How To Autoguide The Compustar:

The Complete Guide

By

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Astrophotography

Astrophotography is more popular today than it has ever been. Electronic imaging has revolutionized the field and high quality digital single lens reflex (DSLR) cameras and charged couple devices (CCD) and are within the price range of many amateur astronomers. With the high sensitivity and linear response of these cameras, amateur astronomers are now capable of producing images from their back yards that only a few years ago would have rivaled those produced by professional astronomers at the world's best observatories. However, astrophotography is unlike all other types of photography. With standard photography, there is ample light to permit bright imaging of the subject in the wink of an eye. Exposures may be a fraction of a second, perhaps thousandths of a second. Despite these incredibly short exposures, each pixel in the camera generally records thousands of photons that comprise the image. Every possible brightness level within the dynamic range of the camera is loaded with ample data.

Not so with astrophotography. Because the subjects of astrophotography, such as star clusters, nebulae, and distant galaxies, are inherently dim, all astrophotography requires time exposures of considerable length to capture enough photons to have a chance at making the subject visible. Exposures range from minutes to hours. Even then, most pixels in the camera register almost no photons or barely a few more photons than the background noise that builds up in the pixels or the background sky brightness during the exposure. The amount of data captured is actually quite small and is confined to a very narrow range of brightness within the darkest shadow region of the camera's dynamic range.

The art of astrophotography comes with the image processing. The trick is to take that data confined to such a narrow range and skillfully stretch it through a much wider dynamic range, similar to that used in daylight photography, so that we perceive the illusion of viewing a bright scene. However, it is an illusion. Were we actually there, as close to a nebula or galaxy as the telescope view makes it seem, our eyes would actually see almost nothing. Thus, it is the combination of the magnification and light gathering power of the telescope, the integration of time exposures to capture as many photons as possible, and the power of image processing that make astrophotography the miracle that it is. We can image that which cannot be seen. No wonder it is so rewarding to those who pursue it.

The Celestron Compustar Telescopes

The Celestron Compustar telescopes were the **first** computer controlled **"Go-To"** telescopes. They premiered in 1987, a full *5 years* before the Meade LX200 series that most people remember as the first mass-produced Go-To telescopes. As the story goes, Celestron contacted computer engineer Mike Simmons and his company, ATI, to help them produce a new line of robotic telescopes. What Mr. Simmons and ATI did, by connecting the relatively simple (by today's standards) computers of the day with a Schmidt-Cassegrain telescope with the use of stepper motors to move the mount, was amazing. The results were the Compustars, telescopes able to automatically slew to any one of thousands of objects in their database. They were produced as 8, 11, and 14-inch versions of their popular SCTs, known respectively as the Compustar 8, Compustar 11 and Compustar 14.

Unfortunately, the Compustars did not hit the home run Celestron hoped they would within the amateur astronomy community, largely due to their high prices. The Compustar 14, at $22,000, still holds the record as the commercial Schmidt-Cassegrain telescope (SCT) with the highest list price. The Compustar 8's list price was $6,500. Although most Compustars were sold for considerably less (about $9,500 for the Compustar 14 and $2,700-3,500 for the Compustar 8), they were still out of the price range of many amateur astronomers. Rather, they were later supplanted by the Meade LX200 series of less expensive Go-To telescopes, largely because Meade purchased ATI and had Mr. Simmons put his efforts into producing the LX200 series. Celestron didn't counter the LX200 with its own Ultima 2000 series until much later, in the late 1990s (hence, the 2000 name, taking advantage of the "millennium fever" of the time). Celestron phased out the Compustars by in the early 1990s and no longer supports them.

The Compustars' other problem was that they were simply ahead of their time. The Compustars were unprecedented in their abilities and there are many among the community of amateur astronomers who think that they have yet to be surpassed as a Go-To telescope. A Compustar slews faster than other telescopes, up to an amazing 10 degrees per second. Its large, 7"x9" computer module screen is capable of simultaneously displaying much more data than any of the small hand controllers of the newer Go-To telescopes. A Compustar can simultaneously display the coordinates of the scope, the object number in the NGC and/or Messier catalogs, the type of object, it's magnitude, its size, double stars and their separations, how many other catalog objects are within a certain distance of the object, whether the object is in Sky Atlas 2000, and a visual rating of the object on a 10 point scale. It is also capable of being programmed for tours of the sky. Want to see all the galaxies that are more than 30 degrees above the horizon, brighter than magnitude 12, rated better than 5 points, and look at each object for 3 minutes? No problem! Just punch in a few keystrokes and the Compustar will take you on that tour. Although there have been criticisms that the pointing accuracy of the Compustars is not very good, this is not completely true. Permanently mounted Compustars with accurate polar alignments have very good pointing accuracy indeed.

Another criticism is that they were only programmed to work through the year 1999, and were not "Y2K" compliant. This is also no longer a problem. Tom Sorbel, of StarChron Solutions (P.O. Box 47143, Plymouth, MN 55447-0143), has made Y2K chips available that will update the Compustars well into the next century. He has even recently released a set of Y2K+ chips that significantly update the NGC catalog (called the CNGC for Compustar NGC) and reference star catalog with additional objects. Note that the Compustar 11 and 14 have a different chip than the Compustar 8.

With all their features, it is no wonder that Compustar owners lovingly care for and maintain these telescopes rather than buy some of the newer Go -To telescopes. It is also little wonder that some owners want to do long-exposure astrophotography with their Compustars.

Tracking Errors During Astrophotography and Their Sources

Unfortunately, one cannot simply attach a camera to the Compustar (or any other telescope), frame the subject in the camera, take a long exposure, and expect good results. Rather, the stars in the image will be trailed and the subject blurred. The reason for this is that no telescope clock drive and mount are perfect. They all make tracking errors. Most of these are what are known as periodic errors caused by the imperfections in the gear mechanism of the clock drive. At some times, the gears will lag behind the stars in pushing the telescope toward the west. Other times, it will push it just a little too far. Because the drive gear is typically a rotating gear, like a worm gear, the pattern of errors will repeat after one full revolution, or period, of the gear; hence the name, periodic error. Periodic error will not bother you during visual observing, as these errors are fairly small and the subject generally stays quite well centered in the eyepiece, but they will ruin all time exposures of any significant duration. Other errors arise from inaccurate polar alignment of the mount. This causes the image to drift north or south in the field of view over time. Still other tracking errors come from flexure of the mount. If the telescope is tracking something from the east side of the meridian, the mount may be flexing or bending in that direction under the weight of the telescope and camera. At the same time, the clock drive is having to push the telescope “uphill” and may have difficulty doing that. As the telescope crosses the meridian, the problems reverse. The mount will flex toward the west and the drive may begin accelerating “downhill” toward the west. These problems can all cause tracking errors.

Schmidt-Cassegrain telescopes are prone to one other type of tracking error, namely that caused by mirror flop. Schmidt-Cassegrain telescopes focus by moving the position of the primary mirror forward or backward along the axis of the central baffle tube. Thus, the primary mirror is not fixed, but can wobble, or flop, slightly from side to side around the baffle tube. A slight flop can cause a significant shift in the position of the image. It can even change the collimation of the telescope. The author’s Compustar C14 sometimes requires re-collimation for imaging near the poles compared with more southerly declinations. Also, regardless of recollimation, SCTs may be particularly prone to mirror flop as they cross the meridian. Fortunately, that type of mirror flop can be minimized by the simple technique of always approaching focus by turning the focus knob counterclockwise. This is because turning the knob counter clockwise results in the mechanism pushing the mirror away from the rear cell. Thus, the push pins of the focusing mechanism are always in contact with the rear surface of the mirror, stabilizing it somewhat and reducing its ability to flop from side to side. Conversely, turning the focus knob clockwise moves the pins of the focusing mechanism toward the rear cell, requiring the mirror to follow them under tension from a mechanism. Friction and other factors may prevent the mirror from moving all the way against the pins, leaving it prone to mirror flop.

What Is Guiding?

Because of these tracking errors, virtually all astrophotographs must be guided. That is, the tracking of the drive and mount are monitored in both the east-west and north-south direction throughout the exposure and all tracking errors are promptly corrected. Traditionally, this has been done manually by the astrophotographer using a device known as a drive corrector. Drive correctors typically have hand controllers with four directional buttons, one each for north, south, east and west corrections. When one of these buttons is pushed, electronic switches activate drive motors to move the mount by a small amount in the corresponding direction, thus correcting a tracking error. In the case of the subject drifting too far south, pushing the north button on the hand controller activates the drive motor on the declination axis to move the mount northward. The east and west buttons affect the clock drive motor on the right ascension axis, moving the telescope east or west, as required.

During the exposure, the astrophotographer cannot actually see the subject being imaged by the camera. To guide, the astrophotographer has to monitor a star, known as a guide star, being tracked by the same telescope drive and mount as the camera. The goal is to detect tracking errors and correct them before they would cause noticeable trailing on the final image. To do this, the astrophotographer has to have some frame of reference around the guide star. This is provided by a guiding eyepiece, also known as a guiding reticle. The guiding reticle projects an illuminated red cross-hair into the field of view of the eyepiece (Figure 1). The guide star is centered on the cross-hair which makes guiding errors, and their direction, immediately apparent. The astrophotographer has to remain at the telescope, essentially playing a simple “video game”--if the star drifts north, move it south, if it drifts west, move it east, and so on,-- for the entire duration of the exposure(s), which might be hours. Staring at a guide star, being essentially motionless for these long periods of time, one can get very cold (normally, much of one’s body heat comes from muscle movement) and mentally fatigued and this can easily lead to guiding errors that may degrade the image.

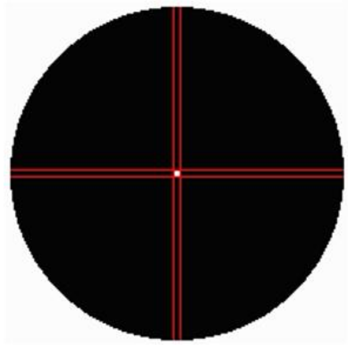


Figure 1. An illuminated red cross hair reticle. This reticle has a double cross hair. The guide star is centered in the cross hairs so that guiding errors can be detected and corrected by returning the guide star to its intended position in the cross hair using the motion keys on the drive corrector.

Notably, the Compustar has a manual drive corrector incorporated directly into the computer module. The four motion control keys in the upper right hand corner that are used for slewing and setting the telescope can also be used for making guiding corrections. However, the “SLEW” and “SET” speeds are far too fast and jerky for guiding corrections. Before manually guiding, one must switch the speed on the drive motors to “GUIDE” speed by pushing the “SPEED” button followed by the “GUIDE” button. The Computer module will beep three times indicating that it has changed the drive rates to guiding speeds. “GUIDE” speed is usually some fraction of the sidereal rate, which is an appropriate speed for guiding corrections.

Two Main Techniques Used for Guiding

How does one acquire the guide star? There are two main approaches: one is to use a separate guide scope and the other is to use an off-axis guider. Each has advantages and disadvantages.

A guide scope is another telescope, often a refractor, mounted on the same mounting as the imaging telescope. The guiding reticle eyepiece is inserted into the viewing end of the guide scope. Although the guide scope is mounted roughly parallel with the main imaging telescope using mounting rings or a dovetail plate, there are provisions by which the aim of the guide scope can be adjusted a fair amount in any direction. This accounts for the chief advantage of the separate guide scope. Namely, it provides an ample selection of suitably bright guide stars. The guide star can be quite some distance from the subject being imaged and this increases the odds that one can select a fairly bright star guide star that is easier to track.

The chief disadvantage of a separate guide scope is differential flexure. The guide scope and the main imaging telescope are two independent optical systems on the same mount and, as the mount moves, they may not remain stationary with respect to one another. Rather, the telescope tubes and their mounting hardware may flex in different directions and at different rates. With Schmidt-Cassegrain telescopes, the primary mirror may experience mirror “flop” as the mount crosses the meridian, but this will not occur in the guide scope. Thus, even if the guide star is tracked perfectly in the guide scope, differential flexure between it and the imaging scope can result in a trailed image. Ironically, efforts to thwart this problem can be counterproductive. Attaching the guide scope to the imaging scope using rigid hardware may reduce the flexion, but it adds a significant weight load to the drive, making drive rate errors more likely. The other disadvantage of the guide scope is cost; one has to purchase a separate telescope for guiding. Usually, this is a refractor.

An off-axis guider is a T-shaped connector (Figure 2A) placed between the telescope and the camera (Figure 3). The cross bar of the T is the main imaging axis through which light passes from the telescope to the camera. Inside the stem of the T is a small 90-degree reflecting prism, called a pick-off prism (Figure 2B), which is positioned (generally) outside the field of view of the imaging camera, but still within the field of view of the imaging telescope. The light from the prism is directed to an eyepiece holder, which comprises the stem of the T. The guiding reticle eyepiece is placed in that holder (Figure 4). The telescope is focused so that the image in the camera is sharp. Accordingly, the guiding eyepiece cannot be focused using the telescope's focusing knob, but must be focused by sliding the eyepiece in and out of the eyepiece holder, so as to not disturb the focus of the imaging telescope. The chief advantage of the off-axis guider is that the guiding optics and the imaging optics are one and the same. This eliminates the problem of differential flexure. Even guiding errors due to mirror flop of Schmidt-Cassegrain telescopes will be properly corrected. Other advantages to off-axis guiders are low cost and low weight. Off-axis guiders are inexpensive. They are also light weight and do not require additional mounting hardware and therefore do not add a significant weight load to the drive motors.

Figure 2A (left). An off-axis guider is a T-shaped connector that connects to the threads of the rear cell of the Compustar with the threaded ring at left. The threads to the right accept a T-ring for a camera or other adapter. The vertical "stem" of the T accepts an illuminated cross hair reticle eyepice with which the precise position of the guide star and guide errors can be judged.

Figure 2B (right) A view through the main optical axis of the off-axis guider shows the small pick-off prism that directs light from the guide star into the eyepiece barrel that accepts the cross hair guiding reticle eyepiece.

The chief disadvantage of off-axis guiders is their limited choice of guide stars. The field of view of the prism in the off-axis guider is quite small. Finding a suitable guide star that appears in prism at the same time that the subject is *anywhere* in the field of view of the camera is one of the most exasperating problems in astrophotography. Once the subject is centered in the field of view of the camera, no guide star may be visible in the prism. Then, the entire camera/off-axis guider complex can be rotated around the optical axis of the telescope to see if a star appears at some other angle. If that fails, the subject can be shifted slightly in the frame of the camera and the process repeated. This can take a considerable amount of time. The problem is particularly acute when imaging galaxies, which tend to be in the portions of the sky less populated by foreground stars in our own Milky Way. Thus, the farther the subject is from the plane of the Milky Way, the more the choice in guide stars diminishes.

Obviously, once a suitable guide star is located, the subject may not be ideally framed in the field of view of the camera. It may be somewhat off-center, or even near a corner of the frame. This is not a problem with separate guide scopes in which the subject can always be framed as desired and a reasonably bright guide star can be selected quite far afield from that by adjusting the aim of the guide scope. Furthermore, acquiring the only suitable guide star may result in the off-axis guider being oriented at some very inconvenient angle for monitoring the guide star, like pointing down toward the ground (Figure 3). The author has spent many hours guiding astrophotographs while in these uncomfortable positions.

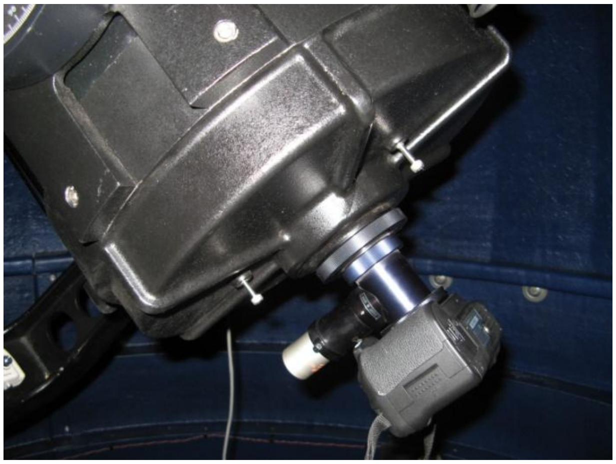


Figure 3. Off-axis guider and DSLR attached to the author's Compustar 14. This is a classic example of an uncomfortable position of a standard illuminated cross hair guiding reticle eyepiece in an off-axis guider. Imagine positioning yourself beneath the eyepiece to guide a long exposure astrophotograph.

There are a few strategies to mitigate some of these problems. The rotation of the off-axis guider's field of view relative to the camera's field of view can be changed by loosening the set screws on the camera's T-ring, rotating the off-axis guider as desired, and then re-tightening the set screws. This can permit better framing of the subject with certain guide stars. High-end off-axis guiders have provisions for easy rotation of the off-axis prism and some even permit adjusting the position of the prism farther in or farther out from the center of the camera's field of view. These strategies provide some flexibility in the framing of the subject with a particular guide star. The most effective strategy is to actually determine one's choice of guide star prior to the imaging session. This can be done fairly accurately if one spends the time determining the field of view of the camera through the imaging telescope, the field of view of the guiding prism/eyepiece through the off-axis guider, and their relative separation on the sky (for details on how to do this, see the author's article in Sky and Telescope, February 1993). One can then make an overlay showing the fields of view of the camera and off-axis guider/eyepiece at the same scale as the sky depicted in star atlases, photographic atlases, or planetarium software. The overlay can be used to determine the orientation of the camera frame's long and short axes relative to the cardinal directions on the sky, the position of the off-axis guider stem relative to the camera frame, and the actual guide star to be used. This saves a tremendous amount of time during the actual imaging sessions. Planetarium software often has provisions for making such overlays for use with that program.

Lastly, the image of the guide star through the off-axis guider may not be very good. The off-axis guider acquires stars, as the name implies, quite far off the optical axis of the telescope, where coma from an SCT's optics is more apparent. This gives comma shaped stars on which to guide. To make matters worse, the optical quality of the small pick-off prism in an off-axis guider is generally not very high. The alignment of the prism may not be perfectly perpendicular to the optical axis of the telescope. These factors can result in distorted images of guide stars, which make it difficult to judge its true position during guiding. These problems are further accentuated when a focal reducer-corrector, like the Celestron f/6.3 reducer-corrector, is inserted in the optical train ahead of the off-axis guider. Then, guide stars may be subject to a considerable amount of distortion and a marked drop in brightness due to vignetting of the reducer, making it very difficult indeed to track a guide star. Obviously, these are not problems with separate guide telescopes through which the image of the guide star will be of much higher quality.

Autoguiding

With knowledge of all the technical difficulties with guiding, one can see other reasons why astrophotographers were so proud of their images. Each represented a triumph over potentially dozens of technical problems and stood as a testament to the hours spent in the cold, holding oneself in some uncomfortable position, yet still competently correcting all the guiding errors.

Autoguiding proved to be a revolution in astrophotography. As the name implies, it is a process by which the mount guides itself during exposures. It liberated astrophotographers from the grueling hours described above and even permitted them to sleep while their exposures were being collected. The first commercially available autoguider was produced by the Santa Barbara Instrument Group (SBIG) of Santa Barbara, California, in 1989 and was officially known as the Star Tracker 4, but is more commonly known as the ST-4. The ST-4 consists of a small CCD camera, inserted in place of the guiding eyepiece, and a computer that sends commands via cables to the mount to make the guiding corrections. The ST-4 was later discontinued and followed by the ST-V, which has since been replaced by the ST-G. Currently, many other autoguiding systems are commercially available. Autoguiders can even be built by astrophotographers, as is the purpose of this article.

Regardless of their origin, all autoguiding systems consist of the same six components. These components are: 1. A guide scope or an off-axis guider, 2. A guiding camera to detect and monitor the guide star, 3. A computer, 4. Autoguiding software, 5. A link between the computer and the mount, 6. A guide port for the telescope mount to receive input from the computer. The guide scope or off-axis guider was discussed above; the others are discussed below:

Guiding Camera

The guiding camera is not to be confused with the actual imaging camera at the prime focus of the telescope. Rather, it will be inserted where the guiding reticle eyepiece would have been placed. The guiding camera can be any one of a variety of imaging devices. It can be a small CCD designed specifically for autoguiding, as with the SBIG ST-4 autoguider. It could also be a dedicated CCD camera, an Orion StarShoot, a Meade Deep Sky Imager (DSI) or Lunar Planetary Imager (LPI), a Celestron NexImage or LPI, or just a modified webcam (Figure 4). In fact, the Meade and Celestron cameras are basically modified webcams. The guiding camera detects the guide star on its imaging chip and sends the image to the computer for interpretation. Generally, webcams can detect and track guide stars as faint as magnitude 7 fairly reliably. Cooled CCD cameras can detect and track still fainter guide stars.

Figure 4. Examples of guiding cameras. From left to right, a modified webcam, the Meade DSI, the Orion StarShoot, and the Celestron NexImage.

Computer

Clearly, the guiding camera takes the place of the astrophotographer's eye. The computer takes the place of the astrophotographer's brain. It is responsible for determining the position of the center of the guide star on the guide camera's chip, comparing that to the intended position of the guide star on the chip, calculating the differences, if any, and translating those into the requisite commands to be sent to the mount to make any necessary guiding corrections. It can do a better job of this than the human brain and can even do it with a comma shaped star in an off-axis guider, as it can accurately determine the position of the point of maximum brightness within the distorted star image and track that consistently. The computer is often a laptop computer, but could also be a desktop computer. The electronics boxes that came with the ST-4 and V units were stand alone computers that did not require the astrophotographer to provide a separate computer. The computer does not need to be a particularly fast computer to accomplish these tasks. Often, an older laptop can be relegated to this task after one purchases a faster new one for image processing, for example. However, the number of other applications that the computer has running during autoguiding should be limited as much as possible.

Autoguiding Software

Obviously, you can't just connect an imaging camera to a computer and expect it to begin interpreting the images and put out guiding correction commands that can be sent to the mount. That requires autoguiding software designed specifically for those tasks. In the case of the ST-4 and ST-V, proprietary autoguiding software was provided inside the electronics box. In other cases, the astrophotographer must obtain autoguiding software and load it into the computer. Many image acquisition and/or image processing software packages include autoguiding software. These include MaxIM DL, MaxDSLR, CCDOps, K3CCDTools, and AstroArt. In addition, autoguiding software programs are available as freeware. These include GuideMaster (www.**guidemaster**.de/index_en.asp), GuideDog (*www.barko**software**.com/**GuideDog***), and PHD Guiding (*www.stark-labs.com/**phdguiding**.html*), to name a few. One must be careful in selecting the autoguiding software to ensure that it will dovetail properly with all the other components of the autoguiding system you are assembling. For example, the software may not support the type of guiding camera you are using. Alternatively, it may require an output to communicate with your mount, such as a parallel port, that your computer does not have.

Link Between Computer and Mount

During an imaging session, the autoguiding software will interpret the position of the guide star on the chip of guiding camera, calculate the amount of correction needed, and translated those into electrical signals to send to the mount to make those corrections. For this to occur, the signals have to be conducted from the computer to the mount. This requires a proper link between the computer and the mount. The link itself has several components.

The first component is an output port on the computer. The output port can be a USB port, a parallel port, or a serial port. The autoguiding software will let you chose which type of output port is used, but some software may have restrictions. If your computer is responsible for doing other tasks during imaging besides acquiring the image from the guiding camera, such as acquiring the image from the main imaging camera and storing it in an external drive, it makes sense to preserve certain outputs for those purposes and try to select a different type of output for communicating with the mount. For example, all the other mentioned tasks may require USB ports. If your computer has a parallel port, you might want to select that for communicating with the mount so that all the USB ports are still available for the other tasks.

The second component will be a connector attached to whatever USB port, parallel port, or serial port you have selected as the autoguider output from your computer. The job of this connector is to route signals from the computer to the next component in the link, which is a cable. In the case of autoguiding, it is a very specific type of cable called an RJ-11 cable (Figure 5). This cable may be referred to as an RJ-12 cable by some.

Figure 5. Two examples of RJ-11 autoguiding cables, a flat ribbon cable on the left and a coiled cable on the right.

An RJ-11 cable looks a just like a telephone cable, complete with modular telephone jacks, but it is ***not*** a telephone cable. RJ-11 cables will be discussed in detail below, but the important point to understand now is that the connector device must plug into the computer port you've selected and also have a female RJ-11 modular jack plug, which looks like a female telephone jack plug.

Such connectors are commercially available. An excellent source is Shoestring Astronomy (www.shoestringastronomy.com). They provide parallel port to RJ-11 adapters, sold as a GPINT-PT device (Figures 6A and 7), and USB to RJ-11 adapters, sold as a GPUSB device (Figure 6B). The website contains useful manuals for these devices that you may download and read.

Figure 6A (left). A GPINT connector, available from Shoestring Astronomy. Note the male plug to be connected to the parallel port on the autoguiding computer and the female RJ-11 modular jack port with copper connection pins, where the RJ-11 cable can be attached.

Figure 6B (right). A GPUSB connector, available from Shoestring Astronomy. Note the USB cable that can be connected to the autoguiding computer and the female RJ-11 modular jack port with copper connection pins, where the RJ-11 cable can be attached.

After the connector is attached to the proper port on the autoguiding computer, the jack on the RJ-11 cable will be inserted and locked into to the female modular jack plug on the connector (Figure 7). So, where does the other end of the RJ-11 cable go?

Figure 7. The GPINT connector attached to the parallel port of the autoguiding computer and a coiled RJ-11 cable inserted into its female modular jack plug.

Guide Port for the Telescope Mount

Newer telescopes mounts have conspicuous guide ports where they receive computer input for autoguiding. They consist of another female RJ-11 modular jack plug that resembles a telephone modular jack port (Figure 8). One simply plugs the opposite end of the RJ-11 cable into the modular jack port on the mount and all connections are in place for autoguiding. But there is no such guide port site on the Compustar. Obviously, the million dollar question is, “Does the Compustar have some other type of guide port?”

Figure 8. A female RJ-11 modular jack guide port, with copper connection pins, on a modern telescope mount. One simply inserts the jack on the opposite end of the RJ-11cable into this guide port to complete the link between the autoguiding computer and the telescope mount to enable autoguiding. However, the Compustars don’t have such a guide port.

The Compustar Can Be Autoguided

Fortunately, the answer is "Yes, the Compustar does have some other type of guide port", and that almost seems like a miracle. It is another testament to the fact that the Compustar design was far ahead of its time. When Celestron began producing the Compustars, the concept of autoguiding barely existed. Other telescopes of that era had no provisions whatsoever for autoguiding. It was not at all clear in what direction the field of autoguiding might go. Celestron did not know if it would later produce autoguiders for the Compustars, or any of its other telescopes for that matter. It was not known what type of equipment might be produced by other manufacturers that might come to dominate the field, as occurred with SBIG's ST-4 (which was not introduced until 1989, several years after the Compustar was designed) and ST-V. Despite all these unanswered questions, the designers of the Compustar had the wisdom and foresight to put autoguiding capability into it for possible future use. The autoguiding feature is briefly mentioned in the Compustar Instruction Manual on pages 56, 59, and 60. Note that on page 56 it clearly states autoguiding is not yet supported.

The Compustar Guide Port

The guide port on the Compustar is not located on the mount. It is actually located on the front edge of the computer module (Figure 9). The front edge has 3 female computer ports, known as DB-9 ports. DB-9 ports and plugs are D-shaped and use 9 pins (Figure 10).

Descriptions of the functions of these three DB-9 ports are printed in the Compustar Instruction Manual. The right port is for an optional joystick that can be used to steer the mount. The left port is for output to a printer. It is the **center** DB-9 port that is the guide port (it can also be used for a second joystick). However, we obviously have a problem here. The output from the autoguiding computer is being transmitted via an RJ-11 cable with 6 pins. The Compustar computer module will accept inputs for autoguiding via a DB-9 port with 9 pins. One cannot take the RJ-11 cable from the autoguiding computer, cut it and splice the wires to some of the pins on a DB-9 plug, connect that to the center DB-9 port on the Compustar computer module and expect it to work. We have to know how to these connections should be wired so the commands from the autoguiding computer make sense to the Compustar computer module.

Figure 9. The front edge of the Compustar computer module showing its three female DB-9 ports. Each port receives 9 pins. The right port is for an optional joystick, the left port is for output to a printer. The center DB-9 port is the guide port for autoguiding input.

Figure 10. A computer cable with a male DB-9 connector plug. The connector is D-shaped and has 9 pins.

We have to know which wires on the RJ-11 cable go to which pins on the DB-9 plug. But when it comes to making a connection between an autoguiding computer and the Compustar computer module, there is another extremely important issue, and that is the issue of electrical isolation.

Many older telescopes, likes the Compustar, require electrical isolation between the electronics of the autoguiding computer and those of the telescope computer. Failure to do this can cause fatal damage to the telescope electronics. Being the Compustar computer module is not replaceable, we cannot afford to let this occur. The required electrical isolation will be provided in the form of electrical relay switches.

So, completing the connection between the autoguiding computer and the Compustar computer module isn't as simple as knowing which wires of the RJ-11cable are connected to which pins of the DB-9 connector. We have to insert relay switches between these two connections. To understand this fully, we will need to cover a few more topics, including relay switches, the wiring of RJ-11 cables, and autoguiding "languages".

Relays

The relays are one of the most important components required for autoguiding the Compustar. They take the electronic correction signal output from the autoguiding computer and use them to open and close electrical switches that activate the drive motors in the mount to actually carry out the corrections. In other words, they take the place of your fingers pushing and activating the motion control buttons on the upper right corner of the computer module. Also, as mentioned above, they isolate the electronics of the autoguiding computer from the electronics of the Compustar computer module so that the former does not damage the latter.

For the longest time, the issue of relays for the autoguider confused the author. It wasn't clear from the Compustar Instruction Manual, or any other literature source on the topic of autoguiding, whether relays were already provided as part of the electronics inside the Computer module. If they were, then it really might be a fairly simple matter of wiring the connections between the RJ-11 cable and the pins of a DB-9 plug. Make no mistake about it; there are no relay switches inside the Compustar computer module. They must be provided by the Compustar owner and they must be positioned in the link between the RJ-11 connection coming out of the autoguiding computer and the DB-9 plug entering the Compustar computer module. In other words, they are an integral part of component number 5 in the list of components that make up an autoguiding system shown above. Later, we will assemble a relay box to insert between the autoguiding computer and the Compustar computer module. It will relay the signals from the RJ-11 cable to the DB-9 connector.

RJ-11 Cables

As mentioned above, RJ-11 cables look like ordinary telephone cables with modular jacks on either end, but they are ***not.*** It is critical that the reader not try to substitute a telephone cable for an RJ-11 cable. Telephone cables usually have only 4 colored wires that connect to 4 copper pins on their male modular jacks. RJ-11 cables have 6 colored wires connected to 6 copper pins in their modular jacks. However, even if one procures an RJ-11 cable, not all RJ-11 cables are wired suitably for autoguiding the Compustar. The key issue is the relative orientation of the modular jacks on the opposite ends of the cable. There are two ways the modular jacks can be connected if the ribbon of cable is out laid out flat, (which can be a little difficult with a coiled cable, but one can keep track of which side is which from one end to the other.). One way is with the retaining clips on the same side of the cable, the other is with the retaining clips on opposite sides. RJ-11 cables suitable for autoguiding the Compustar have the retaining clips on the opposite sides (Figure 11).

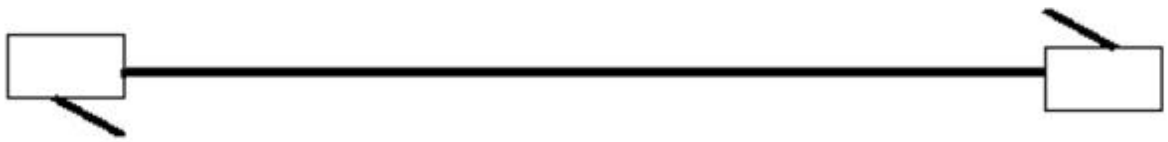


Figure 11. Orientation of the retaining clips on the modular jacks of an RJ-11 cable suitable for autoguiding the Compustar. Note, with the cable laid out flat (this is a side view), the clips are on opposite sides.

The wires of the RJ-11 cable are both numbered and color coded. If you look down on the copper pins of the modular jack of an RJ-ll cable with the cable toward the left and the modular jack toward the right (Figure 12), then the wires and their corresponding copper pins are numbered 1 through 6, with 1 at the top and 6 at the bottom. The wires are color coded and must be in a particular order. The correct order is wire 1=white, wire 2=black, wire 3=red, wire 4=green, wire 5=yellow, and wire 6=blue.

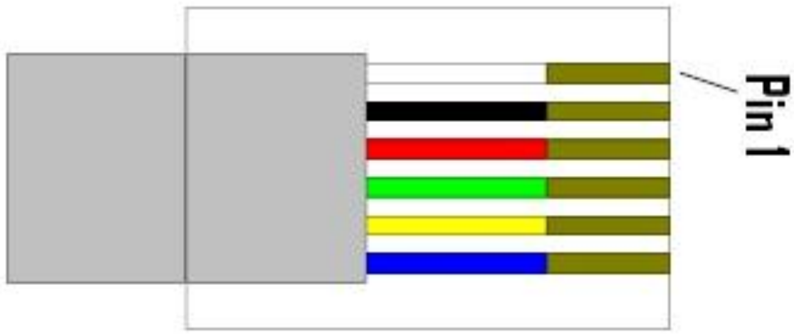


Figure 12. The color coding and pin numbering of an RJ-11 autoguiding modular cable jack. With the cable to the left and the copper wire pins of the modular jack to the right, the pins are numbered 1 through 6 from top to bottom and the order of colors of the wires connected to them is white, black, red, green, yellow, and blue, respectively.

It is for this reason that the modular jacks on opposite ends of an RJ-11 cable must have the retaining clips on opposite sides. That is the only way that the white wire goes to pin 1on the top of both jacks, the red wire goes to pin 6 on the bottom of both jacks, and all the wires in between are connected to the same numbered pins on both jacks. Thus, with an RJ-11 cable that is suitable for autoguiding the Compustar, it won't matter which modular jack you choose to check the wiring. You will see the same order regardless of which you choose. It is critical that the RJ-11 cable be of this type. If you procure an RJ-11 cable with the retaining clips on the same side, then pin 1 on one jack connects to pin 6 on the other. The wire on pin 1 may be white or blue, depending upon which side you choose. If you put the two modular jacks beside each other in the orientation shown in Figure 11, each modular jack will be the mirror image of the other. Only one of the modular jacks will have the necessary wiring scheme described above. Using this type of RJ-11 cable can result in improper connections, short circuits, and permanent damage to the autoguiding computer or, worse, the irreplaceable Compustar computer module. The safest way to ensure proper wiring is to purchase an RJ-11 cable from an astronomy dealer. RJ-11 cables that are certified safe for autoguiding are available from Shoestring Astronomy, for example, but always be sure to check the modular jacks before using any RJ-11 cable.

This particular arrangement of the colored wires and pins of an RJ-11 cable modular jack implies a reciprocal arrangement of the copper connection pins in a female port for an RJ-11 cable. The reciprocal arrangement implies that if one looks into the port with the pins on the top and the receptacle for the retaining clip on the bottom, then pin 1 for the white wire will be on the left, and so on, with pin 6 for the blue wire on the right (Figure 13).

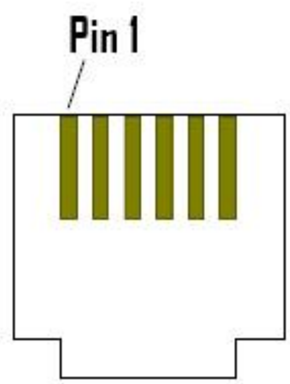


Figure 13. View into a female RJ-11 modular jack port with the pins at the top and the receptacle for the retaining clip on the bottom, indicating how pin 1 for the white wire will be on the left. Pin 6 for the blue wire will be on the right.

Autoguider "Languages"

The color-coded wires in the RJ-11 cable will be used to carry electrical impulses from the autoguiding computer to the Compustar mount, commanding it to move right or left in the horizontal direction (that is along the Right Ascension, or R.A., axis), or up or down (that is along the Declination, or Dec., axis). These directions are often referred to as +X, -X, +Y and -Y, respectively, in autoguiding software and autoguiding wiring diagrams. However, be aware that they may also be referred to as +R.A., –R.A., +Dec. and –Dec, respectively. Consider them interchangeable.

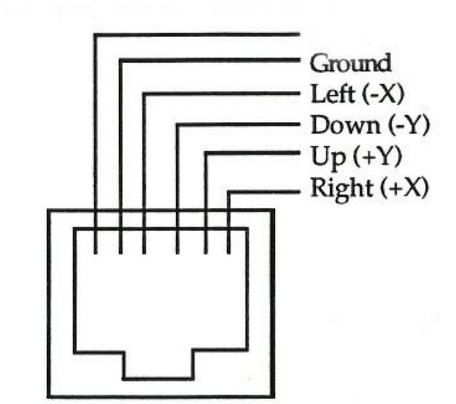
The issue is which wires in the RJ-11 cable will be used to carry which commands. Which wire is connected to which lead on a plug, such as an RJ-11, is known as its pin out. Using one combination of wiring, or pin out, to carry the 4 command directions as opposed to another is essentially using one autoguider "language" instead of another.

Unfortunately, there is no universal, or even a standard, language for autoguiding. However, the pin out used by SBIG for the ST-4 autoguider is one of the most commonly used languages and it is the one we will use for autoguiding the Compustar. Many autoguiding software programs use this particular language. Check both the autoguiding software AND the computer output connector that you intend to use with your Compustar to ensure that they both use the ST-4 language/pin out. All connectors produced by Shoestring Astronomy use the ST-4 language.

In ST-4 language, the pin out for an RJ-11 cable (repeat, cable) is as follows:

Pin #	Wire Color	Direction
1	White	Not used
2	Black	Ground/common
3	Red	-X
4	Green	-Y
5	Yellow	+Y
6	Blue	+X

Thus, when the autoguiding computer issues guiding commands, they will pass through the selected USB port, parallel port, or serial port into the connector. The connector is properly hard wired to its integrated female RJ-11 modular jack port to ensure that the +X commands are connected to pin 6 in the top right (using the same view into the port used for Figure 13), the +Y commands will be connected to pin 5, and so on (Figure 14A). The reciprocal connection to the male RJ-ll cable jack will in turn ensure that the +X commands are conducted to pin 6 and its blue wire, the +Y commands are conducted to pin 5 and its yellow wire, and so on for the other pertinent wires (Figure 14B).



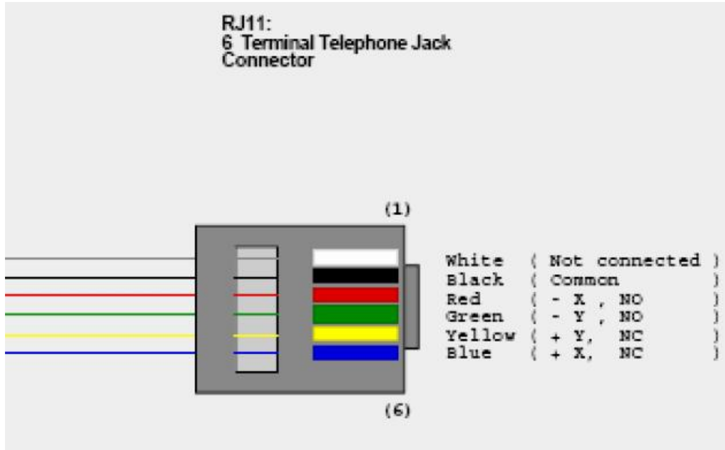


Figure 14A (left). The pin out of a female RJ-11 modular jack connector, such as one on a GPINT or GPUSB connector. The female plug will have pin 1 at the left and pin 6 on the right in systems using the ST-4 language. This will be the pin out on the connector coming out of the autoguiding computer.

Figure 14B (right) The pin out and color coding of wires of an RJ-11 male jack and cable using ST-4 language. This is the pin out of the cable carrying the signals away from the autoguiding computer toward the relay switches and, ultimately, the Compustar computer module guide port.

Commands are now being carried from the autoguiding computer toward the Compustar mount along 4 of the 6 wires of an RJ-11 cable, plus we need to use a ground on wire 2. However, the DB-9 connector that will connect to the Compustar computer module guide port has 9 pins. So, we will have to know how to make the correct connections from the wires in the RJ-11 cable to pins on the DB-9 connector so that these commands make sense to the Compustar computer module. Also, don't forget that we need to insert relay switches between the RJ-11 and the DB-9 to provide the electrical isolation and open and close the movement switches for us. As mentioned above, it is best if these connections, relays and other electrical parts are wired and contained in a small, portable box, which will be referred to as the "relay box" or the "interface box". However, we will need a wiring diagram to show how it should be done.

The Wiring Diagram

The wiring diagram that shows how the wiring should proceed from the RJ-11 pins coming out of the guiding computer to the relay switches and then to the correct pins on the DB-9 that will be plugged into the autoguider port on the Compustar computer module is show in Figure 15. This is a modification of a wiring diagram that has been published by Dennis Borgman in at least two places. One is the Compustar Users' Fan Page (http://home.online.no/~gibala/astro/cct/index.htm) and the other is the Yahoo Compustar User's

Group (http://tech.groups.yahoo.com/group/CelestronCompustar-User/). Mr. Borgman published this in response to a request for autoguiding wiring posted on the Yahoo Compustar User's Group. He indicated that he had done this wiring for an observatory in Texas and would be happy to share the schematic.

The diagram has two portions. It shows the wiring scheme for an autoguider relay box, or interface box, on the right side of the diagram and, on the left side of the diagram, the wiring for an optional joystick that can be plugged into the joystick port on the right side of the Compustar computer module. We will be interested in just the right side of the diagram. However, his diagram showed how to wire the relay box from either RJ-11 pins coming from an ST-V or the DB-9 male pins on an SBIG ST7, 8, or 9. They all use autoguider languages other than the ST-4 language we will be using, so we can't use the pin out wirings shown (still labeled as RJ-11 Pins for ST-V and DB-9 pins for ST7,8,9 in small print on the upper right of the diagram).

The wiring diagram has been modified to show how it should be wired to work with an RJ-11 cable using the ST-4 language. This is indicated by "RJ-11 Pins" printed in larger font at the extreme upper right of the diagram. Beneath that are the pin outs for the RJ-11 cable we are using, and the connections to the relay box are shown with colored lines corresponding to the corresponding wire colors on the RJ-11 cable.

The relay box with the relay circuits and other parts will have to be assembled from parts by the reader, provided they are competent at interpreting these diagrams and translating them to circuits. For those who are not, like the author, it should be built by some competent individual, -like an electrical engineer. The parts list for this relay interface box is listed below.

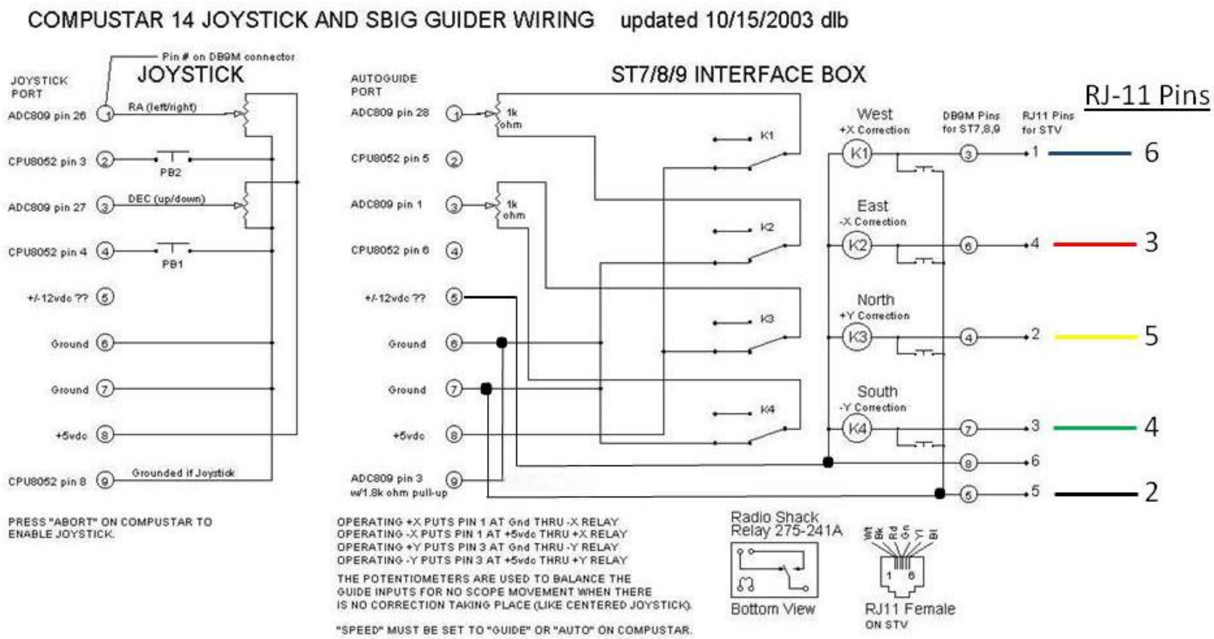


Figure 15. The modified wiring diagram for the relay interface between the RJ-11 cable from the autoguiding computer to the DB-9 connector for the guide port on the Compustar computer module, using the ST-4 language. The left side of the diagram shows wiring for an optional joystick to be connected to the joystick port on the right side of the Compustar computer module.

<u>Parts List for the Compustar Autoguiding Relay Interface Box</u>

<u>Quantity</u>	<u>Part</u>
1	RJ-11 cable with modular jacks
1	Plastic electrical container box
4	Radio Shack 275-241A 5V relay switches (275-240A relays also work)
2	1k ohm potentiometers
1	Small circuit board, cut to fit in the box
1	DB-9 cable with male connector pins

The parts list generally goes in order of the diagram, reading from right to left, with the wiring, relays, and potentiometers inside the plastic electrical container box. The RJ-11 cable will be connected with one of its jacks into the output connector from the autoguiding computer and receive commands for moving the mount in the four directions as indicated on the RJ-11 wiring diagram shown above. The RJ-11 cable pin out is shown on the right side of the wiring diagram. (The reader can ignore the labeling of the pin outs for the ST-V and ST-7,8, or 9, unless they are autoguiding directly from one of those devices instead of using an RJ-11 cable from an autoguiding computer. If the reader will be using one of those devices, then they may simply follow the indicated pin out for the wiring of the relay box. However, not having any experience with such cameras, the author advises readers attempting to autoguide with them to consult a competent electrical engineer before proceeding.) The RJ-11 cable will enter the plastic box, but once inside it will be cut and the 6 color-coded wires splayed out to permit the wires to make connections within the box. Thus, as implied earlier, the modular jack plug on the opposite end of the RJ-11 cable will not be used.

Next the wiring diagram shows the RJ-11 wires leading into 4 push buttons on their way to the relays. However, these buttons are not necessary (see **Enabling the Autoguider** below) and may be safely omitted. Rather, the color-coded RJ-11wires can be connected directly to the components of the relay box as shown in the wiring diagram above. Thus, the guiding computer outputs that are conducted along their corresponding RJ-11 wires will open and close the proper relay switches inside the box to effect changes in the drives for the X and Y axes. The DB-9 cable, also cut with its wires splayed out inside the box, will exit the other end of the box, terminating in the male DB-9 connector pins that will be plugged into the female guide port on the Compustar computer module. The wires will lead to various pins of the DB-9 connector as indicated on the left side of the wiring diagram. Pin 1 of the female DB-9 connector on the Compustar computer module controls the +X and –X movements and pin 3 controls the +Y and –Y movements. Whether the motions in the respective axes are in the + are – direction depends upon whether the corresponding relay switches are opened or closed. The relay box will derive power to operate the relay switches by drawing +5V DC from the Compustar computer module off pin 8 of the DB-9 connector. DB-9 pins 6 and 7 provide ground for the relays.

Lastly, there will be 2 potentiometers wired into the system on the circuit board within the relay box and connected to pins 1 and 3 of the male DB-connector. These are provided to balance the inputs to the X and Y axes so that there is no movement of these axes when no corrective input is commanded by the autoguiding computer. In other words, if the inputs are not balanced, simply connecting the autoguider relay box and activating it can start movement of the mount in one direction or the other in one or both axes. Adjusting the potentiometers can balance the inputs and null out the motion. Thus, access to the potentiometers from outside the box must be provided so they can be adjusted, if necessary. They are usually adjusted by turning screw heads with a small screwdriver. Access can be as simple as small holes drilled in the side of the box to allow passage of a small screwdriver.

It is also important to note that pin 9 on the DB-9 male connector must be grounded. On the left side of pin 9, the wiring diagram indicates that it is connected to pin 3 of the ADC809 chip (analog to digital converter chip) inside the Compustar computer module with 1.8k ohm pull up. The original Borgman diagram also indicated “no connection” on the right side of pin 9 (this has been deleted on the modified diagram). The experience of the author was that the autoguider relay box would not operate unless pin 9 on the DB-9 connector plug was grounded. Subsequent tests by Tom Sorbel confirmed that pin 9 has to be grounded on any device plugged into the joystick and autoguide ports for it to be recognized as present by the Compustar computer module. However, in the joystick port on the right side, a grounded pin 9 is also a signal to the Compustar computer module to inactivate the 4 motion control buttons. This makes sense, as once the Compustar senses a joystick in the right hand port, it would assume that you will then use the joystick to control movement of the mount. The Compustar computer module "checks" to see if a joystick is connected to the right hand port (sensed by a grounded pin 9) whenever the system is first booted up, or when the user hits the "ABORT" button.

How Relays Work

Basically, a relay is an electrical switch. It is operated by electromagnetism. It has two possible positions, which can be viewed as "on" and "off", but these are normally referred to as "closed" and "open", respectively. That is, if the switch is making contact with one position, then it is said that position is "closed". If the switch is not making contact with a position, then it is said that position is "open". The relay switch has a default setting, which is referred to as "normally closed", often abbreviated as "nc". A small spring holds the switch in the "nc" position. Therefore, current normally flows through the switch via the "nc" position. All the relays in the diagram are shown in their "nc" positions. A relay switch is in close proximity to an electromagnetic coil, indicated by a circle with a "K" inside it. Because we are controlling movement in 4 directions, there need to be 4 relay switches. Thus, the 4 coils in these relays are marked as K1-K4. The 4 coils are drawn to the right of their corresponding relay switch in the diagram. The relay switch is also labeled with its corresponding coil number, such as K1, for example, by its "no" contact point.

If current is applied to the magnetic coil by an electrical input, like from one coming from the autoguiding computer via one of the RJ-11 wires, then a magnetic field is produced in the coil. This magnetic field will magnetically move the switch from its "nc" position to its "no" position, causing the current to go through the circuit differently. When the electrical input to the coil is stopped, then the magnetic field decays and there is no magnetic force holding it in the "no" position, so the small spring flips it back to its "nc" position.

In the diagram, it can be seen that current coming from the autoguiding computer via the blue RJ-11 number 6 wire (referred to as "operating +X" in the diagram) will induce an electromagnetic field in the coil K1, adjacent to relay switch K1 (the uppermost relay on the diagram). That electromagnetic field will switch relay 1 from its "nc" position to its "no" position. That will have the effect of putting DB-9 pin number 1 of the Compustar guider port at ground on DB-9 pin 5, 7 or 9 through the –X relay. This will upset the "balance" in electrical forces on Pin 1 of the DB-9 connector in favor of the +X direction and move the drive in the +X direction (this is extra movement beyond the normal clock drive movement).

When the input stops, the electromagnetic field will decay, the spring will flip the relay switch back to its “nc” position and restore electrical balance on DB-9 pin 1 and movement in the X axis will not be in favor of either the +X or –X direction. Thus, extra movement in the +X direction will cease. Similarly, current coming from the autoguiding computer via the yellow RJ-11 wire number 5 (referred to as “operating +Y” in the diagram) will induce an electromagnetic field in coil K3 adjacent to relay number K3. This will flip relay switch number 3 from its “nc” to its “no” position, putting pin 3 on the DB-9 connector at ground on DB-9 pin 5, 7 or 9 through the –Y relay. This will upset the electrical balance on DB-9 pin 3 in favor of the +Y direction and will move the Y axis drive in the +Y direction. When the input stops, the electromagnetic field in coil K3 will decay and relay number 3 will flip back to its “nc” position, restoring the electrical balance on DB-9 pin 3 and movement of the Y axis drive will stop. The effects of operating the –X and –Y inputs are listed on the diagram for those that wish to pursue this further, but the effects are to put the corresponding DB-9 pins at +5V DC from DB-9 pin number 8 through relays as indicated on the diagram. These actions have the opposite effect by upsetting the electrical balance on DB-9 pins 1 or 3 in the opposite direction, thus moving the corresponding drives in the opposite directions.

When you actually operate your autoguider, you will be able to hear the relay switches inside the relay box clicking open and closed in response to electrical signal commands from the autoguiding computer.

Connecting The Autoguider Relay Box.

Once the autoguider relay box is properly assembled with its RJ-11 cable input and its DB-9 cable output (Figure 16), it can be connected between the autoguiding computer and the Compustar computer module. With both the autoguiding computer and the Compustar booted up, the RJ-11 jack is plugged into the female modular jack plug on the autoguiding computer (Figure 6). The DB-9 male plug is connected to the center port on the Compustar computer module (Figure 16).

Figure 16. The assembled autoguider relay box. The coiled RJ-11 input cable with its modular jack at bottom center is not connected to the autoguiding computer in this illustration (see Figure 7 for illustration of that connection). The male DB-9 connector is plugged into the central port on the Compustar computer module. The computer module is not powered up in this illustration.

Enabling The Autoguider

Compustar users will be familiar with the usual speed settings on the Computer module. These settings affect the speeds at which the four motion control buttons on the upper right corner of the computer module move the telescope mount. All speeds are selected by first pressing the soft key for "SPEED" and then pressing the soft key for the desired speed. The most commonly used speeds are "SLEW" and "SET". "SLEW" is the high speed setting used to move the telescope rapidly from one object or position to another. The Computer module beeps once when "SLEW" speed is selected. "SET" is the slower speed used to center objects in the eyepiece or tour around the field of view and its vicinity. The computer module beeps twice when "SET" speed is selected. Astrophotographers may also know a third speed setting, which is "GUIDE". "GUIDE" sets the speed to a fraction of the sidereal rate that would permit an astrophotographer to manually guide using the four motion control buttons while monitoring a guide star through either a separate guide scope or an off-axis guider. The Computer module beeps three times when this speed is selected.

There is a fourth speed, and that is “AUTO”. As the name implies, “AUTO” is for autoguiding. The computer module beeps four times when “AUTO” speed is selected. This selection switches control from the front right DB-9 port on the Computer module, where a joystick may be plugged in, to the middle DB-9 port, which is the autoguiding input port. Thus, when “AUTO” speed is selected, the computer module is enabled to receive autoguiding commands from autoguiding software through the middle DB-9 port and then transmit those commands to the drive motors in the mount to make the commanded guiding corrections.

It should be noted that when “AUTO” speed is selected, the four motion control buttons on the upper right corner of the computer module are still active. This is very useful for fine positioning of the guide star on the guide camera chip. This is why the push buttons on the relay box are not necessary. This is not the case when a joystick is plugged into the joystick port on the right side of the computer module. When a joystick is active in the right hand port, the Compustar assumes you will be using it to electronically control movement of the mount and therefore the motion control buttons are inactivated. The joystick is sensed by the Compustar computer module if pin 9 in right hand port is grounded when the system is booted up. If a joystick is connected after the system is booted up, it checks for it each time the user hits the “ABORT” key. Thus, hitting the “ABORT” key with a joystick connected to the right hand port will inactivate the 4 motion control buttons. If you intend to have an autoguider and a joystick connected simultaneously, neither the 4 motion control keys nor the joystick will function to move the mount when you hit “AUTO”. The only way you can electronically move the mount is by disconnecting the joystick or switching back to the joystick port by hitting “SPEED”, then “GUIDE”, “SET’, or “SLEW”. You will have to key in “SPEED”, “AUTO” when you are ready to go back to autoguiding. Note that the statement on the wiring diagram that ‘“SPEED” must be set to “GUIDE” or “AUTO” on Compustar’ depends upon which port you will be using, i.e., the right hand port for a joystick or the center port for autoguiding (remember, the wiring diagram also includes instructions for wiring a joystick for the right hand port). Neither the author nor Tom Sorbel could confirm that the Compustar computer can autoguide when set to “GUIDE”. Only “AUTO” works.

Calibrating the Autoguider

Once the autoguider is enabled, it must be calibrated for it to guide properly. Calibration determines how far the autoguiding computer needs to move each axis of the mount to correct for a given guiding error.

The autoguiding software will provide some type of calibration menu (Figure 17). This may be listed under the camera control menu or a separate menu. Calibration routines vary slightly from one software package to the next, but will generally resemble the following steps. First, the user acquires a suitably bright star on the guiding camera chip. Use a star that is fairly bright and isolated. The software can get confused if another star of similar brightness moves onto the guiding chip during calibration. Exposure time for the guiding camera is usually controlled through the autoguiding software. Set the exposure time for the guiding camera so that the star is imaged well, but not saturated. Typical exposures would be 1-3 seconds. You may have to click on the guide star using the mouse to let the software know where your chosen guide star is on the chip. Some autoguiding programs automatically select the brightest star on the chip.

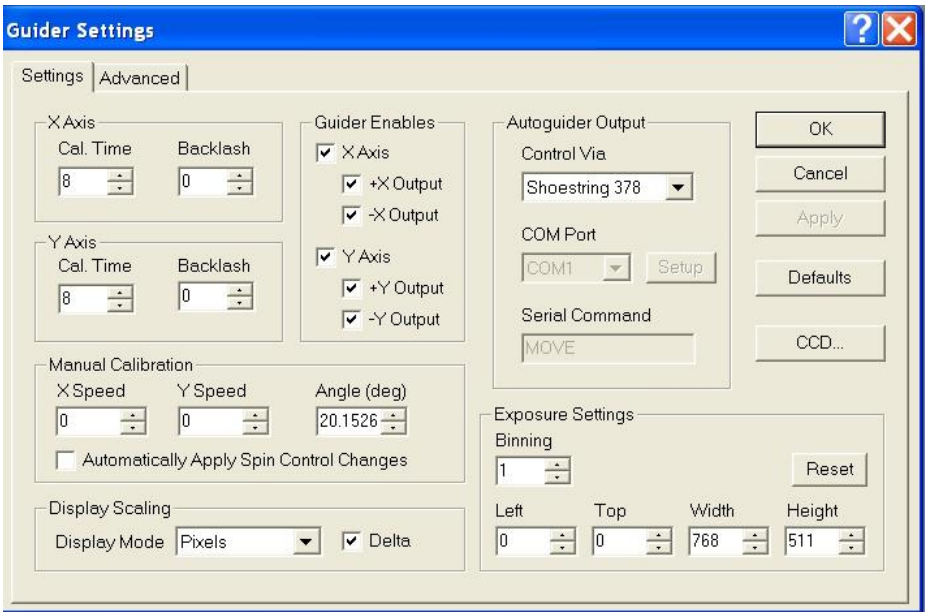


Figure 17. An autoguider settings window. This menu has places to set calibration times for both X and Y axes, as well as autoguider output control to the Shoestring connector. This menu also has places to enter backlash settings for the X and Y axes . Other functions, such as enabling simultaneous corrections in the X and Y axes, which the Compustars are able to do, are under the advanced menu tab.

You will have to specify a calibration time for both the X (RA) and Y (Dec) axes (Figure 17). This tells the software how many seconds you want it to activate the X and Y drives via their relay switches during each calibration maneuver. When you activate the calibration routine, the autoguiding software will begin by taking the commanded exposure through the guide camera. It will then determine the initial position of the center of the guide star on the guiding chip with sub-pixel accuracy. The software then commands the mount to move for the specified calibration time in one direction along the X axis. The autoguider computer then takes another exposure through the guiding camera and measures the new position of the guide star with sub-pixel accuracy. It then attempts to return the guide star to its original position as closely as possible, followed by measuring the new position of the guide star. Next, it repeats this entire process moving the star in each direction along the Y axis, measuring the new position of the star after each move. In other words, it measures the guide star's position after it activates the +X, -X, +Y, and –Y relays in the relay box for the specified time periods. You will hear the relays inside the relay box click as they flip from their "nc" to their "no" positions when the autoguiding computer commands the mount to move in any direction. You will also hear the relays click back to their "nc" positions when the commands have finished. These clicking sounds let you know the relay box circuits are working.

The software then has all the information it needs to calculate how many pixels the mount moves per second in each direction along each axis. This calibrates the autoguiding software so it knows how long a movement it must command via the relays to correct a guiding error of any given magnitude. The software may display a graphical representation of the movements of the guide star during the calibration process and/or a table of the X, Y coordinates of the guide star on the guiding chip after each calibration movement (Figure 18). The results may look like a cross. However, the orientation of the cross with respect to true RA and Dec axes will depend upon the orientation of the guiding camera with respect to those axes. The X and Y axes would be completely reversed if the camera is rotated 90 degrees. For other software, the resulting graph may resemble an "L".

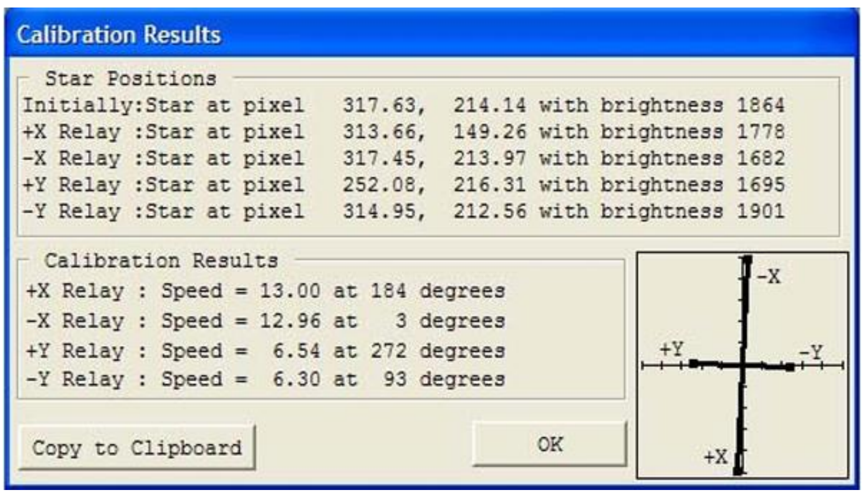


Figure 18. Graphical and tabular results of an autoguiding calibration run. The table at the top shows the coordinates of the initial guide star position on the guiding chip and the coordinates of its position after activation of each of the 4 relays, +X,-X,+Y, and –Y. The graph shows the movement, in pixels, of the star on the chip. The orientation of the resulting cross shows that the guiding camera chip's axes were nearly perfectly aligned with the axes of the mount, being only about 3 degrees off. It is important that the orientation of the guiding camera during calibration be identical to that used for the imaging session.

There are some important issues that will aid in good calibration. One is selecting the correct time interval for the calibration movements in each axis. If the guide star does not move by a minimum amount (often 5 pixels), you will get an error message. However, you have to be careful that you don't select an interval so long that the guide star moves completely off the guide camera chip and is lost. This takes some trial and error, but is best accomplished by placing the calibration star in the center of the guiding chip so it has the capability of moving as far as possible in both RA and Dec directions without leaving the chip. Within these constraints, the time interval selected should be about the same as the longest time required to manually correct the greatest periodic error that the RA drive makes. This can be determined by practicing some manual guiding and timing the corrections. The reason for this is that the Compustar motor drives accelerate during the time that the motion keys are depressed. Thus, if the software commands the drive to move much longer than will actually be needed during autoguiding, the calibrated speeds derived may be faster than those actually required for small corrections. This can result in over correction. Once you know the time intervals that work for calibration of each axis, you can use those times for almost all future calibrations. Another important point is that the orientation of the guiding camera during calibration should be absolutely identical to that used during the imaging session. Otherwise, the software will make guiding corrections in the wrong directions.

If your guide star is fairly bright, you can set up the imaging session and then perform calibration using that guide star before you begin autoguiding. However, particularly with off-axis guiders, the best available guide star may be too faint to obtain a good calibration. You may repeatedly get some type of “Calibration failed” message. That does not mean you cannot use it as a guide star. All that is lacking is a good calibration, which can be obtained with a brighter star elsewhere in the sky. If you are imaging one of the objects in the Messier or CNGC catalogs, then once you have the image set up with the guide star acquired on the guiding chip at the same time that your subject is framed acceptably in the imaging camera, an important trick you can use is to simply push the “SYNC” key. Do this even though the object itself is no longer in the exact center of the field of view. This will have the effect of locking the current position of the center of your astrophotograph composition into the Compustar computer as being the coordinates of the subject itself. You can then manually slew, using the motion control keys (or joystick), to a fairly bright star somewhere nearby in the sky and use it obtain an accurate calibration. You should not rely on commanding the Compustar to slew to the coordinates of that brighter star or even to a nearby Reference Star because the Compustar is now out of “SYNC” with the entire sky. It is best to use your finderscope for acquiring the brighter star. Start by centering the star on your imaging camera’s chip. You then have to be able to shift the position of the star onto your guide camera’s chip, which takes a bit of skill with an off-axis guider. However, if you know where your guiding chip is relative to the imaging chip, you can maneuver the guide star onto the guiding chip in a series of small steps using the motion control keys and “SET” speed.

Once the star is acquired and centered on the guiding chip, perform the calibration routine. Then simply command the Compustar to “SLEW” back to the Messier or CNGC object. Because you hit “SYNC” before you moved the telescope, the Compustar should faithfully slew back to the position of your previous composition, with the guide star on the guide chip and the image framed on the imaging chip, just as you set it up before. With the software properly calibrated for that orientation of the guide camera, it will often be able to accurately autoguide on the fainter guide star, even though it was too faint for calibration.

However, if the guide star and the calibration star are at significantly different declinations, you will have to compensate for this. This is because stars near the celestial equator move faster than stars near the poles and therefore require larger correction movements. The autoguiding software usually has a provision for this correction. There is a window in which you should enter the declination of the star upon which you calibrate. When you are autoguide on a different star, you simply change the entry to the declination of the actual guide star and the software will make the appropriate adjustment to the magnitude of correction movements in each axis. This is simple with the Compustar, which gives a continuous large read out of its declination. You can continue to acquire new guide stars all over the sky and use the same calibration, provided you don't change the orientation of the guiding camera (or off-axis guider) and you enter the declination of each new guide star. This is particularly useful for separate guide scopes in which the orientation of the guide scope and the guiding camera can certainly be kept the same between all imaging targets. One could simply calibrate on a star on the celestial equator and enter the value of zero for the declination, then enter the declination of each subsequent guide star. So long as the orientation of the autoguider camera is never changed in the guide scope, the autoguider does not need to be recalibrated. This approach is not practical with off-axis guiders, for which the orientation is likely to be different with every new subject. However, because the goal is accurate autoguiding, much can be said for re-calibrating on each new guide star for each new image even with a separate guide scope. It only takes a few minutes.

Autoguider Adjustment Settings

You will have to adjust a number of settings for the actual autoguiding session. These are usually listed on the camera control menu, or a separate menu. One of the most important is the aggressiveness setting. This tells the software how aggressive to be when making corrections. Typically, the aggressiveness is graded on a scale of 1-10. If you select 10, then 100% of the guiding error will be corrected with each movement. While this sounds like a temptingly good idea, it generally is not. Imagine if your house thermostat was made with 100% aggressiveness, which also sounds like a good idea. If it was and you set the thermostat to 70 degrees, the furnace would come on and heat the house to 70 degrees, at which point it would shut off. However, as soon as the temperature in the house fell to 69.9 degrees, the furnace would be re-activated, but only for a few seconds until the temperature was again raised to 70 degrees, at which point it would shut off again. But as soon as the temperature dropped to 69.9, the furnace would again be reactivated, and so on. Obviously, this would result in a rapid fire sequence of the furnace being turned on and off. Fortunately, thermostats are not made with this degree of aggressiveness. Rather, they are made with little bit of slop or error in the system. In other words, the furnace will shut off when it reaches 70 degrees, but not be reactivated until the of 67, before being reactivated. This results in much smoother operation of the system.

By the same token, if you set the autoguider aggressiveness to the maximum, you are likely to get rapid fire jerky movements of the mount as the guiding software tries to completely correct every detectable guiding error, no matter how small. This results in overcorrection and, ironically, poor tracking. Usually, an aggressiveness setting of 8 out of 10 gives the best results. It allows some degree of tracking error to occur before it makes a correction, but the error is usually not enough to compromise image quality. Furthermore, the guide star is returned to its intended position in a series of smaller, but smoother steps. If the mount is guiding in a rapid, jerky fashion, try a lower aggressiveness setting. If the image is trailed, try a higher aggressiveness setting. Bear in mind that the X and Y axes may require different aggressiveness settings to get the best results. A setting of 8 is usually a good starting point.

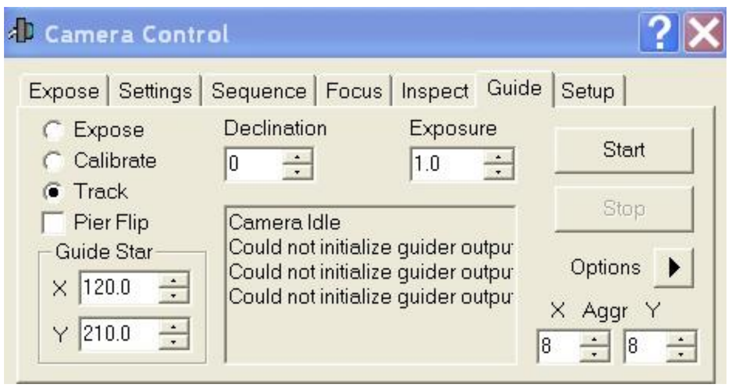


Figure 19. Autoguider control menu showing places to select exposure, calibration, and tracking. The windows for the aggressiveness settings for the X and Y axes are shown in the right lower corner, set to 8 on a scale of 1-10, for both axes.

Other settings include the backlash correction in both X and Y axes (Figure 17). Backlash is the time delay in correction that occurs while the drive motor is taking up any slack in the gear system of that drive axis. Backlash is chiefly encountered when the drive motor has to make a guiding correction by completely reversing directions. That is when any slack in the drive system gears is most likely to become apparent. However, backlash is usually not a problem at all in the X (RA) axis. This is because the clock drive is constantly pushing against the RA gear to move it in the +RA direction at the sidereal rate. Thus, there is rarely any slack in the +RA direction and any additional correction in the +RA direction will usually be immediate. Corrections in the –RA do not invoke backlash either because they are not made by reversing the direction of the RA drive gear. Rather, they are made by simply slowing the drive motor. The correction is provided by allowing Earth's rotation to proceed without being fully compensated by the clock drive, and so the response is immediate. A subsequent full reversal of correction back to the +RA direction will also be immediate because although the clock drive gear was previously slowed, it was still completely engaged with the teeth of the RA motion gear. Thus, it is usually best to leave the backlash compensation in X (RA) set to zero. If there will be any problem with backlash, it will likely to be in with the Y (Dec) axis drive, which sits idle between most X corrections. If the last correction was in +Dec and the drive motor was left engaged against the motion gear teeth in that direction, then there may be some slack that has to be taken up whenever the next correction is in –Dec before the drive engages the gear teeth in the opposite direction. If guiding in Dec does not appear adequate, you may need to add backlash compensation. It may take some experimentation to find the correct setting. If the setting is too low, guiding corrections will be delayed while the backlash is being taken up. If the setting is too high, over correction will occur. You can determine whether a backlash correction might be needed by grasping the telescope with your hand and trying to wiggle it up and down along the declination axis. If you feel movement or hear clicking, then backlash exists and may be an issue. Try tightening the Dec axis lock to stop any movement first. That is the better solution to the problem.

Lastly, there is usually a menu item to select whether both the RA and Dec axes are to be corrected simultaneously as opposed to sequentially (See legend of Figure 17). This is an option because not all mounts can make simultaneous corrections in both axes. Sequential corrections can result in poor tracking. If the guide star moves off target diagonally, then the autoguider has to first correct the error in one axis, say X, and then correct the remaining error in Y. This not only takes longer, but also allows a new error in X to creep in while the previous Y error is being corrected. Fortunately, the Compustar mount is capable of simultaneous corrections in both axes, so do be sure to enable this feature if your autoguiding software offers it.

Balancing the Compustar

Astrophotography will burden the Compustar mount and drive components with considerable extra weight in the form of imaging camera, guiding camera, cables, guide telescope or off-axis guider, and the weight will certainly throw the Compustar out of balance. Rebalancing the Compustar is one of the most important steps for achieving accurate tracking results with an autoguider. It has been said that almost all tracking problems can be traced to improper balance. Regardless of how strong the drive motors of the Compustar may be or how good the autoguiding software is, tracking will be more accurate if the Compustar is properly balanced. Proper balance will also result in less wear on the Compustar's drive components, which may be difficult if not impossible to replace. Therefore, balancing the Compustar for autoguiding will pay off in more ways than one.

Balancing the Compustar should be done with all of the imaging equipment attached in the configuration to be used for imaging. A counterweight bar assembly with counterweights, or other telescope balancing system, is essential. The Compustar 11 and Compustar 14 come with them as standard equipment. As you check the balance of the telescope, you will be releasing the clamp on the Dec axis, which is almost always locked on the Compustar. Be extremely careful that the out of balance telescope does not swing out of control resulting in components striking you, the mount, or other objects in the vicinity of the telescope when the lock is released. Padding the telescope drive base with pillows is a wise precaution during balancing.

Fork mounted telescopes should be balanced first with the optical tube assembly aimed in the vertical direction, then in the horizontal direction. Begin by slewing the telescope so that it is centered on the meridian. Then, slew the telescope straight up at the zenith. While carefully keeping one hand on the telescope, so it doesn't swing out of control, slowly release the lock on the Dec axis and note which way the telescope wants to swing. If the telescope is top heavy, due to the finderscope, guide telescope or other components on the top side, then the front end will swing north. Add weight to the counterweight bar on the bottom side of the telescope (or remove it from the top side) as needed until this tendency is counteracted. If the telescope is bottom heavy, then the front end will swing south. Add weight to the top side (or remove it from the bottom side) until this tendency is counteracted. Where you put the weight along the length of a counterweight bar is not important at this point. That will be addressed during the upcoming horizontal balancing. It only matters that you add it to (or remove it from) the correct side. As you approach vertical balance, the telescope may no longer swing on its own. You will have to give it a gentle nudge in each direction to see if further counterbalancing is needed.

Once the telescope is balanced vertically, relock the Dec axis and slew the telescope southward until the optical tube is horizontal. While gently holding onto the telescope with one hand, slowly release the lock on the Dec axis and see which way the front end of the telescope wants to swing. If the front end swings down, then slide the weights on the counterweight bar toward the rear of the telescope until this tendency is counteracted. This can be done using weights on either the top or the bottom, or both. If the front end swings up, slide weight forward until this tendency is counteracted. Again, as you approach horizontal balance, you may need to gently nudge the telescope each way to see if further adjustment is needed. Once you have completed this task, the telescope is dynamically balanced along all axes. It is a good idea to mark the positions of the counterweights on the counterweight bar assemblies with colored tape for future reference. You may also want to repeat this process with the telescope configured for visual use and mark those positions with a different color of tape. That way, you can quickly rebalance the telescope for visual and photographic use.

So, what just happened? The telescope has 3 axes, the RA axis, the Dec axis and a longitudinal axis (not to be confused with the RA axis), which runs right down the center of the optical tube. The telescope rotates around the RA and Dec axes, but not the longitudinal axis. All three axes intersect at a point half way between the left and right fork arm swivels. Any object rotates around its center of gravity. The mount and drive motors of the Compustar are designed to turn the telescope around a center of gravity located at the intersection of the three axes. It is with the center of gravity at that point that the drive motors will have their optimal lever arms (force times radius of rotation) which, in turn, will require the least amount of torque to rotate the telescope around either axis. Moving the center of gravity away from this point by adding equipment produces a different lever arm for the drive motors, which in turn requires more torque to move the telescope along any axis. This puts more wear and tear on the drive components and, in some cases, the torque required may be beyond what the drive motors can generate. All these problems result in guiding errors. The goal of rebalancing the telescope is to put the telescope's center of gravity back at that intersection, to restore optimal function of the system.

By first balancing the telescope vertically, you ensure that the telescope's center of gravity lies somewhere along the longitudinal axis. If the telescope swings north, that means the center of gravity is actually somewhere above the longitudinal axis. If the telescope swings south, then it is somewhere below the longitudinal axis. This is why you must add weight to the opposite side until the movement stops, which indicates that the center of gravity has been put back somewhere along the longitudinal axis. At this point, where the weight is added along the longitudinal axis is totally irrelevant. That will be dealt with during the horizontal balancing. However, if the center of gravity is not somewhere along the longitudinal axis, then sliding weights either forward or backward during the horizontal phase of balancing has no hope of putting the center of gravity back on the intersection point of the three axes. It will always be somewhere above or below that intersection point.

You will learn whether the added weight has put the center of gravity in front of or behind the triple intersection point when you start the horizontal phase of balancing. If the front end drops down, then you have put the center of gravity somewhere along the longitudinal axis in front of the triple intersection. If the front end swings up, then you have put the center of gravity somewhere along the longitudinal axis toward the rear of the triple intersection point. When you have counteracted any movement, then you have achieved putting the center of gravity on the triple intersection point and the telescope is dynamically balanced. This is also why just sliding counterweights forward or backward along the counterweight bar until the telescope seems balanced when aimed at the its imaging target, which is what most people do, doesn't properly do the job of balancing the telescope.

There are some practical pointers. If most of the weight you add to your Compustar is camera equipment at the rear cell, then the additional weight will be centered along the longitudinal axis and the telescope will likely remain in vertical balance. Therefore, you will not need to add any weight on either the top or bottom counterweight bar assemblies. Unfortunately, this will leave you lacking any ballast that you can slide forward or backward to achieve horizontal balance. The solution is to add an equal amount of weight to both counterweight bar assemblies anyway. This will maintain the telescope in vertical balance and still provide you with the ballast you need to ultimately balance the telescope horizontally.

If you are really smart, you are wondering about balancing the telescope in the third direction, along the axis between the two fork arm swivels. Measures have already been taken to balance the unique configurations of the Compustars in that third dimension. For example, the 8x50 finderscope on the Compustar C8 has been shifted from the left rear side of the optical tube to the lateral side of the left fork arm to counterbalance the weight of the declination drive box on the right fork arm. The Compustar C11 and C14 have finderscopes in their usual positions, but have counterweights in the left fork arm to counterbalance the declination drive box on the right fork arm. Most locations where equipment can be added to the Compustar are intentionally placed along the longitudinal axis of the telescope halfway between the right and left fork arms, like imaging equipment at the center of the rear cell, or the mounting brackets on the center top and bottom of the optical tube. Adding weight in these locations will only shift the center of gravity above or below, or forward or backward, along the longitudinal axis. It will not shift the center of gravity sideways along the Dec axis. Thus, with the left and right fork arms balanced at the factory, you will only need to balance the telescope vertically and horizontally. However, any equipment mounted on either side of this center line, like a new finderscope, a Telrad, or a guide scope, can move the center of gravity to the left or right of the triple intersection along the Dec axis. If this is the case, then the final step you need to take will be to release the RA axis lock and see if the telescope wants to swing east or west. Add weight to the opposite fork arm until the tendency is counteracted and you will have put the center of gravity back on the triple intersection point.

Self-Guiding SBIG CCD Cameras

There is another option for autoguiding besides using a separate guide scope or an off-axis guider that has not yet been discussed. The SBIG CCD cameras, including the ST series and the STL Research series, contain an additional small CCD chip, just off one edge of the main imaging chip. This chip is for autoguiding the CCD. It entirely replaces the separate guiding cameras discussed in other sections. Furthermore, because the guiding chip is in a fixed position relative to the imaging chip and is illuminated by the same telescope optics as the imaging chip, this system is a form of off-axis guiding. However, because everything is built into the CCD camera body, no off-axis guider device is required. Because it is a valid form of off-axis guiding, it too completely eliminates problems of guiding errors due to differential flexure and mirror flop. In this context, the autoguiding is called self-guiding because the CCD camera guides itself. Self-guiding is patented by SBIG, so it is currently only available on some of their CCD cameras, which is why it was not discussed earlier, as not all readers will be using these particular SBIG CCD cameras.

Self -guiding has tremendous advantages over traditional off-axis guiding. With no pick-off prism, the image of the guide star will be of much higher quality, even when a focal reducer-corrector is being utilized. Because the guiding chip is in the same focal plane as the imaging chip, the guide star will always be in focus when the telescope has been focused on the imaging chip. The extra step of focusing the guiding camera is never required. Furthermore, because the guiding chip is a sensitive, cooled CCD chip, it is much more sensitive than the other types of guide cameras mentioned earlier. Therefore, it can guide on considerably fainter guide stars. With such sensitivity, odds are very high that whenever a subject is framed on the imaging CCD chip, a star suitable for guiding will fall on the guiding CCD chip. SBIG has calculated that the odds of this occurring at f/6.3 or lower ratios are 95% in the sparsely starred regions of the sky *away* from the Milky Way. Odds approach essentially 100% as one images subjects progressively closer to the Milky Way.

Another wonderful feature about these cameras is that the much larger imaging chip can be used to calibrate the autoguiding software for making guiding corrections using the guide chip (many autoguiding software programs allow you to chose which chip to use during the calibration). This means that there is little fear of moving the calibration star completely off the chip. The good news is that the SBIG self-guiding CCD cameras are extremely easy to use with the Compustars once the autoguiding relay box described above has been constructed. The SBIG cameras have a female DB-9 port on their casing for output of the self-guiding commands. SBIG supplies an adapter plug with a male DB-9 connector on one side and a female RJ-11 port on the other. This adapter properly connects the pins of the CCD camera's DB-9 connector to those of its female RJ-11 port such that its output is converted to the ST-4 language. Thus, all that has to be done is to connect the adapter to the CCD camera (Figure 19A), plug the RJ-11 modular jack on the relay box into that adapter (Figure 19B), connect the DB-9 connector on the relay box to the central port on the Compustar computer module (Figure 16), and proceed as usual.

Figure 19A (left) The author’s SBIG STL 11000M CCD camera with the adapter plug (labeled RC-7) plugged into the camera’s autoguider output port. The female modular jack for an RJ-11 cable can be seen on the opposite end of the adapter, between the two metal set screws.

Figure 19B (right). The SBIG STL 11000M CCD camera with the RJ-11 modular jack from the autoguider relay box plugged into the adapter on the CCD camera. The relay box can be seen in the lower left, with the DB-9 output cable leaving the left side of the image, heading to the central port on the Compustar computer module.

Why Autoguide?

Autoguiding has a definite advantage aside from liberating the astrophotographer from the drudgery of guiding. Astrophotographers guide manually by pushing a button, often with a quick jab, trying to quickly correct a small guiding error. They also make a best guess at how long to push the button to correct the guiding error. The drive may slowly accelerate up to guiding speed as it is first activated and may decelerate for a period of time after the button is released. The drives of the RA and Dec axes may have different speeds and different reaction times that may be difficult for the astrophotographer to keep straight. These factors result in over correcting or under correcting guiding errors. Astrophotographers can become cold, uncomfortable and fatigued. The author has manually guided astrophotographs for long periods of time with no errors, only to make a single error pushing the wrong button just once, near the end of the exposure. This ruins the image by adding a small trailed blip to every bright star on the image.

None of these issues are problems with autoguiding. Autoguiding is calibrated so that the computer knows precisely how much to move each axis to correct guiding errors, putting the guide star back exactly where it needs to be and does so with sub-pixel accuracy. The autoguider will not fatigue and it will not become uncomfortable. In fact, the autoguider camera will easily remain in that uncomfortable position looking up into an off-axis guider from beneath the telescope (Figure 3) as long as required (Figure 20).

Autoguiding is not the solution to all guiding problems. The telescope mount should have a good, if not excellent, polar alignment. The mount should be as rigid as possible, with all connections tightened. If using a separate guide telescope, its mounting on the Compustar should be as rigid as possible within reasonable weight limits. The drive motors should be in good condition and as free of backlash as possible. The telescope should be properly balanced.

Figure 20. The Meade DSI serving as an autoguider camera in an off-axis guider in the same awkward, uncomfortable position shown in Figure 3. The autoguider can perform competently and tirelessly in this position, as long as required.

<u>The Author's Experience With The Compustar Autoguider</u>

The imaging results that can be obtained with autoguiding the Compustar can be gratifying, indeed. Formerly, the author did all his imaging using a Canon 20D DSLR (which provides one shot color) by taking many, many 30 second sub-exposures. This was because 30 seconds was the longest period that the Compustar could ever track an exposure without noticeable trailing. However, with the periodic error of the Compustar drive, only one-third of all exposures were actually useable; the other two-thirds had unacceptable trailing and had to be discarded. This was very inefficient. In order to obtain two or three hours of useable exposures, one had to collect exposures for a total of six to nine hours! Furthermore, for deep sky objects requiring such long exposures, one ultimately had to stack 240 to 360 of the 30 second sub-exposures. While stacking multiple exposures totaling 2-3 hours does increase the signal to noise ratio of the deep sky object in the final image to something very similar to that obtained with a single equivalent long exposure, each sub-exposure also adds a certain amount of imprint noise that cannot be subtracted with calibration frames. Thus, when stacking sub-exposures, one reaches a point of diminishing returns where any further gain in signal to noise ratio begins to be offset by an increase in imprint noise from the large number of sub-exposures. However, trying to obtain better imaging results by acquiring longer exposures with a cooled CCD camera would be futile without autoguiding. The images would certainly be trailed and unusable.

The author first verified that excellent autoguiding results could be obtained throughout the 30 second sub-exposures with his DSLR. Using the autoguider, an off-axis guider, and a Meade DSI as the guider camera, virtually every 30 second sub-exposure was adequately guided and completely useable, resulting in much greater imaging efficiency. The sub-pixel accuracy of autoguiding also produced much sharper images (Figures 21 and 22) than could be achieved by stacking only the very best “unguided” images.

Figure 21. M57, the Ring Nebula in Lyra. This is one of the author's first autoguided images obtained with his Compustar 14 and the autoguider described in this article using a focal ratio of f/11. This image shows that despite the C14's impressive focal length of 3900 mm, the Ring Nebula, measuring only 230 arcseconds, takes up only a small portion of the image. The image was acquired with an unmodified Canon 20D DSLR as the imaging camera, a Meade DSI as the guiding camera, and an off-axis guider. The image was taken from Portland, Oregon, on 7/4/2010 at 8:14 UT. It is composed of 80 (yes, 80) 30-second sub-exposures for a total exposure of 40 minutes at ISO 800. This is shown for comparison to Figure 22.

Figure 22. M57, the Ring Nebula in Lyra, enlarged and cropped from the image in Figure 21. Note the fine structure detail in the upper right portion of the ring and the wisps of nebulosity visible inside the ring around the central star. The fact that the above image can bear this degree of enlargement and still show this amount of detail is amazing and is largely due to the sub-pixel accuracy of the autoguiding used to acquire the data.

With this initial success, the author felt he could confidently move on to long exposure imaging with a cooled CCD camera and purchased the SBIG STL 11000M shown in Figures 19A and 19B, which is one of SBIG's self-guiding cameras. The results, some of which are shown in Figures 23 and 24, show dramatic improvements over those obtained with the DSLR.

Figure 23. The author's "first light" image of M51, the Whirlpool galaxy and NGC 5195, obtained with the SBIG STL 11000M and the Compustar C14 and a 0.75x focal reducer (f/8). Admittedly, the galaxies are not centered because it was decided to use the brightest available guide star in the vicinity for this first attempt at autoguiding. Self-guiding has since been successful on much fainter stars, permitting better framing of subjects (see Figure 24). The image is still interesting showing the wide field of the STL 1100M, with colorful field stars, and there are at least 40 faint background galaxies visible. The latter include the small blue face-on barred spiral IC 4278 above the bridge and the edge-on spiral IC 4277 above the large, diffuse "E" formed by the tidal spray of stars from NGC 5195. The image was taken from Portland, OR, on 05-08-2011 beginning at 23:16 UT through Baader Planetarium LRGB filters LRGB=184:70:70:70 = 7hrs:04min total exposure.

Figure 24. M63, the Sunflower galaxy a self-guided image taken using the autoguider on the Celestron Compustar 14 with a 0.75x focal reducer (f/8). The image data were aquired on multiple nights from 2011-06-04 to 2011-06-20 using the author's SBIG STL 11000M CCD camera with Baader Planetarium LRGB filters. About 20 faint background galaxies are visible in this image. Exposures: LRGB=152:48:48:52 minutes=5:00hours total exposure.

Conclusion

Autoguiding has become the premier technique for obtaining high quality astrophotographs. It is indeed fortunate that the designers of the Compustar had the foresight to include autoguiding capability into the circuitry of the Compustar computer module, even though the concept was still in its infancy at the time. Unfortunately, hardware to support the autoguiding feature on the Compustars was never produced by Celestron and virtually all hardware that has since been produced by any vendor is not compatible with the Compustar. This has left Compustar owners under the assumption that if they want to autoguide their astrophotographs, they will have to upgrade to a newer model of Go-To telescope that has conventional autoguiding capability. This would be a tragedy considering how exceptional the Compustars are and how much their owners treasure them. The Compustars are considered the most exclusive telescopes that have ever been mass produced. It is estimated there are only 500 Compustar 14 telescopes, a number smaller than any other commercial model.

Fortunately, this is not at all necessary. By building the autoguider relay assembly and connections described in this article, any Compustar can be autoguided and used to obtain beautiful long-exposure astrophotographs.

The author has endeavored to increase awareness and appreciation for the Compstars by posting images obtained with his Compustar 14 on several websites, including the Reader Photo Galleries of Sky and Telescope and Astronomy magazines, as well as Celestron's astrophotography website, CelestronImages.com. Some of the images have been selected as "Editors' Choice" by Sky and Telescope. Celestron uses some of these images as background astrophotographs on their main Celestron website. Celestron has also selected more of these images for display on their website as examples for demonstrating what the optics of the C14 are capable of than from any other astrophotographer using any other version of the C14. This has helped, however much, to keep the Compustars in the public eye and recognized as some of the most valuable telescopes that Celestron has ever produced. It is the author's hope that this article will provide other Compustar owners with the capability of autoguiding their astrophotographs using these amazing telescopes.

Acknowledgements

The author wishes to thank Mr. Dennis Borgman for his published wiring diagram for the relay box connections between the RJ-11 cable and the DB-9 connector on the Compustar computer module. Publication of his diagram has made autoguiding the Compustar possible for the author and, hopefully, many others.

The author gratefully acknowledges the generous assistance of Mr. Tom Sorbel of StarChron Solutions, Plymouth, MN. Tom already deserves tremendous credit for the countless hours he has devoted to developing the Y2K chip for the Compustars and updating the Compustar database in the Y2K+ chip. These chips are the reason that Compustar owners can continue to use and enjoy their Compustars throughout the 21st century. Tom donated many hours of his time helping the author produce this manuscript, providing encouragement, assistance with technical issues, testing of electrical circuits, and editing. His extensive knowledge of the Compustar electronics, computer module, and its programming is, in the author's opinion, unmatched. Thank you, Tom.

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