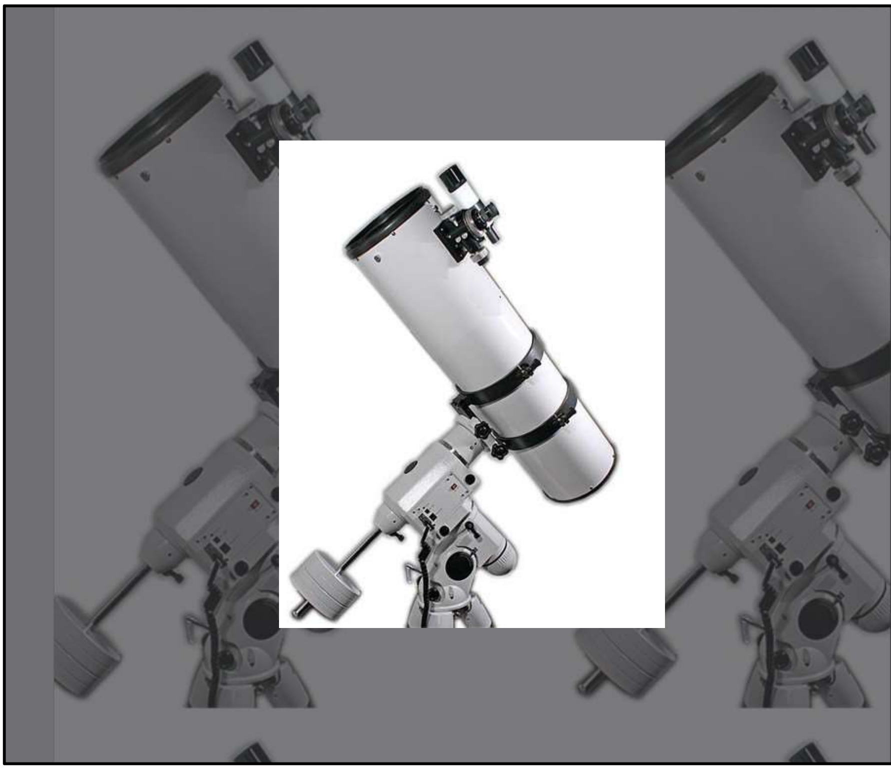


Collimating a Newtonian Telescope

A simple guide for the every day amateur astronomer.

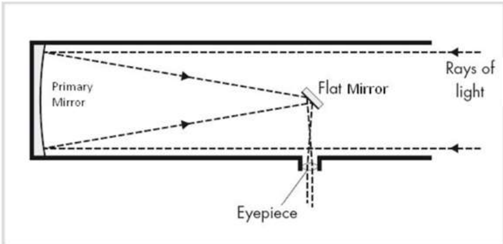
Contents

Definition – what is it?

collimate [**kol**-*uh*-meyt]

verb (used with object), **col·li·mat·ed, col·li·mat·ing.**

1. to bring into line; make parallel.
2. to adjust accurately the line of sight of (a telescope).



So, collimation has everything to do with making your telescope optics line up with each other and also making sure that all of the light that enters into the aperture of your telescope also enters the eyepiece and your own eye.

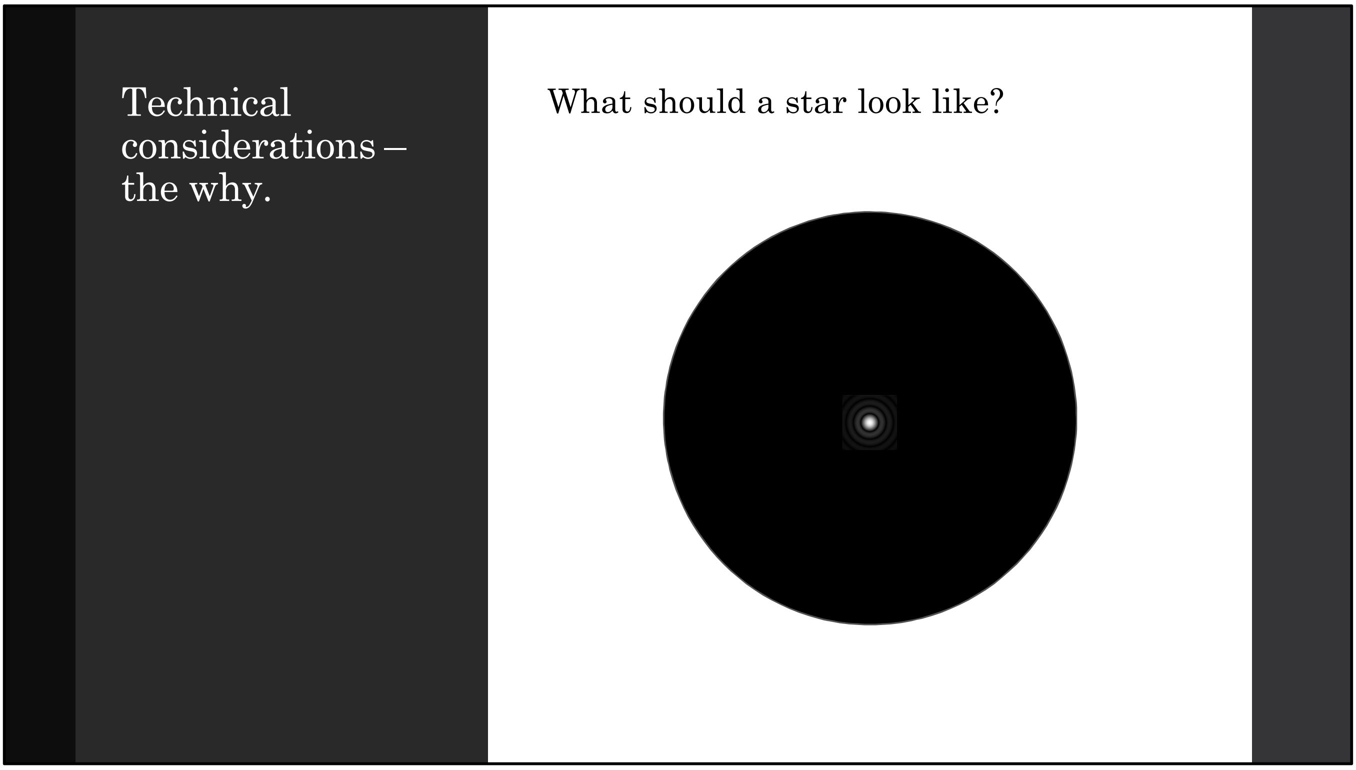
Technical considerations – the why.

- What should a star look like?
- Diffraction
- What do your stars look like?

This is the point where we have a little look at some physics that help us to understand what a star (which is a point source of light) looks like in a telescope.

But before we start this the optical alignment will alter by small amounts as the telescope is moved and gravity has an effect on the primary and secondary mirrors. So getting things aligned well in the first place will ensure that during normal usage the optics stay very well aligned.

It is worth checking your alignment every now and again though, a star test will show you if anything has moved. Certainly you should re-check if you've transported the telescope for observing at a remote location or if you've moved house. The vibrations from the vehicle will contribute to the movement of the optics far more than every day use. But bear in mind that trying to collimate in the dark is not easy.

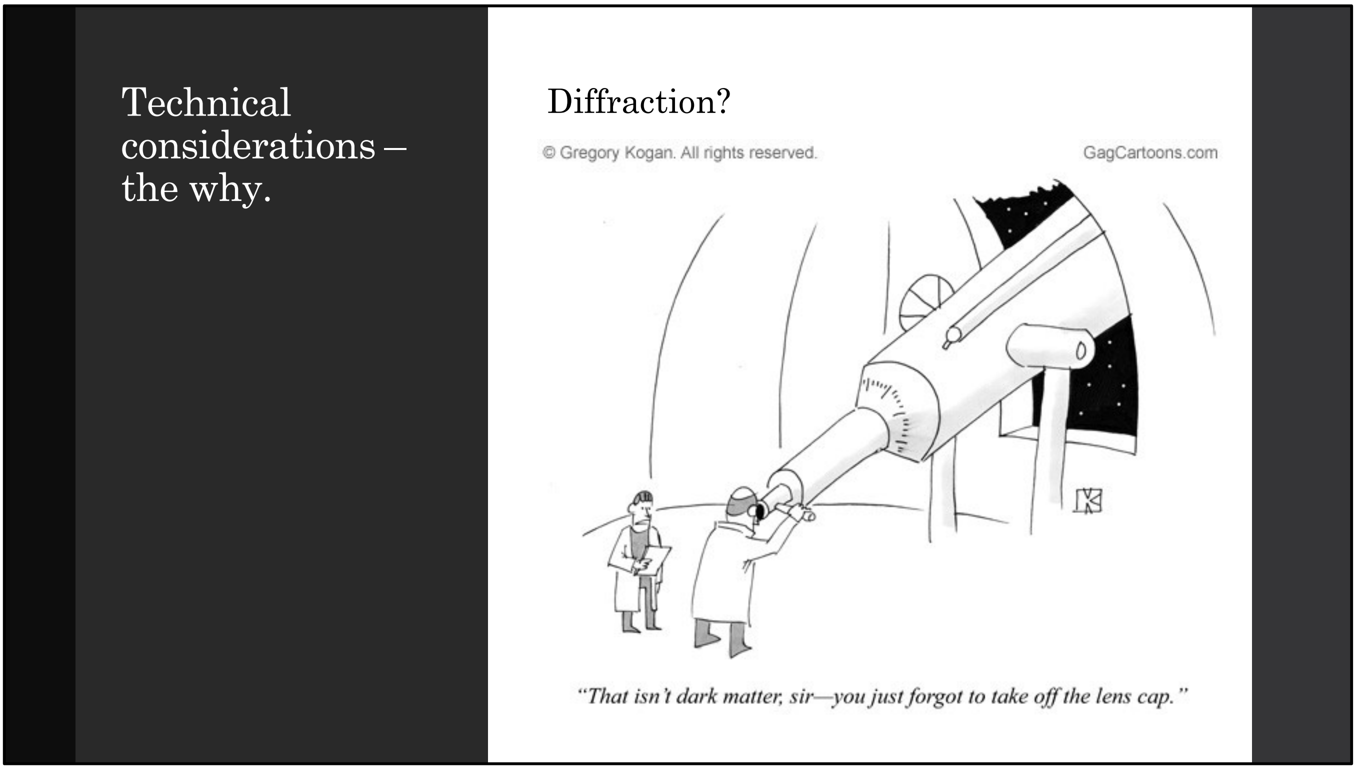


So you probably know that a star is a point source of light – it’s so far away that it does not present a disk, so it’s just going to look like a (maybe white, maybe coloured) dot in my field of view.

In reality it presents what is known as an Airy Disk, which is the result of light diffraction through the aperture of your telescope.

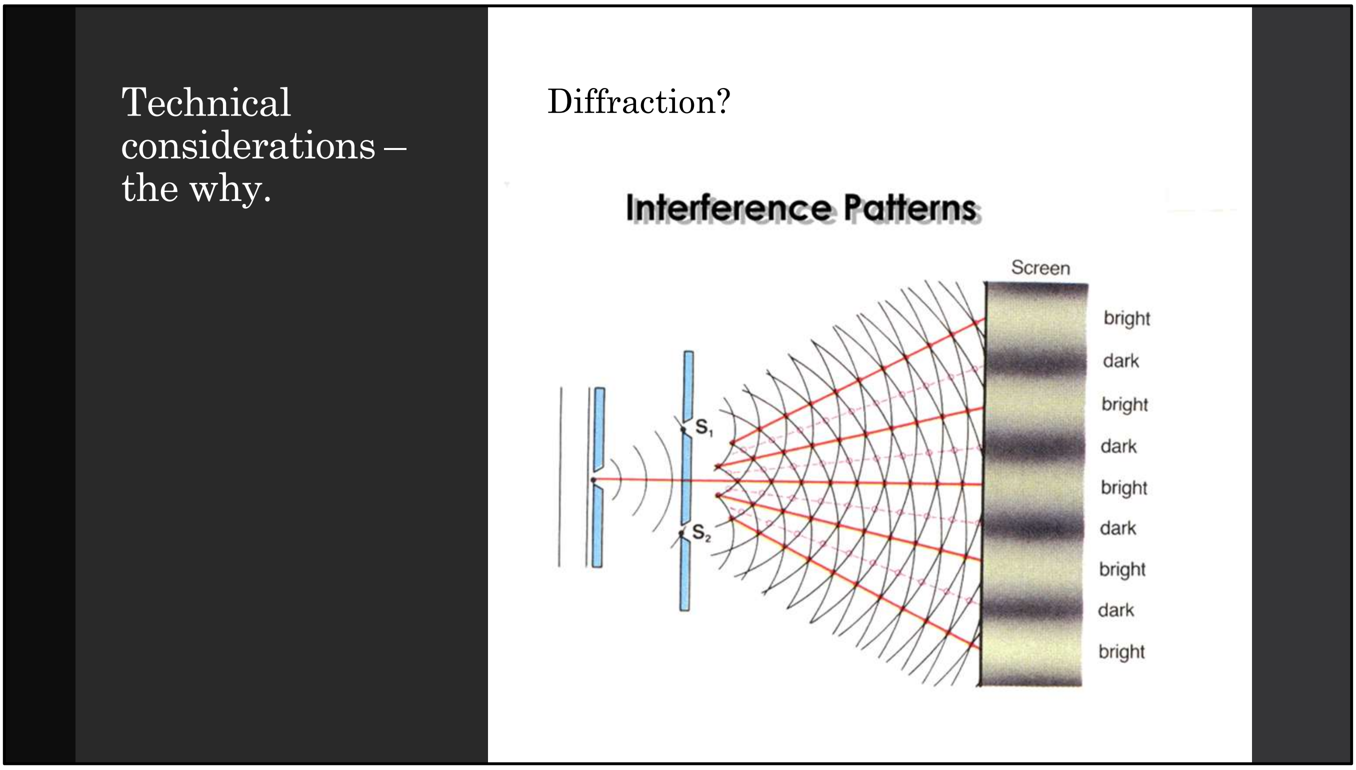
So you can see that there is a bright central “point” of light surrounded by rings of light that get fainter as they recede from the centre – this is especially apparent if you defocus the view of the star slightly.

Why does it appear like this?



At this point in the presentation it is useful to take a step back and say to ourselves "what does my telescope look like to the star?" because this helps to explain the view that you get when you look at the star in your telescope.

Well of course because your telescope is as far from the star as the star is from your telescope the aperture of your telescope just looks like a tiny hole.

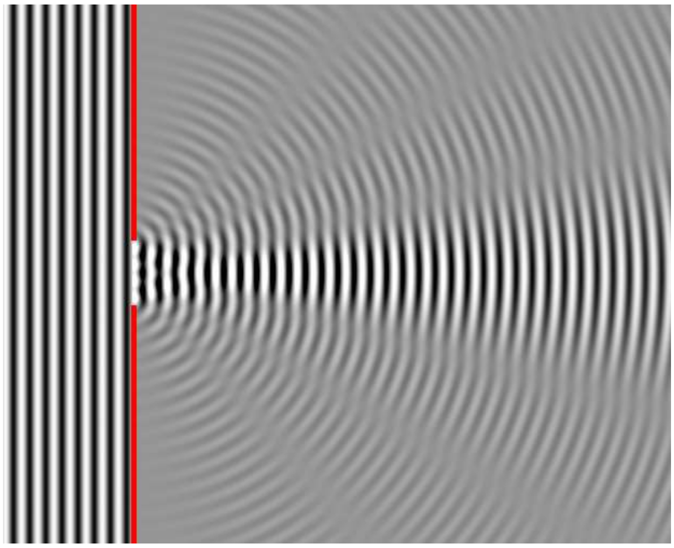


So how does light behave when it goes through a tiny hole?

We've probably all seen pictures of the effect when light passes through a pair of narrow slits, the light is diffracted at the edges of the slits and interferes producing a series of bright and dark lines.

Technical considerations – the why.

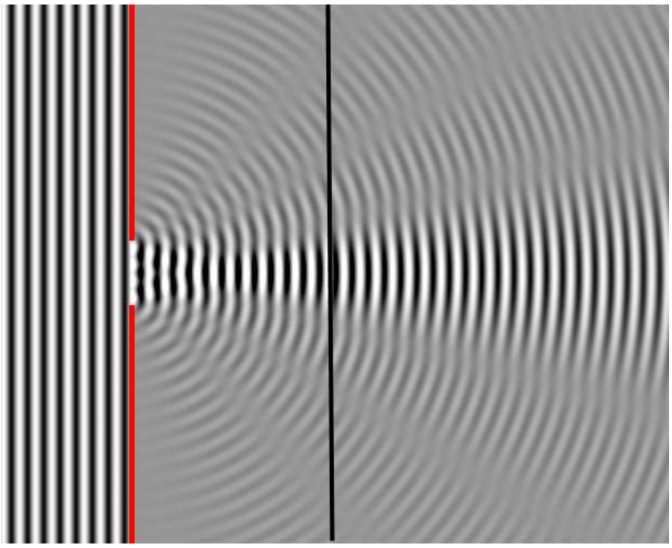
Diffraction?



If we reduce the slit to a circular hole then we get bright and dark circles instead.

Technical considerations – the why.

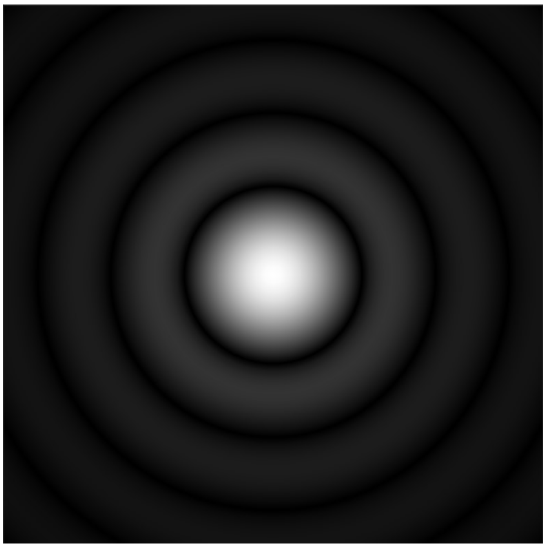
Diffraction?



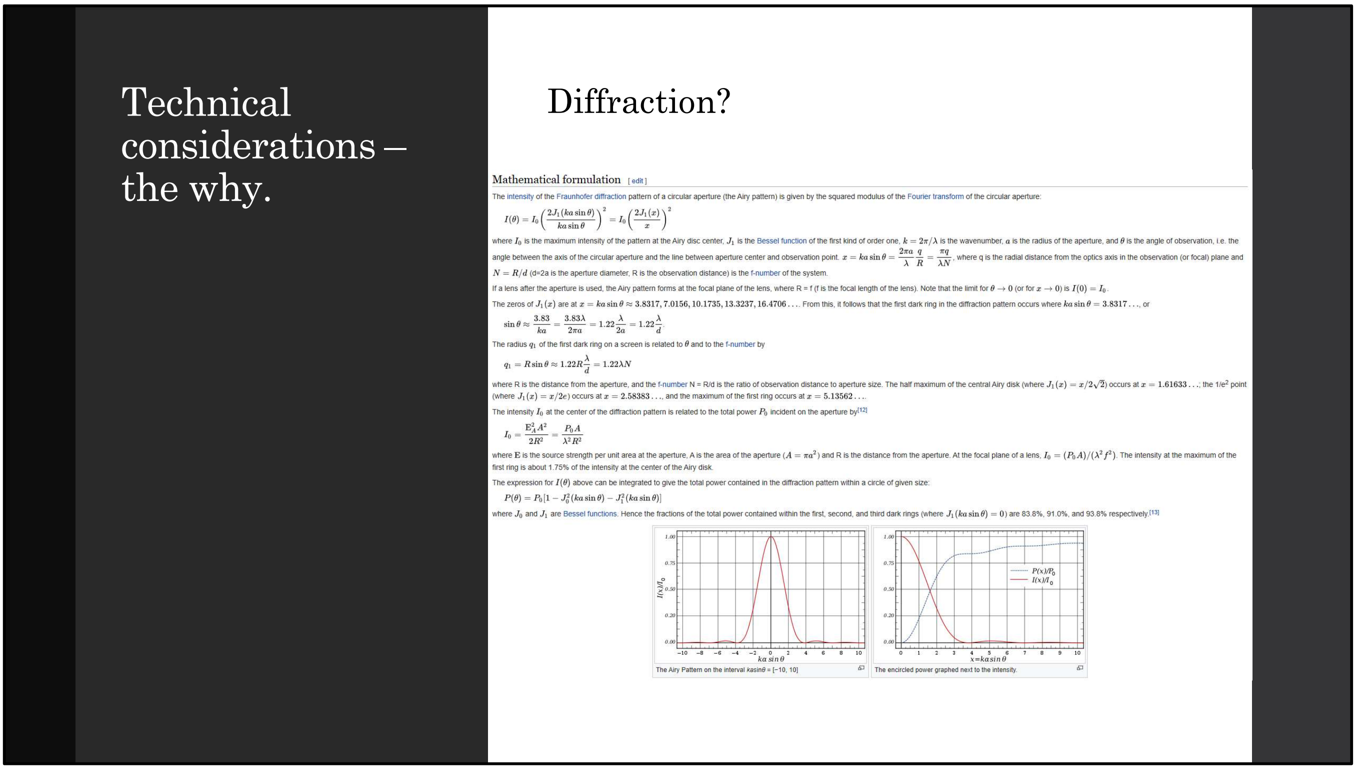
So if we now introduce a focal plane to this image, as we move from the axis towards the edge, we see bright, dark, bright, dark etc. so we see concentric bright and dark circles – the Airy Disk.

Technical considerations – the why.

Diffraction?



So we want to achieve a perfect Airy pattern for a star when we look through a telescope.



The intensity of the Fraunhofer diffraction pattern of a circular aperture (the Airy pattern) is given by the squared modulus of the Fourier transform of the circular aperture:

$$I(\theta) = I_0 \left(\frac{2 J_1(ka \sin\theta)}{ka \sin\theta} \right)^2 = I_0 \left(\frac{2 J_1(x)}{x} \right)^2$$

where I_0 is the maximum intensity of the pattern at the Airy disc center, J_1 is the Bessel function of the first kind of order one, $k = 2\pi/\lambda$ is the wavenumber, a is the radius of the aperture, and θ is the angle of observation, i.e. the angle between the axis of the circular aperture and the line between aperture center and observation point. $x = ka \sin\theta = \frac{2\pi a}{\lambda} \frac{q}{R} = \frac{\pi q}{\lambda N}$, where q is the radial distance from the optics axis in the observation (or focal) plane and $N = R/d$ (d=2a is the aperture diameter, R is the observation distance) is the f-number of the system.

If a lens after the aperture is used, the Airy pattern forms at the focal plane of the lens, where R = f (f is the focal length of the lens). Note that the limit for $\theta \to 0$ (or for $x \to 0$) is $I(0) = I_0$.

The zeros of $J_1(x)$ are at $x = ka \sin\theta \approx 3.8317, 7.0156, 10.1735, 13.3237, 16.4706\ldots$. From this, it follows that the first dark ring in the diffraction pattern occurs where $ka \sin\theta = 3.8317\ldots$, or

$$\sin\theta \approx \frac{3.83}{ka} = \frac{3.83\lambda}{2\pi a} = 1.22\frac{\lambda}{2a} = 1.22\frac{\lambda}{d}.$$

The radius q_1 of the first dark ring on a screen is related to θ and to the f-number by

$$q_1 = R \sin\theta \approx 1.22 R \frac{\lambda}{d} = 1.22 \lambda N$$

where R is the distance from the aperture, and the f-number N = R/d is the ratio of observation distance to aperture size. The half maximum of the central Airy disk (where $J_1(x) = x/2\sqrt{2}$) occurs at $x = 1.61633\ldots$; the 1/e^2 point (where $J_1(x) = x/2e$) occurs at $x = 2.58383\ldots$, and the maximum of the first ring occurs at $x = 5.13562\ldots$.

The intensity I_0 at the center of the diffraction pattern is related to the total power P_0 incident on the aperture by[12]

$$I_0 = \frac{\mathrm{E}_A^2 A^2}{2R^2} = \frac{P_0 A}{\lambda^2 R^2}$$

where E is the source strength per unit area at the aperture, A is the area of the aperture ($A = \pi a^2$) and R is the distance from the aperture. At the focal plane of a lens, $I_0 = (P_0 A)/(\lambda^2 f^2)$. The intensity at the maximum of the first ring is about 1.75% of the intensity at the center of the Airy disk.

The expression for $I(\theta)$ above can be integrated to give the total power contained in the diffraction pattern within a circle of given size:

$$P(\theta) = P_0 [1 - J_0^2(ka \sin\theta) - J_1^2(ka \sin\theta)]$$

where J_0 and J_1 are Bessel functions. Hence the fractions of the total power contained within the first, second, and third dark rings (where $J_1(ka \sin\theta) = 0$) are 83.8%, 91.0%, and 93.8% respectively.[13]

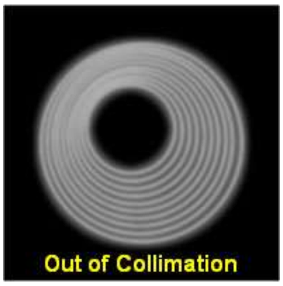
The Airy Pattern on the interval kasinθ = [−10, 10]

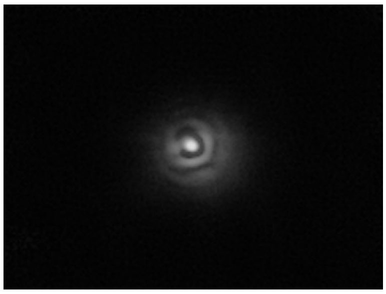
The encircled power graphed next to the intensity.

Oh and if you are really interested, here's the mathematical explanation, but let's not go there.

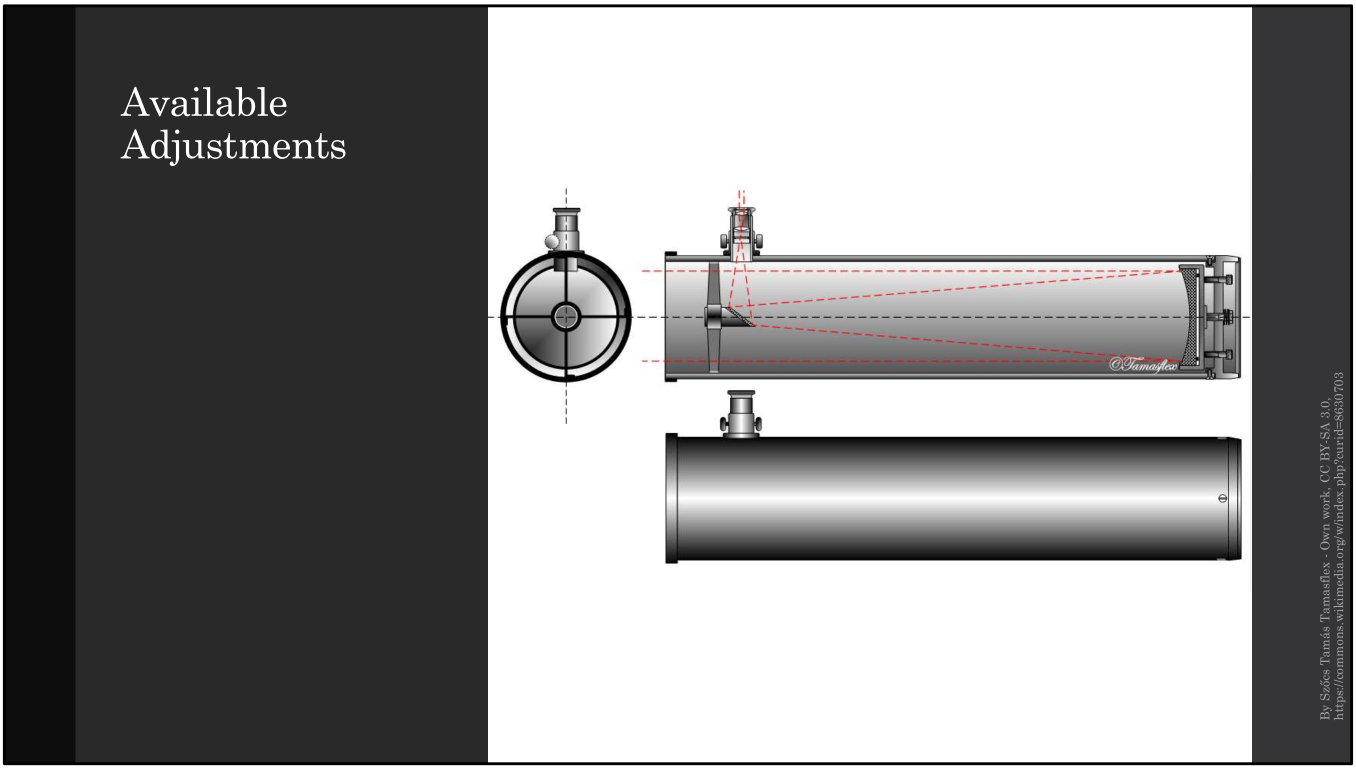
Technical considerations – the why.

What do your stars look like?





So if you are out of collimation, your stars will look like this. The bright center (or the shadow of the flat) will be off to one side and the rings will be brighter on one side.

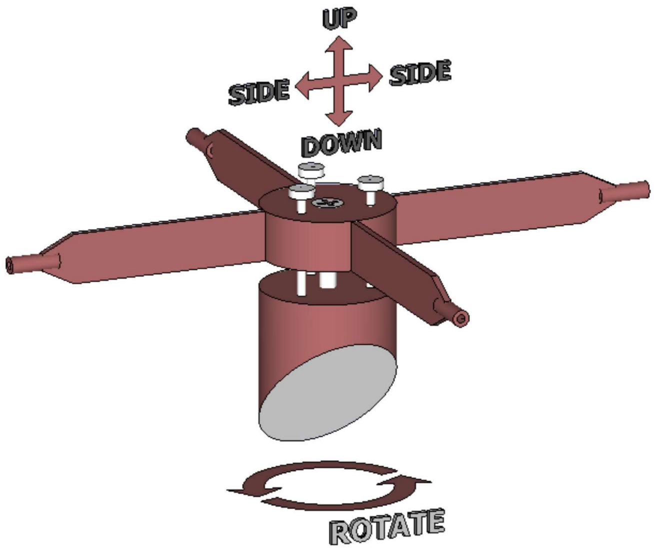


I think that we can safely assume that the manufacturer of your telescope has got the placement of the focuser, the spider and the primary mirror cell correct, so there is usually no means to make adjustments to these. Additionally the axis of the focuser will be at right angles to the main telescope axis, so again there is no means to adjust this.

So to make it clear we are able only to adjust the position of the secondary and primary mirrors relative to the tube.

The secondary mirror holder.

There are many different designs for secondary mirror holders.



But typically there are adjustments for,

Up and Down – allowing the flat to be moved towards and away from the primary mirror.
Rotation – allowing the flat to be rotated in the tube.
Tilting – to enable the flat to be moved and adjust the angle of the mirror. This is usually implemented with a three-point adjustment system.

Not so typical is the ability to move the flat,

Side to side – allowing it to be correctly centred in the tube.

The primary mirror cell.

The primary mirror cell is designed to support the mirror without distorting it.

The primary mirror usually only has adjustments for,

Tilting – to enable it to be tilted to adjust the axis of the reflected image. Again this is normally a three-point system.

Collimation,

Pre-requisites

This is a list of things it is useful to have and to do before you start the process,

- Understand how your telescopes adjustments work
- A collimation eyepiece
- A couple of pieces of plain white paper and some Sellotape
- A centre spot on the primary mirror
- An assistant (useful for aligning the primary mirror).

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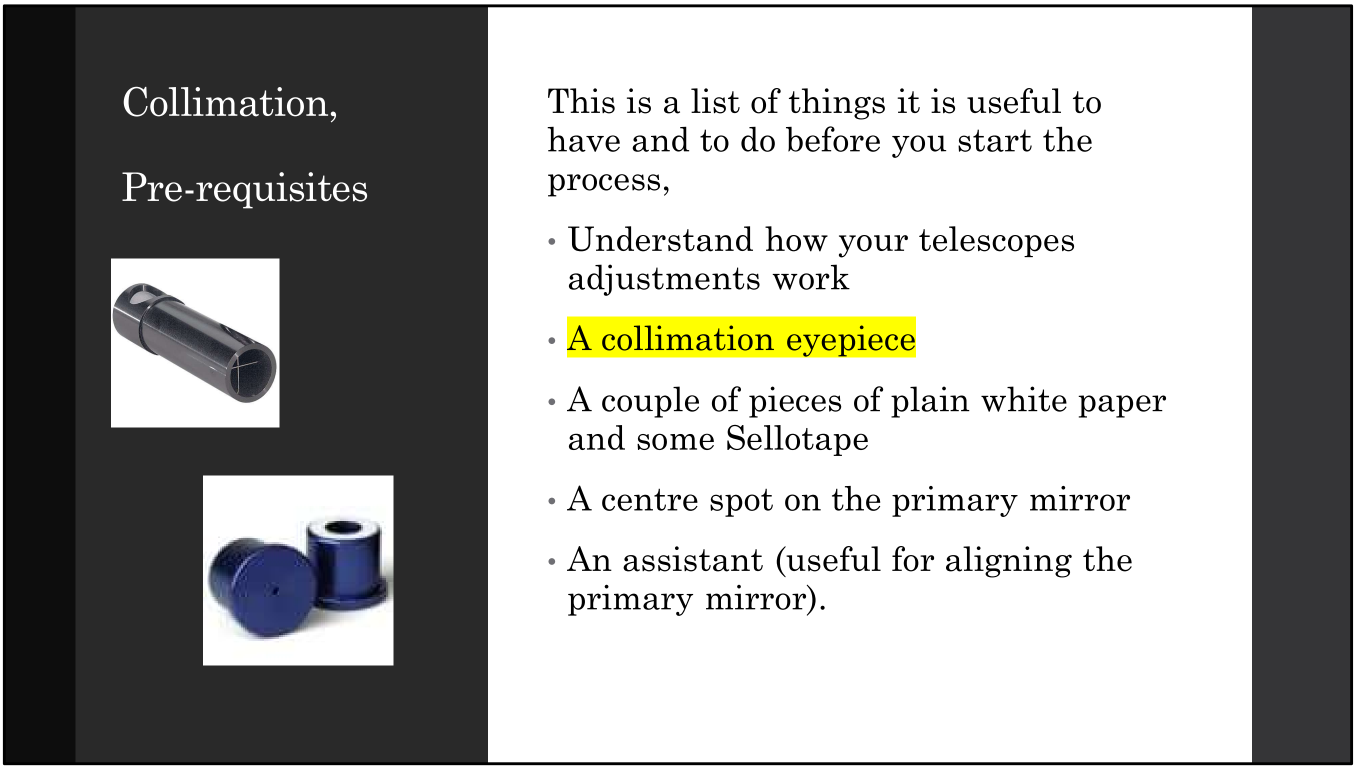
You'll need to understand how the adjustments work on your telescope, different manufacturers will have slightly different ways of working, for example the 3 screws used for adjusting the mirrors may actually be 6 this is called antagonistic, one set for making the movements, one for locking in place. Or they may be spring loaded. Whichever it is, it is best to start with them in the middle of their range.



These come in many forms, some incorporating lasers, but a very simple aluminium (or wood) plug that fits snugly into your focusing tube with a small diameter centre hole will do.

Collimation,

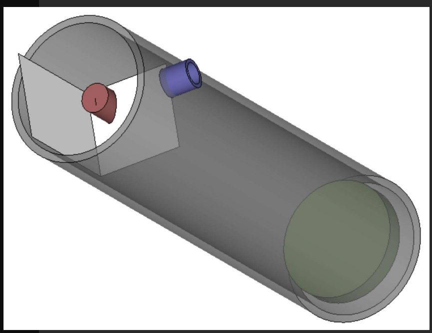
Pre-requisites

- A collimation eyepiece

This is a photo that Roger Jackson has taken of his home made collimating eyepiece. He describes it as “home made 1.25" diameter collimator with a 5mm diameter viewing hole at one end and cross hairs at the other. I actually want to shorten this as at 4" long it obscures the end of the draw tube and the full diameter of the secondary”. So yes, I’ll agree that it is probably too long as it is important to be able to see the end of the drawtube and the whole of the primary. The 5mm diameter hole is also a bit large as head movement will introduce parallax.

Collimation,

Pre-requisites



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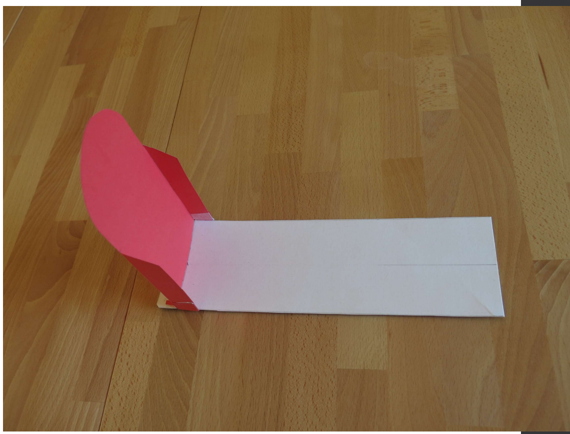
- A centre spot on the primary mirror
- An assistant (useful for aligning the primary mirror).

When adjusting the flat a piece of plain white paper behind the flat makes it easier to see the outline of the flat and its holder. A further piece between the flat and the primary mirror eliminates the reflection of the primary so the view of the flat is much less confusing.

Collimation,

Pre-requisites

- A couple of pieces of plain white paper and some Sellotape



Roger Jacksons “baffle” is a very nice example of this principle.

Collimation,

Pre-requisites

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- Understand how your telescopes adjustments work
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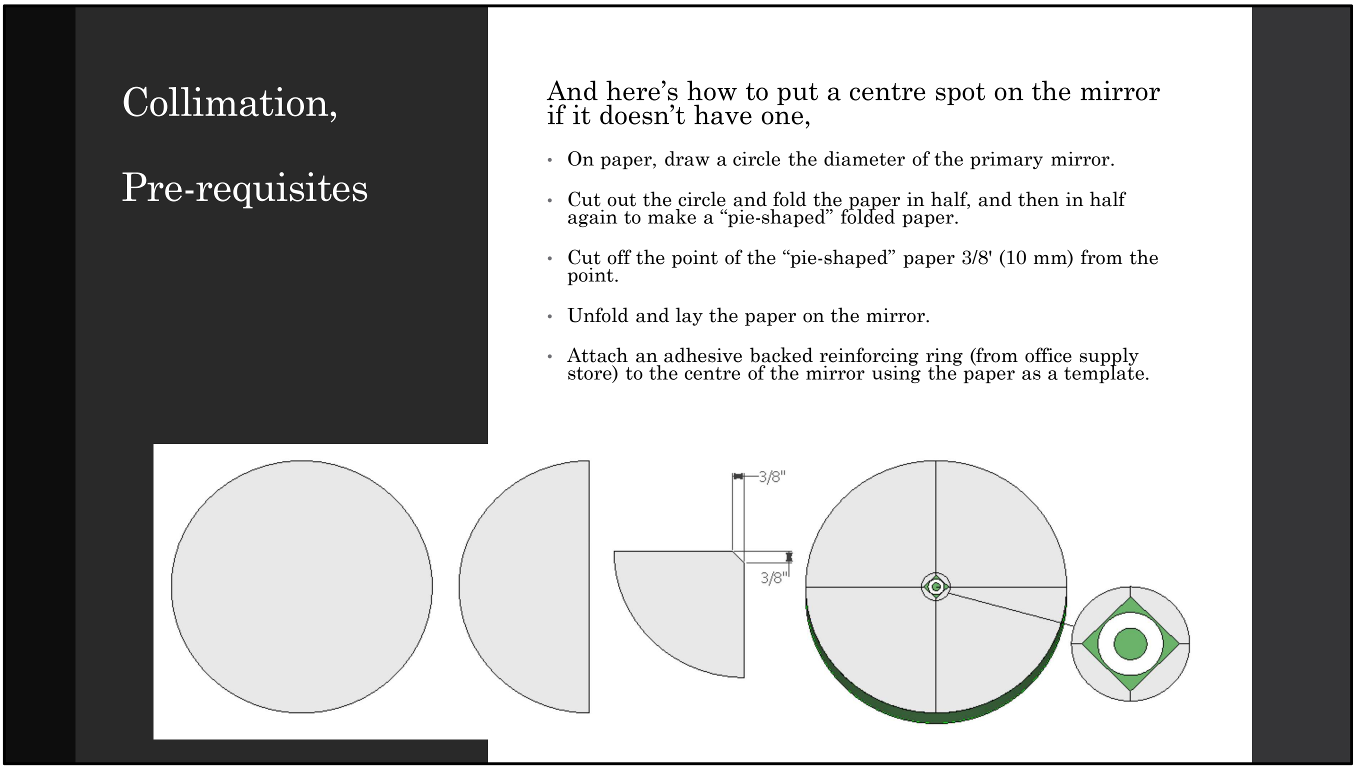
- A couple of pieces of plain white paper and some Sellotape
- A centre spot on the primary mirror
- An assistant (useful for aligning the primary mirror).

Without a mark in the centre of the mirror it is difficult to know where the centre is exactly.



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Collimation,

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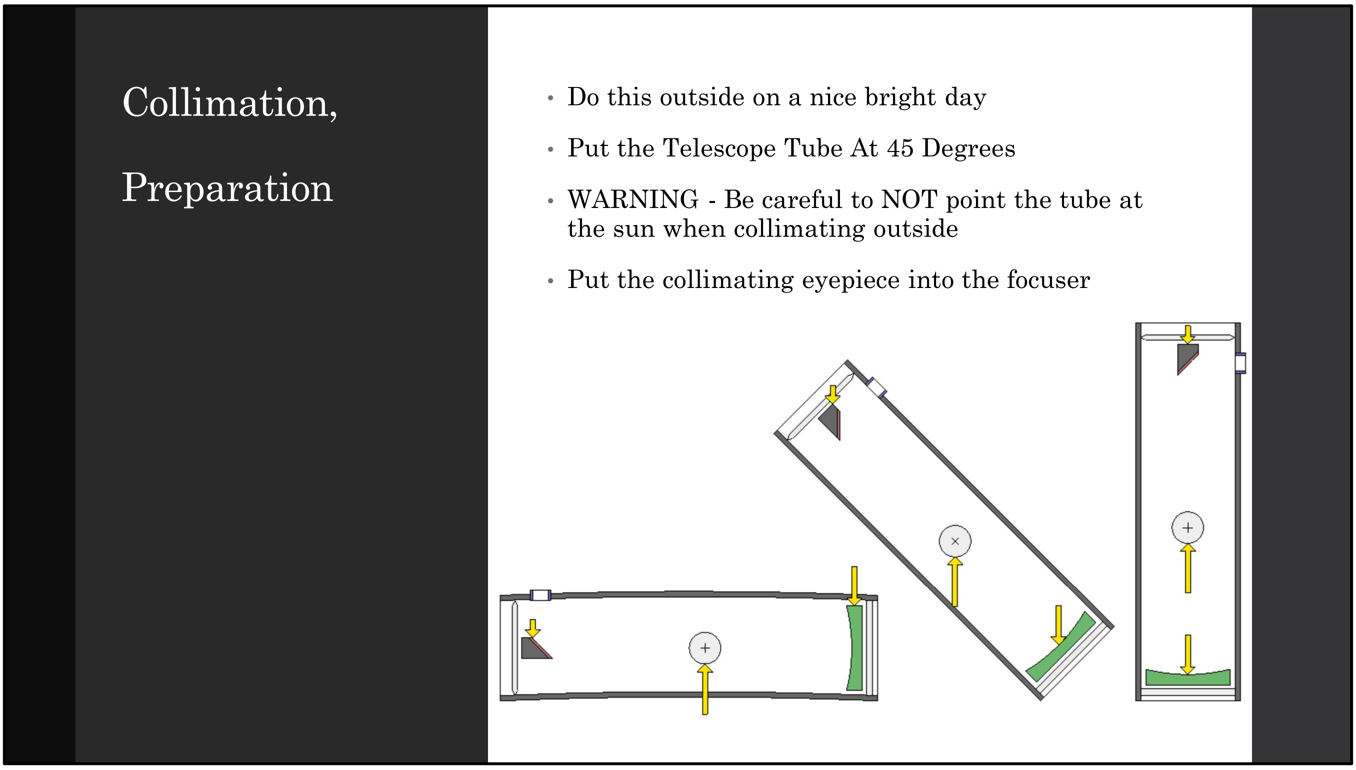
- A centre spot on the primary mirror
- An assistant (useful for aligning the primary mirror)

Unless your arms are long enough to reach the mirror cell while you are doing this it simplifies the process and avoids going from the eyepiece to the other end of the telescope and back again multiple times – you are bound to make the alignment worse at least once.

However this particular assistant is of no use whatso-ever.



When the tube is vertical, gravity is in line with the light path. Gravity pulls the diagonal mirror straight down from the spider. It pushes the primary mirror straight down into the mirror cell.

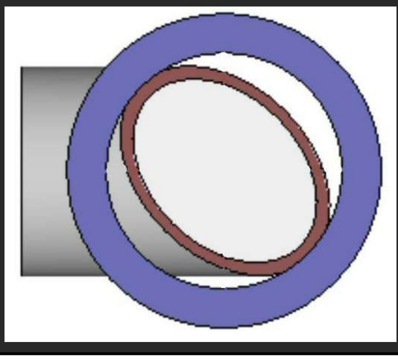
When the tube is horizontal, gravity is perpendicular to the light path. The diagonal mirror and primary mirrors are cantilevered from their mounts. Gravity tries to deflect the mirrors from the light path. The mirrors push down on the ends of the tube and the altitude bearings push up, trying to bend the tube. Therefore, there **may be a slight change in collimation** when the tube moves between vertical and horizontal.

45 degrees is in the middle of the observing range. Collimating the telescope at 45 degrees minimizes any difference in collimation that may result from the effects of gravity.

There is another advantage of collimating with the tube at 45 degrees. If a tool is dropped while adjusting the diagonal mirror, it will slide down the inside of the tube and **NOT drop on the primary mirror**.

Collimation,

The Flat



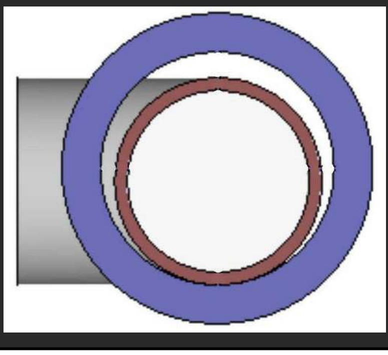
Adjust the diagonal mirror so it aligns with the focuser. There will probably be a combination of mis-alignments.

Here, the diagonal mirror is rotated, loosen the rotation lock and rotate the mirror until the view of the flat is circular.

Don’t work about any other misalignment at this stage.

Collimation,

The Flat

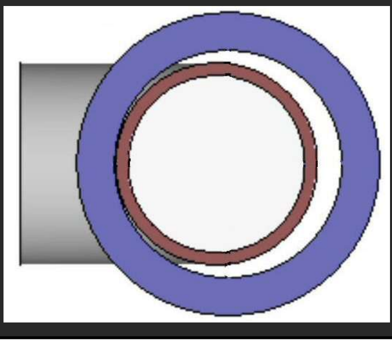


Adjust the diagonal mirror so it aligns with the focuser. There will probably be a combination of mis-alignments.

Here the diagonal mirror is tilted with respect to the axis. Adjust the tilt until the diagonal mirror is an equal distance from both the top and the bottom of the focuser tube.

Collimation,

The Flat

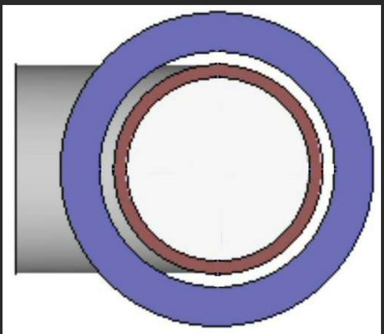


Adjust the diagonal mirror so it aligns with the focuser. There will probably be a combination of mis-alignments.

Here, assuming that the primary mirror is to the right, the diagonal mirror needs pushing down the tube a little.

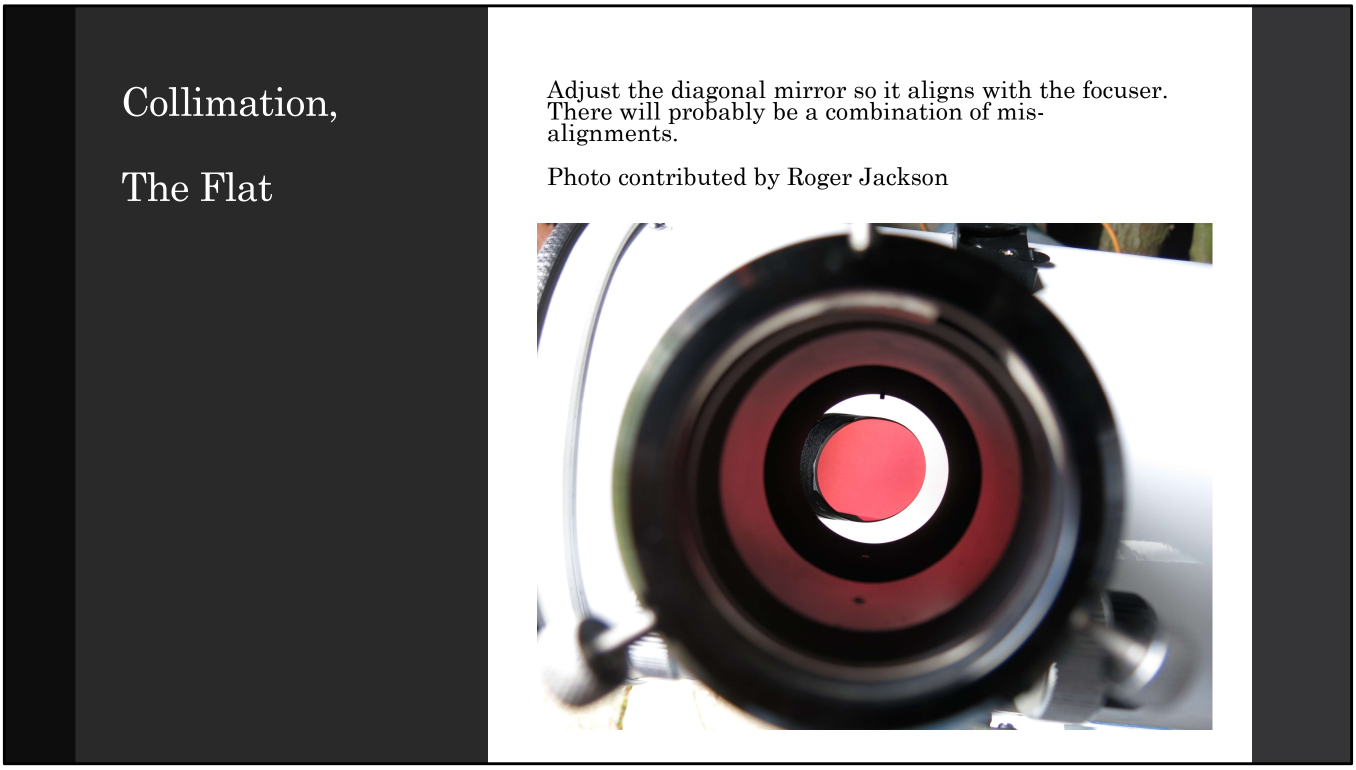
Collimation,

The Flat



Adjust the diagonal mirror so it aligns with the focuser. There will probably be a combination of mis-alignments.

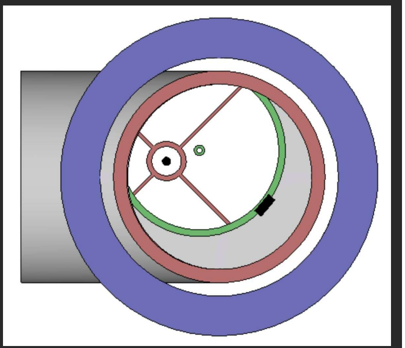
Once you have made all of the previous adjustments, and maybe more than once each, your flat will be perfectly aligned with the focuser tube. All of the circles that you see should be concentric



So this photo shows a misaligned flat. What we are seeing here is the view down the draw tube towards the flat (without a collimating plug). The outer red ring is the inside of the draw tube reflecting the coloured baffle. We can also see that the secondary mirror is not circular, so it need to be turned a little, and that it is not central, it is ok top/bottom, but needs moving down the tube a little.

Collimation,

The Flat



Adjust the diagonal mirror so it aligns with the primary mirror

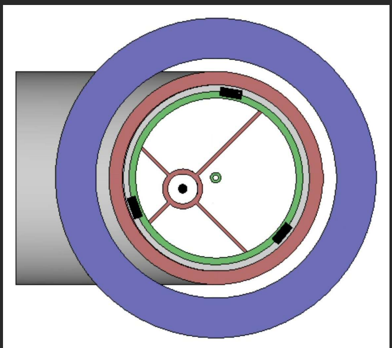
Remove the piece of paper that blocks the light path between the diagonal and primary mirrors.

- The edge of the diagonal mirror is shown in red. The edge of the primary mirror is shown in green.

- The diagonal lines are the vanes of the diagonal spider.

Collimation,

The Flat

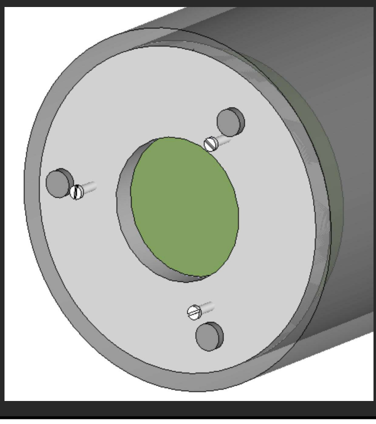


Adjust the diagonal mirror so it aligns with the primary mirror

- Adjust the screws on the end of the diagonal mirror support to centre the little reinforcing ring in the centre of the primary mirror.
- Or perhaps a little easier is to use the screws to align the image of the primary mirror so that it is concentric with the diagonal mirror.

Collimation,

The Primary Mirror



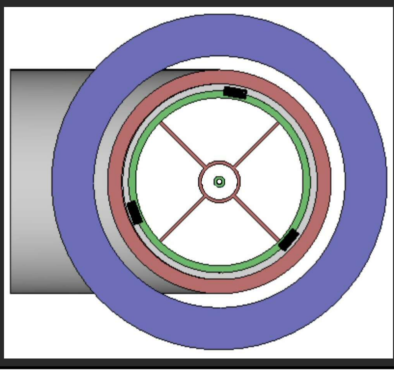
Typical Primary Mirror Cell

- The primary mirror typically has a "push-pull" design. The three small screws push against the mirror cell. The three thumb screws pull the mirror cell against springs.
- To adjust the angle of the primary mirror, loosen the three small screws. Then turn the three thumb screws to adjust the angle of the primary mirror. After the mirror angle is adjusted, tighten the small screws.

The three thumb screws are typically in the middle of their adjustment range. If a thumb screw reaches the end of adjustment BEFORE the primary mirror can be adjusted, readjust all three thumb screws to the middle of their range, and then proceed with mirror adjustment.

Collimation,

The Primary Mirror



Typical Primary Mirror Cell

- This is where an assistant comes in handy, the assistant makes the adjustments as you watch the effect on the image you see.
- Loosen the three tensioning screws at the bottom of the primary mirror.
- Turn a mirror adjustment screw and watch what happens with the image. If the diagonal image gets closer to the centre, good. If not, turn the screw the opposite direction.
- Turn the mirror adjustment screws one at a time, as required, until the image is concentric as shown.
- After everything is concentric, snug down the tensioning screws. Your image will be similar to the image here with EVERYTHING concentric.

The three thumb screws are typically in the middle of their adjustment range. If a thumb screw reaches the end of adjustment BEFORE the primary mirror can be adjusted, readjust all three thumb screws to the middle of their range, and then proceed with mirror adjustment.

Collimation,

The Primary Mirror

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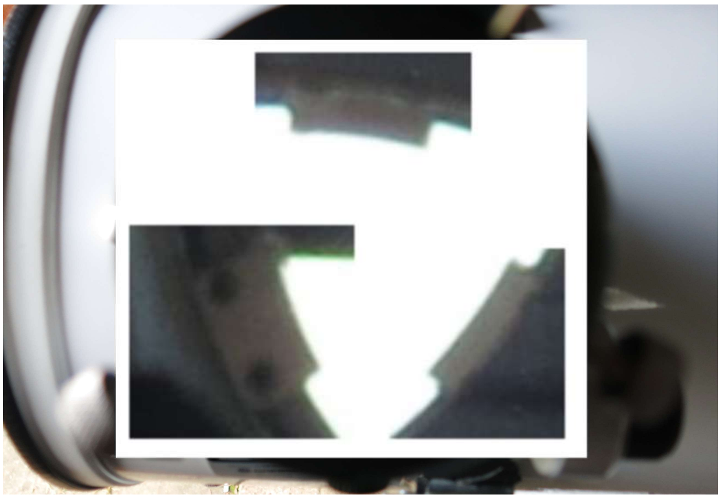
Photo contributed by Roger Jackson



Another great photo from Roger “View through the draw tube at the end of collimation, with no adjustment thought necessary of the primary”. But unfortunately not correct. The bottom end of the drawtube protrudes into the view, but it is possible to see the screws on the mirror holding clip under here and not on the others, so the image of the primary mirror is not concentric.

Collimation,

Star Testing

Starry night, driven mount helps.

- Obviously this has to be done at night on a real star. Choose one at about 3rd to 4th magnitude.
- Examine the slightly out of focus image of the star, use as low a magnification as you can, but you still need to be able to see the Airy Disc.
- If the Airy Disc has concentric rings then you're done, if not then,
- Adjust the mirror cell again to bring these rings concentric. Very small movements are required.

An assistant is very helpful, as you are now looking at a magnified image of the star and any adjustment of the primary mirror cell not only changes the "shape" of the Airy Disc, it also moves the star in the field of view. Large movements could move the star out of the field of view and you won't know which way it has gone if you were not watching it.

Turn a mirror adjustment screw (pick at random) note the direction that the star moves, has it improved the image?

If not then reverse the operation.

If it has then re-centre the star in the field of view with your slow motions.

Repeat this process (you may have to adjust all of the screws) until you are happy that your Airy Disc is a good as you can get it.

After everything is concentric, snug down the tensioning screws, again do this carefully as it is likely to affect the image when it is done (movement and shape).

You're done.

Acknowledgements

Wikipedia

How to Collimate a Reflector Telescope (https://www.dbpeckham.com/Telescope/Collimation/Collimation.htm)

Roger Jackson’s photo’s.