The Photonewton Collimation Primer

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...adjusting Newtonian telescopes is actually quite simple! ;-)
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There are many myths about Newtonian alignment, often it is said to be difficult. Many instructions are on the web, some unfortunately poor, others unnecessarily precise. But in fact it is very simple and logical - pure geometry, no higher mathematics. I like to compare it with cycling: If you can't do it, you wonder how it's ever possible. Once you have learned it, you wonder where the problem was in the first place. It is important to know: Adjustment can be learned by anyone, there is absolutely no mystery about it.

All the tutorials I know deal with alignment for **visual** purposes. One hopes that it must then also fit for **photography**. This is theoretically true, but in practice, as a photographer, you need accuracy not only on axis, but also in the corners of the image. This often requires additional steps, which I have developed and know that they are absolutely purposeful. The procedure is described in simple steps, first with the laser, and then with the camera attached. This system leads unerringly and depending on practice relatively fast to best possible star imaging also in the field.

Use a pleasant full moon night to get to know the procedure - where there is nothing else to do, without hectic and with calmness, systematic procedure and astronomical peace of mind are very beneficial.
The Newton has only two optical elements, which have to be aligned, a parabolic primary mirror (PM), and an optically inactive plane mirror, which only deflects the light (the secondary mirror, SM).

Principle and goal of the adjustment:
The secondary must deflect the axis of the focuser exactly into the center of the primary (which has a mark in the center for this purpose, which should be exactly centered), and at the same time itself must sit centrically in front of the focuser. The primary must be aligned so that its optical axis coincides exactly with the axis of the focuser. Nothing more, that's all.

In many instructions, the first point is to **align** the focuser with the tube. But this is **unnecessary** work. The focuser does **not** have to sit exactly 90° straight on the tube, because it is the very task of the adjustment to make the optical axis of the parabolic mirror congruent with the focuser axis. For example, in the Lowrider Dobsonian, the focuser is at 45° to the tube, but it is not tilted at all. The image plane of the parabola is always perpendicular (90°) to the optical axis - if the optical axis is congruent with the axis of the focuser, the image plane is also perpendicular to the axis of the focuser.

Alignment tools:
For alignment, you need a device that can be used to define a line. The **Cheshire** eyepiece is a peephole with crosshairs at the other end, but is the crosshairs really exactly on the axis of the Cheshire tube? The **Concenter** is a good way to check that the secondary is centered in front of it. But how exactly can you adjust with a 95mm long alignment aid at all, if you want to magnify 200x afterwards? I therefore recommend the **alignment laser**, because you can adjust it yourself, and the laser beam is ideal because you can physically see the line. The laser beam itself and especially the points where it hits the secondary

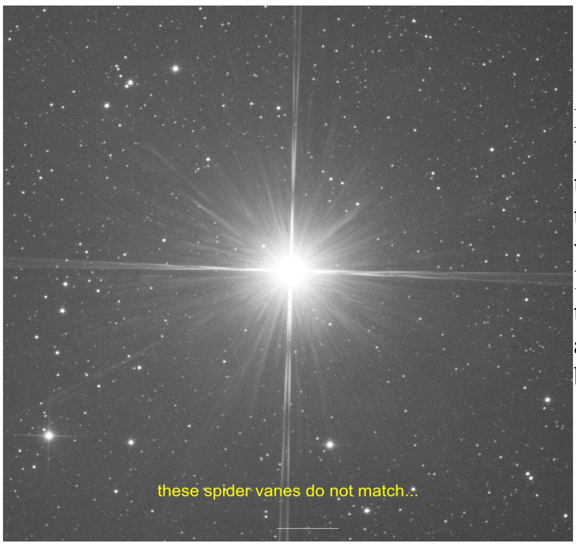
and primary mirror can be seen easily, and this makes the adjustment much easier. With other tools like the Cheshire or Concenter, you first have to understand which elements of the optics and mechanics you are looking at - and which of them to consider and which to ignore for a particular adjustment step.

Adjust with corrector! So that all optical elements used are also included in the adjustment. The laser is best screwed to it to avoid tilting. In any case, the corrector itself must be in order - the **rotation test** is suitable for checking this: Press the corrector into a suitable 2" sleeve (e.g. in a zenith mirror) and rotate it slowly. Mount the laser separately and send the beam through the corrector as desired, so that the laser dot can be seen at some distance on the wall. When rotating the corrector, the laser dot on the wall should only rotate in itself and not describe a small circle. This would be a sign of rotational asymmetry of the corrector and a reason to change it.

With the OctoPlus focuser, the extension tube first takes over the guidance, the corrector fits and can only tilt by the slip dimension. The clamping alone is not precise enough for the alignment. Only such a slip fit or a screw connection is sufficiently reproducible. Here in the picture, the laser is screwed to the first GPU prototype and is inserted into the focuser.

Position of the telescope during adjustment: The tube should point upwards, just like when photographing or observing. Preferably in the 45° inclination - if the tube has a flexibility, this gives you a middle position. But never adjust with the tube horizontally in the horizontal! Because the primary is not fixed by its holding clamps, but only secured against falling out - and it likes to tilt a bit forward in the horizontal position.

It makes sense to have the focuser **as far extended** during adjustment as it is during photography, i.e. in the **focus position**. Only in theory is the alignment of the focuser tube exactly the same over the entire stroke. Likewise, with rotatable focusers, the **axis of the rotator** will be slightly different from the axis of the focuser tube. So also **adjust the rotational position** of the focuser before adjustment. If it is planned to rotate the focuser more often, only move it as far as absolutely necessary from the adjustment position - i.e. rotate it only +/- 45°. With this, all image orientations are possible!



Before adjustment, also check the **secondary spider**. With most Newtons, it is attached to the tube with 4 tension screws. These screws must be well tensioned, so that the spider is stabilized and does not bend under the weight of the secondary when the Newton is swiveled. I like to think of this as a piano string, so really tighten them well! Opposite spider legs must be exactly aligned, otherwise the spikes on the photo are not sharp but run apart. Put on a ruler to check this.

After these preparations, you are ready to start:

The basic adjustment with an alignment laser

The adjustment of a Newtonian telescope is very easy once you have understood the principle: Check alignment laser, adjust secondary, adjust primary mirror.

1. check if the alignment laser is self-aligned - i.e. if the laser beam comes out exactly perpendicular to the support surface of the laser. Either in a 1.25" or 2" socket or if it is screwed to the corrector (better!) press the corrector flush and rotate it carefully. Check whether the laser dot on the primary remains stationary and only rotates in itself. If not, adjust the laser (see below). Now clamp gently so that the laser dot on the primary remains where it fell when pressed on.

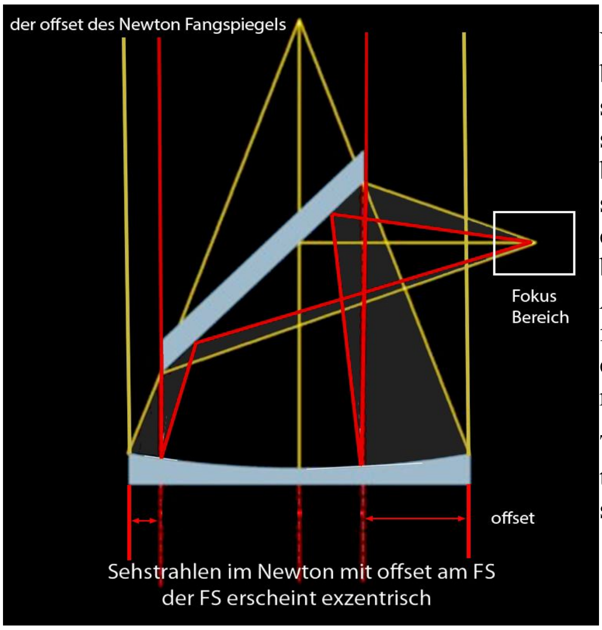
Adjusting the laser itself:

The laser can be misaligned by transport and shock, but adjusting it is easy:
- Insert into the focuser, press flat and rotate, observe the laser dot on the primary.
- If the laser dot describes a circle, it must be readjusted.
- remember where the center of the circle is: this is where the laser dot must be brought to.
- in the laser there is a small finger-shaped laser unit, which can be adjusted mostly with three small grub screws in 120° distance all around
- with these screws direct the laser into the center of the circle, turn again and determine the center again
- at the end the laser point should only rotate in itself (it is seldom exactly circular), and the grub screws should fix the laser unit well

2. Secondary adjustment. First, the secondary must be adjusted, 2 conditions must be met:

- the secondary should be placed centrically in front of the focuser
- the secondary must deflect the laser beam exactly into the center of the primary

The secondary mirror is elliptical, it cuts the light cone arriving from the primary obliquely (conic section). So the laser beam would have to hit the secondary in the center, and thus it would automatically be centered to the focuser tube. But this is too simple thinking, the geometry beats us here a snip. We want the conically converging light cone coming from the primary to be directed completely into the focuser. But the part of the secondary further away from the focuser hits the light cone further down, where it is even larger. So the secondary must be shifted further there than further up where the light cone has become smaller. This shift is called the **offset**. The following sketch should make it clear.

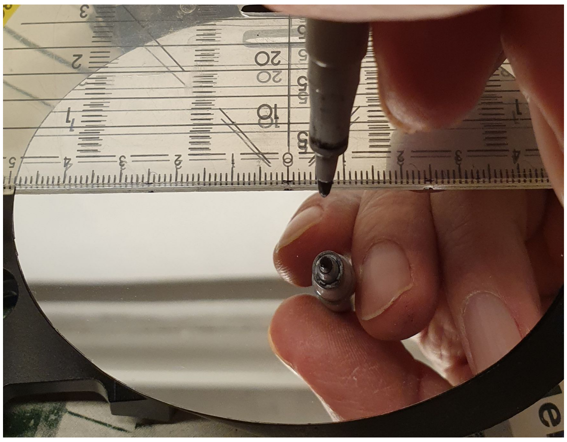


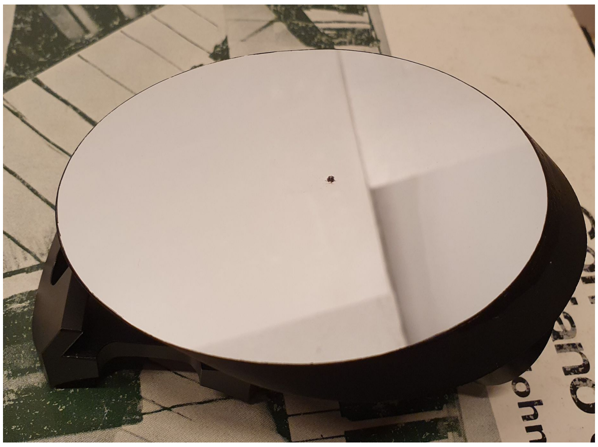
Yellow is the light coming from infinity, which is bundled by the primary and deflected by the secondary in front of the focal point. Red is the shadow which the secondary cuts out of the light bundle. From the focus, you can see that the secondary actually redirects the entire yellow light cone correctly. However, it is not centered in the tube, but shifted to the side farther away from the focuser. Accordingly, it cuts out an eccentric circle from the incident light. This geometrical fact must be considered especially for Newtons with fast focal ratio.

The laser beam is the yellow line pointing straight to the left from the focuser, and it does not hit the secondary in its center, but in the offset point.

The point where the laser hits the secondary is therefore offset a few millimeters in the direction of the focuser. Many secondaries have a fine marking there, otherwise you take about 6mm for f/4 Newtons and 4mm for f/5 (applies to 200 and 250mm primary, larger Newtons need more). Want it more precise? See hint at the end of this chapter.

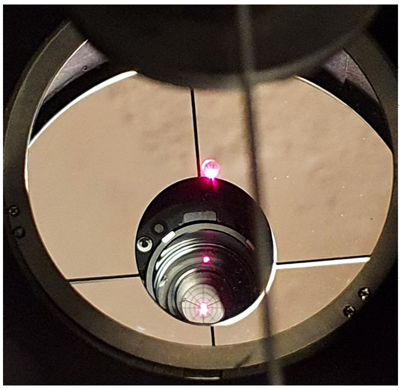
If there is no marker, then you can estimate the point of impact - or make a mark on the secondary yourself with a good marker. The point is exactly on the long axis of the ellipse and offset by the offset from the geometric center upwards (to the focuser). Here it is 6mm:





Most secondaries have already been glued to their mounting base with this offset by the telescope manufacturer, so you simply attach the base to the spider and the spider legs can stay nice and straight. So setting the correct position of the secondary in front of the focuser is now easy, the laser just has to hit this point. But it also has to hit the primary center. So there is only one position of the secondary where this really happens. This position has to be found.

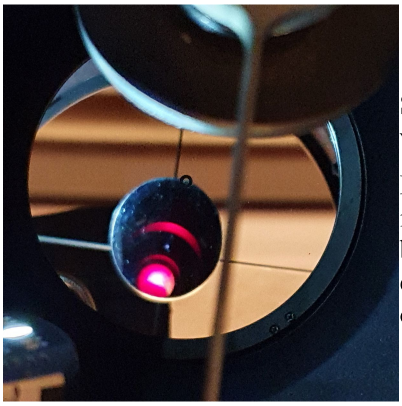
Since you cannot see the secondary surface directly, you have to look into the tube from above and pay attention to the reflection of the secondary in the primary. At first, the fine mark on the secondary may be difficult to see, and you have to provide the right illumination so that it is not overpowered by the laser beam. But once you know where it is, you will find it.



View from above into the Newtonian tube. You can see the primary with the center marking, where the laser beam does not yet hit the very center.

In the primary mirrored you see the secondary and the point where the laser hits it.

In the secondary mirrored you can see the focuser tube with the exit aperture of the laser itself and the disk around it.



Suitable illumination of the secondary surface should be provided, whereby the primary can be used as a reflector.

However, the bright laser dot is dazzling and obscures the inconspicuous marking on the secondary. Remedy: Cover the laser beam with a finger directly after its exit aperture. Then the marking is easy to see. This allows you to flash the laser dot and position the mark on the secondary.

The **height of the secondary in front of the focuser** is adjusted with the **center screw** of the secondary base, which engages the thread in the base of the secondary. In most cases, this does not have to be redone if the height has already been set correctly - this will hardly change. The center screw is the actual retaining screw of the secondary, so do not set it too low, it could loosen from the screw and fall onto the primary! The 3 **counter screws** are not only used to fix the secondary base, they also determine its **inclination**. First loosen all 3 counter screws considerably so that the base can move freely.

Hold and align the secondary base with one hand and adjust the center screw with the other until the laser beam hits the secondary at its mark.

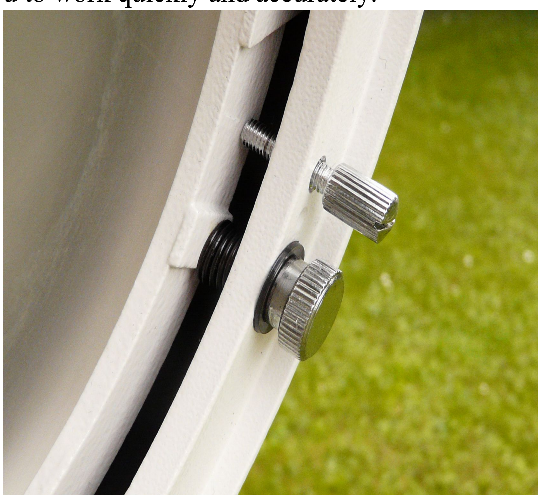
When the laser is close to the target point of impact, start paying attention to where it hits the primary. The secondary now hangs only on the center screw and can otherwise be moved freely. By **rotating** the secondary around the longitudinal axis and **aligning it laterally**, you can ensure that the laser also hits the center mark of the primary centrally after the target point on the secondary.

This is already the ideal position of the secondary!

There is only one position of the secondary where the rotation, lateral alignment and height match so that both markings (secondary **and** primary) are hit by the laser. Now just tighten the counter screws so that exactly this position is maintained. Gently at first, and then gradually build up more and more pressure so that they are finally hand-tightened and nothing can move by itself. Some counter screws have sharp tips and cause pits in the secondary socket, where they then tend to slip in - filing these tips flat helps.

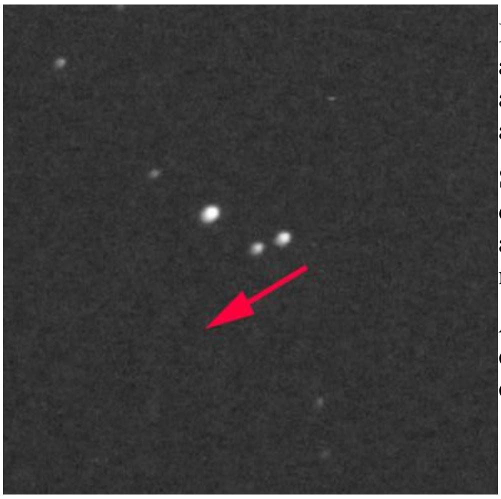
Hint: You don't have to be super precise with the offset. The secondary is a plane mirror and has no optical power - a small shift of the position of the secondary in front of the focuser only changes the illumination but not the star image. The center of the primary marking, on the other hand, has to be hit by the laser as precisely as possible, this is about the precise deflection of the optical axis of the parabolic mirror! Who likes it more exactly, uses an offset calculator. Attention, the values given there concern the lateral displacement of the secondary, to find the distance from its center to the surface, multiply this value by 1.4 (square root of 2).

3. Adjust the primary. This is now quite simple. The primary lies in the mirror cell on its holder (either a simple ring or a more elaborate multipoint holder). This mount can be adjusted at 3 points with tension and compression screws. It is advisable to tighten all 3 pairs of screws at the beginning so that you can assume a stable system. Now open and change only one pair at a time, and watch how the returning laser dot moves at the laser. After an adjustment, always fix the counter screw as well, taking into account the small movement of the laser dot that causes this. This allows you to work quickly and accurately.



The tilt of the primary is now adjusted so that the laser beam returns to the laser itself, exactly in the hole where it originates. This ensures that the secondary is centered in front of the focuser and correctly aligned with the primary, and that the optical axis of the primary is correctly guided into the axis of the focuser.

Thus, the Newton system is adjusted accurately enough for most applications!



For **visual observation** at high magnification, it is sufficient to adjust the remaining coma directly using an observed star. Just adjust the primary so, that the star moves in the same direction as the coma tail (red arrow).

Slightly out of focus helps to identify faint coma. The defocused star should be equally bright all around, a brighter and opposite darker spot is typical for coma. The star must be moved with the primary towards the darker spot.

Attention: Without coma corrector this is only true in the center of the image! The Newton telescope shows increasing coma off axis without corrector.

The stability of the adjustment

It is useful to check the stability of the adjustment before fine-tuning. The adjustment is unstable if ***something*** in the system **moves too much** when the telescope is tilted. **Rule of thumb**: the laser dot on the primary should not move more than 1-1.5mm away from the target position. All elements involved can be weak points, quite systematically check if something can be bent or moved.

- spider vanes well tensioned and secondary base tightened?
- primary without lateral play in the cell?
- tube wall around the focuser stable enough?
- focuser and extension tube mounted stably?
- Camera adaption stable (check bayonet rings!)?

A good test is to load the focuser + screwed laser with the simulated weight of the camera at the nominal distance, and to slew the telescope in all directions, from zenith to horizon and on both sides of the mount. The focuser as a moving part must be allowed a minimal amount of play, but the above rule of thumb should be followed. If the allowed value is significantly exceeded, troubleshooting and elimination is essential.

the fine adjustment for photography

Principle and aim of photographic adjustment

While for visual purposes good imaging in the center of the field of view is usually sufficient, photography also requires good imaging across the field, **right into the corners** of the sensor. The high resolution of today's sensors shows errors mercilessly, and the faster the focal ratio of the telescope, the smaller the tolerances and the more accurate one has to work.

The Newtonian telescope with its parabolic mirror has excellent imaging on axis, but off axis coma and also astigmatism appear. The coma corrector should primarily correct the very asymmetric offaxis coma, but it must also accurately level the image field curvature of the image dish of the parabola. These corrections require a defined working distance from the corrector to the sensor, usually 55mm, but at short focal lengths the corrector has to work harder for the stronger image field curvature and the nominal distance can then be somewhat smaller.

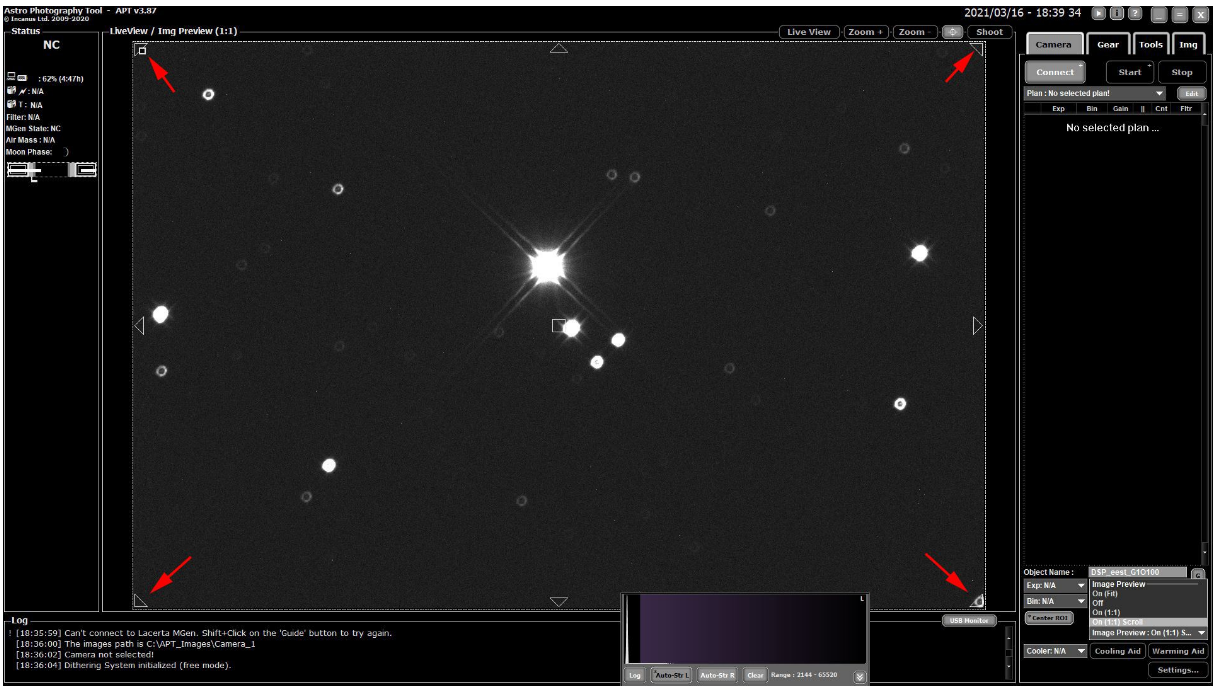
Using these features correctly, it is possible to **use the connected camera as a measuring instrument** for fine adjustment!

For best possible imaging in the field these conditions must be met:

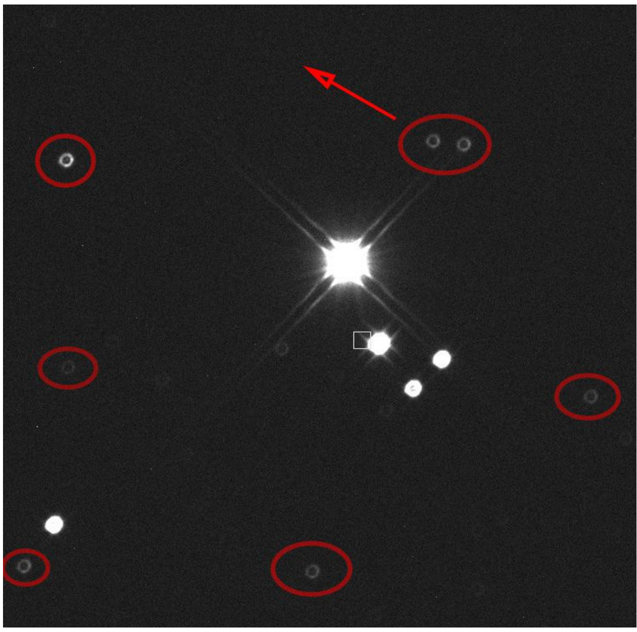
- the optical axis must meet the sensor in the center of the image
- the optical axis must be perpendicular to the sensor
- the working distance to the corrector must be met

There is a systematic way to achieve all this by analyzing the image from the camera. For this purpose, we use the **startest**, a method that helps to qualitatively detect the errors occurring in the center and in the image corners and to minimize them in a targeted manner. The star test is performed on the **defocused** telescope, it is thereby **0.1-0.5mm** inward (intrafocal) out of focus. The closer you are to the focus the more sensitive is the test, but it is important that you can see the shapes and light distribution in the disks well.

To evaluate the shape of the star discs, take a few seconds exposed image at high Iso number, and then control the correction movement with the **DSLR** on the liveview with the screen magnifier. With **CMOS/CCD** cameras one proceeds similarly. It is good to use a program that allows a fast display of the images, and at the same time a fast control of the 4 image corners. You can save on the quality of the images, and increase the USB traffic, and/or use the ROI feature for the center. APT for example has a 1:1 scroll mode, where the image corners are displayed immediately by double clicking on the small triangles in the corners of the displayed image.



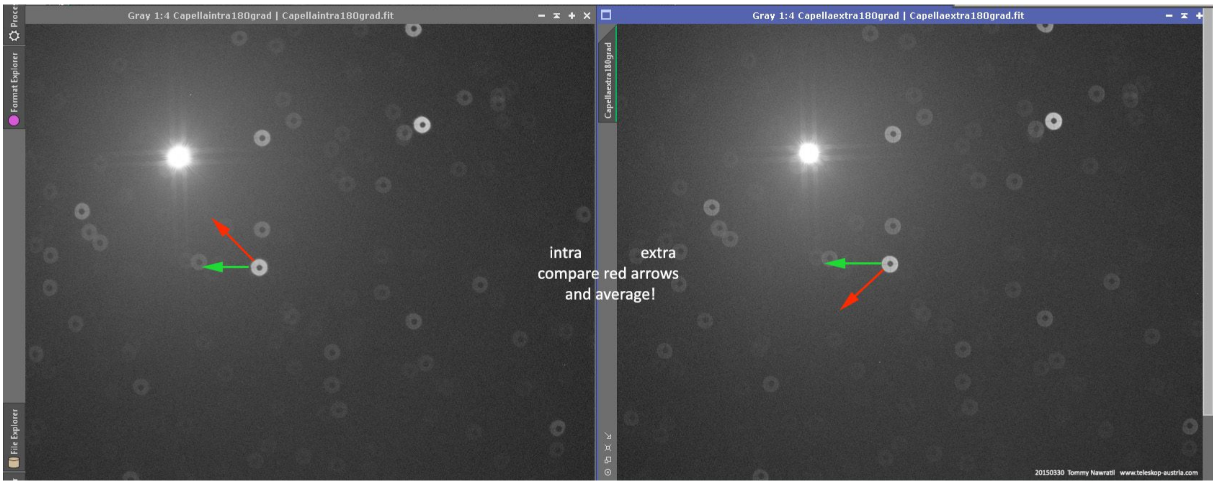
a) Fine adjustment of the primary mirror



First, you look at the star disks in the **center** of the image and judge if the brightness at the edge of the slices is the same everywhere or if there is a place where it is a bit darker. The less bright disks show it more clearly. The donuts in the example image are darkest in the upper left corner.

The primary is adjusted so that the disks move about 20-40 pixels in this direction (red arrow). The brightness distribution must become more balanced. Find the point where it is **well balanced all around**.

A more accurate method of detecting **coma** uses the **position of the secondary shadow** in the intrafocal and extrafocal star disks. If you change from intrafocal to the other side of the focus, the secondary shadow also changes sides. The star disks should look like mirrored. If this is not the case, determine where the light donuts are thickest (red arrows) and average the two directions (green arrows). The correction at the primary should move the stars in the averaged direction:

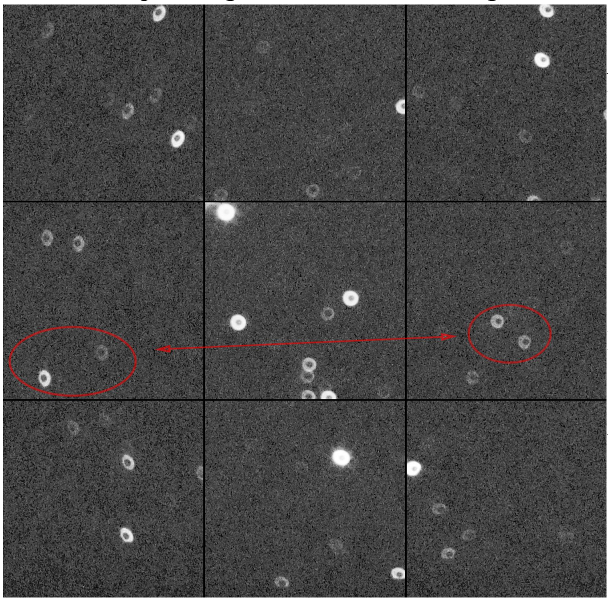


For more details see the hints below! This more accurate method does not have to be used if the coma is obvious from the uneven brightness distribution of the star disks. It is usually sufficient to use it at the end of the adjustment.

When tightening the counter screws, make sure that the stars on the liveview do not move as a result. Use the set screws to counteract this. This preserves the found position of the primary.

b) Fine adjustment of the secondary mirror

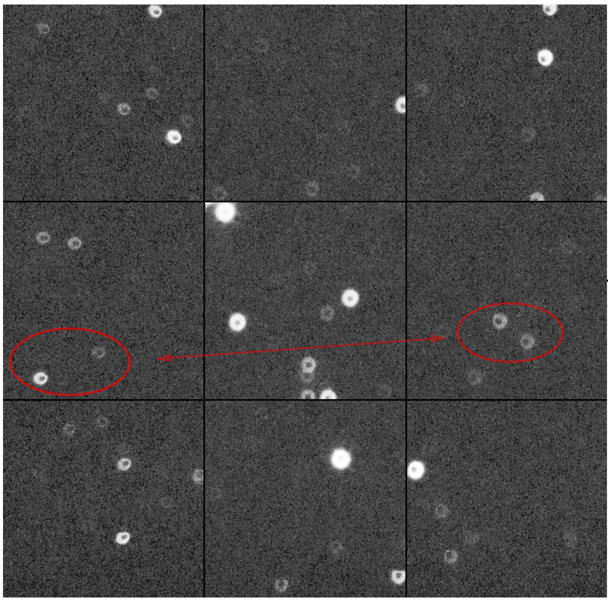
In these sample images, sections of the image corners and center are combined in full resolution.



Now we look at the **edge of the field** with the 4 image corners and **compare the shapes** of the star disks. In the image corners, a certain residual astigmatism is normal, namely **intrafocally** the star discs are flattened towards the image center.

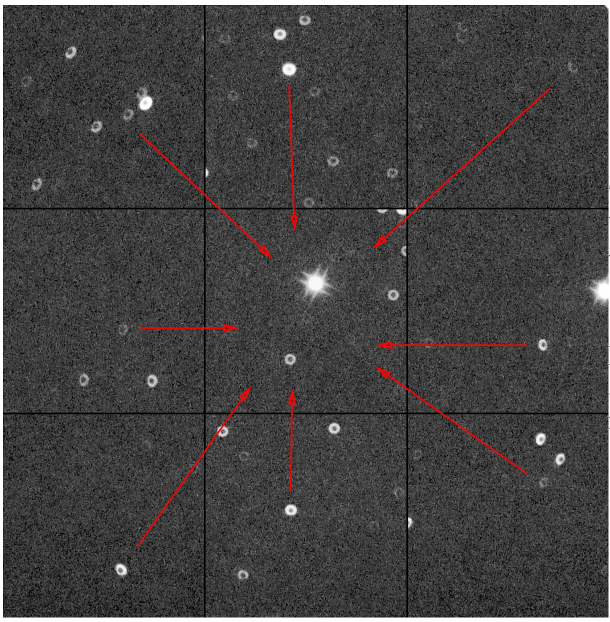
The shapes of this flattening at the edge of the field should ideally be **symmetrical to the image center.**

In addition, there is a vignette which cuts off the outer part of the slice, sometimes up to the secondary shadow. The flattening is the same in all 4 corners with ideal adjustment. If you see stronger flattened disks in one corner, then they are less flattened or even elongated towards the center in the opposite corner.



In some cases, it is advisable to view the shapes of the star discs **extrafocally** as well. Extrafocally, the star discs are elongated radially away from the image center due to the astigmatism at the edge of the field - exactly the opposite of intrafocally. Thus, the symmetry towards the center is sometimes easier to judge.

You look for the direction in which the deviations are greatest and adjust the secondary at the 3 **counter screws** so that the stars on the image move approx. 10-20 pixels in the direction of the **more flattened** corner (red arrow). Very sensitive! Each movement of the secondary changes the position of the optical axis twice as much as a movement of the primary.



The result will be that the flattening will be more balanced and the star slices at the edge of the field will be more symmetrical towards the center.

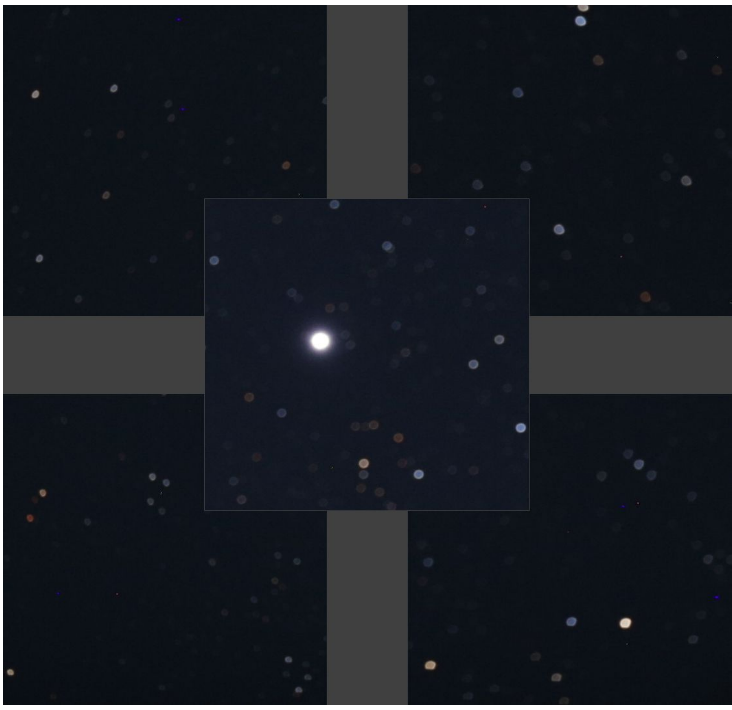
However, the secondary movement will cause the alignment of the primary to be off, and coma will return to the center of the image.

c) Refine step by step

Now check again in the center, and if necessary adjust away the coma as described in a). Then perform step b) again, etc. In this way you can quickly achieve that the distortions in the corners are well symmetrical and the center is coma-free.

A certain tolerance is allowed, a 100.0% adjustment is very difficult to achieve and not necessary at all. The star test near the focus is very sensitive. Thus primary and secondary are aligned, and the optical axis hits the center of the image. The image plane is perpendicular to the optical axis, but is it also the sensor?

d) Sensor tilt



Now check whether the star disks are the same size everywhere in the image. To do this, it is best to go quite **close to the focus**, as the differences are best visible there. If they are different sizes, there is a tilt and a tilt adapter is needed. The smaller star slices are closer to the focus intrafocally, and the tilt adapter must be spread open a bit on the opposite side. This is because the image of the camera is internally mirrored both vertically and horizontally. In this way, you can achieve that the star slices are approximately the same size.

This example is taken from a Takahashi FSQ130 and Eos6d, you can see that the star disks are clearly larger on the right side. But the offaxis aberrations are symmetrical.

e) Working distance to the corrector

Now focus in the **center** of the image. If the stars are well rounded in the corners, you have hit the working distance well. If they appear flattened towards the center, as in this example, the corrector has too strong an effect and the distance must be reduced. If they are elongated towards the center, then the corrector has too little effect and the distance must be increased.

If they are distorted only in one corner or on one side, the distance may still not be well hit and a small remaining tilt may push the stars out of the tolerance range there.

With fast focal ratio like f/4, the sensor distance has to be kept quite accurate. Once the inquiry came whether the corrector distance is perhaps dependent on the temperature. During the night it had become cooler by more than 10 degrees and the correction had changed from too much to too little. After some research, it became clear that the DSLR, made of plastic, had contracted by a few tenths of a millimeter due to the cooling!

Refocusing: The flattened stars at the edge of the image are a result of the remaining astigmatism - which the corrector cannot correct - plus a not quite flat image field. When the focus passes through, they change their direction by 90°. By focusing not in the center of the image but halfway towards the edge, the error can be mitigated if only a minimal blur in the center of the image is the result.

Compensate for tilt with the primary: Since the image plane is perpendicular to the optical axis, tilting the axis also causes tilting of the image plane. Minimally astigmatically distorted stars in the image corners can therefore be favorably influenced by intentionally tilting the primary. *If you do something wrong in the right way, the wrong thing will work right.* Some focusers have screws at the base to adjust the tilt of the whole focuser. This can also be used in an emergency, knowing that it will fundamentally change the alignment. This should only be a temporary emergency measure, a clean un-tilt of the sensor is of course the better way, also regarding rotation of the camera.

Software tools: There are image analysis tools like CCD Inspector or the FWHM Eccentricity Script in PixInsight. They are very useful for checking, but don't tell you which screw to turn next. In combination with this guide they can be used for refinement.

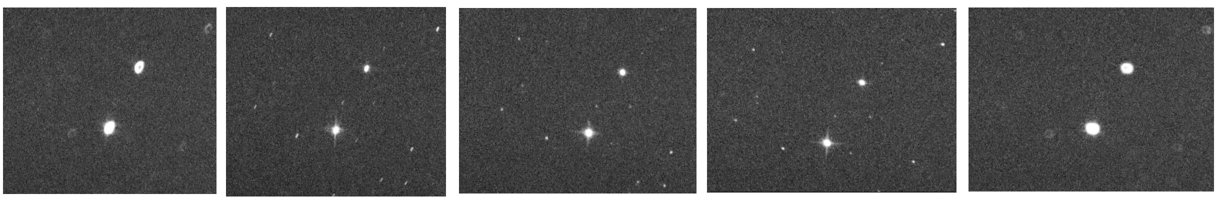
Background information on this method:

Although the primary and secondary must be adjusted during alignment, it is important to realize that **only the primary is the optically active element** that focuses the incident light rays and creates the image. The secondary is a **plane mirror** that only deflects the light but has no other optical power. The parabola of the primary has an optical axis, and the image errors are symmetrical about this axis.

The **corrector** is involved in that it corrects for off-axis coma and field curvature, but it cannot completely correct away the astigmatism that the parabola has off-axis. We use the symmetry of this astigmatism here to find the optical axis and bring it to the center of the image.

The corrector can only work properly if the optical axis passes through it **centrally**. If the optical axis does not hit the center of the image, coma will occur despite the corrector. This coma could also be adjusted away only at the primary, which may be sufficient for visual observation. But then the optical axis can still arrive crooked, and the image plane is tilted against the sensor and the astigmatism in the field is asymmetrical.

At the **edge** of the image, only **precisely focused** stars are round, in contrast to the center of the image where stars can be out of focus but remain round. The **critical focus zone** at f/4 and 3.7µ pixels is only about 40µm! The astigmatism, together with a tilt and/or field curvature determines the star shapes at the image edge. When passing the focus, the astigmatically deformed stars change direction by 90°. Try minimum intra and extrafocal exposures to get a feel for how even 0.1mm of defocus turns the stars at the edge of the image into small dashes. Here the lower right corner on a f/4 Newton with GPU coma corrector:



intrafocal focal extrafocal

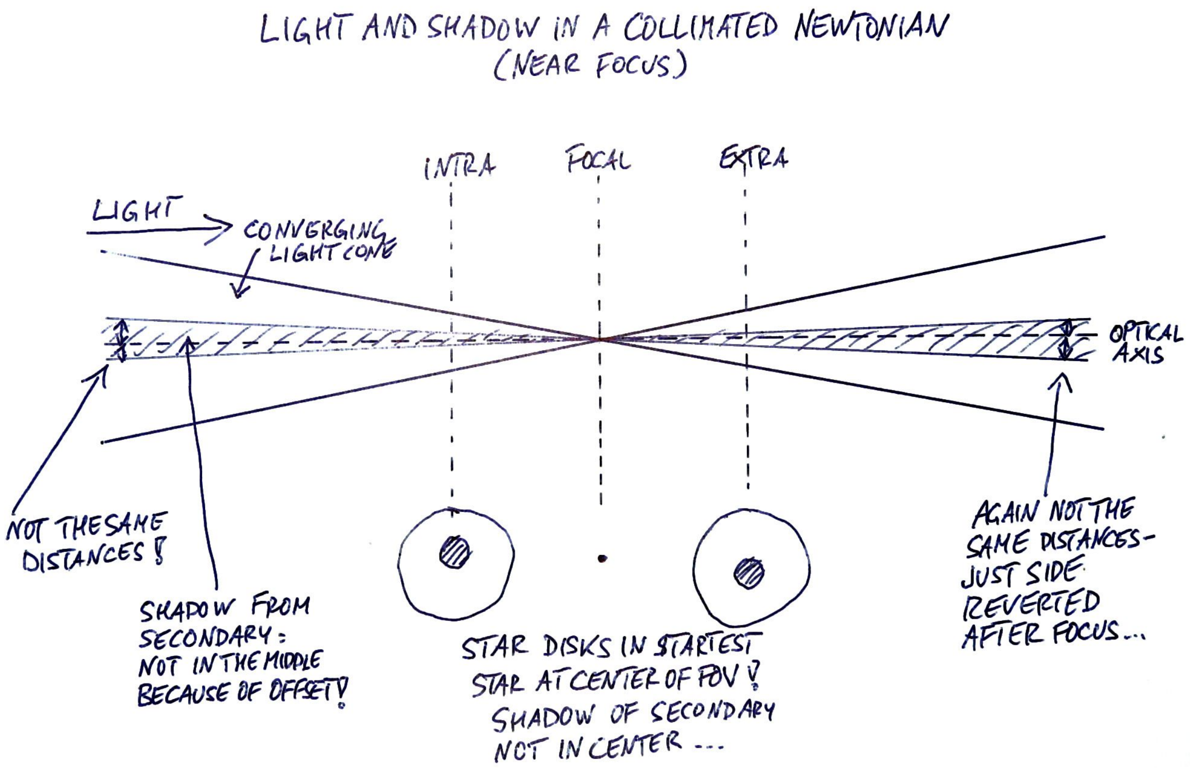
This is why the correct corrector distance is so important. On the other hand, a slight tilt of the sensor can also be mitigated by a corresponding counter-tilt of the primary. This can also be achieved with this method - because it is the camera itself that is used as the measuring instrument.

When inspected again with the laser after successful fine adjustment, the laser dot often does not quite hit the center mark, nor does the returning beam hit the emitting hole. Now you know some reasons why. Photograph these laser positions for future reference!

Hints, Error Analysis, FAQ

Doesn't the shadow of the secondary have to be in the center of the star disk in the star test?

No! Since the secondary is eccentric in the optical path because of the offset, it must also be eccentric in the star slice. When passing through the focus, it changes the side. The following sketch illustrates the ray path in the vicinity of the focus.



The beam cone comes from the left, and the shadow cone cast by the secondary sits eccentrically in it. In the focus, the cones converge, and the shadow disappears in the diffraction disk. Behind the focus, however, the two nested cones reappear, and now the shadow cone is eccentric to the other side - simply because the light continues to travel straight. Now we look for two points intra and extrafocal, which are equidistant from the focus. Far enough so that the shadow is quite clear, and not obscured by diffraction near the focus. Below we see the cross sections through the light cone with the shadow in it, as the defocused star disk appears on the image. The eccentric shadow changes sides!

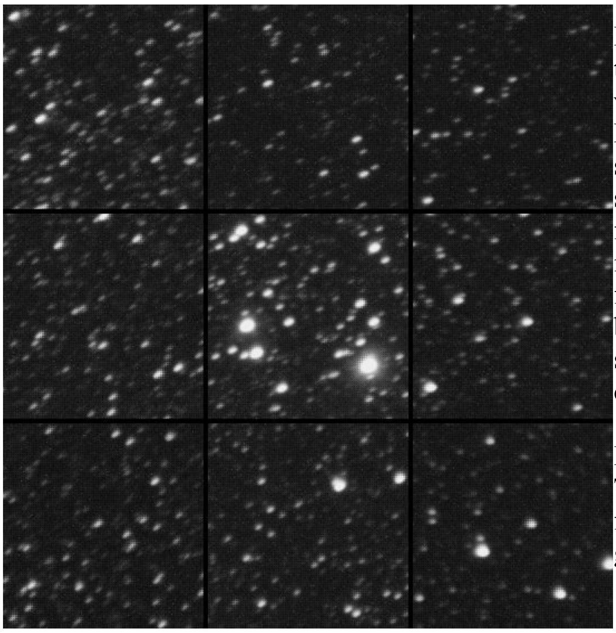
This is a sensitive method to test for remaining coma in the image center. If the optics is well formed, as the startest also shows even slight optical flaws. After successful adjustment, the star test should ideally look like this (10" f/4 Lacerta Photonewton, Eos600d). The thickest parts of the donuts are of the same thickness and are 180° opposite to each other:

intrafocal focal extrafocal

How can alignment errors be separated from tracking errors?

Short exposures! With very short exposures, tracking errors will not have an effect. Pointing the telescope at Polaris is also helpful. In a long exposure image, tracking errors can be recognized by the fact that the stars are **equally distorted over the whole image field**, while alignment errors do not look the same for all stars. **Rule of thumb**: If there are round stars anywhere in the image, then the tracking is ok. Tracking errors elongate stars the same everywhere in the image (exception: image field rotation), and the errors add to the alignment errors that may also be present - they never subtract. To reduce tracking errors, expose shorter - this separates them from alignment errors.

You mentioned image field rotation - what is that?



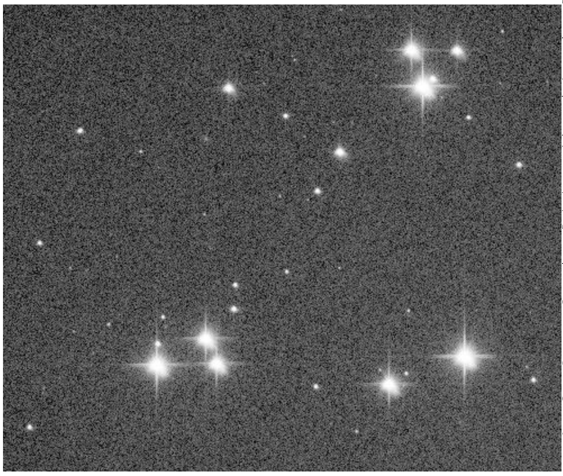
If the mount is not well aligned, the stars drift slowly through the image. Mostly you use an autoguider, which prevents the drift and keeps a star in position. Because the hour axis does not hit the pole, there is still a smaller differential drift - around the guide star. If the guide star is in the center of the image field, this image field rotation remains inconspicuous. But if the guide star is clearly away from the center, the line traces on the averted side become longer and longer. The elongation of the stars is not the same over the whole image, but centered on the guide star.

In this example the guide star is on the lower right. The effect appeared only after two hours of problem-free exposure. One mount leg may have sunk into the ground.

Help, strokes are coming out of my stars!

Mounts are usually driven by a worm and worm wheel. Between the two components there can be some **backlash**, and the mount can float in it. This affects both axes, and more often the DEC axis, because in RA the worm is always pushing due to the ongoing tracking. You can **compensate** for the backlash by providing a slight imbalance - a small weight that pulls the DEC axis to one side. In RA you can position the counterweight accordingly. You should minimize the backlash mechanically as much as possible, but too close a contact will cause the tracking to hook, which cannot be compensated.

Regulate heaters!

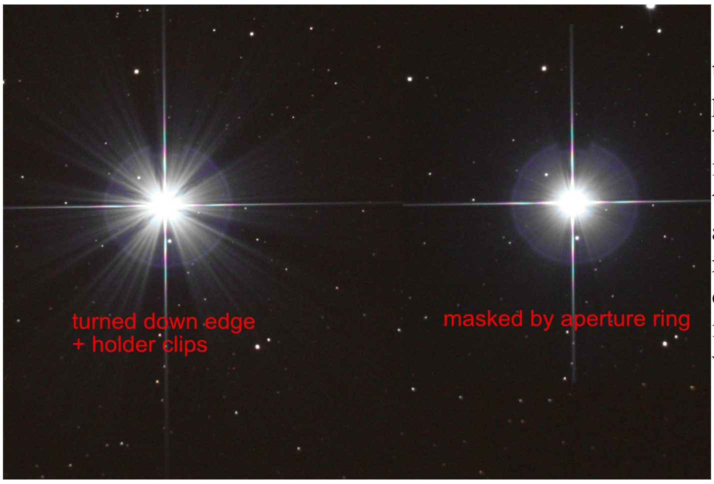


To prevent dewing up, it is practical to attach a heater to the FS. However, if the heater heats too much, the warm air will rise into the beam path and cause light spikes on brighter stars throughout the image. Heat only as little as necessary!

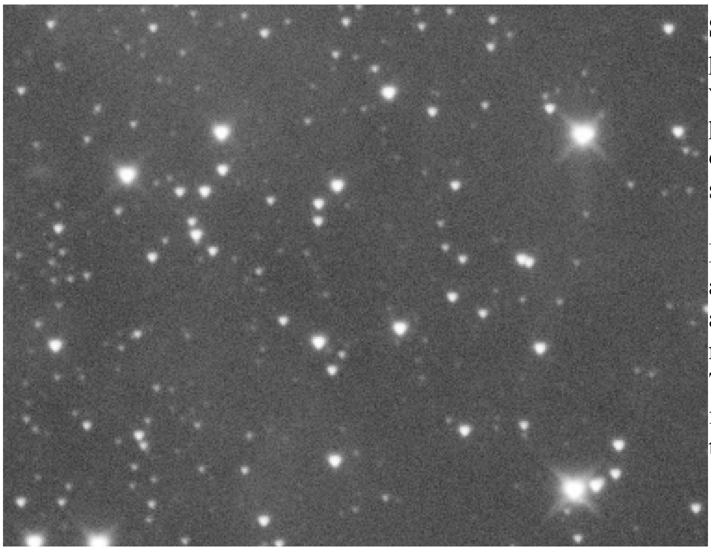
Poorly cooled telescopes also exhibit this phenomenon. The warm air rises from the HS and forms a warm air tube in the tube, which refracts the incident rays differently than normally tempered air.

Characteristic: If you move the tube, the direction of the disturbance to the stars changes, because the warm air always rises upwards.

Optical problems



turned down edge: After the grinding process, some mirrors have a small zone on the edge that has been ground too flat. Often it is only half a millimeter. The light is transported far out of the diffraction disk and floods the surrounding image field. The retaining clips cover this in their area and dark recesses form. Masking with a black inkpen or a diaphragm eliminates the effect without costing much aperture.



Strained optics: If the retaining clips of the primary are tightened too much, the mirror will deform. They must not touch the primary at all, only secure it against falling out. A deformed optics produces deformed stars in the whole image.

But this example here shows how deceptive a quick judgment can be. It looks similar to a strained optic, but the telescope was merely misaligned and had strong coma. The star test shows the difference immediately: With tension, the disks are triangular, but equally bright all around.

Reflexes

some examples from the unpopular realm of reflexes...

Adapters attached to the telescope are usually round. If they are not well matted blackened inside, bright stars outside and inside the field of view can cause these arc-shaped reflections.

Another possibility to get such arcs is with Ritchey-Chretién telescopes: The aperture tube is then wrongly dimensioned and starlight can fall just past the secondary directly into the baffle tube and onto the sensor.

Fluted, but still shiny adapter inner sides can also act like a grating spectrograph.

The best way to find the shiny areas is to point the telescope at a bright surface and look into the focuser from behind through the adapters. Everything that shines brightly should be matted black - applying velour foil or matte black varnish is recommended.

However, straight surfaces can also be involved. Here on the left is the reflection from a non-matted secondary strut.

The spikes of 52 Cygni are very long here. If you don't like this, you can cover the secondary spider with black velour, which effectively scatters the diffraction and makes the spikes less long and conspicuous.

Literature: Startesting Astronomical Telescopes, H.R.Suiter, Willmann-Bell

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