each target in the list.

Step

Click this button to acquire the pointing sample for the selected target only.

Run At Selection

Click this button to start the script at the selected target, then all subsequent targets.

Stop

Click this button to stop acquiring pointing samples.

TPoint needs at least six calibration points before improving the telescope's pointing accuracy. As more calibration points are

collected during an automated pointing calibration run, you can still use the Super Model feature (page 22) to improve the pointing model as you go.

Pointing Data Manipulation

The *Pointing Data* spreadsheet on the *Calibration Run* tab of the *TPoint Add On* windows can be used to view and sort the pointing samples, and turn off erroneous pointing samples.

Removing Pointing Samples

The Super Model feature (see page 21) automatically removes bad pointing samples for you.

Recording one or more "bad" pointing samples is a common occurrence. They usually stick out like a sore thumb on the scatter diagrams. Ignoring the bad pointing sample is easy.

1. Click the *TPoint Add On* command from the *Telescope* menu.
2. Click the *Calibration Run* tab.
3. Click the *Pointing Data* tab near the bottom of the *Calibration Run* tab.
4. On the *Pointing Data* spreadsheet, turn off the checkbox next to the pointing sample you wish to ignore.

When the *Automatically Update Model* checkbox is turned on, the new model is computed. You should notice a decrease in the computed Sky RMS when removing the bad sample.

You can also turn off a pointing sample by clicking on the scatter diagram, then selecting the *Ignore Pointing Sample Number <N>* in the context menu, where *<N>* is the pointing sample number.

Suggest Telescope Modeling Terms

The Super Model feature (see page 21) takes all the guess work out of creating an optimal model for your pointing data. We strongly recommend relying on the Super Model, rather than trying to create your own model.

TPoint can suggest model terms to analyze the polar alignment and to minimize the RMS pointing of your telescope. After collecting about 15 to 20 pointing samples, click the **Suggest** button to add the "next best" term to the model.

If adding additional terms gives little change in the RMS value (less than about 20 percent) or the PSD begins to increase, you're done. No more terms are necessary as the data cannot support it. As a rule of thumb, adding six to twelve *harmonic terms* is sufficient; more terms generally cannot be supported by the data.

The ***Suggest*** button on the ***Model*** tab typically allows 30 to 40 arcsecond RMS pointing without having to understand any of the complicated mathematics behind *TPoint*. Another general rule of thumb is that fewer terms is always better, and do not add terms if you are unsure.

Note that adding too many terms can "pollute" the model and lead to incorrect or meaningless RMS pointing and polar alignment information.

After adding six to eight harmonic terms, the polar alignment can be evaluated. From *TPoint*, click the **Polar Alignment Information** tab.

Note: Additional harmonic terms must be added to the *TPoint* model for the polar alignment information to be accurate.

When 30- to 40-arcseconds RMS is achieved, you will generally have accurate polar alignment information from *TPoint*.

Polar Alignment Hints

- Any adjustment to the mount requires a new *TPoint* calibration run. Collect small sets of data points (less than 30 points) in one area of the sky while determining polar alignment.
- Stay on one side of the Meridian and start in a small area of the sky. This helps minimize errors when collecting data.
- Choose a constellation with bright stars and "star hop."
- After collecting the first six pointing samples, pointing should improve significantly. This allows you to make longer slews to collect calibration points in different areas of the sky.

Importing Pointing Data

The following steps are used to import pointing data from an ASCII text file. This can be useful to use existing pointing data from *TPoint for Windows*, for example.

1. Select the ***Import*** command from the ***Pointing Data*** menu button on the right side of the ***Calibration Run*** tab of the *TPoint Add On* window.
2. Navigate to the folder that holds the text file to import, select it, and click the ***Open*** button.

Exporting Pointing Data

The following steps are used to export pointing data to an ASCII text file.

1. Select the *Export* command from the *Pointing Data* menu button on the right
    side of the *Calibration Run* tab of the *TPoint Add On* window.
2. Enter the name of the text file, then click the *Save* button.

Start Calibration Run Dialog

The *Start Calibration Run* dialog is displayed each time the *Start* button on the
Calibration Run tab is clicked. Under most circumstances only the temperature and
pressure need to be entered. The default values for the other settings are normally
sufficient.

Figure 26: The Start Calibration Run dialog.

Telescope

The telescope that was selected in the *Telescope Setup* window (*Telescope* menu) is
listed by default. You can enter a different the here if you want. This name will
appear on the bottom of the *TPoint* graphs.

Temperature

Enter the approximate temperature during the observations in degrees Celsius.

Pressure

Enter the approximate atmospheric pressure in mB. If your telescope automatically
accounts for refraction (for example, all Meade Instruments telescopes) enter 0.

Humidity

Enter the relative humidity in the range 0.0 (zero percent) to 1.0 (100 percent).

From TheSkyX

Latitude

TheSkyX's latitude is listed here for convenience. You can change the latitude from the ***Custom*** tab of the ***Location*** dialog (***Input*** menu).

Elevation

TheSkyX's elevation, in meters, is listed here for convenience. You can change the elevation from the ***Custom*** tab of the ***Location*** dialog (***Input*** menu).

Advanced Options

Turn this option on to reveal more settings.

Advanced Options Group

Observing Wavelength

Enter the observing wavelength in micrometers, default 0.55. The default value can be used in nearly all circumstances.

Tropospheric Lapse Rate

In degrees K/m, default 0.01. The default value can be used in nearly all circumstances.

Equinox

Enter the equinox of the telescope coordinates. This is only required if the recorded telescope positions are "mean" positions (If *TheSkyX* is used to collect the data, leave this blank). Only one equinox (typically, it is B1950 or J2000) may be specified, and this applies to all pointing samples.

Pole Checking

Pole checking rejects pointing samples in places that may cause problems – very close to the celestial pole, for instance. This option should be checked unless specific circumstances require turning pole checking off.

Diurnal Aberration Correction

The correction for diurnal aberration (maximum 0.3") should be disabled if the telescope control system itself omits it.

The Geometrical Terms

The six standard geometrical terms used by *TPoint* are described below. These terms quantify the various mechanical inaccuracies of the optical tube assembly (OTA) and telescope mount. Even the most expensive telescope mounts exhibit mechanical errors that ultimately affect the telescope pointing performance. Mechanical adjustments *can be* made to the telescope system to minimize the misalignments. However, eliminating them entirely is impossible, so telescope pointing can be improved through telescope modeling.
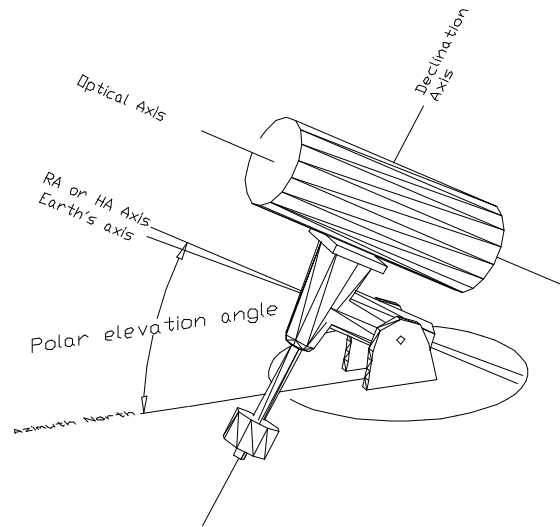
Figure 27: A German equatorial Mount.

Figure 27 and Figure 28 show the two most popular telescope mount designs. The following discussions relate to equatorial mounted telescopes. The Right Ascension (RA) or Hour Angle (HA) axis is pointed closely to the celestial pole.
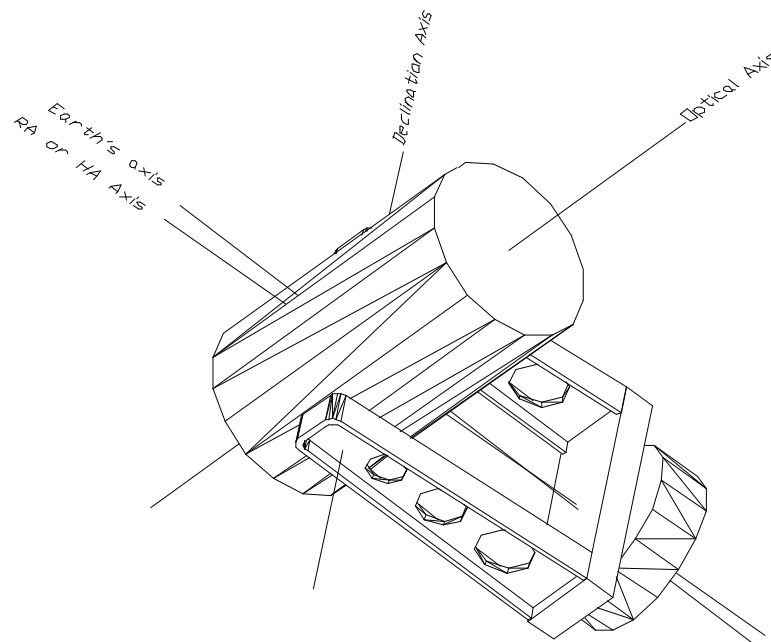
Figure 28: A Fork Mounted Telescope.

Index Errors in Hour Angle (IH) and Declination (ID)

The index errors are simply offsets to the hour angle and declination values such that the distribution of pointing errors across the sky is best fit. Looking at the scatter diagrams below, you can see that adding index error terms to the model moves the entire data set towards the center, thereby improving the overall pointing. Since the control system is typically synchronized on a star by a sighting through the optical path of the telescope, this initial sighting is "polluted" by all errors in the system at the time of the sighting. An average from all the pointing samples results in more accurate pointing.

Sky RMS =2565.69 PSD =2565.69

Sky RMS = 350.04   PSD =
IH-Index Error in HA   -
ID-Index Error in Dec
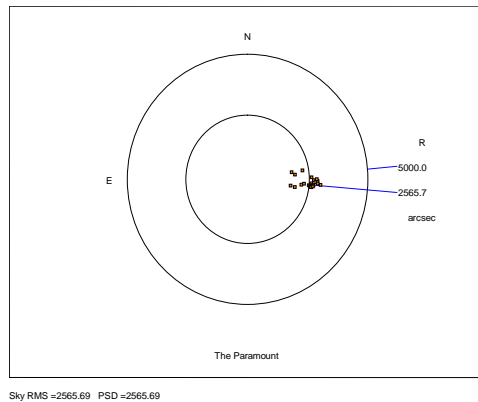
Figure 29: Data with Index Error term.   **Figure 30: Data without Index Error term.**
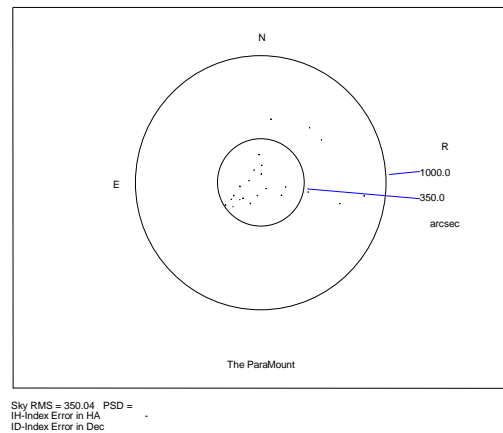
Declination/Optical Axis Non-Perpendicularity

In order to achieve repeatable pointing, the optical tube assembly must be rigidly attached to the mount so that no motion occurs between the two as the OTA is slewed about the sky. Ideally, the optical axis should also be perpendicular to the declination axis. In practice, this can be difficult to achieve by simple mechanical means since the true optical path probably does not coincide with the physical telescope tube.

The following diagrams graphically illustrate the OTA/Declination axis term (CH) for two different telescope mounts.
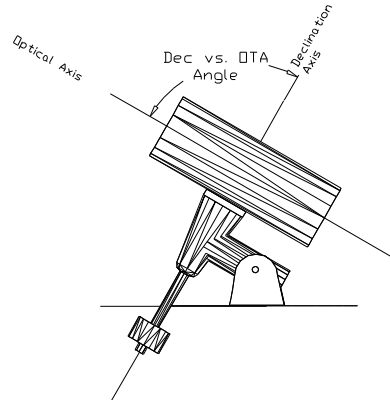
Figure 31: Side view of a German equatorial telescope mount.

After a sufficient number of *TPoint* pointing samples are collected, the magnitude of the OTA/declination non-perpendicularity can be quantified, and if it is large, mechanical adjustments can be (but *do not necessarily have to be*) made to minimize the non-perpendicularity.

While this source of *pointing error* can make centering stars difficult initially, it does not affect the *tracking performance* of the mount. In general, if the telescope is permanently mounted, and the pointing data can be collected automatically then no adjustment is necessary; once a model is established, *TPoint* will automatically correct for this error when the telescope is slewed. If the telescope is used in a portable setup, and stars are located visually, then you may wish to minimize this
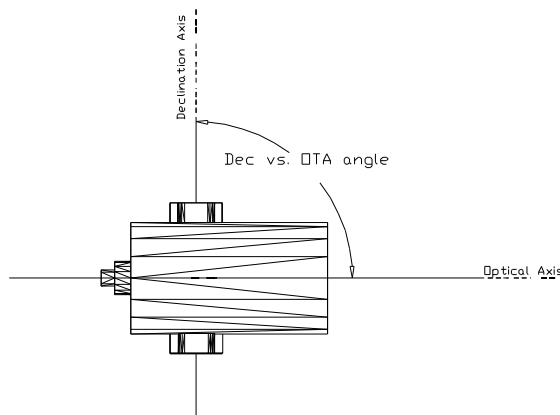
Figure 32: Top view of a fork mount.

error so that unmodeled pointing is improved.

Change EW on the sky equal to coefficient CH. For a fork mount operating above the pole or for a GEM observing stars east of the meridian, positive CH displaces the pointing axis to the west of where it would otherwise be.

Note that CH and IH both move stars east or west in the field of view. The difference is that the displacement is constant for CH whereas the displacement due to IH shrinks as you approach the pole.

RA or HA axis/Declination Axis Non-perpendicularity

For north declinations, and for a fork mount operating above the pole, or for a GEM observing stars east of the meridian, positive NP displaces the pointing axis to the west of where it would otherwise be.
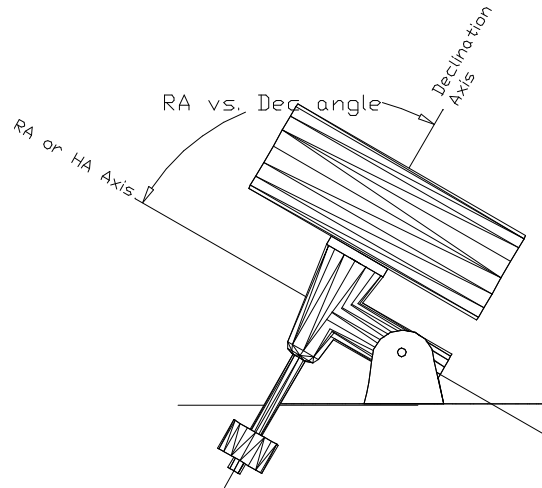
Figure 33: An equatorial mount.
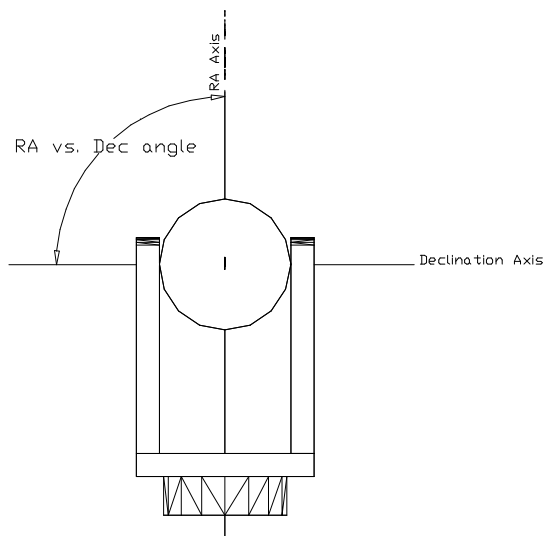
Figure 34: The front view of a fork mount.

Polar Alignment Error in Azimuth

In the Northern Hemisphere, a positive MA means that the pole of the mounting is to the right of due north. In the Southern Hemisphere, a positive MA means that the pole of the mounting is to the right of due south.

When making adjustments to correct for the MA term (polar misalignment in azimuth) you need to rotate about a vertical axis through a larger angle than MA itself. This is because MA is really a rotation about the point Hour Angle = 0, Declination = 0. The factor to inflate MA by before rotating the mount is 1/cos(latitude).

Polar Alignment Error in Elevation

In the Northern Hemisphere, a positive ME means that the pole of the mounting is below the true (unrefracted) pole. A mounting aligned on the refracted pole will have a negative ME. In the Southern Hemisphere, a positive ME means that the pole of the mounting is above the true (unrefracted) pole. A mounting aligned on the refracted pole will have a positive ME.
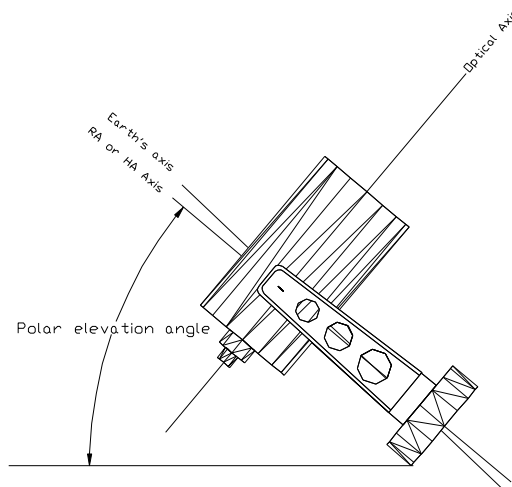
Figure 35: Fork mount.
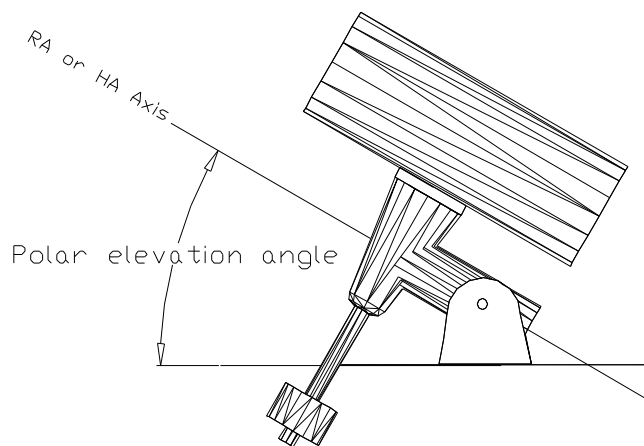
Figure 36: Equatorial mount.

***

The TPoint Graphs

Fourteen different graphs are available for plotting the pointing data to reveal systematic errors in the telescope system. Choose which graph to display by clicking the **Graph** pop-up menu on the **Setup** tab of the *TPoint* window (Telescope menu).

The general telescope analysis strategy is to plot different components of the errors against vs. time or position. Terms can then be added to the model to target any systematic effects that are seen. Some plots are more likely than others to have a mechanical interpretation and attention should be initially confined to these plots.

Pointing samples are saved in time order. Therefore, graphing y-data vs. N plots are useful for exposing shifts or drifts that have occurred during the pointing run. Other x-axis meanings can be contrived by appropriately sorting the observation file.

The numerous plots have a variety of presentation and diagnostic roles.

Scatter Plot

The scatter plots residuals as a scatter diagram, like a shooting target. As well as being a good way of presenting overall pointing performance, the scatter plot exposes errant observations and abnormal distributions.
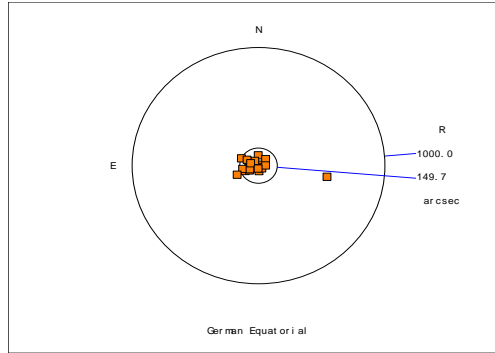
Figure 37: Scatter Plot Example 1

Figure 37 contains a pointing sample error. Errors are more likely to occur with a large number of samples since using fainter stars increases the possibility of misidentification. Note how the errant star causes a misleading tight clustering of the remaining stars by changing the overall plotting scale.
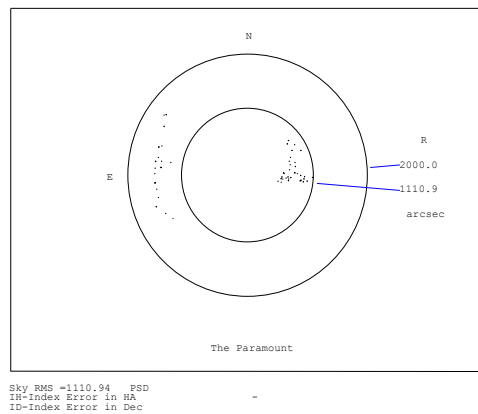
Figure 38: Scatter Plot Example 1 (continued)

Figure 38 shows two distinct distributions of stars. This is the result of a very large Declination axis and OTA non-perpendicularity on a German Equatorial mount. On the East side, the angle causes observations to be misplaced in one direction while on the West side, they are misplaced in the opposite direction.

Sky RMS = 358.47   PSD = 369.07
IH-Index Error in HA   -1713.0
ID-Index Error in Dec   199.1
CH-Non perpendic. Dec & OTA   -1108.7
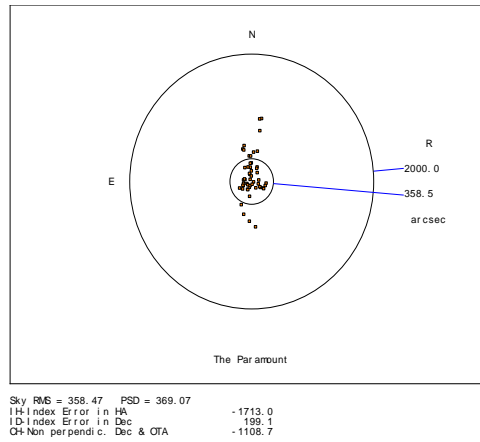
Figure 39: Scatter Plot Example 1 (continued)

Figure 39 shows the same data after the Dec/OTA term has been added.

Error Vectors – Orthographic

Figure 40 displays the residuals as error vectors on an orthographic projection (a distant view of the celestial sphere looking down on the zenith from above). The vectors (lines projecting from the square symbols that mark star positions) are the great circle continuations of the pointing residuals.

Sky RMS =1110.94   PSD =1132.51
IH-Index Error in HA   -2120.5
ID-Index Error in Dec   199.1
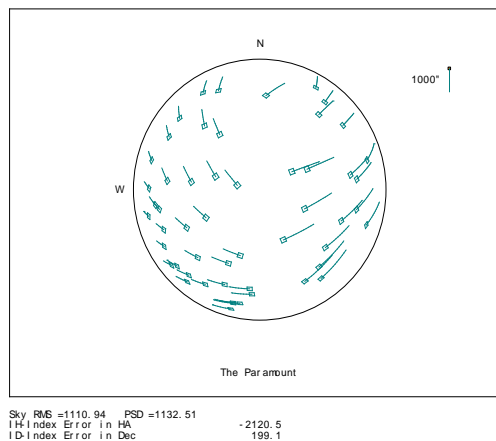
Figure 40: Error vectors graphed using an orthographic projection.

Error Vectors – Cartesian

Figure 41 plots error vectors on a Cartesian Cylindrical projection, either HA/Dec or Az/El.
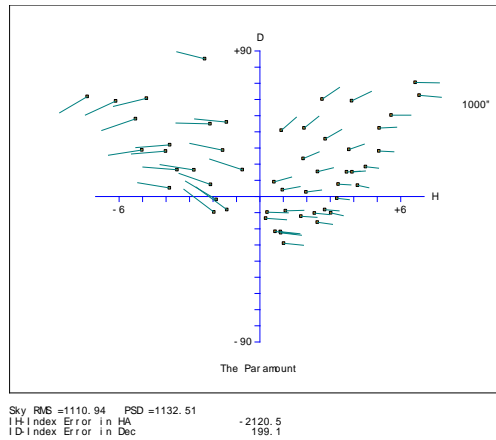
Figure 41: Error vectors on a Cartesian Cylindrical projection.

Hysteresis

Figure 42 looks for hysteresis by drawing the error vector at a position that indicates the direction from which the telescope has come. This assumes that the data file contains all the observations in the correct order, and that hysteresis is related to the direction of the large-scale movements in cylindrical coordinates (either HA/Dec or Az/El). Summing the residuals oriented relative to the telescope movements makes a numerical estimate of the hysteresis.
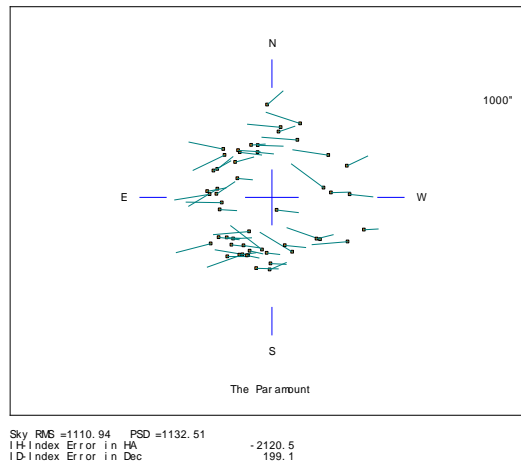
Figure 42: Error vectors vs. telescope direction.

Changing Axis Alignment

This graph looks for changing polar/azimuth axis misalignment. Each residual is interpreted as being due to a misalignment of the specified "roll" axis–either polar or azimuth as specified. A histogram is plotted to show if the residuals do, in fact, favor one particular direction. The mean direction is calculated and reported, and then the component of each residual in the direction of this misalignment is plotted.

Error Distribution

Sky RMS =1110.94   PSD =1132.51
IH-Index Error in HA   -2120.5
ID-Index Error in Dec   199.1
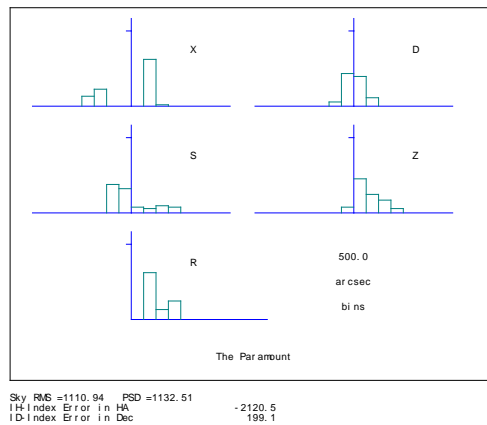
Figure 43: Error Distribution graph

Figure 43 plots multiple histograms that show various sorts of error distribution, and is useful for testing whether the residuals are reasonably normal. In the example the X (east-west) plot shows a suspicious double peak.

Other Graphs

The following graphs can be selected from the *TPoint Add On* window:

- Observation number vs. Declination
- Observation number vs. Hour Angle
- Hour Angle vs. EW on sky
- Declination vs. Declination
- Zenith Distance vs. Zenith Distance
- Declination vs. EW on sky
- Hour Angle vs. Dec
- Hour Angle vs. HA/Dec non-perpendicularity

Determining an Observation Number from a Graph

Bad observations usually stand out in one or more of the graphs. For example, in Figure 44, most of the observations are clustered tightly, while there appears to be a single observation that is inconsistent with the remaining data.
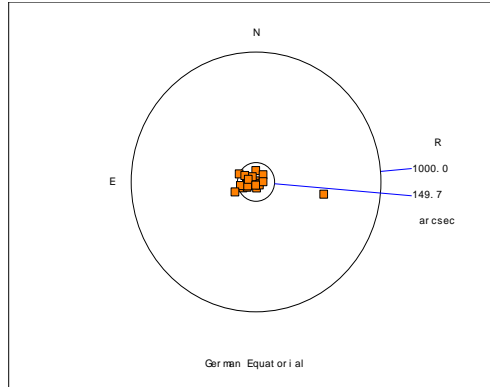
Figure 44: Scatter diagram with erroneous pointing sample.

Left click on the orange rectangle, then click the ***Ignore Pointing Sample Number <N>*** command in the pop-up menu to remove it from the model.
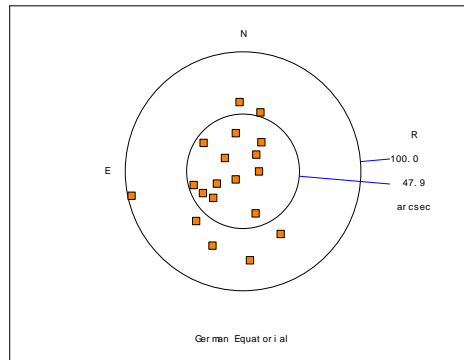
Figure 45: Scatter diagram without errorneous pointing sample.

Generic Terms

There are two types of Generic terms defined in *TPoint*, where the name of the coefficient spells out the required polynomial or harmonic formula.

Polynomial Terms

Polynomial terms have names in the form:

P*rc*[*i* [c[*i*]]]

One example is a term PXH2D1, which models an effect that produced an east-west shift on sky (X) proportional to $h^2\delta$ (H2D1).

The initial P identifies the term as a polynomial.

The *r* field describes the result, and is one of the following:

H	Result is in hour angle.
X	Result is east west on the sky.
D	Result is in declination.
U	Result tilts polar axis up or down.
L	Result tilts polar axis left or right.
P	Result changes HA/Dec non-perpendicularity.
A	Result is in azimuth.
S	Result is left-right shift on the sky.
Z	Result is in zenith distance.
N	Result azimuth axis north or south.
W	Result tilts azimuth axis east or west.
V	Result changes Azimuth/El non-perpendicularity.

The two *ci* fields indicate the independent variables and their powers. Each *i* is in the range 0-9; each c can be any of:

H	Hour Angle.
D	Declination.
A	Azimuth.
Z	Zenith distance.
Q	Parallactic angle.

Harmonic Terms

Harmonic terms have names of the forms:

H *r f c* [*i*] [*f c* [*i*]]
or H r f c i i

One example might be the term HXSH2, which would model an effect that produced an East-West shift on the sky (X) proportional to the sine (S) of 2h (H2).

The initial 'H' identifies this term as a harmonic.

The *r* and *c* fields describe the result and an independent variable respectively, and are as for polynomials, above.

Each *fci, fcii* and *fciii* indicates a function of an integer multiple of an independent variable *c*. The *f* field is either S for sine or C for cosine. Each *i* is in the range 0-9,

allowing frequencies from 0 to 999 cycles per revolution in the case of simple one-coordinate harmonics, and 0 to 9 cycles per revolution in the case of compound two-coordinate harmonics. An omitted *i* defaults to unity, as does an omitted trailing *fci*.

Adding a Generic Term

To add a polynomial or harmonic term to a model, enter the term using the forms described above into the edit box located in the Create New Term group box. The Add Term button will remain grayed until a legitimate term has been typed into the edit box. Legitimate terms are unique terms that follow the form described above.

Once the desired term is entered, click Add Term to add the term to the current model. The Use check box will automatically be marked when a new term is added. The new term is placed at the end of the Terms list box.

For example, to model a gear-centering error in declination, a harmonic term must be created. The result r and the independent variable c are in declination. Both the sine and cosine components must be accounted for in order to allow arbitrary phase, so the two necessary terms are as follows:

HDSD and *HDCD*

To add these to a model, type in HDSD in the Add Term edit box, the click Add Term. Do the same for HDCD. You will now see these new terms listed at the end of the terms list box.

Suggest Terms (Legacy Feature)

The Super Model feature (see page 21) takes all the guess work out of creating an optimal model for your pointing data. We strongly recommend relying on the Super Model, rather than trying to create your own model.

Click this button to have *TPoint* analyze the existing pointing data, then list all the possible terms that may be added, sorted by magnitude of the correction. This option is a handy way to determine which terms have the greatest impact on the RMS pointing.

Sizes of the Coefficients

The mathematical expressions used by *TPoint* are rather simple and designed to give results of adequate accuracy when not too close to the pole of the mounting and *when the pointing errors of the telescope are small*. Flexures and misalignments of up to a few arcminutes are unlikely to give problems; they will not interact significantly with

one another, and will be calculated by *TPoint* to sufficient accuracy. However, terms with larger coefficients may not be so well behaved, especially near a pole.

In practice, a particular source of problems is collimation error, the non-perpendicularity of the chosen pointing axis with respect to the declination or elevation axis of the mounting. If the measuring device – eyepiece, video, CCD etc. – is offset too far, there may be unmodeled pointing errors due to such effects as optical distortion. The best plan is to ensure that the measuring device is offset no more than a few minutes of arc. If this is impossible try to pre-process pointing observations to remove the bulk of the offset before the *TPoint* run. This might involve rigorous calculation of the tangent-plane projection and optical distortions.

Advanced Modeling

The Super Model feature (see page 21) takes all the guess work out of creating an optimal model for your pointing data. We strongly recommend relying on the Super Model, rather than trying to create your own model.

TPoint allows a straightforward model for a telescope to be generated easily and without requiring great cunning or insight, but also provides the tools more experienced and determined users will need when conducting more exhaustive analyses.

As already described, the general strategy for modeling a telescope from scratch is to load a data file, set up the basic geometrical model (clicking Equatorial on the Fit Data dialog) and watching the term values and selected graph.

With the various graphs, plots of residuals can then be made and inspected for signs of systematic error. Plausible flexure terms can be tried, and any others that the particular telescope design suggests.

When adding new terms, pay attention to the standard deviation of the new coefficient, the effect on other terms, and whether the population standard deviation has gone down. A new term will almost always reduce the RMS pointing but population standard deviation is a better indication of whether the improvement is real.

If an attempt is made to use two terms that are more or less indistinguishable (for example, the identical terms, CH and PXH0), the condition will be reported. If this occurs, eliminate one of them. In such ill-conditioned cases, the singular value decomposition (SVD) methods used by FIT will normally return a meaningful model, with the "true" value of a duplicated term being shared out between the two (or more) coefficients involved. Two common cases are (i) if two inseparable terms are present from the start, they each receive an equal share of the value, and (ii) where a new term is added to an already fitted model, and that term is inadequately

distinguished from something already present, then the new term will be left close to zero.

Do not try to extract more information from a given sample of data than the size of the sample justifies. A preliminary assessment of a telescope's capabilities can be made using perhaps 20-30 stars. Routine fitting of a typical operational telescope model, consisting of six geometrical terms, two or three flexures, and perhaps a few scale adjustments, centering corrections, etc., calls for 50-100 stars, well-distributed over the whole observable sky. A campaign to expose high-frequency flexures and bumps should not be embarked upon without a sample of 500-1500 stars. Even with this large number of stars, fitting a full set of polynomials or harmonics up to the required degree in one go is impractical, and new terms must be tried out in groups of no more than about 20.

When first analyzing a new telescope, it is not uncommon to see obvious systematic residuals on the simple graphs of error in one coordinate plotted against that or another one--plotting error in zenith distance versus against zenith distance (Z Z plot) for example. However, once these straightforward effects have been treated, systematic errors can still hide in what looks like noise. Some of these can be exposed by using more specialized plots – zenith distance errors against parallactic angle (Z Q plot), errors in HA/Dec non-perpendicularity plotted against HA (P H plot), and so on. However, certain effects that depend simultaneously on two coordinates may prove more stubborn; given a data set of adequate size, the solution is to use the MASK and UNMASK commands to select bands in one coordinate, allowing the residuals for that one band to be plotted.

At various stages the Hysteresis plot should be examined to assess whether the current pointing accuracy seems to be limited by hysteresis.

When pursuing low-level flexures and irregularities, difficult questions may arise. To what extent is the model physically meaningful? Has adding empirical terms affected the supposedly well-understood underlying model? Is it worth trying to keep a grip on physical reality, or wouldn't it be just as good to fit a massive set of polynomials or harmonics?

An approach that seems to preserve the considerable advantages of having a model firmly based on mechanical reality, yet allows all the power of empirical modeling to be unleashed, is to construct a model that includes both physical and empirical terms. At no stage should both sets be free to float during fitting.

Finding Harmonics: An Example

Often times after the geometric terms have been added to a model, other systematic errors present themselves in the various graphs generated by *TPoint*. Though not always obvious, close examination of the various graphs reveal patterns that provide insight into which additional terms should be added. The following example

illustrates how adding two harmonic terms to the pointing model below improved the RMS pointing from two arcminutes to about one arcminute.

First, examine the graphs on the *TPoint Add On* window. Taking a close look at the delta-declination vs. declination graph shows as it shows a strong pattern in the form of the cosine function. The frequency appears to be 1-1/2 cycles per 90 degrees or 6 cycles per revolution.

A harmonic term that that produces a declination shift on the sky proportional to the cosine (C) of 6*d* (D6) should be added to the model. The term name is HDCD6 (i.e. **H**armonic **D**eclination proportional to the **C**osine of **D**eclination*6).

On the **Model** tab, add the term HDCD6. Once the term you have added has the correct syntax and is unique (i.e. the term is not already present in the list of terms) the **Add Term** button will become undimmed. Click **Add Term** to include this new term in the model.
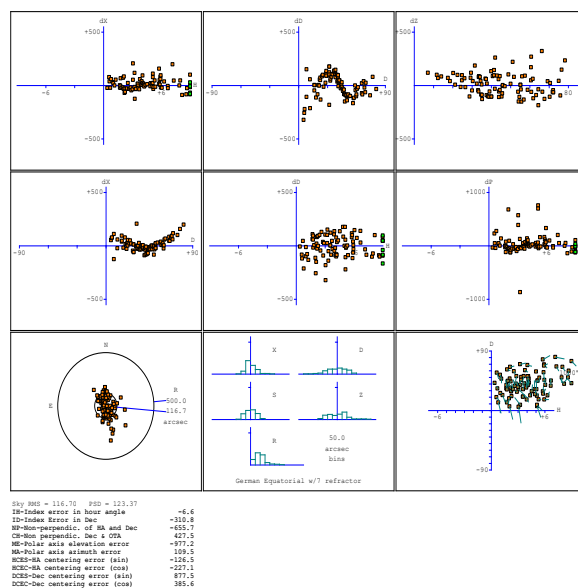
Figure 46: Multiple graphs.

```
Sky RMS = 116.70   PSD = 123.37
IH-Index error in hour angle              -6.6
ID-Index Error in Dec                   -310.8
NP-Non-perpendic. of HA and Dec         -655.7
CH-Non perpendic. Dec & OTA              427.5
ME-Polar axis elevation error           -977.2
MA-Polar axis azimuth error              109.5
HCES-HA centering error (sin)           -126.5
HCEC-HA centering error (cos)           -227.1
DCES-Dec centering error (sin)           877.5
DCEC-Dec centering error (cos)           385.6
```
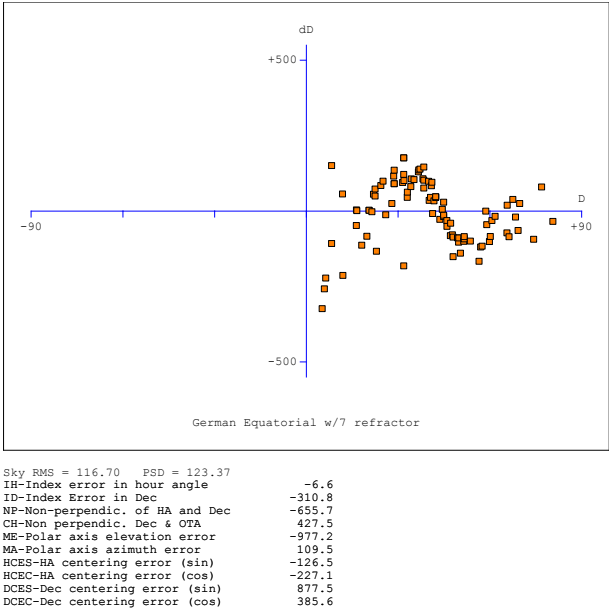
Figure 47: Figure 46: Graph of dD vs. Declination Before Adding the HDCD6 Term (RMS Pointing = 116 arcseconds).

```
Sky RMS =  76.39   PSD =  81.24           HDCD6-HDCD6                    143.4
IH-Index error in hour angle              -11.7
ID-Index Error in Dec                    -222.0
NP-Non-perpendic. of HA and Dec          -669.1
CH-Non perpendic. Dec & OTA               444.1
ME-Polar axis elevation error            -979.9
MA-Polar axis azimuth error                94.5
HCES-HA centering error (sin)            -130.3
HCEC-HA centering error (cos)            -241.8
DCES-Dec centering error (sin)            722.1
DCEC-Dec centering error (cos)            433.5
```
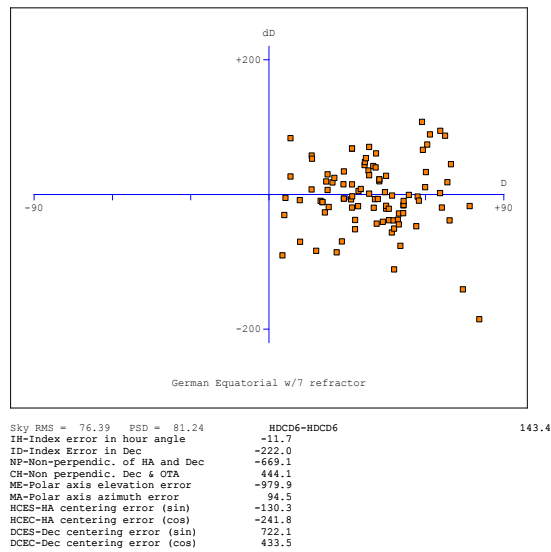
Figure 48: Graph of dD vs. Declination After Adding the HDCD6 Term (RMS Pointing = 76 arcseconds)

Note the RMS pointing decreases from 117 arcseconds to 76 arcseconds. Also note the scale of the Y-Axis changes from +/- 500 to +/- 200 arcseconds.

Examining the various graphs on the terms dialog shows another harmonic present in the dX vs. Declination graph.

In this case, a harmonic term that produces an east-west shift on the sky proportional to the cosine (C) of 2*d* (D2) should be added to the model. The term name is HXCD2 (i.e. **H***armonic* **X** *(east-west shift) proportional to the* **C***osine of* **D***eclination*2).*

```
                                             dX
                                           +500 —


                                              |                          ■
                                              |                        ■
                                              |           ■       ■  ■■
                                              |        ■ ■■■    ■■■          D
  -90                                         |■■■■■■■■■■■■■■■■■■■           +90
                                              |    ■■■■■■■■■■■■■
                                              |        ■

                                           -500 —

                                  German Equatorial w/7 refractor
```

Sky RMS = 76.39   PSD = 81.24   HDCD6-HDCD6   143.4
IH-Index error in hour angle   -11.7
ID-Index Error in Dec   -222.0
NP-Non-perpendic. of HA and Dec   -669.1
CH-Non perpendic. Dec & OTA   444.1
ME-Polar axis elevation error   -979.9
MA-Polar axis azimuth error   94.5
HCES-HA centering error (sin)   -130.3
HCEC-HA centering error (cos)   -241.8
DCES-Dec centering error (sin)   722.1
DCEC-Dec centering error (cos)   433.5

Figure 49: Before Adding the HXCD2 Term (RMS = 76 arcseconds).


```
                                             dX
                                           +200 —

                                              |                        ■
                                              |        ■        ■  ■
                                              |       ■ ■  ■ ■■■    ■
                                              |      ■ ■■■■■■■■ ■■          D
  -90                                         |■■■■■■■■■■■■■■■■■■           +90
                                              |    ■■■■■ ■■■■■
                                              |      ■

                                           -200 —

                                  German Equatorial w/7 refractor
```

Sky RMS = 60.76   PSD = 65.00   HDCD6-HDCD6   143.5
IH-Index error in hour angle   -4HXCD2-HXCD2   406.9
ID-Index Error in Dec   -220.9
NP-Non-perpendic. of HA and Dec   187.3
CH-Non perpendic. Dec & OTA   -98.8
ME-Polar axis elevation error   -971.2
MA-Polar axis azimuth error   91.5
HCES-HA centering error (sin)   -174.6
HCEC-HA centering error (cos)   -262.6
DCES-Dec centering error (sin)   724.6
DCEC-Dec centering error (cos)   429.2

Figure 50: After Adding the HXCD2 Term (RMS = 61 arcseconds).

TPoint Workflow

The Super Model feature (see page 21) takes all the guess work out of creating an optimal model for your pointing data. We strongly recommend relying on the Super Model, rather than trying to create your own model.

The following real-world *TPoint* modeling example using Paramount ME is intended to show the general workflow for analyzing data and how to optimize the model to get the best possible pointing.

Before doing *any* modeling, take some time to assess the mount's pointing *accuracy* versus the mount's pointing *repeatability*. Pointing accuracy relates to how close the telescope points to a given star or object after a slew. Pointing repeatability relates to how close the mount points to a star after slewing to a star that is 15 degrees (or so) away, then back again.

Try this simple "litmus" test with your mount. Slew to any star, then center the star in the eyepiece. Next, slew about 20 degrees away, then slew back to this star. Is the star centered in the eyepiece? If not, your mount probably suffers from "non repeatable errors" (including backlash, out of round gears, mirror slop or other errors) that make it less than ideal for telescope modeling.

The most common source of random error is mirror slop. Mirror slop is motion of the primary or secondary mirror as the telescope is slewed to different positions.

General Pointing Improvement Suggestions

- If your mount uses a Schmidt-Cassegrain (SCT) optical tube assembly, minimize SCT mirror flop and mirror shift for best overall pointing performance. LX200 owners might consider Scope Stuff's LX200 Mirror Stabilizer product.
- Use a motorized focuser (an Optec, RoboFocus, JMI SmartFocus, or other model focuser) to minimize mirror shift. Although this will not improve pointing performance directly, it will make using your telescope much easier.

If the mount does not point accurately, then *TPoint* will help. If the mount is unable to point reliably, then there are most likely random errors that will degrade the overall pointing performance. In order to achieve good all sky pointing, every effort should be taken to minimize random telescope errors.

Polar Alignment for German Equatorial Mounts

Probably the most common source of pointing error in a German equatorial mount (GEM) is polar misalignment. This error is most noticeable when a GEM is slewed

to the opposite side of the meridian and the polar alignment error appears as an offset pointing error; the size of the offset is related to the distance the mount's polar axis is from the pole. Use *TPoint*'s Polar Alignment Report to get within one arcminute of the refracted pole before proceeding.

Accurate Time

Accurate time is essential for accurate pointing. Every second of error in time equates to pointing error. Make sure to update your computer's clock using an accurate time base before

Analyzing Your Pointing Data

Let's review a set of pointing data that was acquired with a Paramount ME.

1. Click the **TPoint Add On** command from *TheSkyX*'s **Telescope** menu.
2. On the **Setup** tab, click the **Import Pointing Data** command on the **TPoint Add On Settings** pop-up menu. On the **Import Pointing Data** window, highlight the file named **Burnett.dat** (under Windows, the file name may appear as **Burnett** if the file extensions are not shown) and click the **Open** button.

The *TPoint* scatter diagram should now show the pointing data along with the model's computed Sky RMS and PSD values using the six standard terms IH, ID, NP, CH, ME and MA.

Our goal is to get the best possible pointing (by minimizing the Sky RMS with an eye on the PSD) from this data.

Removing Bad Pointing Samples

Generally, after collecting your pointing data (from 30 to 200 pointing samples, or more, depending on your observing goals, it's time to optimize the telescope's pointing.

The first step is to remove any errors; that is, points where the telescope's coordinates and the coordinates of the observed star do not closely match. There are no hard criteria for choosing outliers, which in most cases are caused by mistaken star identification. Generally, you look for points that stand out from the majority.

For our example data, the scatter diagram in Figure 51 shows a point that is clearly an error. To ignore this point, either click or right click on the small orange rectangle that represents the point on the scatter diagram, then click the **Mask Pointing Sample Number 33** command.
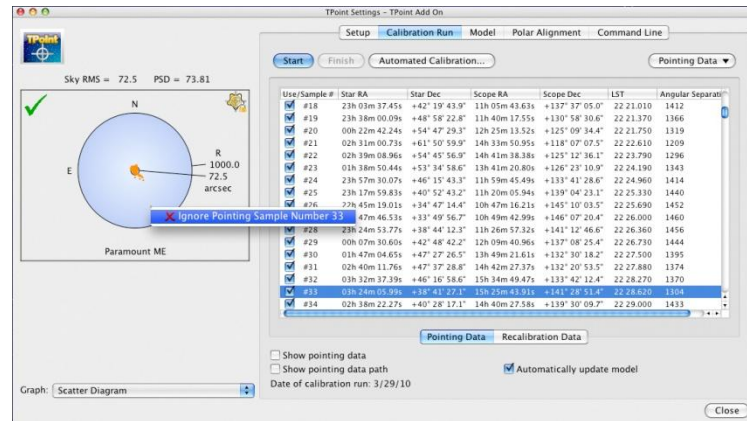
Figure 51: Ignoring an incorrect pointing sample.

Alternatively, you can turn off the checkmark next to pointing sample number 33 on the *Pointing Data* spreadsheet. To view any pointing sample on the pointing sample spreadsheet, click the small orange rectangle on the scatter diagram. Or, click the *Calibration Run* tab, click the *Pointing Data* tab and then scroll the spreadsheet to the desired sample.

When the *Automatically Update Model* checkbox is turned on, the scale of the scatter diagram adjusts to reflect the new model.

Additional points that seem to lie outside the majority are now more prominent, and some of them probably should be excluded as well. How many is purely subjective but the goal is to have to model account for the factors that affect the majority of the pointing and not try to explain each and every odd mechanical effect. A better strategy would be to identify unique mechanical oddities and fix them. In the interim however, excluding several of these outlier points will allow the model to account for the general and predominant mechanical errors of the mount and optics that affect slews to most locations.

Adding Terms

After the "bad" pointing samples points have been removed, in addition to the six standard geometrical terms, more pointing terms should be added to the model (see "The Geometrical Terms" on page 45 for more information).

Only add terms that actually improve the mount's pointing. How do you know *which* terms to add? As terms are added to the model, there are four different values that should be used to decide whether the term should be added, and whether those terms that are already added should be retained. These values are:

- *Sky RMS*
- *PSD*
- *ME sigma*
- *MA sigma*

Sky RMS and PSD are displayed on the top left of the *TPoint Add On* window, below the *TPoint* logo. Sigma values for each term are on shown on the right-most column in the table of terms.
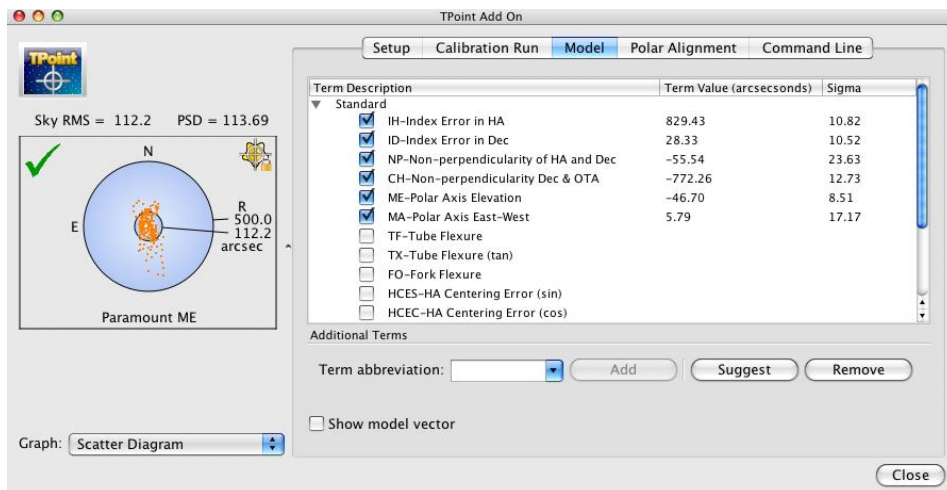

Figure 52: Terms tab on the Model tab of the TPoint Add On window.

There are four qualifications for keeping a term or deciding that prior terms should now be removed. This set of evaluation criteria should be considered for each new term before keeping it in the model:

- Choose new terms only if they reduce the *PSD* by at least 10 percent.
- Discard any term (new or old) if its *value* is not at least 3 times its *sigma*.
- Discard a new term if it causes either the *ME sigma* or the *MA sigma* to increase.
- Watch other added terms (outside the six geometrical terms – IH, ID, NP, CH, ME and MA) and discard them if they no longer meet the above criteria.
- Use TPoint's *Correlation Between Terms* table to pinpoint conflicting terms. From the *Command Line* tab, enter the text *FIT* into the *Command* text box, then click the *Execute* button.
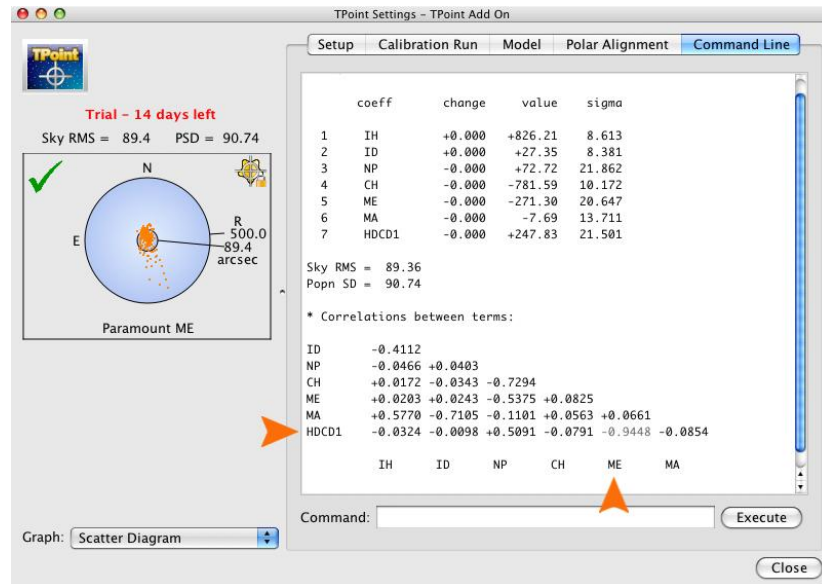
Figure 53: Use the *Correlation Between Terms* table to pinpoint conflicting terms.

A term that negatively affects another term will have an absolute value of 0.9 (or greater) at the intersection of the *causing term* (**HDCD1** in this example) and the affected term (note the orange arrows in Figure 53). In this example, the correlation between the **HDCD1** term and the **ME** term is **-0.9448**. The **HDCD1** term should be removed from the model.

Though **ME** and **MA** terms are the ones we tend to watch more carefully to determine if an added term causes them to increase, in reality, **all** terms should be inspected and removed when the absolute value of the correlation error exceeds 0.9.

Order to Add Terms

Before adding additional terms, make sure the six standard geometrical terms are turned on. These terms are the basis for every pointing model. From here…

- Add the term **DAF** – then evaluate – keep or remove based on those criteria.
- Add the term **HCES-HA** – then evaluate – keep or remove based on those criteria.
- Add the term **HCEC-HA** – then evaluate – keep or remove based on those criteria.
- Add the term **DCES-Dec** – then evaluate – keep or remove based on those criteria.
- Add the term **DCEC-Dec** – then evaluate – keep or remove based on those criteria.
- Add the term **DNP** – then evaluate – keep or remove based on those criteria.
- Click the Suggest Terms button to add one harmonic term at a time until no more terms satisfy the evaluation criteria.

- Add *TX* or *TF* (choose the one with the greatest positive affect) - then evaluate – keep or remove based on those criteria.

Use the *Suggest Terms* button to add one harmonic term at a time until no more terms satisfy the evaluation criteria.

At this point, you should have optimal pointing for your imaging system.

Model Tab Options

Term Abbreviation
Enter the two or four character abbreviation for TPoint terms that are not shown in the *Standard Terms* list. Entering a single character in the text box will all the terms that begin with that character. (See Figure 54.)

Add Button
Click this button to add the term to the model. This button is enabled only when a valid term appears in the *Term Abbreviation* text input.

Suggest Button
Click this button to optimally add new terms to the model.

Remove Button
Click this button to remove the selected term from the model.
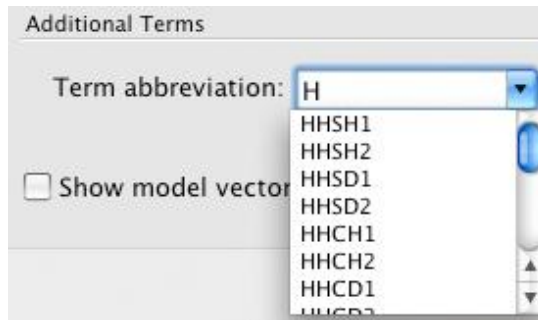
Figure 54: Entering a single character will list all related terms.

Show Model Vector
Turn this option on to draw an arrow at the center of the Sky Chart that indicates the magnitude and direction of the *TPoint* correction.

Appendix A: The Pointing Terms

This appendix defines the *TPoint* pointing terms.

The pointing terms obey the following nomenclature and sign conventions:

- Hour angle: h is positive west of the meridian.
- Declination: δ is positive north of the equator.
- Parallactic angle: q is positive west of the meridian.
- Azimuth: *TPoint*'s internal convention such that A is zero for due south and 90 degrees for due east.
- Zenith distance: ζ the distance from 90 degrees altitude.
- Elevation: E = 90 - zenith distance.
- Hour angle and east-west corrections: Δh and ΔX (= $\Delta h \cos \delta$) are positive when corrected telescope position is west of the uncorrected position.
- Declination corrections: Δd is positive when corrected telescope position is north of the uncorrected position.
- Azimuth and left right corrections: ΔA and ΔS (= $\Delta A \cos E$) are positive when the corrected telescope position is to the left of the uncorrected position as seen by someone standing at the telescope looking at the sky.
- Elevation corrections: ΔE is positive when the corrected telescope position is above the uncorrected position.

TheSkyX provides the sequence of transformations and corrections needed to bridge the gap between:
(i.) the cataloged object's position and
(ii.) where the telescope needs to be pointed to see the object, that is, transforming them to the "observed place."

Term: ACEC
The cosine component of the once-per-revolution cycle errors produced by a mis-centered azimuth setting-circle.

Notes: The sine component is ACES.

Term: ACES
The sine component of the once-per-revolution cycle errors produced by a mis-centered azimuth setting-circle.

Notes: The cosine component is ACEC.

Term: AN

In an alt-azimuth mount, misalignment of the azimuth axis north south: rotation about a horizontal east-west axis equal to coefficient AN.

Notes: AN is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, NPAE, AW.

If AN is positive, the pole of the mounting is north of the zenith.

The other (that is east-west) component of the azimuth axis misalignment is the term AW.

Term: AW

In an alt-azimuth mount, misalignment of the azimuth axis east west: rotation about a horizontal north-south axis equal to coefficient AW.

Notes: AW is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, NPAE, AN.

If AN is positive, the pole of the mounting is west of the zenith.

The other (that is north-south) component of the azimuth axis misalignment is the term AN.

Term: CA

In an alt-azimuth mount, the collimation error is the non-perpendicularity between the nominal pointing direction and the elevation axis. It produces a left-right shift on the sky that is constant for all elevations.

Notes: CA is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, AW, NPAE, AN.

A non-zero CA on its own means there is an area round the zenith inside which the telescope cannot point (irrespective of velocity and acceleration limits close to the zenith).

Collimation error has many causes–misalignment of the optics, an inaccurately centered eyepiece reticle and so on.

Term: CH

In an equatorial mount, the collimation error is the non-perpendicularity between the nominated pointing direction and the declination axis. It produces an east-west shift on the sky that is constant for all declinations.

CH is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, ID, NP, ME and MA.

A non-zero CH on its own means there is an area around the pole inside which the telescope cannot point.

Collimation error has many causes -- misalignment of the optics, an inaccurately centered eyepiece reticle and so on.

Term: DAF

Downward sag of cantilevered declination axis. English cross-axis and German equatorial mountings), proportional to the sine of the zenith distance of the declination axis.

Note: The sign convention corresponds to a declination axis that emerges from the polar axis towards the west when the telescope points at the meridian.

Term: DCEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered declination setting-circle.

The sine component is the term DCES.

Term: DCES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered declination setting-circle.

The cosine component is the term DCEC.

Term: DNP

For an equatorial mount, a change in the non-perpendicularity proportional to sin h.

Notes: The static form is the term NP.

Term: ECEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered elevation setting-circle.

Term: ECES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered elevation setting-circle.

Term: FO

Flexure in an equatorial fork mounting: change in declination proportional to cos h.

Notes: This model of fork flexure is based in the idea that the flexure is at a maximum on the meridian, that it affects only declination, and that at h = 6^h the flexural displacement leaves the pointing direction unaffected. These assumptions are usually borne out well in practice.

Term: HCEC

The cosine component of the once-per-revolution cyclic errors produced by a mis-centered hour angle setting-circle.

Term: HCES

The sine component of the once-per-revolution cyclic errors produced by a mis-centered hour angle setting-circle.

Term: IA

Azimuth index error in an alt-azimuth mount: the zero-point error in A.

Take care with sign conventions: inside *TPoint*, azimuth increases counterclockwise.

Notes: On many alt-azimuth telescopes, IA is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts there is no choice; under these circumstances the IA value returned by *TPoint* has no lasting significance. However, note that IA is not the same thing as a horizontal error on the sky, such as might be caused by a badly adjusted primary mirror; the latter, addressed by the CA term, would produce the same image displacement at all elevations, whereas IA has a lessening effect as the zenith is approached.

IA is one of the six purely geometrical terms that affect all equatorial mounts, the others being IE, CA, NPAE, AN and AW.

Term: ID

Declination index error in an equatorial mount: the zero-point error in declination.

Notes: ID produces a fixed offset of the image north south. On many telescopes, it is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts, there is no choice; under these circumstances the ID value returned by *TPoint* has no lasting significance. It is indistinguishable from other north-south shifts, such as those caused by a badly adjusted primary mirror.

ID is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, CH, NP, ME and MA.

Term: IE

Elevation index error in an alt-azimuth mount: the zero-point error in E.

IE produces a fixed vertical offset of the image. On many alt-azimuth telescopes IE is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts there is no choice; under these circumstances the IE value returned by *TPoint* has no lasting significance. It is indistinguishable from various other vertical shifts, such as those caused by a badly adjusted primary mirror.

IE is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, CA, NPAE, AN and AW.

Term: IH
Hour angle index error in an equatorial mount.

Notes: IH has the same effect on pointing as an error in the clock or using an inaccurate value for the site longitude. On many telescopes, it is arbitrarily set at the start of each night by pointing at a calibration star, and on telescopes without absolute encoders or readouts, there is no choice; under these circumstances the IH value returned by *TPoint* has no lasting significance. However, note that it is not the same thing as an east-west error on the sky, such as might be caused by a badly adjusted primary mirror; the latter, addressed by the CH term, would produce the same image displacement at all declinations, whereas IH has a lessening effect as the pole is approached.

IH is one of the six purely geometrical terms that affect all equatorial mounts, the others being ID, CH, NP, ME and MA.

Term: MA
Misalignment of the polar axis of an equatorial mount to the left or right of the true pole: a rotation about an axis through $h = \delta = 0$ equal to coefficient MA.

Notes: In the Northern Hemisphere, positive MA means that the pole of the mounting is to the right of due north.

In the Southern Hemisphere, positive MA means that the pole of the mounting is to the right of due south.

To avoid unwanted field rotation effects it is best to eliminate MA mechanically by an appropriate azimuth adjustment. To eliminate MA arcseconds of polar axis azimuth error, rotate the mounting MA sec ϕ arcseconds counterclockwise as seen from above.

The other (that is, up and down) component of the polar axis misalignment is the term ME.

Term: ME

Vertical misalignment of the polar axis of an equatorial mount: a rotation about an east-west axis equal to coefficient ME.

Notes: In the Northern Hemisphere, positive ME means that the pole of the mounting is below the true (unrefracted) pole. A mounting aligned the refracted pole (for most telescopes probably the simplest and best thing to aim for in order to avoid unwanted field rotation effects) will have negative ME.

In the southern hemisphere, positive ME means that the pole of the mounting is above the true (unrefracted) pole, and a mounting aligned the refracted pole will have positive ME.

The other (that is left-right) component of the polar axis misalignment is the term MA.

Term: NP

In an equatorial mount, if the polar axis and declination axis are not exactly at right angles, east-west shifts of the image occur that are proportional to $\sin \delta$.

Notes: NP is one of the six purely geometrical terms that affect all equatorial mounts, the others being IH, ID, CH, ME and MA.

The image displacement produced by NP is zero on the celestial equator and reaches a maximum at the pole.

Most telescope sites lie well away from the equator of the Earth and hence the correction for NP tends to be the same sign most of the time. Furthermore, because there is more sky at lower declinations than near the pole there are likely to be fewer pointing observations in a given declination-band near the pole than in a similar band nearer the equator. These two effects conspire so that the NP effect tends to be poorly sampled when pointing tests are made, and hence the NP coefficient is apt to be poorly determined. In some cases, it can be better to omit NP from the model and rely on other terms mopping up any NP-like effects that are preset.

A non-zero NP on its own means there is an area around the pole inside which the telescope cannot point.

Term: NPAE

NPAE is one of the six purely geometrical terms that affect all alt-azimuth mounts, the others being IA, IE, CA, AN and AW.

The image displacement produced by NPAE is zero on the horizon and reaches a maximum at the zenith.

Just as E is always positive, the correction for NPAE never changes sign. Furthermore, because there is more sky at lower elevations than near the zenith there are likely to be fewer pointing observations in a given elevation-band
near the zenith than in a similar band nearer the horizon. These two effects conspire so that the NPAE effect tends to be very poorly sampled when pointing tests are made, and hence the NPAE coefficient is apt to be poorly determined. In some cases, it can be better to omit NPAE from the model and rely on other terms mopping up any NPAE-like effects that are preset.

A non-zero NPAE on its own means there is an area around the zenith inside which the telescope cannot point (irrespective of velocity and acceleration limits close to the zenith).

Term: NRX

In a Nasmyth alt-azimuth mount, a horizontal displacement between the elevation axis of the mount and the rotation axis of the Nasmyth instrument-rotator produces an image shift on the sky with a horizontal component proportional to cosine elevation and a vertical component proportional to minus sine elevation.

(Take care with sign conventions: inside *TPoint*, azimuth increases counterclockwise.)

Notes: The same corrections apply even if there is no Nasmyth rotator, except that the displacement is between the elevation axis and the nominated pointing-origin in the Nasmyth focal-plane.

NRX is positive when the elevation axis emerges from the Nasmyth focal plane to the right of the rotator axis.

Term: NRY

In a Nasmyth alt-azimuth mount, a vertical displacement between the elevation axis of the mount and the rotation axis of the Nasmyth instrument-rotator produces an image shift on the sky with a horizontal component proportional to sine elevation and a vertical component proportional to cosine elevation. (Take care with sign conventions: inside *TPoint*, azimuth increases counterclockwise.)

Notes: The same corrections apply even if there is no Nasmyth rotator, except that the displacement is between the elevation axis and the nominated pointing-origin in the Nasmyth focal-plane. NRY is positive when the elevation axis emerges from the Nasmyth focal plane above the rotator axis.

The NRY correction has an identical form to the two terms NPAE and TF acting in combination. This unfortunately prevents simultaneous fitting of pointing observations to a model containing all three terms. The recommended procedure for

Nasmyth telescopes is to determine a canonical value of TF from observations at a non-Nasmyth focus (prime, Cassegrain, Newtonian etc., and then to fit Nasmyth pointing observations to a model which includes TF fixed at this value.

Term: TF

Classical tube flexure: change in zenith distance proportional to $\sin \zeta$.

Notes: This is the classic tube flexure model, which assumes that the telescope obeys Hooke's Law. In practice there is often a rapid increase in the vertical displacement towards the horizon, and it is sometimes found that a tangent law is a better approximation than a sine law: see the TX term.

Term: TX

Empirical tube flexure: change in zenith distance proportional to $\tan \zeta$.

Notes: The classical tube flexure model, TF, which assumes that the telescope obeys Hooke's Law, is a sine rather than tangent law. In practice there is often a rapid increase in the vertical displacement towards the horizon, and it is sometimes found that the present term, TX, is a better approximation than TF.

Note that TX will compensate for any scaling error in the refraction corrections.

Appendix B: Importing Models from TPoint for Windows

The steps below describe how to use an existing TPoint model from *TPoint for Windows* in the *TPoint Add On*.

Step I: Import the Pointing Calibration Data

1. From *TPoint for Windows*, open the TPoint document (.TPT) that holds your working model (keep TPoint for Windows open for now, you'll need to access it again soon).
2. Export the pointing calibration data ("mapped points" in TPoint for Windows) by clicking *File > Export Text File*.
3. Enter the name of the text file and then click *Save*. Remember the folder where this text file resides.
4. Select the *Import* command from the *Pointing Data* pop-up menu on the *Calibration Run* tab of the *TPoint Add On* window.
5. Select the text file from step 3 and then click the *Open* button.

Your pointing calibration data is now displayed in the *Pointing Data* table and on the scatter diagram.

Step II: Use the Appropriate Terms

The next step is to turn on the terms that were used in the *TPoint for Windows* model in the *TPoint Add On* model.

1. From *TPoint for Windows*, select the *Command Line* command from the *Model* menu.
2. Type the text *"FIT"* (case does not matter, no quotes) in the *Command* text input on the *Command Line* window.
3. Click the *Execute* button. The *coeff* column of the FIT report lists all the terms used in this model. These same terms should be used in the *TPoint Add On* model.
4. From the *Model* tab of the *TPoint Add On* window, turn on the check mark next to the terms that are listed in the *TPoint for Windows* FIT report.

Hint: To turn on multiple terms, type "USE" in the *Command* text input on the *Command Line* tab of the *TPoint Add On* window, followed by the space separated terms. For example, for the following FIT report:

```
* FIT

    coeff change value    sigma

1   IH    +0.194 +824.65  11.699
2   ID    +1.097  +29.47  11.414
3   NP    +0.335  -53.66  25.624
4   CH    +0.059 -772.27  13.814
```

```
5    ME     -0.581   -45.08    9.213
6    MA     +0.683    -3.39   18.542
```

You can type the following text in the TPoint Add On Command text input:

USE IH ID NP CH ME MA

then click the ***Execute*** button. Type FIT then click the Execute button to compare the *TPoint Add On* results with the *TPoint for Windows* results. The *TPoint Add On* model should now be identical to the *TPoint for Windows* model.

Step III: Recalibrate the Model

The last step is to reestablish the IH, ID and CH terms for the pointing data. Please see "A Step-By-Step Guide to Recalibration" on page 35 to proceed from here.

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