A Procedure for Collimating Ritchey-Chrétien and Other Cassegrain Telescopes

Version 1.0
November 15, 2011
Rich Simons – Deep Sky Instruments

Introduction

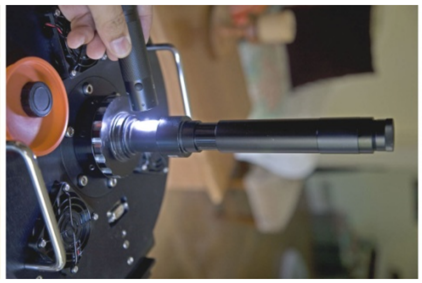
This document describes a procedure for collimating Ritchey-Chrétien and other Cassegrain telescopes. The procedure is simple and does not require a secondary mirror center mark or collimation telescope. The procedure is based on an iterative process of removing on-axis coma and off-axis astigmatism. Everything is done photographically with images taken outside-of-focus.

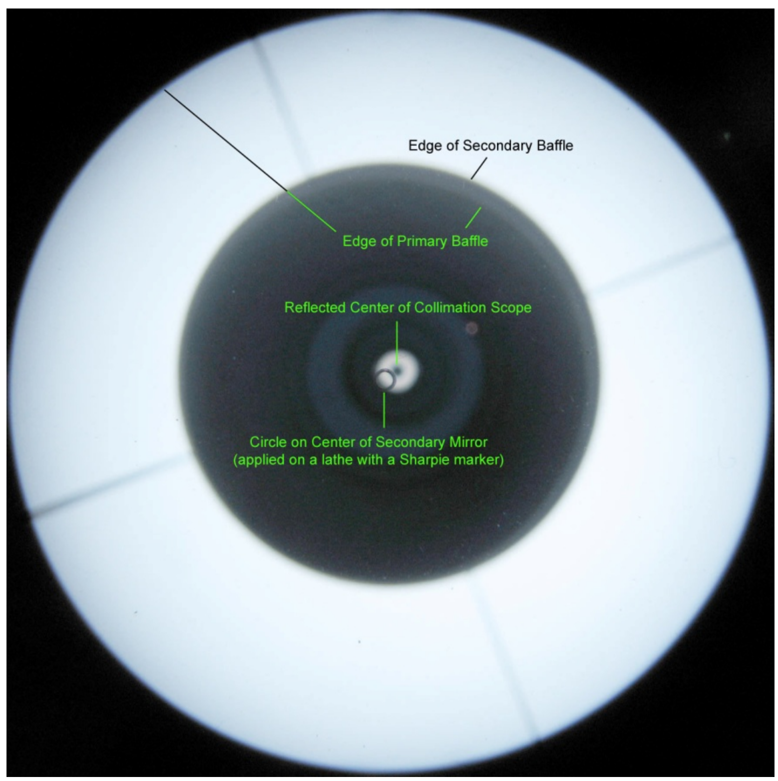
www.DeepSkyInstruments.com
support@DeepSkyInstruments.com
(404) 906-1024

Traditional Collimation Method

As a comparison, we briefly present the traditional method for collimating a Ritchey-Chrétien scope. More detailed explanations may be found elsewhere.

The traditional method is a two step method. First, collimate the secondary mirror with a collimation telescope by aligning the secondary mirror center spot (or circle) with the reflected center of the collimation scope. Then, collimate the primary mirror by making the internal baffle reflections concentric. Below is shown a Takahashi collimation scope being used with a Deep Sky Instruments RC10C astrograph.





To the right is shown the view through the collimation scope before collimation. The collimation scope is looking at the secondary mirror through the primary baffle tube. Everything seen through the primary baffle tube is a reflection in the secondary mirror. Because of this, it can be helpful to imagine that you are located at the center of the secondary mirror looking back at the collimation scope. As you look further out from the center of the scope, you will see the inside of the primary baffle. Past the edge of the primary baffle you will see the primary mirror and anything that is reflected in it. The edge of the secondary baffle is reflected in both the primary and secondary mirror.

The first collimation step would be to adjust the secondary mirror so that the center of the collimation scope fell inside the center of the secondary mirror center circle. The last step would be to adjust the primary mirror so all of the baffle edges were concentric.

Problems with the Traditional Method

The traditional method of collimating references several physical points within the system and relies on certain assumptions that may or may not be true. First, the method requires a center spot (or circle) on the secondary mirror. This spot is usually located in the physical center of the secondary mirror. It assumes the mechanical center of the secondary mirror is also the optical center of the secondary mirror.

Further, the method references the edges of both the primary and secondary baffles. It assumes both baffles are coaxial with the OTA and that the system optical axis will eventually be coaxial with these as well.

Neither of these will be the case to at least some degree. That is why it is often reported that when a scope is collimated with the traditional method that it still does not perform well. Conversely, a well collimated scope may not look collimated when viewed with a collimation telescope.

Here are some specific problem examples:

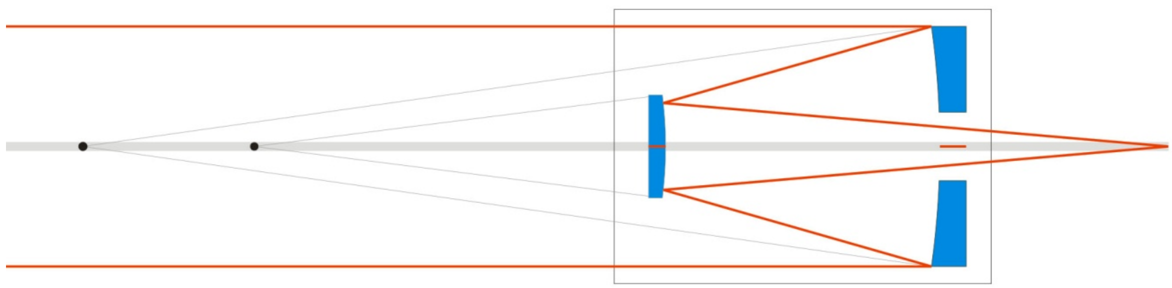
- Secondary mirror has no center spot.
    - Can't use collimation scope to collimate secondary mirror.
- Secondary mirror center spot does not represent the optical center of the mirror.
    - Secondary mirror mis-collimation will result.
- Primary mirror optical center not in center of scope.
    - Optical and mechanical axis can't be collinear.
- Secondary mirror center spot is not in the center of the secondary mirror cell.
    - Second step will fail or result in mis-collimation.
- Primary or secondary baffles not precisely centered.
    - Second step will fail or result in mis-collimation.
- Scope bumped in shipment, is subsequently collimated but performs poorly.
    - Who knows what the problem could be?

While it is possible to adjust the scope at the factory so that it is both optically and mechanically collimated, not many manufacturers do this past adjusting the alignment of the primary baffle. Many rely on their manufacturing tolerances to produce good results and while this may be the case in many instances, collimation is rarely optimum when the traditional method is used. Some manufacturers allow the secondary mirror to be translated within the secondary mirror cell which is good but making this adjustment can be problematic for those not trained to do so. Lastly, if a secondary mirror is center marked incorrectly, the traditional method can't be used to obtain optimum collimation.

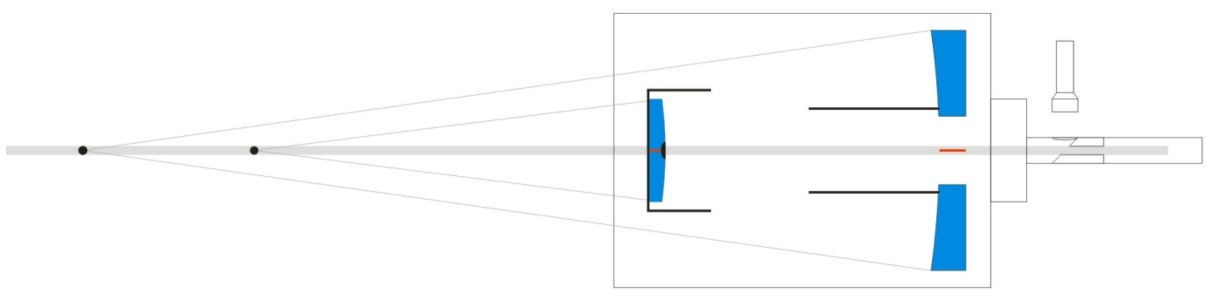
A couple advantages of the traditional method include ease of collimation as well as daytime collimation.

Another Way to Look at Collimation

If you consider only the primary and secondary mirrors, you can collimate a system by simply pointing the primary mirror at the optical center of the secondary mirror AND by pointing the secondary mirror at the optical center of the primary mirror. This is true regardless of any other mirror characteristic such as the baffle locations or a secondary mirror center spot. It is also independent of the relationship of the optical system to the OTA. Here's what that would look like.



This system is perfectly collimated. Moving either mirror relative to the other will change the perfect collimation. We can now add the secondary mirror center spot, primary baffle, secondary baffle and collimation scope to the system. If done ideally, this is what it would look like.



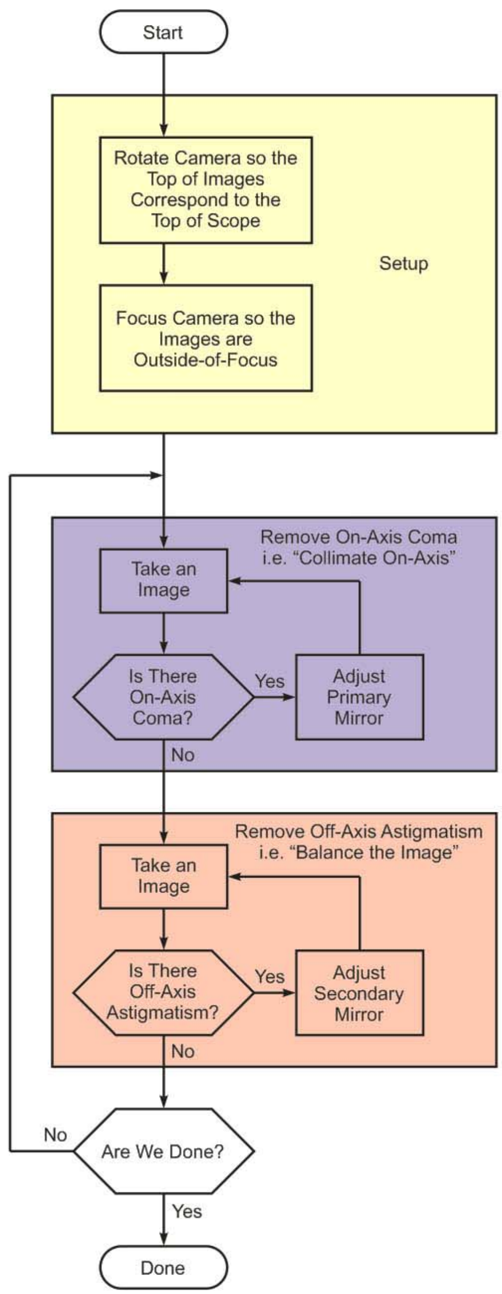
Now, looking through the collimation scope, the secondary mirror spot will look centered and the baffles concentric. But any other non-trivial positioning of these items will result in a view that makes the system look un-collimated (even though the system IS collimated). Any adjustments to either the primary and/or secondary mirrors to make the system look better (through the collimation scope) will result in the system being un-collimated.

Some manufacturers will collimate their scopes and then make adjustments to the baffles and possibly center the secondary. This can help but may not be sufficient. And if something changes during shipment, there is virtually no way to know what changed or how to fix it.

DSI Method - Overview

Collimation Procedure Overview

The procedure used in this method is to first remove on-axis coma by adjusting the primary mirror tip/tilt. Then, off-axis astigmatism is removed by adjusting the secondary mirror tip/tilt. This procedure is iterative and quickly converges to a well collimated condition. The flow chart below illustrates this procedure.



Procedure details are given later in this document.

Theory

Many cassegrain collimation procedures rely on a center mark on the secondary mirror. A collimation telescope is then used to align the optical axis of the secondary with the optical axis of the instrument. This only works if a collimation telescope is available. It is also problematic since the center spot on the secondary mirror generally marks its mechanical center and not its true optical center which is often different.

Another problem with some current procedures is that they rely on the internal baffle rings and edges as a guide to collimating the optics. This can work if everything is perfect both mechanically and optically which is rarely the case. For example, if the primary baffle is slightly off-axis or the resulting optical axis isn't exactly in the mechanical center of the OTA, concentric looking baffle rings will not produce collimated optics.

The mechanical centers of both the primary and secondary mirror are almost never the optical center. They can vary by a few thousands of an inch to as much as a tenth or more. This is often not taken into account when the instrument is assembled. The procedure presented here is very tolerant of this. Optical analysis as well as practical experience shows that this procedure produces good results in the presence of these types of issues.

This procedure relies on neither a secondary center spot nor internal baffle alignment. It is simple to execute and converges quickly. It produces good results over the entire imaging area. The end result of this procedure is an optimally collimated system for the area of interest. It produces balanced results. That is, any residual optical artifacts are minimized and consistent across the image. Cases where star images are elongated in one corner of an image only is typically the result of an unbalanced image.

One characteristic of most Cassegrains this procedure takes advantage of is how adjustments of the primary and secondary mirrors interact. Specifically, adjustments to the secondary mirror will affect off-axis astigmatism and the overall balance of the resulting image. It also affects on-axis coma. However, adjustments to the primary mirror affect mainly on-axis coma. This produces a procedure that converges quickly. Also of note is that any coma induced by an adjustment to the secondary mirror may be removed by an equal but opposite adjustment to the primary.

A Note about Mirror Optical Centers

The mechanical center of a mirror is not necessarily its optical center. This is a problem because there is no direct way to determine the optical center of a mirror. Ideally, you want the optical centers of the primary and secondary mirror located on the mechanical axis of the OTA. Most manufacturers will place the mechanical centers of each mirror on this axis within mechanically controllable tolerances and go from there.

The new method described here does not rely on the optical centers of the mirrors directly. Instead, collimation is optimized based on a procedure that optimizes image quality relative to the CCD image sensor.

Collimation Adjustment Screws

Before discussing the collimation procedure, the mechanical adjustments should be understood. The Deep Sky Instruments RC14C Ritchey-Chrétien Astrograph will be used as an example. The tip/tilt of both the primary and secondary mirrors may be adjusted by three sets of collimation screws. Each set of screws is separated by 120 degrees from the center of their respective mirror cells. The primary collimation screws are labeled A, B and C starting with the first set of screws encountered from the 12 o'clock position moving clockwise as seen from the rear of the scope. Likewise, the secondary collimation screws are labeled X, Y and Z starting with the first set of screws encountered from the 12 o'clock position moving clockwise as seen from the rear of the scope. This is shown below.

Secondary Mirror Collimation Screws
(Seen from Front of Scope)

Primary Mirror Collimation Screws
(Seen from Back of Scope)

Secondary Mirror Collimation Screws
(Seen Through Back of Scope)

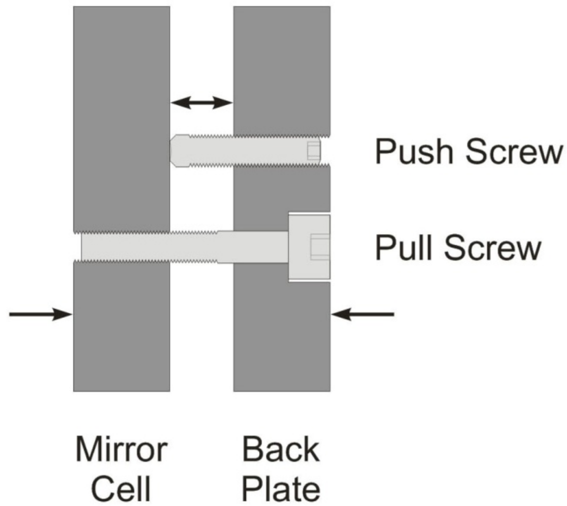
Here are all six sets of collimation screws as seen from the back of the scope.

DSI Method - Conventions

Each set of primary mirror collimation screws consists of three individual screws. The center screw is the pull screw and the two surrounding screws are push screws. The push screws should be tightened with roughly equal force. This minimizes any torque induced in the primary mirror cell. Each set of secondary mirror collimation screws consists of two individual screws. The outside screw is the pull screw and the inside screw is the push screw. This is shown in the figure above.

Adjusting the Collimation Screws

To tip/tilt either the primary or secondary mirror, one or more of the sets of collimation screws may be adjusted. To move one side of a mirror cell closer to a set of screws, the push screw(s) is loosened and the pull screw is tightened in that order. To move one side of a mirror cell farther from a set of screws, the pull screw is loosened and the push screw(s) is tightened. Only light to moderate force should be required to securely hold the mirror cells but if collimation instability is observed, a bit more force may be required.



* Push screw pushes plates apart.
* Pull screw pulls plates together.
* To move plates apart,
  - Loosen pull screw then
  - Tighten push screw
* To move plates together,
  - Loosen push screw then
  - Tighten pull screw

To specify a collimation screw adjustment, the designation, direction and amount of adjustment are typically given.

Collimation Screw Adjustment Examples

Primary Mirror Collimation Screw Adjustment Example

“Tighten A 1/4" means to adjust the “A” collimation set screws by tightening the pull screw 1/4 turn. This is done by loosening the associated push screws, tightening the pull screw 1/4 turn and then tightening the push screws with roughly equal force. Tighten with light to moderate torque. Do not over tighten.

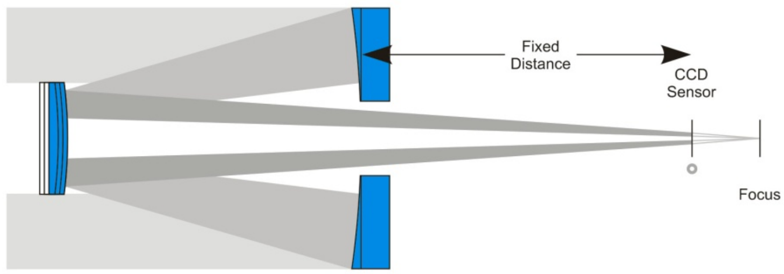
Secondary Mirror Collimation Screw Adjustment Example

“Loosen Y 1/8" means to adjust the “Y” collimation set screws by loosening the pull screw 1/8 turn. This is done by loosening the pull screw 1/8 turn and then tightening the push screw. Tighten with light to moderate torque. Do not overtighten.

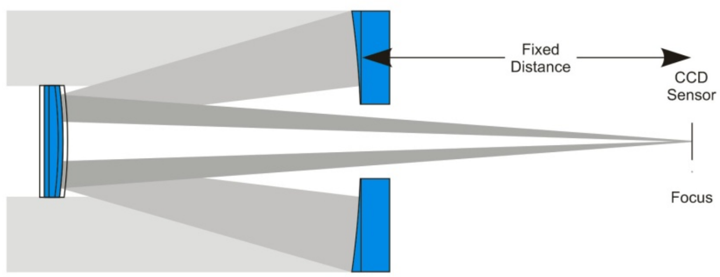
DSI Method - Conventions

Focuser Positions and Directions

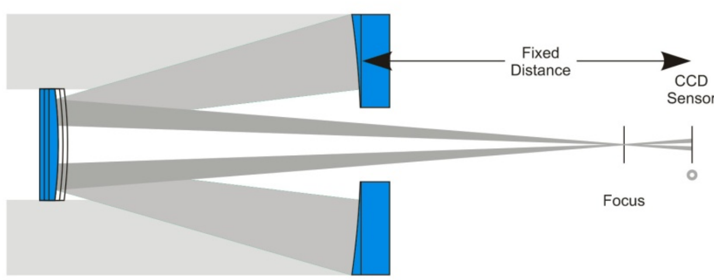
Collimation adjustments are based on out-of-focus images taken outside-of-focus. This is illustrated in the last image shown below. To take outside-of-focus images, you need to move the focal plane IN from a focused position. This means the secondary mirror should be moved IN towards the secondary focuser and away from the primary mirror. The IN button on the focuser controller does this. Outside-of-focus images are typically taken 50 counts from a focused position for an RC14C. Scopes using an external focuser would move the CCD image sensor away from the scope.



INSIDE FOCUS
Focuser Moved OUT from Scope



AT FOCUS
Focuser AT Focus Point



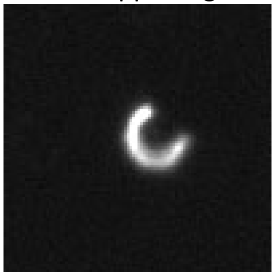
OUTSIDE FOCUS
Focuser Moved IN towards Scope

DSI Method - Conventions

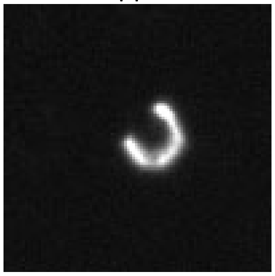
Camera Image Sensor Orientation

It is important to establish the relationship between the camera image sensor and the telescope. This relationship is defined by the observed outside-of-focus star image when a quadrant of the aperture of the scope is masked off. Per our convention, the location of the telescope aperture mask is defined as seen from the back of the scope. If your images don't correspond with the location of the aperture mask, your images will need to be flipped and/or rotated. Optionally, you may be able to rotate your camera to achieve the desired results. Two images must be taken with the aperture mask in different positions to positively determine the orientation of your camera.

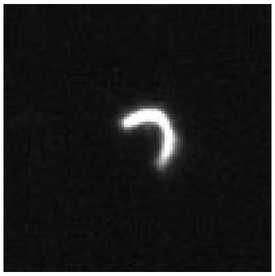
Mask in Upper Right



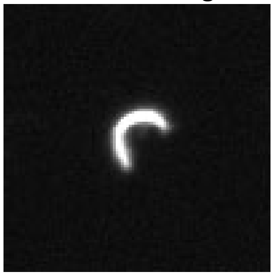
Mask in Upper Left



Mask in Lower Left



Mask in Lower Right



Keep in mind, just like everything else, the mask position is as viewed from the rear of the scope. A quadrant mask in the "upper-right" would appear to be in the "upper-left" when viewed from the front of the scope.

DSI Method - Collimate On-Axis

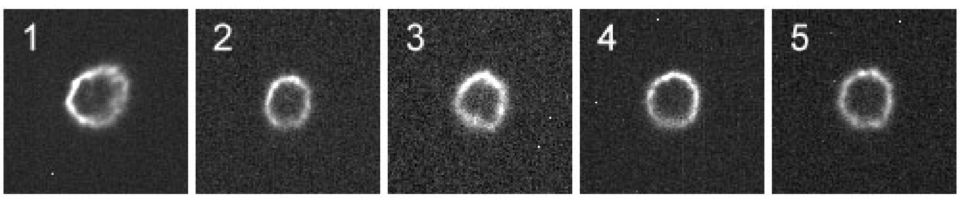
Adjusting the Primary Mirror to Remove On-Axis Coma

There are several techniques for collimating out on-axis coma with the primary mirror. Any method you are comfortable with is fine. The method we use is to look at relative image intensities of on-axis, outside-of-focus star images. Coma is present when star illumination is not uniform.

Rule: ***Tighten the primary pull screw corresponding to the bright side of the image.***

Example of Removing Coma by Adjusting the Primary Mirror

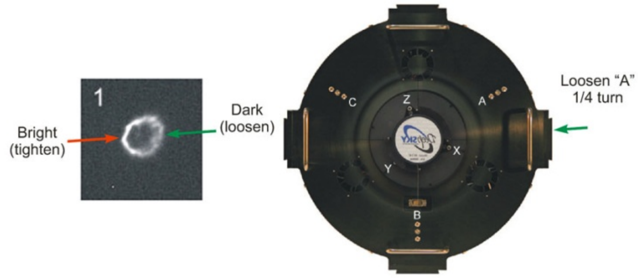
Here is an example of removing on-axis coma. Select a star fairly close to the center of your image. Adjust focus so the image is roughly 50 counts outside-of-focus. This is not critical. The following images are one second exposures based on the brightness of the star selected. After each exposure an adjustment to the primary mirror is made.



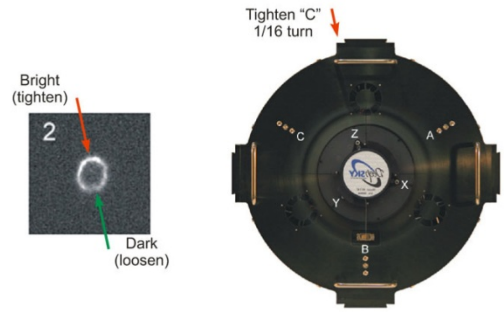
The images below show the individual primary mirror adjustments.

DSI Method - Collimate On-Axis

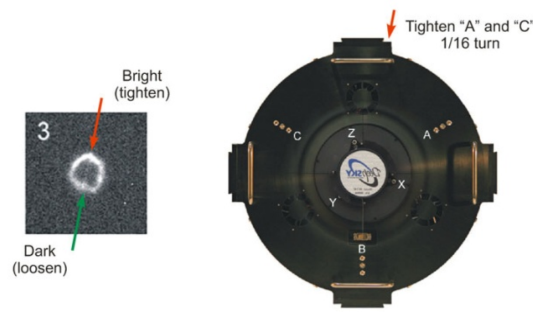
Bright left and down a bit.
Loosen “A” 1/4 turn.



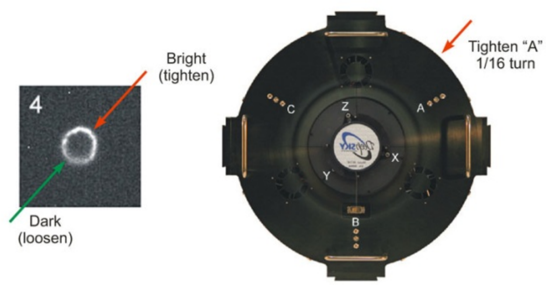
Bright up and left a bit.
Tighten “C” 1/16 turn.



Bright up and right a bit.
Tighten “A” and “C” 1/16 turn.

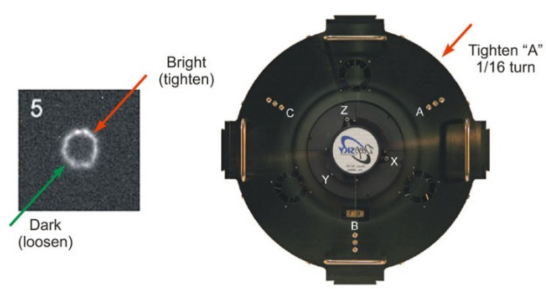


Bright up and right.
Tighten “A” 1/16 turn.



Bright up and right.
Tighten “A” 1/16 turn.

Note: This is close enough to proceed to step 2.



DSI Method - Balance the Image

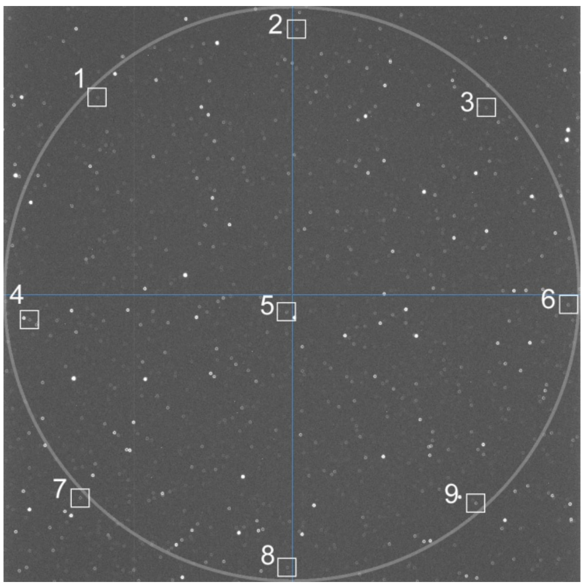
Balance the Image!

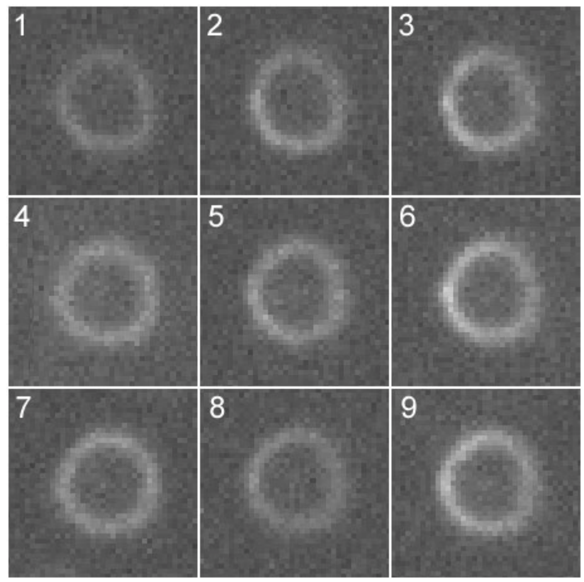
In a well collimated, rotationally symmetrical optical system, any resulting images should also be rotationally symmetrical. We call this **"balanced"**. In a balanced system, off-axis stars will converge to focus uniformly to produce pinpoint star images. This of course is our goal.

A Balanced Image

Here is an example of a balanced image.

> www.DeepSkyInstruments.com/collimation/example_balanced.fit (33MB)
> www.DeepSkyInstruments.com/collimation/example_balanced_compressed.fit (15MB)





The image on the left is an outside-of-focus image taken with a DSI RC14C astrograph (14.5", f/7.0, 2557mm) and a Kodak 16803 (9µm x 9µm, 4096x4096) CCD. It is roughly 0.85° x 0.85° in size. The exposure is ten seconds but can range from five to 30 seconds. The mount should track well and be well polar aligned This is important. Do not rely on short exposures for poor polar alignment.

The image on the right is a composite of nine star images as indicated in the image to the left. The perimeter stars are taken roughly the same distance off-axis as to be comparable.

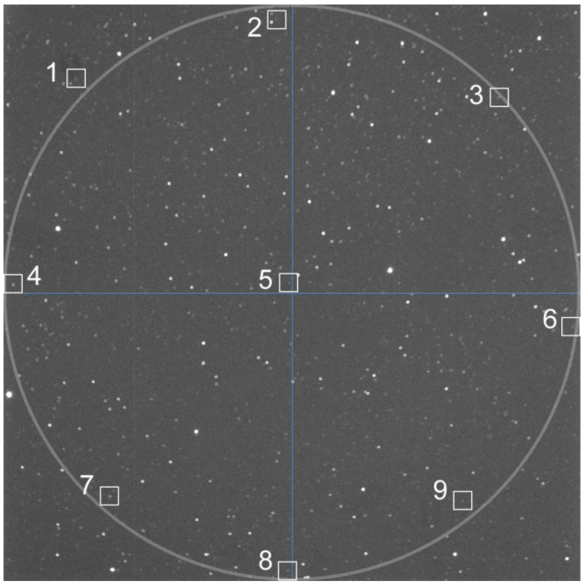
All of the perimeter star images on the right are roughly round and similar. They are rotationally symmetrical. That is, they all look about the same from the perspective of the center of the image indicating good balance. The on-axis star image 5 is uniformly illuminated indicating no obvious on-axis coma. This system is well collimated.

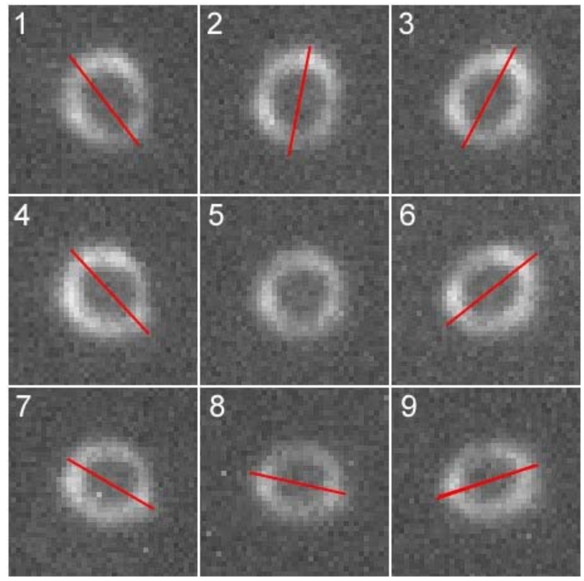
DSI Method - Balance the Image

An Unbalanced Image

In comparison, here's an example of an unbalanced image.

> www.DeepSkyInstruments.com/collimation/example_unbalanced.fit (33MB)
> www.DeepSkyInstruments.com/collimation/example_unbalanced_compressed.fit (15MB)





The image on the left was taken with the same system under similar conditions as the previous image. The exposure was 30 seconds.

The perimeter stars are no longer round but are more oblong. They are not rotationally symmetrical indicating off-axis astigmatism. The on-axis star image 5 is uniformly illuminated indicating no obvious on-axis coma.

Each oblong star has a major axis (long axis, indicated in red) and a minor axis (short axis). It is the relationship of the major axis of these perimeter stars to the image center that will indicate in what direction the system is un-collimated. The degree to which the star images are oblong is also an indication as to the magnitude the system is out of collimation.

If you observe the major axis of the off-axis oblong stars as you progress around the perimeter of an unbalanced image, you may notice that the major axis will rotate a total of 180 degrees. Also, at some location around the perimeter of the image, the major axis will point towards the center of the image. We call these "pointy" stars. Directly across from the "pointy" stars, you will find stars with their minor axis pointing towards the center of the image. We call these "flat" stars.

DSI Method - Balance the Image

Round, Oblong, Pointy and Flat Stars

Let’s introduce another way of illustrating oblong perimeter stars and their relationship to the image center. We’ll use the unbalanced example from before.

Here are three representations of the same thing.

Image 1) Actual perimeter and center star images.

Image 2) ZEMAX ray tracing program generated spot diagrams for the corner and center stars. This system was un-collimated by moving the upper right of the secondary mirror (as seen from the rear of the scope) away from the primary mirror. The primary mirror was then adjusted to remove on-axis coma.

Image 3) CAD drawing of the corner and center stars of a similarly collimated system.

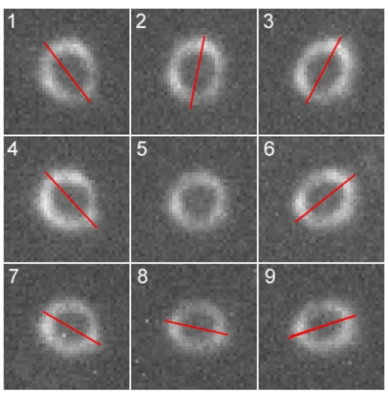


Image 1
Actual Star Images

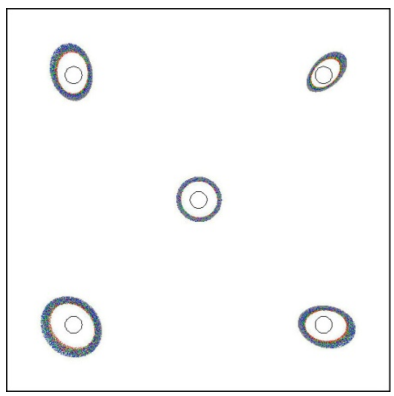


Image 2
ZEMAX Star Images

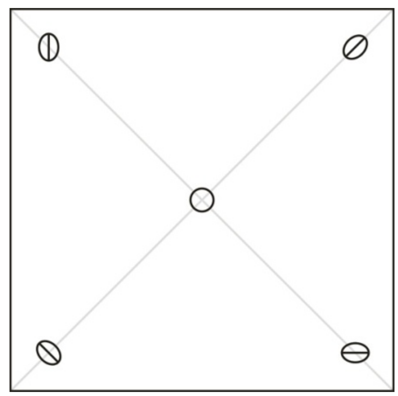


Image 3
CAD Drawn Star Images

Let’s also define some terms. All of these terms refer to outside-of-focus perimeter star images.

Round Star Star shape is round.

Oblong Star Star shape is oval.

Pointy Star Star shape is oval with its major (long) axis pointing towards the center of the image (upper-right in this example).

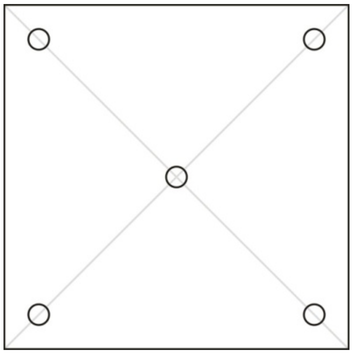
Flat Star Star shape is oval with its minor (short) axis pointing towards the center of the image (lower-left in this example).

IMPORTANT NOTE: The terms “pointy” and “flat” are relative terms. Not all instruments with off-axis astigmatism will have pointy stars opposite flat stars. Some will have “more pointy” and “less pointy” star images while others will have “more flat” and “less flat” star images.

DSI Method - Balance the Image

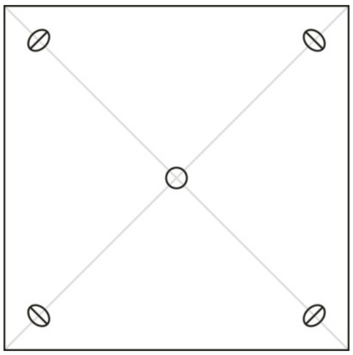
Balanced Image Examples

Here are three examples of balanced images and one of an unbalanced image.



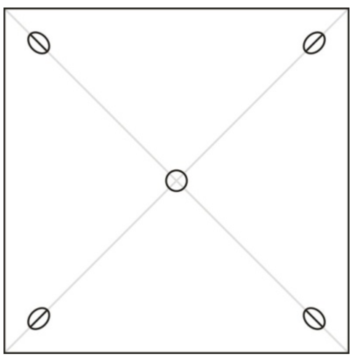
Balanced Image

All of the perimeter stars are **"Round"**.
The image is rotationally symmetrical.
That is, if you rotate it about its center, the perimeter star shapes look the same.



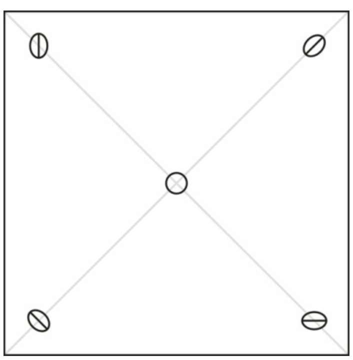
Balanced Image

All of the perimeter stars are **"Flat"**.
The image is rotationally symmetrical.
That is, if you rotate it about its center, the perimeter star shapes look the same.



Balanced Image

All of the perimeter stars are **"Pointy"**.
The image is rotationally symmetrical.
That is, if you rotate it about its center, the perimeter star shapes look the same.



Unbalanced Image

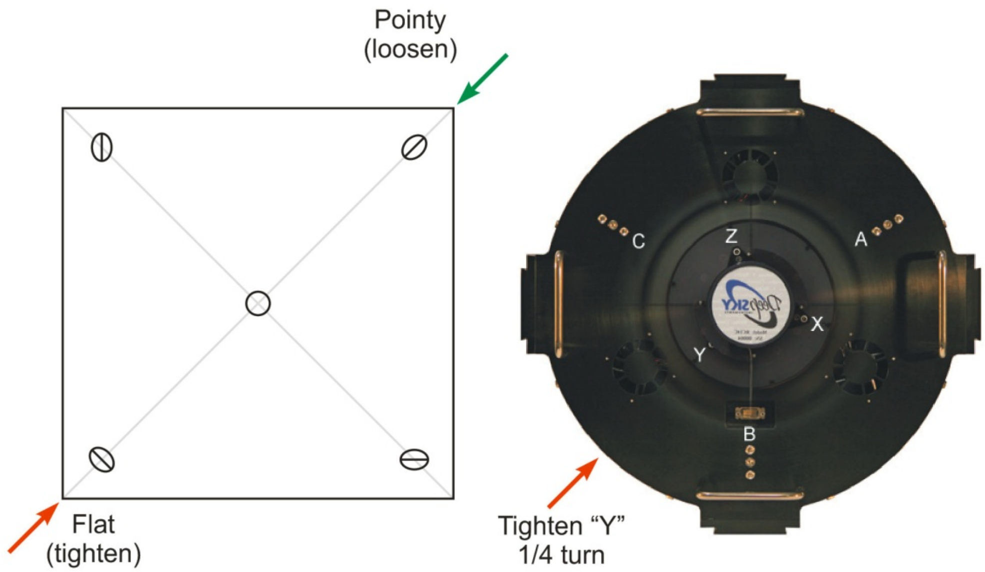
The perimeter stars are mixed.
"Flat" stars are to the lower left.
"Pointy" stars are to the upper right.

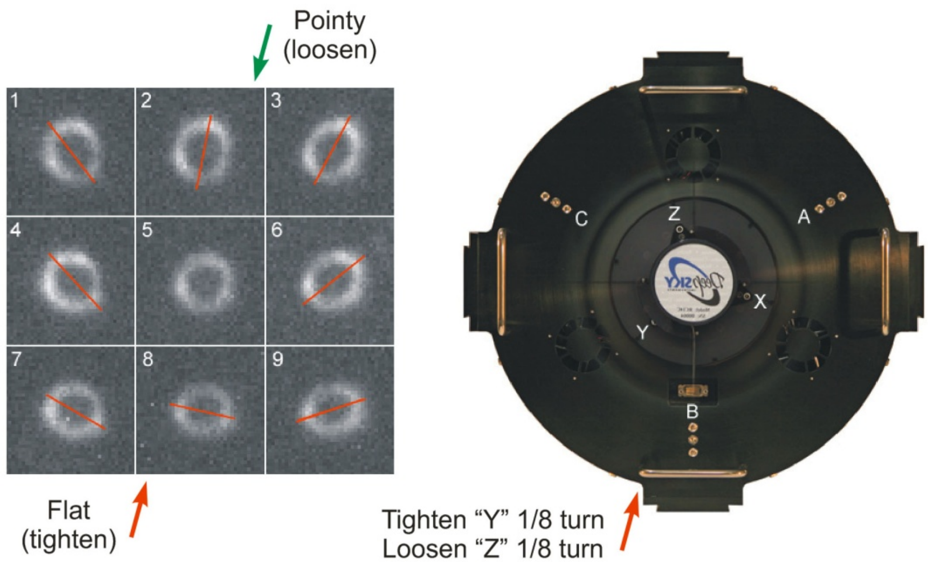
DSI Method - Balance the Image

Adjusting the Secondary Mirror to Remove Off-Axis Astigmatism

The secondary mirror is used to remove off-axis astigmatism and balance the image. This adjustment should be performed after on-axis coma has been removed.

Rule: ***Tighten the secondary pull screw corresponding to the flat stars.***





DSI Method - Summary

Summary of Collimation Rules

Primary Mirror Collimation Rule: **Tighten pull screw corresponding to the bright part of the star image.** This will move the stars away from the collimation pull screw being tightened. Use this rule to remove on-axis coma.

Secondary Mirror Collimation Rule: **Tighten pull screw corresponding to flat stars.** This will move the stars away from the collimation pull screw being tightened. Use this rule to remove off-axis astigmatism.

Summary of Conventions

- All references are as seen from back of the scope.
- All out of focus images are taken outside-of-focus (roughly 50 counts). Use what works best for you.
- Position camera so the top of images correspond to the top of the scope.
- Tighten "A" means to tighten the pull screw.
- Exposures are five to 30 seconds. Fifteen seconds is typical.

Cassegrain Telescope Comparison

Cassegrain Scope Comparison

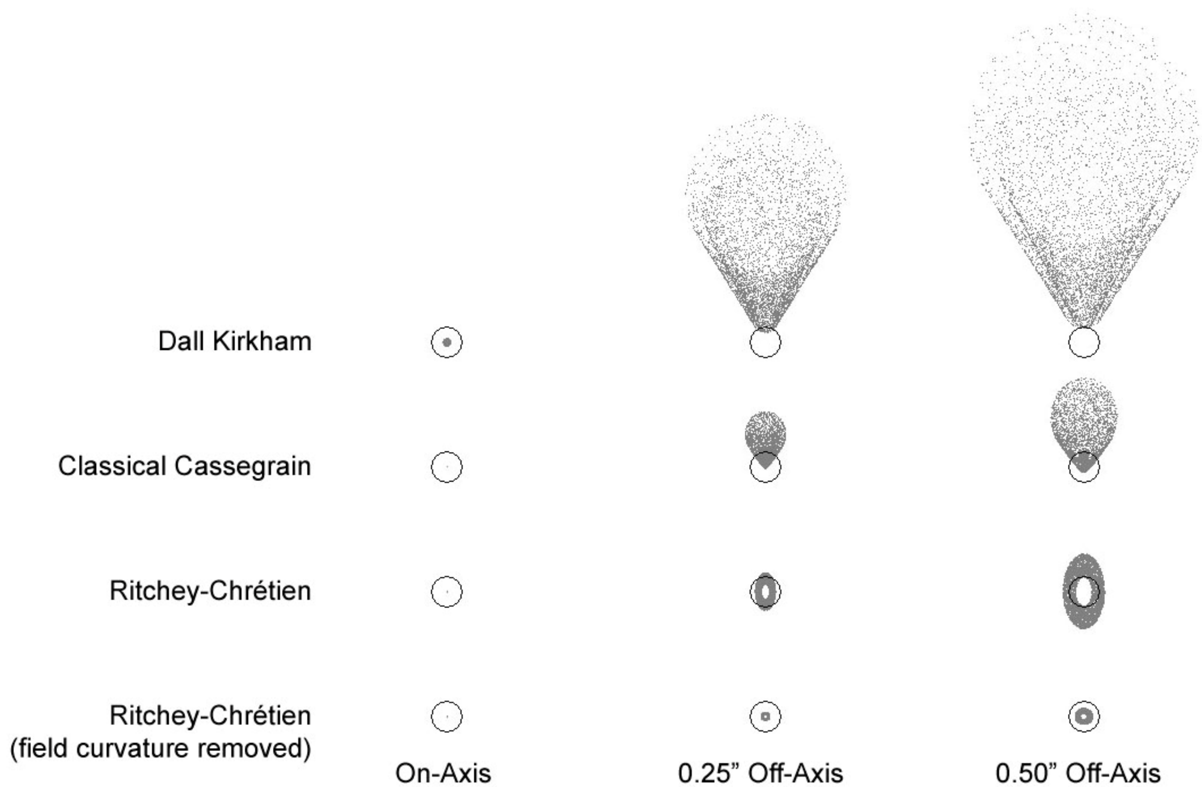
Mirror Figure

	Primary Mirror	Secondary Mirror
Dall Kirkham[1]	Eliptical	Spherical
Classical	Parabolic	Hyperbolic
Ritchey-Chrétien	Hyperbolic	Hyperbolic

Aberrations

	Field Curvature	Astigmatism	Coma	Spherical	Chromatic
Dall Kirkham	✓	✓✓	✓✓✓		
Classical	✓	✓	✓		
Ritchey-Chrétien	✓	✓			

Spot Sizes[2]



12.5” f/10, f/3 primary, 12” back focus, 1” image circle

[1] The Dall Kirkham design cannot be collimated using this technique as tip/tilting the secondary has no effect on a sphere.
[2] Circle represents Airy disk size in center of visual spectrum.

Glossary of Terms

On-Axis	Stars at or near the center of an image that are created by light parallel to the optical axis of the scope.
Off-Axis	Stars around the perimeter of an image that are created by light entering the scope at an angle.
On-Axis Coma	A star image aberration seen in on-axis stars.
Off-Axis Astigmatism	A star image aberration existing when stars images are not symmetrical about the center of the image.
Inside-Focus	Out-of-focus image where the scope focal plane is past the camera.
Outside-Focus	Out-of-focus image where the scope focal plane is before the camera.
Round Star	Star shape is round.
Oblong Star	Star shape is oval.
Pointy Star	Star shape is oval with its major (long) axis pointing towards the center of the image (upper-right in this example).
Flat Star	Star shape is oval with its minor (short) axis pointing towards the center of the image (lower-left in this example).
Balanced Image	An (outside-of-focus) image that is rotationally symmetrical.

Tips and Tricks

- Defocus enough to see star shapes and characteristics clearly.
- Closer to focus will produce smaller star donuts but more subtle details may be seen.
- Exposures are typically 5~30 seconds to avoid tracking issues.
- Your scope mount must track well and your polar alignment must be good. This is true even for short exposures.
- Shoot a star field in the Milky Way if possible. This will help when balancing your images.
- Be consistent to avoid confusion. Stick to the conventions defined.
- Collimate while pointing at a reasonable elevation (ex. 70 degrees from the horizon.
- Tightening a pull screw at one position is equivalent to loosening a pull screw in the opposite position.
- Secondary adjustments will typically introduce on-axis coma. An equal but opposite adjustment to the primary will typically remove it. This tip can save time once you have the procedure down pat.
- This procedure is most useful for large aperture instruments and wide field cameras.
- Adjusting the collimation screws will change your mirror spacing which changes focus. Large adjustments may require you to adjust your focuser.
- It's a good idea to collimate your primary mirror with only two of the collimation screw sets. By leaving one unadjusted, you guarantee the mirror will not migrate over time. This also applies to the secondary mirror. We suggest the "B" and "Z" screws be left unadjusted.
- Final collimation should be verified by taking in-focus images.
- Before spending a lot of time collimating, make sure your scope will hold collimation when pointed to different locations in the sky.
- This procedure provides the best results over the entire imaging field including any tilt that may exist in the optical train. If a rotator is used, you will want to remove any relative tilt between the camera and the rotator.
- As you get closer to optimum collimation, other minor issues with the scope and/or mount will have a greater effect. A more critical eye may be required. Evaluating your images closer to focus may also help.
- Focused images that exhibit elongated stars only on one side of an image are generally not optimally collimated and can be improved upon.
- Images that are balanced but still contain artifacts may have other issues such as the mount, optics, tracking or polar alignment.
- Collimation adjustments will change your focus. You might need to adjust focus if your collimation adjustments are large.
- The procedure takes about ten to fifteen minutes once you become proficient.
- Much of the time spent collimating a scope is waiting for images to download. Using binning and area-of-interest to locate and image on-axis stars when collimating the primary can help save time.
- If you document your collimation adjustments, you can get back to a known state if necessary.

A Quick Note about CCD Inspector

CCD Inspector and other image evaluation tools can be very helpful. But keep in mind that the models used within these tools don't necessarily model your scope accurately. If they work, great. If they don't, don't be surprised. Also, information reported by these tools is relative so you can't always compare their results between scopes. You can use some of the metrics to evaluate a scope once you determine what good numbers are for your make of scope.

I don't recommend using the collimation tools in these programs for two mirror Cassegrain systems where both mirrors are adjustable. If you do use these, my experience is that they require well focused images. That means you need to refocus your system after every collimation adjustment. If you don't, you will get erroneous results.