What I Wish Someone Had Told Me About Telescopes

I have been interested in astronomy ever since I was a kid, but never really pursued it until recently. If you are interested in the story of my journey learning telescope astronomy click here. Otherwise, please read on to see my technical notes on this subject.

Contents

Image Quality Progression

Here is a progression of images of M31 and M42 taken as I improved my equipment and skills. In each case you can see the difference the changes made and understand why the technical points in the rest of the document are so important for taking good astrophotography images. **CLICK IMAGES TO ENLARGE**.

Jan 8, Bought Askar FMA180 scope, CG-4 mount with tracking motors

CG-4 mount w/Celestron tracking motors, FMA180 scope, No filter, 2 stacks, 30sec, gain 252

This was my first "real" deep space image of any real value. I had been using my C8 and was really excited to use the FMA180. Technically this is dim, out of focus, with a poor black background.

Jan 17, Bought RedCat 71 scope and some basic filters

CG4 mount tracking broken, RedCat 71 scope, SVBONY UHC, 1 stack, 5.0sec, gain 252

I had been reading about what a great scope the RedCat 71 was. However, when I got it my CG4 tracking motors broke down so I could only get this quick image which is very poor.

Jan 18, Bought AM5 mount – Bad polar alignment due to clouds and NO auto-focus

AM5 mount, RedCat 71 scope, M31, no filter, 30.0s, gain 252

I got my new AM5 mount which is amazing, but I couldn't get it focused manually with the clouds and consequently also had very poor polar alignment.

Jan 19, Bought ZWO EAF, Good polar alignment, EAF working but VERY cloudy

AM5 mount, RedCat 71 scope, M31, no filter, 5.0s, gain 252

With the new Electronic Auto Focus (EAF) focusing became a snap – even in clouds. However, it was so cloudy that I gave up trying to get a good shot.

Jan 23, Great conditions, Good polar alignment, EAF working

AM5 mount, RedCat 71 scope, M42, SVBONY UHC, 3 stacks, 180.0s, gain 0

I finally got great conditions and was able to do some stacking with longer exposures which came out pretty good. However, the background is still too light and the details are kind of "fuzzy"

Jan 25, Great conditions

AM5 mount, RedCat 71 scope, M31, SVBONY UHC, 5 stacks, 300.0s, gain 252

Jan 27, Bought Optolong L-Pro UHC filter, Great conditions

AM5 mount, RedCat 71 scope, M42, Optolong L-Pro UHC, 3 stacks, 180.0s, gain 0

The L-Pro filter made a noticable improvement over my SVBONY UHC because it is more wideband. This makes the background better and gives some more detail on the objects.

Jan 28, learned how to use Calibration Frames, mixed thin and heavy clouds

AM5 mount, RedCat 71 scope, M42, Optolong L-Pro UHC, 13 stacks, 10.0s, gain 450

Note how stacking removed the thin clouds on the left, but left and orange “smudge” on the right where the heavier clouds were slowly being blown in. Prior to stacking the entire picture was a “foggy” mess. You can’t see it here too much but the calibration frames make a big difference in later images.

Jan 29, Bought ASI120Mini tracking camera, Great conditions, PERFECT PA (0.0”)

AM5 mount, RedCat 71 scope, M42, Optolong L-Pro UHC, 2 stacks, 1800.0s, gain 0

I finally started using a guide scope which allowed me to extend the exposure time to be 10x longer. This allows much more detail to be captured. The guide scope keeps the tracking on target while the mount is moving and prevents the alignment from fading over time and blurring the image.

Also, you can see the difference that the calibration frames did in cleaning up the background noise.

This picture looks about perfect to me and is the culmination of understanding all of the techniques described in this document.

Feb 12, Bought PixInsight and Learned how to Construct Mosaics

Learning PixInsight was a lot of work, but I’m glad I did it as it is an amazing program and allows you to do so many more things with your images. Here you can see a 2x2 mosaic of M42 showing a much larger field of view than would be possible with my telescope and camera alone.

Feb 16, Bought ASI533MC Astronomy Camera

My ASI585MC camera worked great on a handful of the brighter deep sky objects (M42, Andromeda, etc.) but was mediocre to horrible on dimmer DSOs. It looks to me like the ASI585 is good for objects with magnitude 4.5 or brighter. After struggling unsuccessfully for days to capture the Triangulum galaxy, I finally gave up and decided to purchase a better deep sky camera.

It came down to a choice between the ASI533MC and the ASI294MC. I finally decided on the ASI533MC because it was a little less expensive, it was recommended by a friend, and it had no amp glow. The ASI294MC has larger pixels and a deeper well capacity which would have been nice, but I am also thinking of eventually getting a full frame camera like the ASI2600MC so I didn't want to spend too much on what I'm considering a middle-of-the-road camera.

After about a week of setup I was able to get the following snapshot of M42. This is a single 1000 second shot (not stacked) click on it to see it full size. Note the frame is now square as the 533MC has a square sensor (vs the 585MC that has a rectangular sensor) which allows you to see more of the object in a single shot.

Mar 3, Bought Solar Filter for FMA180 Telescope

See the Solar Observation section – I was able to start taking videos of the sun which was quite fun actually using my telescope during the day time!

Mar 5, Bought Sky Quality Meter (SQM)

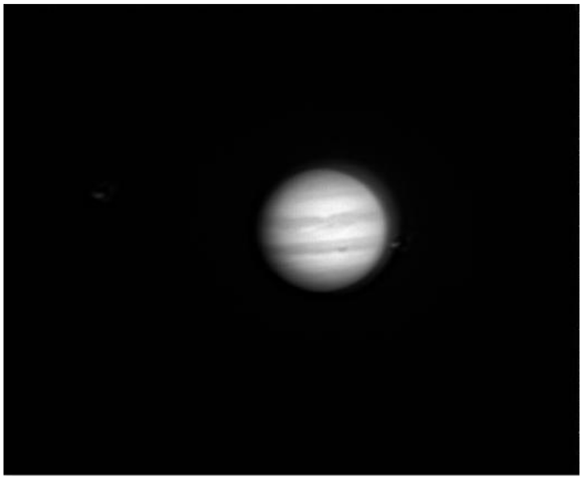
See the Sky Conditions section – I am now able to determine the actual amount of light pollution at my viewing site and make the necessary corrections.

Mar 7, Bought C8 Dew Shield and Started Using Guide Camera on C8

After measuring the light pollution in my area and realizing that views looking straight up were quite good, but looking lower on the horizon suffered from noticeably higher light pollution, I decided to add a dew shield to my C8 (see picture below.) This should eliminate quite a bit of city light pollution.

Additionally, I had been using my C8 without a guide scope. I had figured that my exposure times were very low because I was using the C8 for planetary observation – where I was looking at bright objects with low exposure times. However, I noticed significant image jitter when taking video of Jupiter. Adding the guide scope dramatically reduced this jitter.

You can see the improvement in the left image below (with guide scope and dew shield) compared to the image taken a few days before on the right. You can even see two of the moons on the left and there is much more detail.



Both of these images were processed using only ASIStudio using the following camera settings. The videos were stacked and then the contrast was adjusted up.

```
[ZWO ASI585MC]
Bin = 1
Capture Area Size = 640 * 480
Colour Format = RAW8
Exposure = 0.012 Sec
Flip = None
Gain = 250
StartX = 1600
StartY = 840
Temperature = 20.3 C
Bayer = RG
White Balance (B) = 88
White Balance (R) = 45
Duration=123 Sec
```

```
[ZWO ASI585MC]
Bin = 1
Capture Area Size = 640 * 480
Colour Format = RAW8
Exposure = 0.002 Sec
Flip = None
Gain = 255
StartX = 1600
StartY = 840
Temperature = 27.3 C
Bayer = RG
White Balance (B) = 88
White Balance (R) = 45
Duration=60 Sec
```

It’s kind of hard to see in these small clips, but if you click on the images to see the full size, you will notice that the level of detail in the left image is significantly higher. On the right image I had to turn the exposure time very low to reduce the blurring effect of the camera shaking (due to lack of guiding.) This made it much dimmer – no planets are visible

Telescope Types

Here's how to pick a scope in a nutshell: $ - beginner, just curious, $$ - serious or doing photography, $$$ - professional photographer.

Telescope Characteristics

The following lists the major characteristics that distinguish one telescope from another.

Aperture

Larger aperture (diameter of the lens/mirror) translates to higher resolution per camera pixel. This will enable you to zoom in more, get more detail, and is defined as a lower Dawes Limit value.

Focal Length

Larger focal length translates into the ability to provide more magnification, and consequentially smaller fields of view.

F-Ratio

Smaller f-ratio translates into shorter exposure times required for photography and the ability to see dimmer objects both in photography and visual observation.

Optic Quality

High quality optics (the mirrors and lenses) make the difference between an average image and a professional image. As a beginner you would probably stay away from high quality optics because of the large price difference. However, as you progress and have decided that you truly enjoy astronomy, then you should consider only buying high quality optics.

Flat Field

Flat field scopes are prized for photography (see this section for more details) but are generally more expensive.

Refractors

Use lenses to focus the light rays to your eye/camera. These are prone to chromatic aberration. These are typically better for lower F settings (important in photography) and wider field of view – that is they are better when you only need a little magnification to see a very large object (like a galaxy or nebula.)

Typically, you can buy the same telescope configuration in either APO or Petzval designs, and you will typically pay about double for the Petzval. But if you are a beginner and don't care about getting everything perfect, you can save a lot of money by getting APO scopes.

Basic - $

Basic beginner scopes.

Apochromat (APO) - $$

These improve significantly on the chromatic aberration of Basic scopes – for full details see Wikipedia. Back focus is an issue for these scopes to get focus at the edge of the field.

Petzval Flat Field - $$$

These eliminate field curvature thus eliminating the back focus requirement to ensure the entire image is in focus – for full detail see Wikipedia.

Reflectors

Use mirrors to focus the light rays to your eye/camera. These are immune to chromatic aberration. These are typically better for high F settings and narrower field of view – that is they are better when you need lots of magnification to see a small object (like a planet or a star.)

Basic - $

Average Quality - $$

HD Quality - $$$

These incorporate a field flattener specific designed to optimize this specific scope so as to eliminate the field curvature issues.

Important Math to Understand

There are numerous good articles about this on the internet, I would recommend reading Pixel Size and Critical Sampling.

Image Scale

Image scale describes the angle subtended by a single pixel on your camera sensor. In other words, it describes what portion of the visible sky light falls onto each pixel.

The sky is broken into the normal 360 degrees (only 180 degrees of which are visible from any point on the earth.) Each degree is then broken down into 60' (minutes – denoted by '), and each minute is further broken down into 60" (seconds – denoted by ").

$$\theta = 206 * \frac{S}{L}$$

Where:

- θ is the image scale (in ")
- S is the camera sensor pixel size (in µm)
- L is the telescope focal length (in mm)

So, for example, using a C8 telescope (L = 2032mm) and an ASI585MC camera (S = 2.9 µm) would result in the image scale (θ) of each pixel being 0.2940".

Note that image scale is affected by Binning because it increases the physical pixel size programmatically. The examples in this section assume binning = 1 (off.)

Field of View (FOV)

Once you understand image scale, FOV is easy. The field of view of the camera sensor is simply the image scale multiplied by the number of horizontal/vertical pixels on the camera sensor.

Using the example described in the Image Scale section the ASI585MC sensor has 3840x2160 pixels in the sensor which yields the following field of view for this equipment:

$$FOVx = 0.2940 * 3840 = 1{,}128.94" \text{ (or } 1{,}128.94"/3600 \ = \ 0.31 \, degrees$$

$$FOVy = 0.2940 * 2160 = 635.03" \text{ (or } 635.03"/3600 \ = \ 0.18 \, degrees$$

So, using a C8 telescope with an ASI585MC camera you would be able to take picture of the sky that is 0.31 x 0.18 degrees wide.

For examples of FOV please refer to the Field of View Examples section.

Critical Sampling

This is the art of getting your telescope and camera matched to get the best picture possible. The way to calculate the ideal relationship between pixel size, focal ratio, and wavelength is:

$$S = 1.22 * \lambda * \frac{F}{N}$$

Where:

- S is the camera sensor pixel size (in µm)
- λ is the light wavelength (in µm) of concern
- F is the telescope focal ratio (the F number)
- N is #of pixels covering smallest feature scope can resolve (basically current viewing conditions)
  - 5 = perfect clear dark skies (where you can see details down to 1")
  - 4 = good skies (where you can see details down to around 2")
  - 3 = average skies (where you can see details down to 3")
  - 2 = overcast (where you can see details down to 4")
  - 1 = heavy clouds (where you can only see details over 4")

Simplifying the equation for average skies (N = 3) and normal visible light (λ = 500nm) you get the following which says to achieve critical sampling you should use a pixel size equal to your telescope focal ratio divided by 5.

$$S = \frac{F}{5}$$

So, if you are using a C8 scope (F = 10) your critical sampling pixel size would be 2µm. If you are using an ASI585MC (S = 2.9µm) camera, this means that you are under-sampling - because your actual pixel size is larger than the ideal pixel size for this scope and you are losing detail in the picture. Essentially the scope is providing detail that your camera is unable to capture.

Under-sampling is bad on small objects that provide a lot of detail (planets, sun, moon, and some smaller planetary nebulae and galaxies. However, under-sampling is generally not an issue on larger targets where you are trying to capture a large field of view on a large dramatic object where tiny detail does not matter.

Over-sampling is the opposite problem where your camera is providing more detail than your scope can deliver. Over-sampling is always bad because it increases noise (decreasing your signal to noise ratio) and it makes your images larger with no benefit.

Spreadsheet Calculating Values

I created a spreadsheet that automatically calculates all of the values described above, and suggests binning values and shows the binning effect. The top section is useful to see how different F# scopes react to different conditions.

General Telescope Values for a Range of Telescope Focal Ratios

		Critical Sampling		Suggested		Field of View (degrees)		Field of View BINNED		
Focal Length Increment	Focal Ratio	Pixel diameter (um)	Image Scale (arc ")	Bin	Bin Image Scale	X	Y	X	Y	Over-sampling (physical pixel is SMALLER than critical value)
0.5	1	0.61	8.41	1	8.41	8.98	5.05	8.98	5.05	Under-sampling (phyical pixel is LARGER than critical value)
	1.5	0.92	5.61	1	5.61	5.98	3.37	5.98	3.37	Binning recommended (image scale is LESS than current conditions allow you
Focal Length Start	2	1.22	4.21	1	4.21	4.49	2.52	4.49	2.52	Currently selected scope range(s)
1	2.5	1.53	3.37	2	6.73	3.59	2.02	7.18	4.04	
	3	1.83	2.80	2	5.61	2.99	1.68	5.98	3.37	
	3.5	2.14	2.40	3	7.21	2.56	1.44	7.69	4.33	
	4	2.44	2.10	3	6.31	2.24	1.26	6.73	3.79	
Spectrum of Interest	4.5	2.75	1.87	4	7.48	1.99	1.12	7.98	4.49	
Wavelength (um)	5	3.05	1.68	4	6.73	1.80	1.01	7.18	4.04	
0.5	5.5	3.36	1.53	4	6.12	1.63	0.92	6.53	3.67	
Telescope	6	3.66	1.40	5	7.01	1.50	0.84	7.48	4.21	
Aperture (mm) Focal Length Focal Ratio	6.5	3.97	1.29	5	6.47	1.38	0.78	6.90	3.88	
71 348 4.901408451	7	4.27	1.20	6	7.21	1.28	0.72	7.69	4.33	
Camera	7.5	4.58	1.12	6	6.73	1.20	0.67	7.18	4.04	
Pixel Diameter (um) Xres Yres	8	4.88	1.05	7	7.36	1.12	0.63	7.85	4.42	
2.9 3840 2160	8.5	5.19	0.99	7	6.93	1.06	0.59	7.39	4.16	
Atmospheric Conditions	9	5.49	0.93	8	7.48	1.00	0.56	7.98	4.49	
#pixels/smallest feature	9.5	5.80	0.89	8	7.09	0.94	0.53	7.56	4.25	
1	10	6.10	0.84	8	6.73	0.90	0.50	7.18	4.04	
Min Image Scale (arc")	10.5	6.41	0.80	9	7.21	0.85	0.48	7.69	4.33	
5	11	6.71	0.76	9	6.88	0.82	0.46	7.34	4.13	
	11.5	7.02	0.73	10	7.32	0.78	0.44	7.80	4.39	
	12	7.32	0.70	10	7.01	0.75	0.42	7.48	4.21	
	12.5	7.63	0.67	11	7.40	0.72	0.40	7.90	4.44	
	13	7.93	0.65	11	7.12	0.69	0.39	7.59	4.27	
	13.5	8.24	0.62	12	7.48	0.66	0.37	7.98	4.49	
	14	8.54	0.60	12	7.21	0.64	0.36	7.69	4.33	

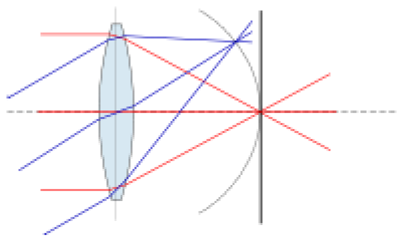
The bottom portion is more practical and shows values specifically for the scope and camera that you have specified (in this case a Redcat 71 with and ASI585MC camera) in different viewing conditions.

Specific Telescope values for ALL Atmospheric Conditions			Critical Sampling		Suggested		Field of View (degrees)		Field of View BINNED	
#pix/feat	Min Image Scale (arc")		Pixel diameter (um)	Image Scale (arc ")	Bin	Bin Image Scale	X	Y	X	Y
5	1	Perfect Skies	0.60	1.72	1	1.72	1.83	1.03	1.83	1.03
4	2		0.75	1.72	1	1.72	1.83	1.03	1.83	1.03
3	3	Average Skies	1.00	1.72	2	3.43	1.83	1.03	3.66	2.06
2	4		1.49	1.72	3	5.15	1.83	1.03	5.49	3.09
1	5	Heavy Clouds Pollution Etc	2.99	1.72	4	6.87	1.83	1.03	7.32	4.12

You can get a copy of this spreadsheet by clicking on this link.

Field Curvature

See Petzval field curvature - Wikipedia for full details. The image of what you are looking at through the telescope comes into focus at a point somewhere behind the back of the telescope. The image, or “field”, however is typically not “flat” as can be seen in the picture below.



This curvature is inversely proportional to lens aperture (larger aperture has less curvature.)

This is a problem when taking pictures with a camera – because it has a flat sensor element – and may cause the pixels around the edges of the picture to be out of focus. This is not a problem looking at something with your eye, because the back of your eye is also curved and can compensate for the focal differences.

Certain types of telescopes do not suffer from field curvature – most notably Petzval Refractors. This is because the entire lens assembly moves as you adjust focus, as opposed to only part of the lens assembly in most other telescopes. If you use one of these you don’t have to worry about field curvature.

Back Focus

Telescopes usually compensate for field curvature with special lenses that produce a “flat” field. The problem is that this “flat” field only exists at an exact distance behind the telescope back. This distance is specified as the “back focus” distance.

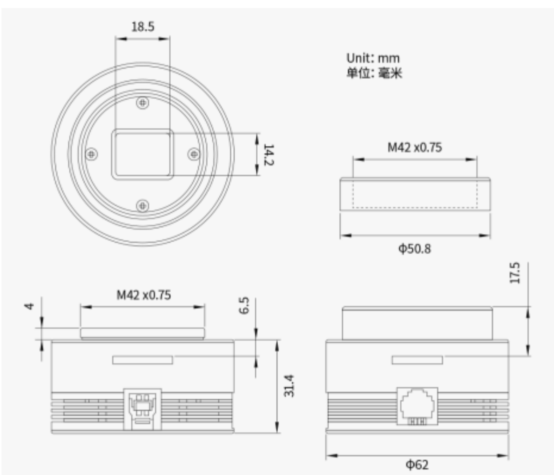
By using spacers between the back of your telescope and your camera, you can position the camera in such a way that the sensor element is exactly where the telescope produces a “flat” field image, thus ensuring that your images will be in focus all the way across the camera sensor. Here is an excellent article explaining this process.

When Does This Matter

It only matters if you are using a camera.

It only matters if your camera uses a “full field” sensor – that is to say that the sensor element is physically large enough to capture “all” of the light from the telescope. Typically, this only occurs in the larger, more expensive professional cameras. Most entry level cameras have a sensor that is smaller than the beam of light from the telescope.

For example, the ZWO ASI585 has a sensor that is 18.5x14.2mm, resulting in a “diagonal” measurement of 12.84mm. Telescope beams are typically 1.5” (38.1mm), 2” (50.8mm) or larger. So, even with the smallest beam (38.1mm) the 12.84mm sensor diagonal comes nowhere near the curved edges of the beam.



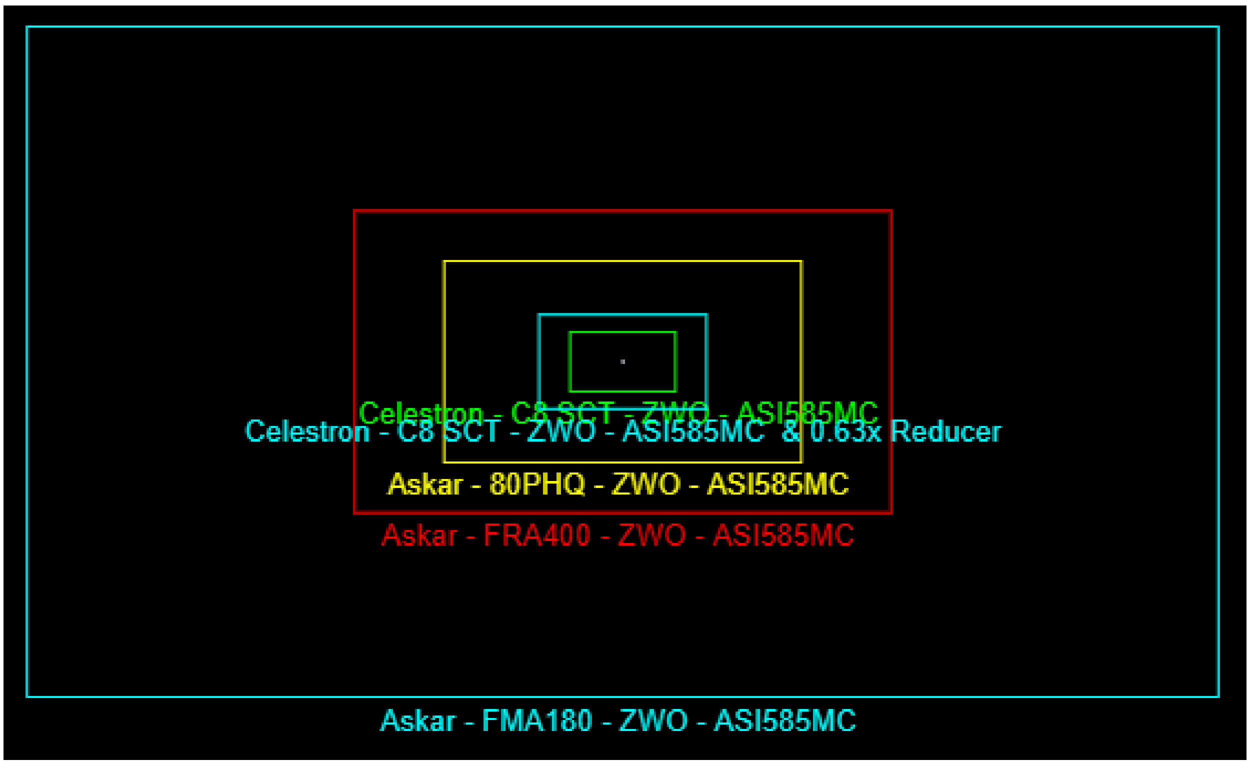
So, if you are using this type of camera setup you really don’t have to worry about back focus – you only need to make sure your camera is not so far away that it is out of the practical focuser range and you will get good pictures.

And after reading many astronomy threads, it also becomes apparent that many non-perfectionists just don’t care if the picture is slightly blurry around the edges. You could also just crop the edges out with a photo editor as well if they don’t contain required image data.

Field of View Examples

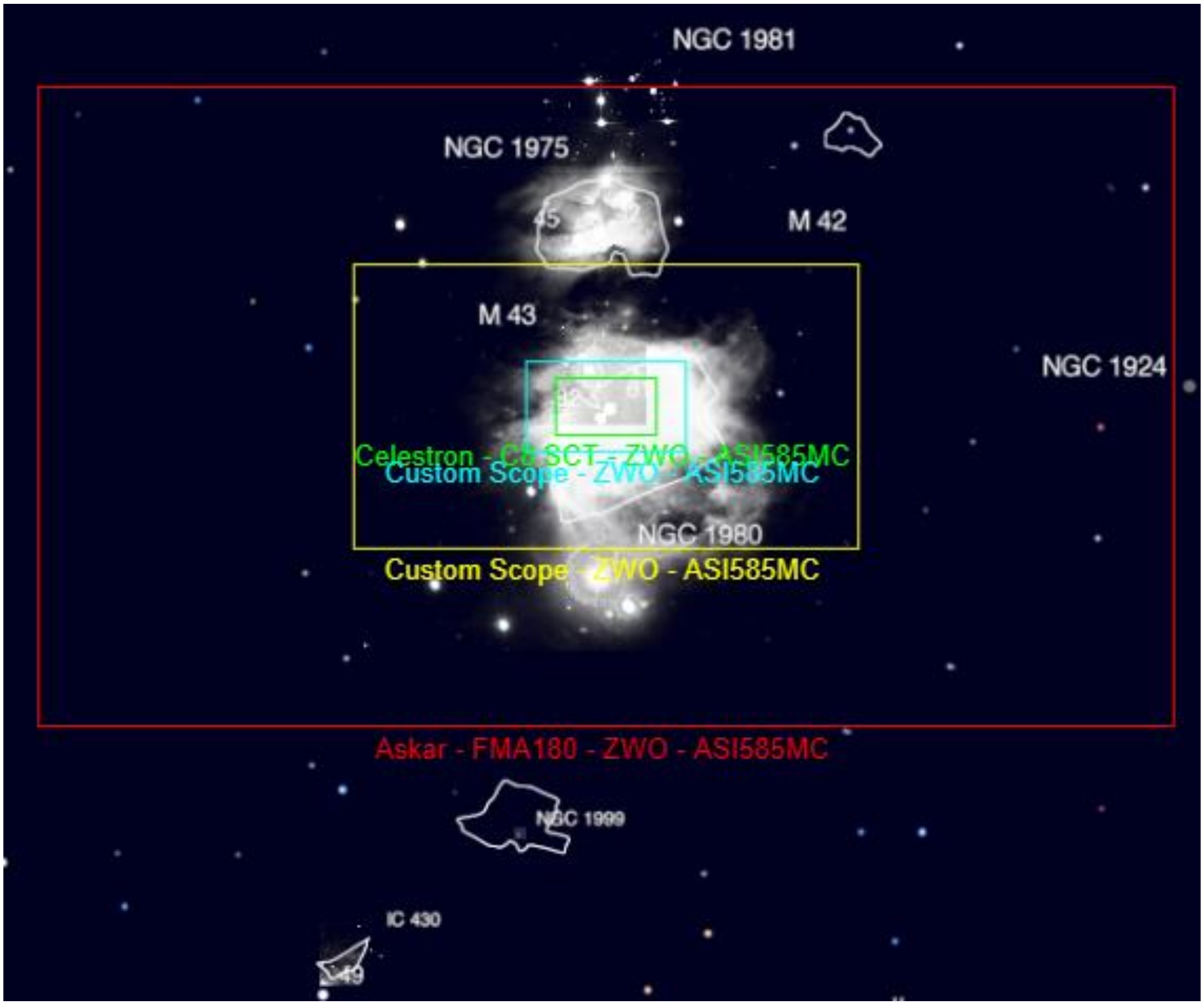
Field of View is what you will actually see on your telescope camera or eyepiece and it depends on the equipment you are using. Here is an excellent website tool that allows you to see the image change as you alter your equipment. For a description of how the math for this works, please refer to the Important Math section.

The following shows what the tool describes for 5 different telescope configurations. As can be seen, using the FMA180 configuration the object will only appear as a tiny dot in the middle of a large field. Clearly the FMA180 is not a good choice, and the Celestron C8 SCT would be much better as it would provide a more detailed image.



Wide field of view (ex: FMA180) is important when viewing large objects like galaxies, and narrow field of view (Celestron C8 SCT) is important for viewing small distant objects like planets and stars.

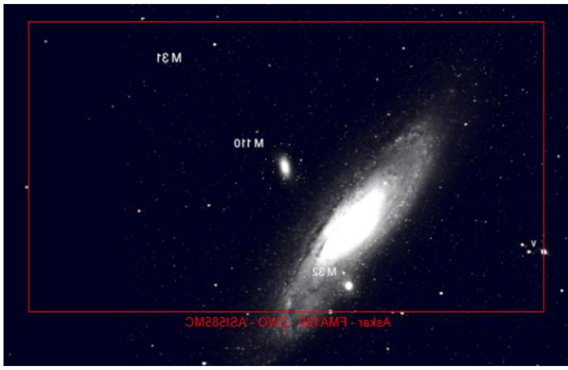
The following illustrates the benefit of a wide field of view telescope like the Askar FMA180 on very large objects. This view would be impossible to capture with the narrower field of view Celestron C8 SCT.



This is an excellent tool to see if the telescope you are thinking of buying will actually help you see the astronomical objects you really care about.

It is important to note that the telescope “F” number is NOT the only factor when determining field of view – the aperture is also important. Two telescopes with matching “F” numbers will show different results if they have different apertures – the larger aperture will have a narrower field of view because it provides more magnification.

IMPORTANT – this tool uses images taken by the best telescopes in the world so what you see with your camera will likely be MUCH worse. The tool is intended to show you the field of view of different telescope configurations and NOT to show you what you will ACTUALLY see. To illustrate this point, here is what the tool shows for my telescope configuration viewing the Andromeda galaxy (left) and what I actually see through my telescope (right.)



My image was a 5-minute exposure on a tracking mount with an average color camera. Doubtless a higher quality camera with longer exposure times would have produced a larger image. What I am seeing in my image is the very bright core of the galaxy – and not the dimmer outlying arms. The result is that my image appears to be smaller, and not quite as exciting as the image on the left – which was probably taken with the Hubble space telescope.

For a full JPG file of my shot of the Andromeda galaxy above click here.

I later found the following video which shows taking photographs of deep space nebula using my exact same camera (ZWO ASI585MC) with very good results.

Tracking Mounts

You can purchase a telescope mount that has built-in motors for tracking, or a simple mount. There is a huge price difference and it is important to understand the difference.

Tracking mounts are designed for two reasons:

1. To track (i.e. keep the telescope pointing to the same object) stars as the earth rotates.
2. To automatically “find” stars and point the telescope towards them.

Item (1) is really only critical when you are taking pictures of very distant and dim objects that require camera exposure times longer than 3 seconds. This is because the earth does not rotate enough in 3 seconds to cause the image to blur.

If you are just getting started with photography (or just want to look with your eye), you will be wasting your money buying expensive tracking mounts just to take pictures of the moon, Jupiter, Saturn, etc. You can do this just as well with a manual mount.

When you eventually get to the point of photographing deep space objects you will want to invest in a quality tracking mount.

Item (2) is often a matter of convenience. Having a computerized tracking mount – which typically comes with the “GoTo” feature – allows you to quickly find all the major stellar objects with the press of a button. You can do the same thing using a manual mount but it involves a lot more work because you need to look up the object’s position on an astronomy program (ex: Stellarium) and then adjust your mount manually to point to those coordinates, and you will need to manually track the object after you have found it.

However, if the objects you are looking for are too dim to be seen in a finder scope you may waste hours of time trying to get a good picture (and would benefit from buying a good tracking mount.)

Weight Capacity

Each mount will be rated for the amount of weight (scopes, cameras, etc..) that it can support. If you want it work smoothly for photography you should try to stay under 50% of the rated weight so that the mount movement remains smooth.

Portability

Many of the really expensive tracking mounts are expensive because they are lighter and easier to carry to your viewing site. If, however, you are only planning on observing in your back yard you can save money by purchasing a cheaper heavier mount, that is assuming you don’t have back issues.

Integrated Tracking vs Add-Ons

There are two ways to get a tracking mount: 1) you can buy a mount that has built-in tracking, or 2) you can buy a basic mount, and later add tracking hardware. I highly recommend that you NOT use option (2) as you will likely find that it is a giant waste of time and money. Getting an integrated mount is the way to go because everything is designed to work together.

I tried two add-on tracking solutions: 1) Celestron CG-4 Dual Axis Motor Drive $193 and 2) EQStarProEQ3 – EQ drive upgrade kit for EQ 3-2, CG-4, Orion Astroview mounts $309.

The Celestron kit was one step above a toy and had no computer tracking at all, only a four button "joystick." It did work but was difficult to control and position with the manual buttons. It often took several minutes to get it centered on the object, and this was after you eventually found the object because there was no "goto" functionality. However, after about two months the hardware stopped working and I wasted several days trying to figure out what was wrong and fix it. I eventually gave up and decided to get a better solution.

The EQStarPro kit was much more promising as it included better motors, and an actual computer control so that you could guide the mount with "goto" functionality – however this still required an external guide computer such as an ASIAIR or laptop. The first drawback was that the unit was shipped from the Ukraine and there was a war going on there so it took just over 3 weeks to receive the product. The instructions for assembling the unit were unclear and I had to reconfigure the gear/belts multiple times before I got them in a working state. Even at this point as I slewed the mount on the RA, the RA gear hit the CG-4 RA clutch handle stopping the motion and sending the motor into an overcurrent state. I had to file down part of the clutch handle to allow the gear to clear. Although the RA motor worked fine, I was never able to get the DEC motor to work for more than a few seconds before it would shut down. I worked with the kit's creator – Alexander who was very helpful – to overcome this problem for almost 3 days to no avail. His final suggestion was to change some motor configuration values, but the Windows driver needed to run his configuration utility kept failing to load on my PC. I was never able to use this product and it is now collecting dust in a box.

I ended up purchasing the ZWO AM5 tracking mount $2,298 which worked perfectly the moment I took it out of the box and has been working great ever since. It costs more, but when you consider all the time I wasted on the other solutions, I think it was actually cheaper AND it works MUCH better.

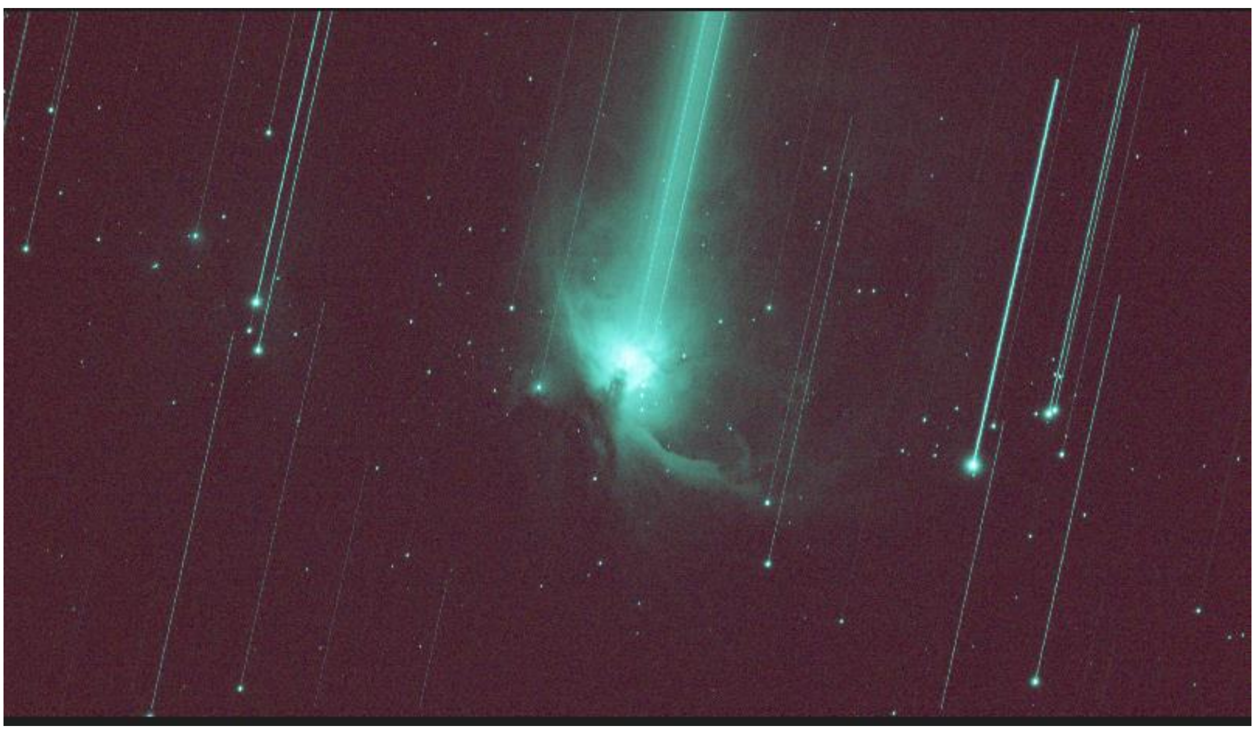
Tracking Issues

Crossing the Meridian (Equatorial Mounts Only)

The meridian is an imaginary line in the sky stretching from the north to south poles in the middle of the sky. This line separates the east half of the sky from the west half. Because of the way equatorial mounts work, you will need to flip your telescope from one side of the mount to the other as you track an object across the meridian.

A good tracking mount will have a feature to automatically flip the telescope from side to side as it crosses the meridian. On a cheaper mount, you will have to manually watch for this and flip the telescope by hand.

On my AM5 mount this feature exists but is turned off by default (in mount settings.) I ran into this tracking the Orion Nebula across the meridian while stacking images. The target crossed the meridian after the second stacked image – which resulted in the mount turning off tracking. This resulted in the third stacked image showing highly noticeable streaking as this was using 3-minute exposures. You can see the results in the image below.



At first, I thought that I had captured the shot of a lifetime – a meteor shower in front of a nebula! Only after I tried to take more shots did I realize that the telescope had stopped tracking!

Cable Management

It is important that you route any cables going from the mount head (which moves during tracking) to any outside connections. This includes power, USB, control, etc.… cables. I failed to do this during one of my tests and was surprised to see the results of my image after a 3-minute exposure.

What had occurred was that my USB camera cable had gotten caught on the mount head and was stretched to the limit and keeping the mount from rotating properly – and probably damaging the cable.

I originally had all of the cables loose dangling everywhere (image on left below), and resolved the issue by bundling all of the cables in a cable harness (image on right below – different scope but you get the idea.)

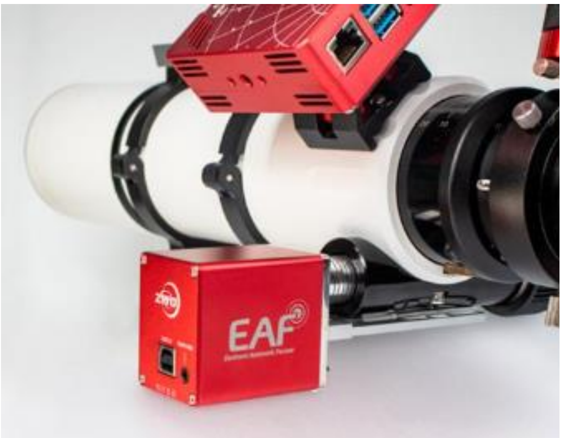
I also had to move where the ASIAir was mounted as it and the cables coming out of it would hit the tripod in extreme cases. Additionally, I wanted the ASIAir mounted to the tripod so that I wouldn't have to move it between telescope mounts when switching telescopes for different targets.

In extreme cases, you may also need to add a pier extension to raise the telescope higher above the tripod as can be seen in the picture below.

This really helps when the telescope is pointing straight up and the camera tends to hit the tripod legs as it rotates. Needless to say, the pier raises the center of gravity and makes the whole assembly less stable, so you should consider adding extra weight to the tripod (in the hanging bag below) to make it more stable.

EAF – Electronic Auto Focus

EAF replaces you having to manually turn the focus knob to focus the telescope. Instead, it uses a small motor (the EAF unit) connected to the focus knob, a camera, and a computer system. The computer looks at the camera image and using advanced algorithms, determines how far to adjust the focus knob.



At first, I thought this was just a luxury for people who were too lazy to focus the telescope. However, I now see this as an essential part of astrophotography for the following reasons:

- The EAF can move the knob in extremely tiny increments – almost to 0.001", whereas your hand can not get anywhere near this level of precision.
- If the focus is not exact, the computer plate solving will often fail even though you have clear stars. This makes polar alignment and finding objects painfully slow with many retries.
- Manually focusing requires you to move the knob and visually see if it looks "better." Often times your eye can't tell the difference between one position and the next. This is painfully slow and very inaccurate.
- The camera and computer can detect minute differences in focus and apply advanced algorithms to determine the exact best position for focus.
- Some telescopes (like my Redcat 71) use about 80% of the focus movement for close objects and only the remaining 20% of the focus movement is used for celestial objects. This is because the Redcat can also be used for bird watching, etc. using manual focus. So, the focus on stars has to be very precise.
- An EAF focused telescope can see stars even through light clouds, whereas a manually focused telescope will only be able to see the stars on a clear night.

Be aware that you will need a custom bracket for each different type of telescope to mount the EAF. I recommend BuckeyeStargazer for these brackets.

Configuration

Since the EAF unit is just a motor, it knows nothing about your particular telescope and how it is focused. Therefore, you need to configure it before your first use. **Note that there are 5,760 steps per revolution on a ZWO EAF**.

In this example I am using an ASIAir controller, but the idea is the same for any controller. Configuration involves setting up the following values for the EAF unit in your computer software.

- 'Current Position' – this is, as the name describes, the current position of the motor in the telescope focuser range.
- 'Limit' – this is the upper limit position of the focuser range. The range goes from 0 to this value.

In order to set these values, you should follow this workflow.

- Determine the 'useful focus range' on your telescope. Many scopes can also be used for ground observation as well, so you typically want to exclude the focus positions for ground from the auto focus process as they will not work for observing stars.
  - Using an eyepiece (or camera) on your scope, adjust the focus from 0 up to infinite and observe where distant things (like the moon) start to come into focus.
    - A good rule of thumb is this is usually around 70% focus movement from zero.
  - If your focuser has a printed scale, you might observe that from 0 to 6 the moon is blurry, but after 6 it starts to come into focus.
  - In this example you would want to use the focuser setting of 6 as the 'zero position' for your EAF configuration, and the focuser setting of infinite as your EAF 'Limit' setting.
  - Leave the focus knob in the 'zero position' found in the previous step.
- Connect the EAF motor to your telescope focus knob.
- In your computer EAF configuration set the 'Current Position' setting to 0.
- Using your computer EAF tools, make the motor move the focus knob to the 'infinite' position. You may have to flip the 'Reverse' setting if the motor is going in the wrong direction. Don't forget to hit the 'Stop' button when it gets to the end or the motor may try to tear the knob off.
- In your computer EAF configuration set the 'Limit' value to a little less (so the motor doesn't go quite to the end of travel and damage the focuser) than the value currently being displayed in the 'Current Position.'

That's it! Now when you use the auto focus feature, the motor will only use the focuser settings you have configured as valid for astronomy viewing on this telescope.

NOTE: on focusers that do NOT have a printed scale (like the Celestron Cx SCT series) you are safer connecting the EAF at the top of range and the setting the 'limit' and 'current position' = '#of turns from useful focus position to top of range' * 5760. This avoids knob damage when top of range is hit.

Sharing EAF motors between telescopes

Ideally, because you have to spend time calibrating the EAF for the particular telescope, it is better if you can purchase an EAF (you don't need a separate computer because the EAF configuration settings are stored in the EAF motor unit – not the computer) for each scope – and NOT share them.

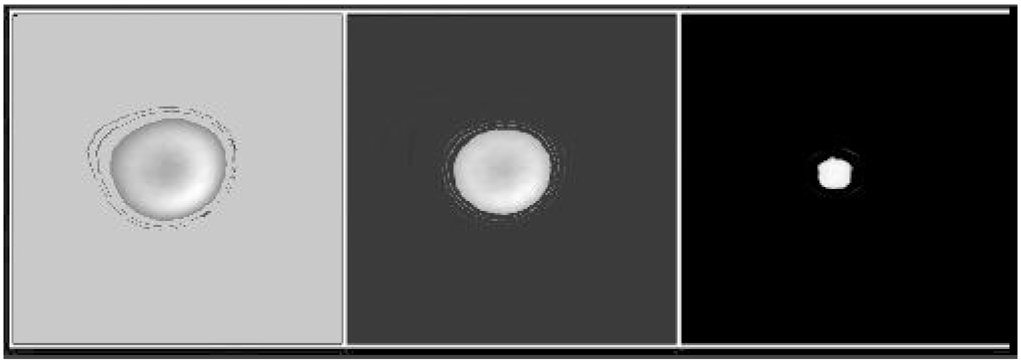
However, you can share a single EAF unit between multiple telescopes using the following steps.

- Before removing the EAF unit from the current scope, move the current position to zero.
- Lock the scope focus ring/knob (if the scope has this feature) so the zero position is not lost.
- Write down the configuration 'Limit' and 'Reverse' values for this scope so they can be re-entered when you start using this scope again later.
- Physically move the EAF unit from this scope to the new scope you want to use. This can be tedious and may involve taking apart lots of stuff.
- If the new scope was already configured (otherwise you will need to configure it – see Configuration Section) do these steps:
    - Get its previous 'Limit' and 'Reverse' values from your records and enter them into the EAF 'Limit' and 'Reverse' configuration value.
    - Unlock the focus ring/knob if it has a lock, otherwise make sure it is still at the zero position manually.

You should now be ready to go. As should be obvious, this process introduces more error margin and slowly degrades your equipment every time you do it due to wear and tear.

Focusing using the Electronic Focuser

Disclosure: the images below are actually from the internet and depict images of an atom using an electron microscope. However, at this point they are the closest images I could find to what star focus looks like. I retouched the backgrounds to show that an out of focus star looks almost like the background and is very hard to find. Only when it comes into focus does the contrast increase.



Out of Focus Better Focus In-Focus

The auto-focus feature uses the fact that an out of focus star has a big “halo” surrounding the center star image – this is what it refers to as star “size”. The “size” becomes smaller as the star comes into focus. The other characteristic (which these images don’t capture) is that the star becomes “brighter” as it comes into focus.

The auto-focus process measures the “size” and “brightness” of the star on a camera image. It then adjusts the focus motor one way or the other, and determines if the “size” and “brightness” have gone up or down. In this way it can determine which direction needs to be used to focus properly, and by charting the “size” to focus position values, build a chart (which looks like a parabola) and determine the proper focus point as the minimum on the parabola.

The problem with all this is that you can’t just press the auto-focus button and expect it work like a magic wand. If the telescope is really far out of focus, there won’t be enough contrast between the star halo and the surrounding space – which is almost the same color as the halo – to determine what is a star and what isn’t for the computer. If you are doing this and seeing star sizes like 350, 500, 750, ... this means you are WAY out of focus. Star sizes should be in the 0-20 range generally.

So, what you need to do BEFORE using the auto-focus feature is to use the manual focus buttons and get the focus roughly correct first. This is very simple, and consists of capturing an image, pressing the manual up/down focus buttons, repeat until the stars look reasonably in-focus. Then you can run the auto-focus and it will set the focus with pin-point accuracy.

Generally, you only need to do this manual focus step when first setting the scope up (or any time you alter the light path – like adding filters.) Once the scope is focused on one star, you can generally use the auto-focus feature on the next star.

Also, auto-focus doesn’t seem to work well on planets, so focus on a star BEFORE moving to the planet.

Guide Scopes

A guide scope is needed ONLY for astrophotography, and ONLY when you are taking exposures over about 2 minutes, and ONLY if your mount supports computer-controlled tracking.

Its purpose is to provide feedback to the mount tracking software so that minor corrections can be made to keep the telescope pointing at its objective. This is necessary because over long periods of time, small errors in the mount motor gearing accumulate and can cause substantial blurring of your image.

Here is a good article on the subject (link to article) which I have summarized on this page.

The guide scope focal length should be roughly 1/3 of the telescope focal length.

Mounting the guide scope on top of the telescope tube can introduce “flexure” issue – where the guide scope and telescope end up pointing to slightly different areas. The ZWO ASI120MM Mini along with the ZWO 30mm f/4 Mini Guide Scope is an excellent choice for non-OAG setups.

Using an Of Axis Guide (OAG) scope is much more reliable because it eliminates flexure and it is able to view the exact same light path that is going to your primary camera.

Cameras and Filter Wheels

Cameras come in either "color" or "monochrome."

Filters are also used to improve the image quality and take color pictures with monochrome cameras.

The following article describes camera characteristics in great detail and should be read in full before making a decision on which camera to buy. Even though the article describes ZWO cameras, the information is applicable to any brand.

Agena AstroProducts Guide to ZWO Astronomy Cameras

Below you will find some of my personal observations, but everything you need will be found in the article above.

Color Cameras

Color cameras are much easier to get started with and are a good choice for a beginner.

These cameras use 4 sensor elements for each pixel combined with a Bayer Filter on the sensor element. This allows the electronics to produce a color image.

The camera "resolution" and "pixel size" are typically for the combined 4 sensor elements – and not the underlying sensor elements. So, an 8.29MPixel camera would produce an image with 3840x2160 (8.29M) color pixels – even though the sensor actually has 7680x4320 (33.18M) monochrome sensor elements grouped in sets of 4 to produce the actual pixels.

There are several drawbacks to this method.

1. When imaging very faint objects because the sensor basically loses about 75% of the light received due to the Bayer Filter. This is because a 'red' photon that falls on a non-red filter element is lost, so only red photons that fall on red filter sensors are registered.
2. Since it takes 4 sensor elements to produce a single pixel, 75% of the potential sensor resolution is lost.
3. The Bayer filter precludes the use of filters that use non-visible light (ex: UV, etc.) So, you can only capture pictures of objects that emit visible light.

The main benefit to color cameras is that they are very easy to use for normal visual tasks.

Planetary vs Deep Space Cameras

From my experience so far, it looks like planetary cameras (like the ASI585MC) are good for deep space objects with magnitude 4.5 or brighter, but are basically useless for dimmer objects. Likewise, DSO cameras are not very good for taking planetary images. So, there is no "perfect" camera and you will need to choose based upon which targets you want to capture.

Monochrome Cameras and Filter Wheels

To overcome the drawbacks of the Bayer Filter on color cameras, monochrome cameras are preferred by professionals.

However, to get a color image using a monochrome camera requires a lot more work. You need to take three separate pictures of the same object using red, green, and blue filters, and then merge the three pictures together into one color picture using appropriate software.

In order to facilitate quickly taking the three filtered pictures a filter "wheel" is typically employed. This wheel is a mechanical device that holds all the filters and can quickly move the "next" filter into the optical path in front of the camera.

Monochrome cameras are also used with special filters to take pictures of objects that emit light outside of the visible spectrum (ex: Ultraviolet) which would not be possible with color cameras. Note that the filter should always be placed as close as possible to the camera sensor in the optical pathway.

Cooled Cameras

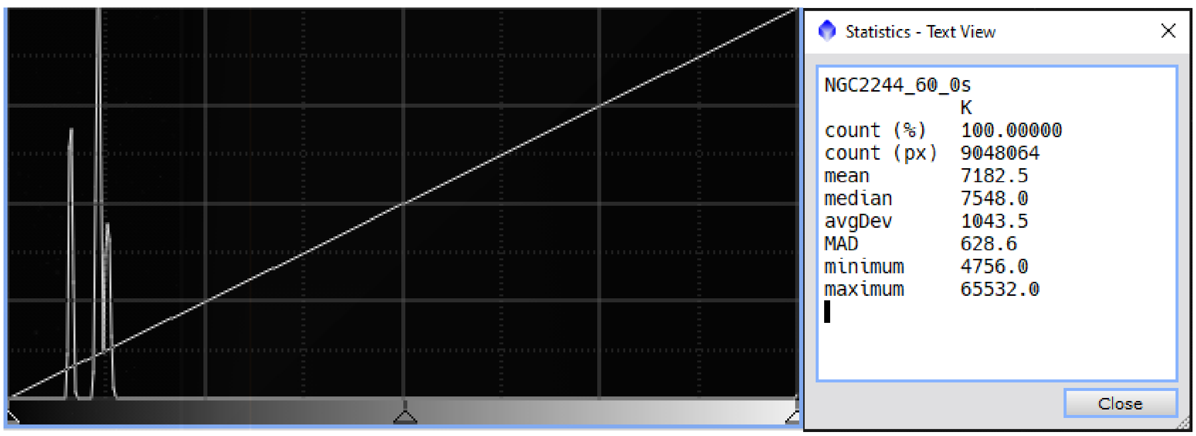
Cooled cameras allow you to take very controlled images by keeping the camera sensor at a specific temperature using an electric cooling unit. This becomes very important when you are trying to apply calibration frames to your image because the calibration frame and the image frames both need to be taken at the same sensor temperature for the process to work ideally.

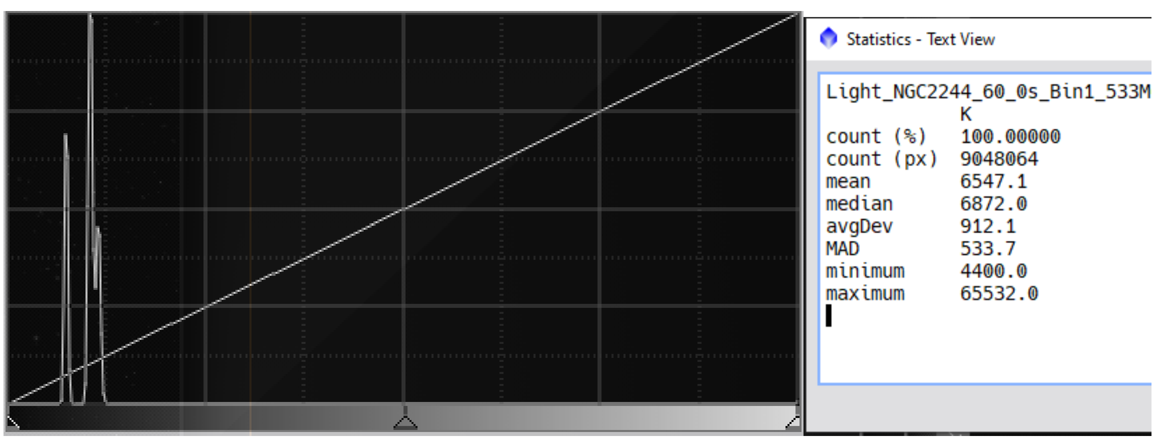
Cooled cameras are a waste of money if you are just tinkering around, but become essential when you get more involved with astrophotography and want to get your pictures to come out perfect.

Example Showing Sensor Thermal Sensitivity

I didn't realize just "how" sensitive the camera sensor is to temperature until I wasted hours trying to figure out why some longer exposures of the same target ended up looking "darker." It turned out that the three images I was comparing were recorded at -0.2C, -0.1C, 0.0C. I assumed this "tiny" of a temperature difference would only have "miniscule" effect on the image, but I was very wrong.

I proved this to myself by comparing the histogram data of the -0.2C (on top) and -0.1C (on bottom.)





As you can see just a 0.1C sensor difference noticably changes the resulting image!

Camera Usage

Here is an excellent article about cameras and pre-processing: [Guide to Cameras and Preprocessing]

Using Calibration Frames to Overcome Issues with your Camera Sensor

If you are just getting started and have enough things to worry about, you can forget about this section for a while. If, on the other hand, you are comfortable taking pictures and want to know how you can improve the quality of your images, you will definitely want to understand this section.

Here is an excellent article to get you up to speed on calibration Frames:

https://practicalastrophotography.com/a-brief-guide-to-calibration-frames/

Basically, what this says is that no camera is perfect and each pixel on your camera sensor measures light a little differently due to various factors (manufacturing tolerances, un-even ambient heat, etc.)

In order to correct these minor imperfections, you need to take a series of calibration frames with the lens cap on (no light reaching the sensor), and a set with an "even controlled" amount of light reaching the sensor.

These calibration frames are then used during imaging to "subtract" out the imperfections in the camera sensor to produce an image wherein **all** of the camera sensor pixels record the light received in **almost** the exact manner.

You need to create calibration frames using the same (ideally, or close works for most cases) optical path conditions. This includes: exposure, gain, sensor temperature, filter used, camera rotation, and binning that you used for taking the images that will be corrected with these calibration frames.

Then when taking live images (previews are not affected by calibration frames) you can specify the calibration frame that most closely matches your camera settings and the computer will apply the calibration frame offsets to your image after it has been captured. Alternatively, you can apply the calibration frames when you are doing the post-processing on your computer.

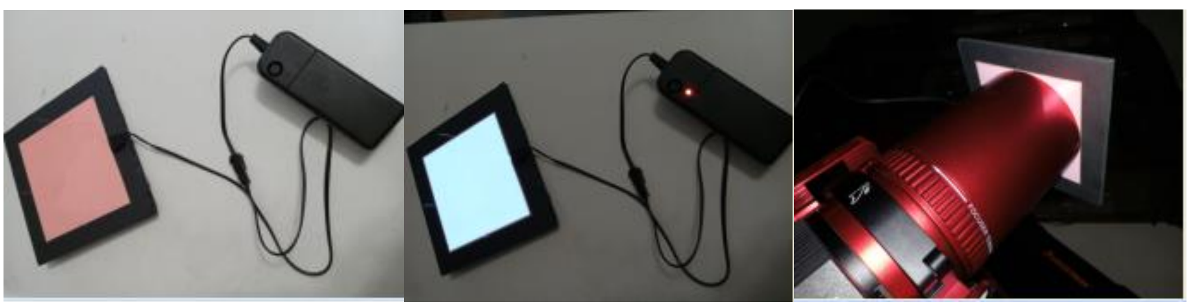
How to Build a Flat Frame Tool

Flat frames are the hardest to take because you need to provide a uniform light field to the telescope, at night, after you are done taking your light shots. The consensus is to put a white tee shirt over the telescope objective and point it at a light source, but it's much simpler to use an EL panel; especially one that fits on your telescope.

Custom astronomy solutions are available commercially (Redcat 71 example) but they cost hundreds of dollars. It is really simple to make one yourself for much less and here are the steps.

- Buy an EL panel that is just slightly bigger than your telescope objective.
  - I bought this one on Amazon for $19.
- Get a rigid piece of cardboard that is slightly larger your EL panel.
- Glue the EL panel to the cardboard (I used Gorilla glue)
- Poke 3 pins through the cardboard – one each at the top, and both sides so that they position the EL panel centered on your telescope objective.

That's it! Now you can hang the assembly on your telescope objective and take your flat frames.



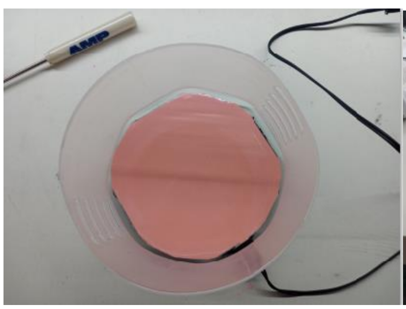
Improved Solution

I found that using the pins to hold the EL panel on the telescope was pretty flimsy and tended to fall off easily – especially with even a slight wind. So, I did some more research and found a company (ClearTec Packaging) that sells plastic sleeves in multiple sizes that would be ideal for holding the EL panel at the end of the telescope.

For my RedCat 71, I ended up choosing part number RT105080PP00S9 (Products-Round Packaging Tubes-RT Series Round Telescopics) because it had an inside diameter of 4.134". This is just slightly larger than the telescope objective so it will be snug but not tight, and it only costs about $11.50.

I traced the container outline onto the EL panel and trimmed it to that size – note I left a square of the underlying cardboard to support the wire connection point. I then cut a small rectangular hole in the bottom of the container so that the wires could be fed through, and put four roughly equal size blobs of Gorilla glue on the bottom (see picture.)


I then slid the EL panel into the container and levelled it as best I could by pressing on different points of the EL panel to spread the glue out. I put a spray can in and balanced it to be level so that the glue would dry without shifting the position.



This results in a much more stable solution that can be slid over the telescope objective to take your flat frames.

Are flat frames needed for Petzval refractors?

Since the Petzval produces a completely flat frame, you might wonder whether vignetting is an issue with this type of telescope. According to Petzval lens - Wikipedia, the answer is yes.

> The lens consisted of two doublet lenses with an aperture stop in between. The front lens is well corrected for spherical aberrations but introduces coma. The second doublet corrects for this and the position of the stop corrects most of the astigmatism. **However, this results in additional field curvature and vignetting**. The total field of view is therefore restricted to about 30 degrees. An f-number of f/3.6 was achievable, which was considerably faster than other lenses of the time.

Are flat frames needed for non-full-frame cameras?

Since vignetting is an artifact that occurs around the edges of the optical path, a small camera sensor that does not extend to these outer regions of the optical path will not record any vignetting. However, full-frame cameras will always be subject to vignetting.

For example, the ZWO ASI585MC has a sensor diagonal of 12.84mm. When used in a 42mm light path, the sensor comes nowhere near the edge of the light path image and thus will not be subject to vignetting.

So, if you are using a small camera sensor with a high-quality optic telescope (thus reducing the imperfections in the optics) you may be able to get away with skipping flat frame calibration in many cases. If, however, you want your image to be “perfect”, then you will not want to skip the flat frame calibration.

Are Bias and Dark frames really needed?

While you are taking these calibration frames you start to understand why they are so important.

For example, when taking the ‘dark’ frames you immediately see that, even though no light is reaching the sensor, the calibration frame image is a light grey color! You would expect the image to be black, but it isn’t. So, if you want your black backgrounds to be blacker, you will want to use the dark and bias calibration frames.

Additionally, when taking the calibration frames, if you watch the camera sensor temperature, you will notice it slowly creeping upwards while the frame is being captured. Because heat (infrared) is light, it will show up in your image and distort it. This is why you need to take dark frames with different exposure times, as more heat is generated in longer exposures.

This clearly highlights why you might want to spend more money and get a camera with a “cooler” built-in so that your images are taken at a constant, lower, temperature – which causes less distortion to your final image.

Saving Image Files and Workflow

When you save an image, the camera takes the image currently on the screen and saves it to a set of files on the camera – this is generally a '.jpg' and '.fit' file.

I wasted a lot of time trying to get the '.jpg' file to look right because I didn't understand the image file workflow and didn't know what a '.fit' file was.

What the camera does when you save an image is:

- Save the image on your screen to a '.jpg' file. This image is usually rather small (low resolution) because you are generally looking at it on a phone or tablet. You should think of this file as 'thumbnail' image – something useful to see what is in the picture at a glance.
- Save the full image (high resolution) to a '.fit' file. This is the file that you will use later (after you are done with your astronomy session) to generate a quality image using a FITS editor program.

So, once you understand this the workflow everything becomes more natural. Here are the steps you should take to generate an image that you will be happy to share with people.

- While using your telescope to observe things
  - In 'preview' mode, capture an image (but don't save it)
  - Using the 'histogram' tool and the lessons learned in the Histogram Section adjust the camera gain/binning/exposure time until the histogram looks good.
  - Save the image.
- After you are done observing things and are back in the house on your computer
  - Transfer the saved image files from your camera to your computer.
  - Open your FITS editor on the computer.
  - Using the 'histogram' tool re-adjust the settings to be like you had them when the picture was originally taken.
  - Add any additional tweaks that you might like.
  - Save the resulting image to a '.jpg' or '.png' file on your computer.

The resulting saved file from the FITS editor will be the one that you will actually look at and share with others.

Histograms

At first, I didn't understand the benefit of histograms, and after reading this excellent article I realize that histograms are the most essential part of determining if your camera settings are correct for the object you are photographing.

[Signal noise and histograms]

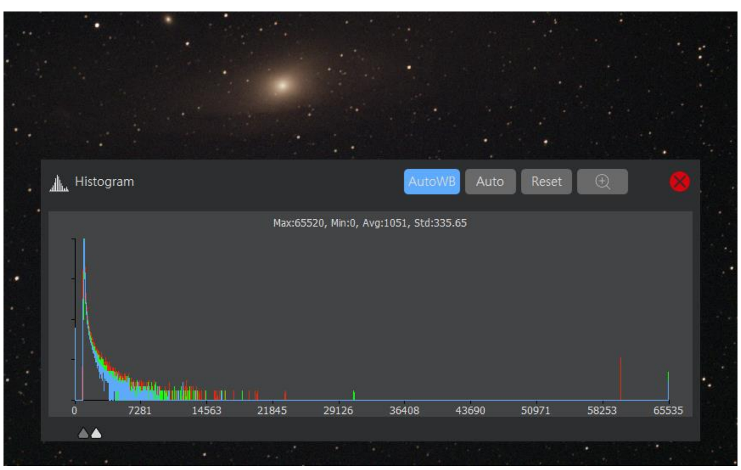
Gain and binning together are like a camera's ISO setting. The higher the gain and binning the more sensitive the camera will be to light. They should be used roughly as follows:

- Bright objects (moon, etc…) – no binning, gain 0, short exposures.
- Less bright objects – no binning, medium gain, medium exposures.
- Dim objects – no binning, higher gain, longer exposures.
- Very Dim objects – lower binning, higher gain, longer exposures.
- Extremely Dim objects – higher binning, higher gain, very long exposures.

You should adjust these settings using 'Auto' mode so that the histograms black/white limit markers are adjusted automatically. After you get a good histogram curve, then you can play with the black/white limit markers to try and fine tune things – like trying to make the background 'blacker', etc.

Additionally, I was thinking that a gain of 0 would be the camera sensor operating with NO gain. However, it appears that a gain of 100 is the sensor operating with NO gain, and a gain of 0 is actually applying a NEGATIVE gain to the sensor values.

So, what you need to do is play around with these settings in 'Preview' mode until you get the histogram to look correct for the object you are photographing, and only then move to 'Live' mode and start the stacking process to capture an actual image. Of course, make sure that your 'Live' mode settings match your ideal 'Preview' mode settings where you got the histogram to look good. The following is an example of a 'Poor' quality histogram.



Gain & Exposure Time

Here is an excellent article about gain and exposure time that I wish I had read earlier as I thought that using gain of zero would reduce noise, but the opposite is actually true.

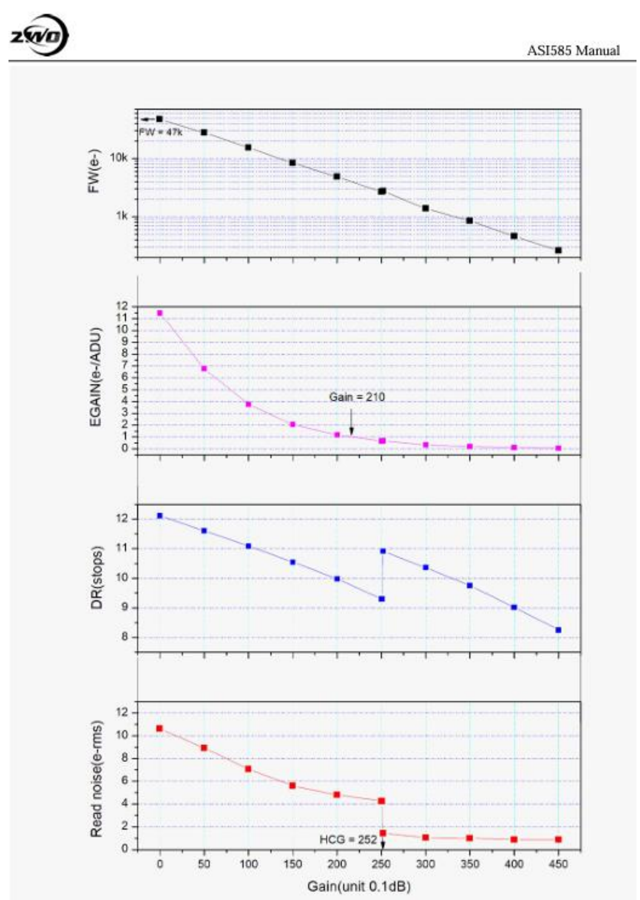
How to set astronomy CMOS camera gain (part I) - astrojolo

Another important point is that the number you use to specify gain in your camera is NOT linear – in other words changing the gain from 100 to 200 will NOT double the gain (in fact it almost quadruples it.) On ZWO cameras increasing the gain by 60 essentially doubles the gain. Here is a good article that explains this.

Is gain linear? - ZWO User Forum (zwoastro.com)

It is also important to find and review your camera specifications (my ZWO ASI585MC specs are shown to the right) to see if there are any “sweet spots.” In my case the camera dynamic range and read noise dramatically improve at a camera gain of 252.

So naturally you would want to try and keep the camera gain above this spot, if possible, to improve the quality of your pictures.



Example Images with Histograms

Here are some images and histograms of M33 (Triangulum Galaxy – magnitude 5.72) taken at different gain and exposure times on an ASI585MC camera. These have not been Debayer'd. If you have been doing this a while, you will say that these are obvious, but for a beginner, these are helpful to visualize what happens with different setting values.

Note that it is hard to see the actual stars in these small images (generally the stars look clearer as the gain/exposure increases) but you can see how the images get washed out. I'm more focused on the histograms here as a means of comparison.

As can be seen, similar results can be obtained using different gains and exposure times. For example, the 'Gain 0, Exposure 1800' image is very similar to the 'Gain 120, Exposure 600' image. Given the previous article (Is gain linear? - ZWO User Forum (zwoastro.com)) that showed that increasing ZWO gain number by 60 doubled the pixel value, it is odd that going from 0 to 120 gain (2 x 60, or 4 x pixel value) would be the same as multiplying the exposure time by 3 (600 to 1800 seconds.) I would have expected to have to bump the exposure time up to 2400 (600 x 4) to get this result.

Reasons to use Less Gain/Exposure

As gain/exposure is increased the left side of the histogram starting point is pushed to the right – essentially reducing the dynamic range of the image.

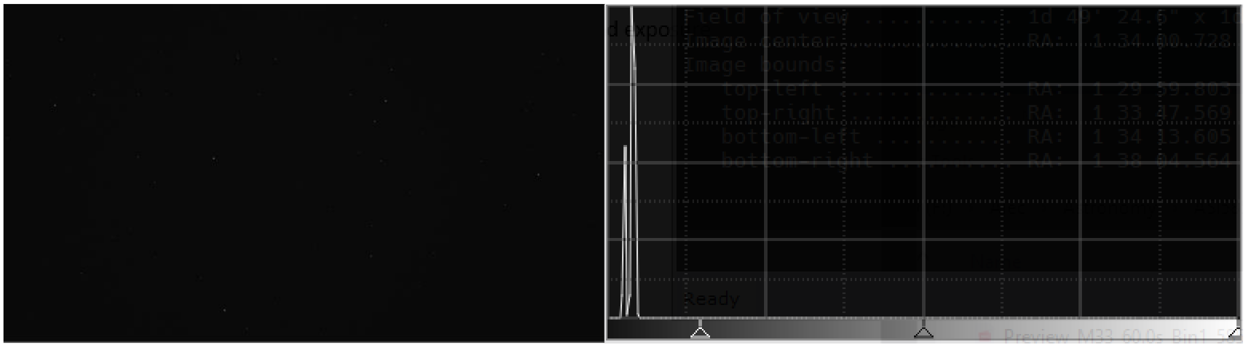
As gain is increased the "speed" with which the histogram moves to right side increases. This effectively reduces the number of exposure settings that are "usable."

Reasons to use More Gain and Less Exposure

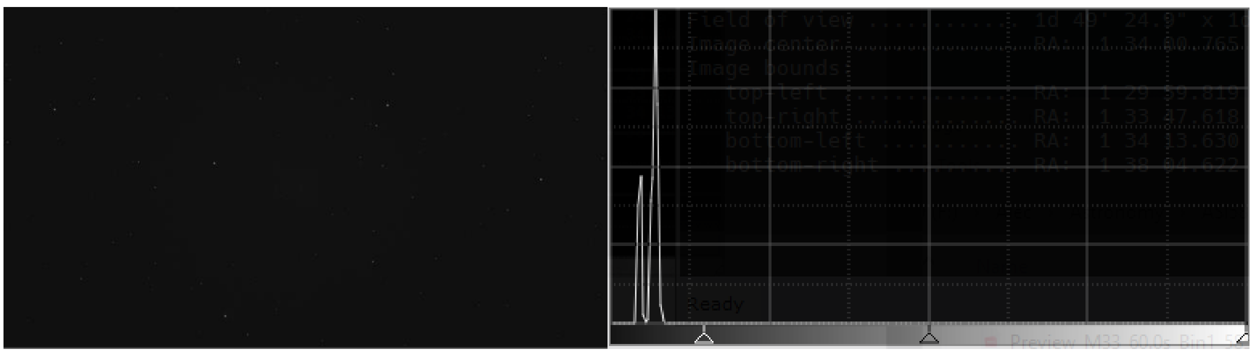
You can get the same result with a shorter exposure time, both reducing the time spent imaging, and reducing the chance that something (clouds, airplanes, satellites, etc.) will taint your image.

Your signal to noise ratio decreases, improving image quality.

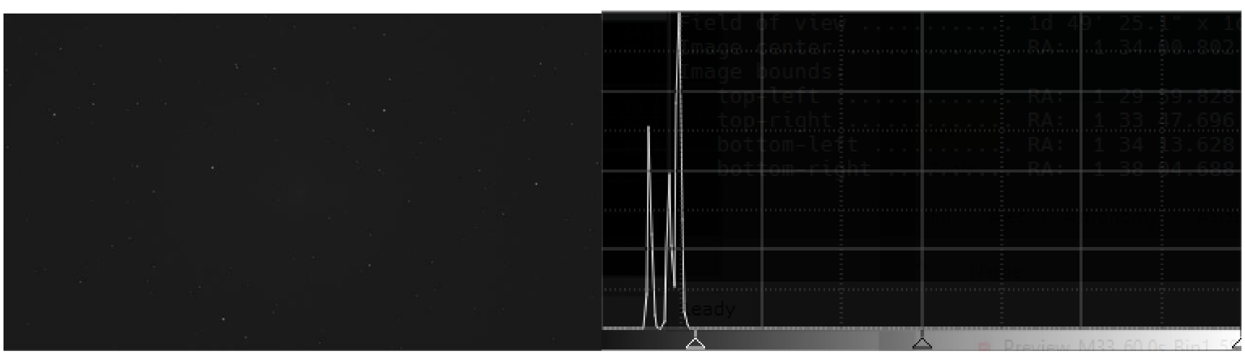
Gain 0, Exposure 300 seconds



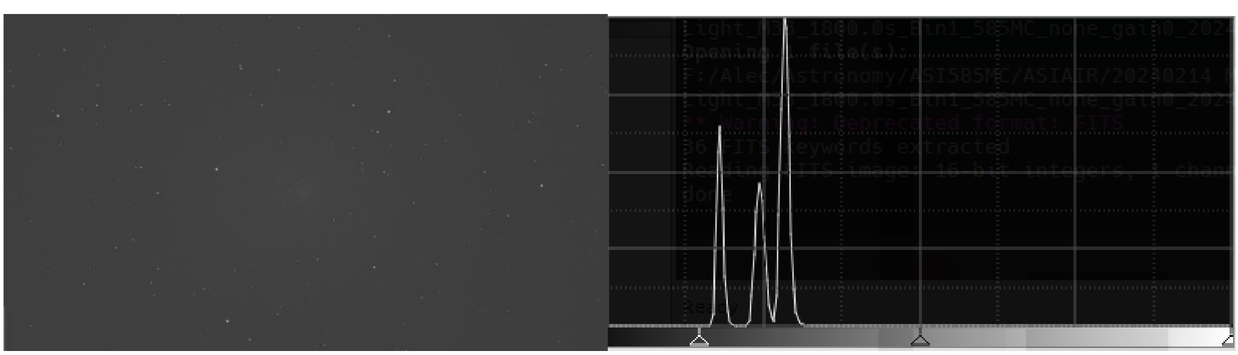
Gain 0, Exposure 600 seconds



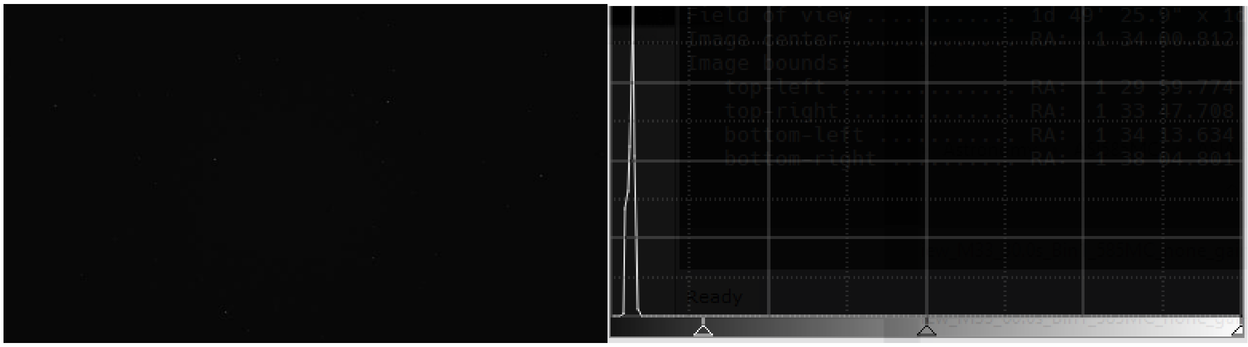
Gain 0, Exposure 1000 seconds



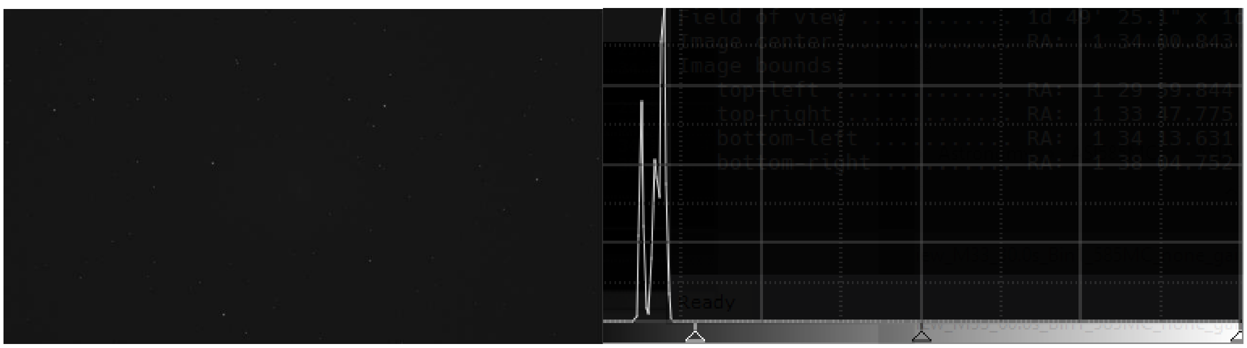
Gain 0, Exposure 1800 seconds



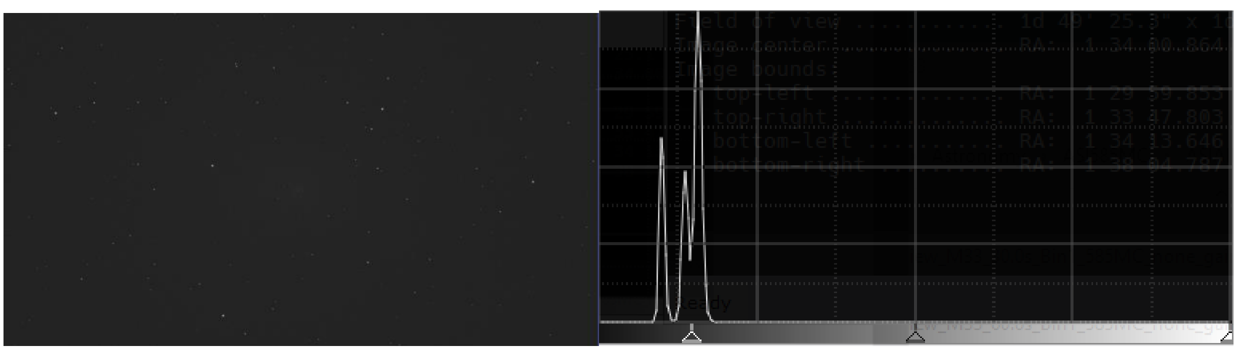
Gain 120, Exposure 60 seconds



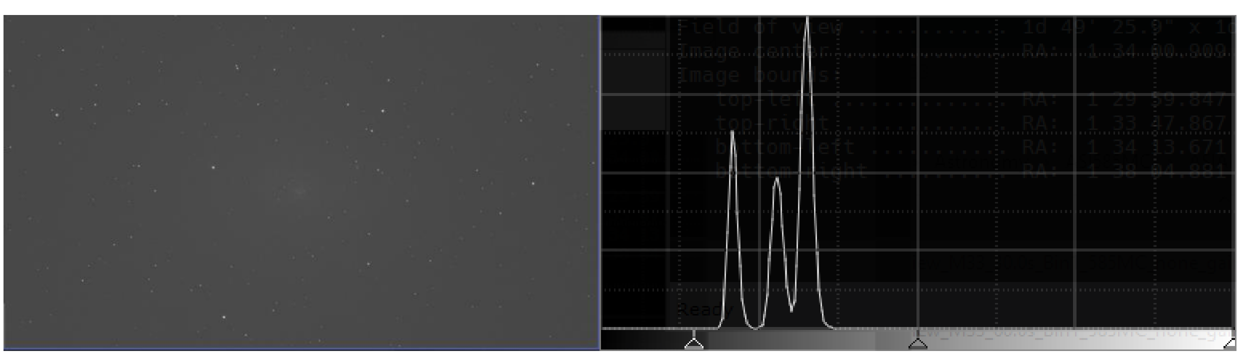
Gain 120, Exposure 180 seconds



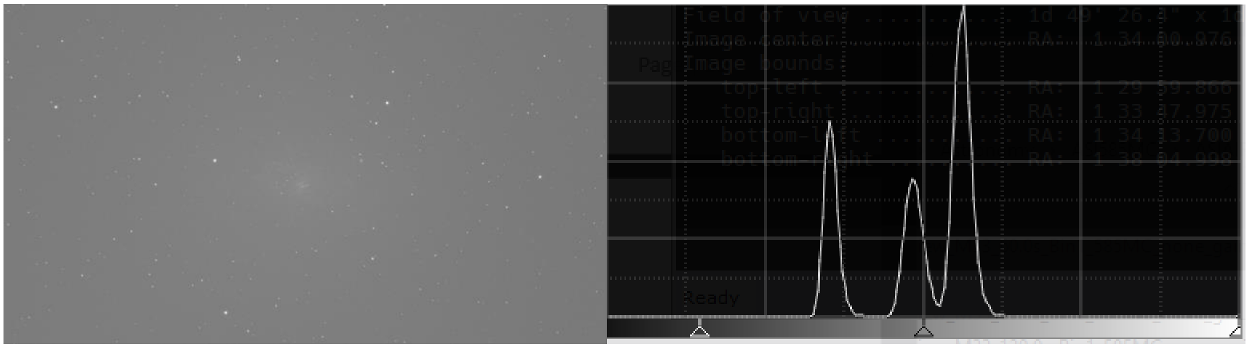
Gain 120, Exposure 300 seconds



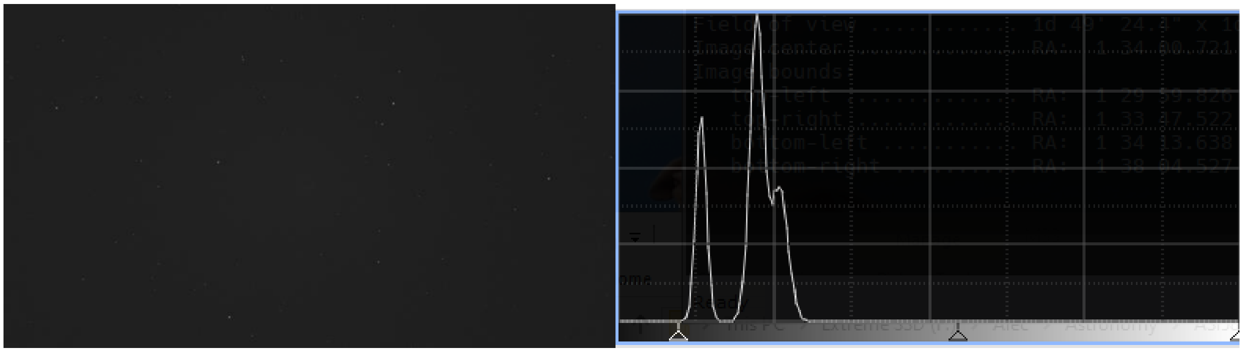
Gain 120, Exposure 600 seconds



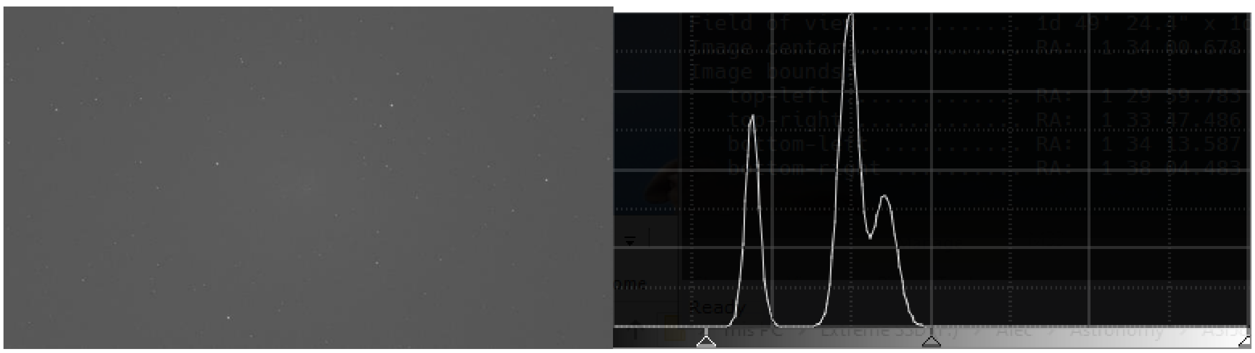
Gain 120, Exposure 1000 seconds



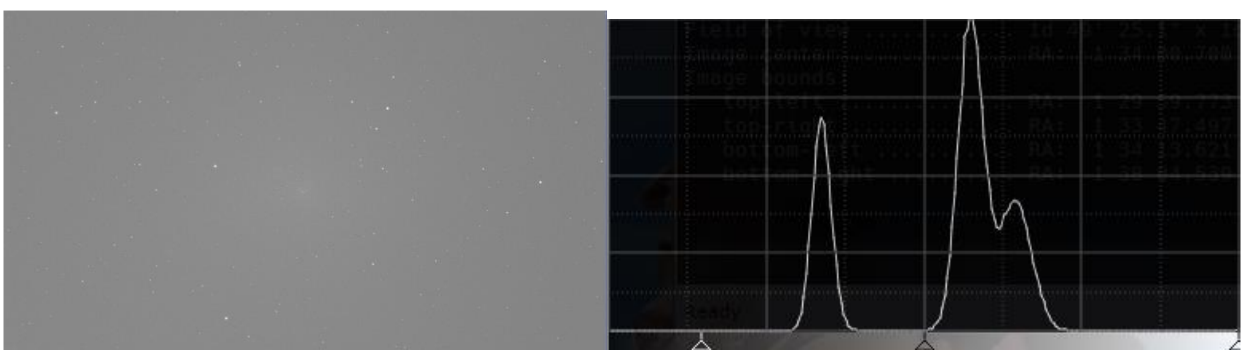
<u>Gain 252, Exposure 30 seconds</u>



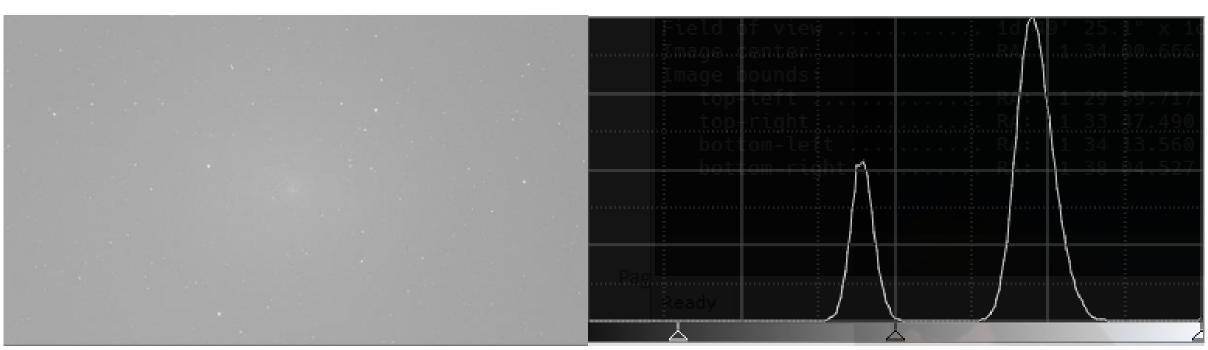
<u>Gain 252, Exposure 60 seconds</u>



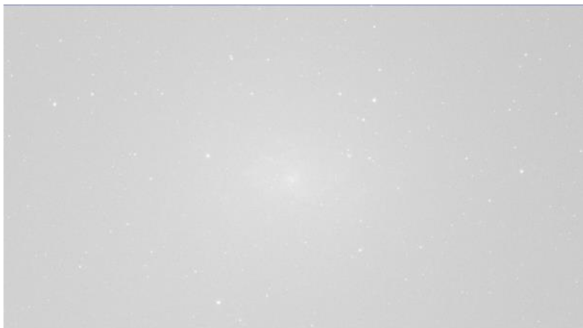
<u>Gain 252, Exposure 120 seconds</u>

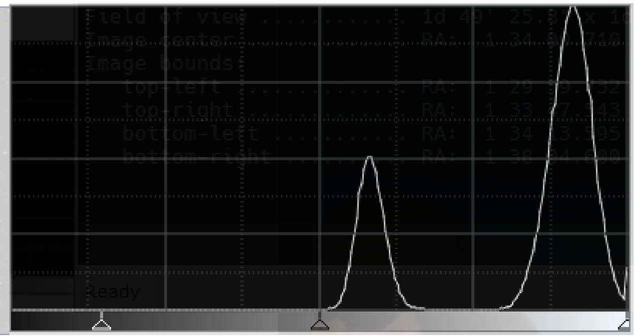


Gain 252, Exposure 180 seconds

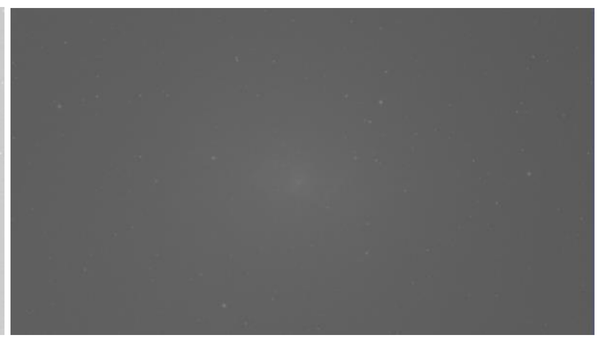


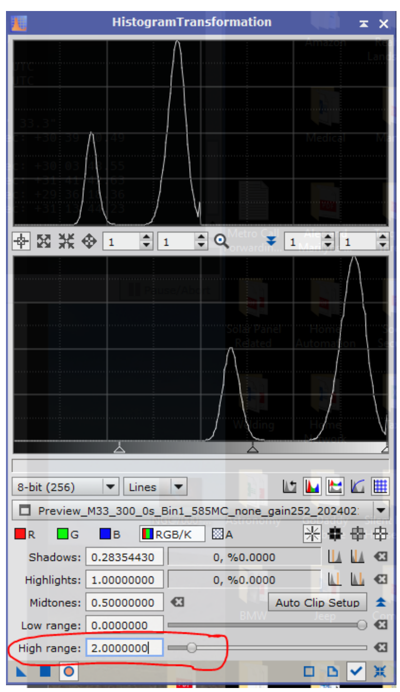
<u>Gain 252, Exposure 300 seconds</u>





Note that, even though this image (gain 252, exposure 300) “appears” completely washed out, you can still “fix” it (except for the missing clipped data) by adjusting the histogram “high limit” value as shown below (left = before, right = adjusted.) However, this does not restore the dynamic range or clipped values.



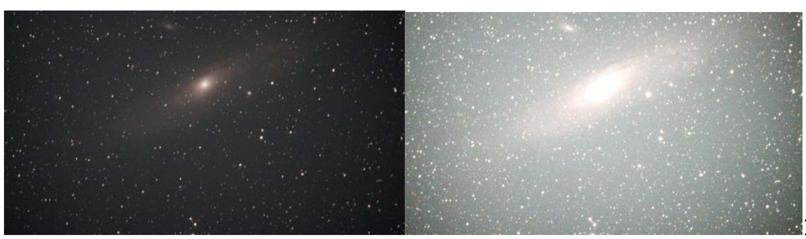


The following pictures (Andromeda Galaxy – magnitude 3.44) illustrate the effect of gain and exposure time on the image. The left column is with gain of zero, and the right column is with gain of 252 (medium.) No filters were used.

5 Sec

60 Sec

120 Sec



180 Sec

Note how these are much clearer than the previous M33 shots, this is because M33 is much dimmer at magnitude 5.72.

Stacking

Stacking is the process of taking multiple images of the same object over time and then merging them together in order to eliminate the differences. This has the effect of cropping out distractions (shooting star, airplane, light clouds, etc.) and improving the detail of the object.

Below is an example of stacking on the Orion nebula taken through high mixed clouds where I was unable to even see the constellation with my eyes. This set of images show the unstacked progress of the light clouds (haze over image) with a heavy cloud (orange color) approaching from the right side of the image.




And here you can see a stacked image of the nebula taken after the ones above, and over a few minutes before a large denser cloud was going to obscure the nebula from the right of the image.

Stacking has dramatically cleaned up the left side of the image (and smudged the right side.)

Things that affect Exposure Time

Barlows

Barlows aren't designed to produce wide, flat fields of focus so adding a Barlow will add curvature to your field of focus – effectively ruining the benefits of an expensive Petzval refractor.

Additionally, your effective f-ratio will be changed by the magnification factor of the Barlow, so a 2X Barlow will make the telescope's f-ratio increase by a factor of two (and that means a 4X increase in the needed exposures). Lastly, most Barlows change magnification depending upon the Barlow-to-sensor spacing and, in most cases, the greater the spacing the greater the magnification.

F-Ratio

As noted above, exposure time varies by the square of the f-ratio, so doubling the f-ratio will require four times longer exposure times. And likewise halving the f-ratio will cut the exposure time by a factor of four.

Binning

Binning is the process of having the camera "combine" several physical pixels (actual pixels on the camera sensor) into one logical pixel (pixels in the generated image file.) This is a trade-off between resolution and light sensitivity.

The benefit of doing this is to increase the number of photons collected for each logical pixel so that you can view dimmer objects better by reducing exposure time. The effects of binning can be seen in the table below.

Binning Level	Effect on Image Scale	Effect on Exposure Time
1	x1	x1
2	x2	x1/4
3	x3	x1/9
4	x4	x1/16

As can be seen the effect on image scale is linear because each level of binning increases the pixel diameter linearly. The effect on exposure time is inversely proportional the square of the binning because each bin level increases the pixel area by the square of the diameter increase – allowing it to accumulate more light and reduce exposure time.

Binning provides these benefits at the expense of image resolution which is generally a trade-off. However, in the case where your image scale is already smaller than current viewing conditions allow you to see anyway (roughly 1.5" in good to excellent viewing conditions) then you can use binning without any loss in "real" resolution.

Binning also reduces the signal to noise ratio of your image – but ONLY when using a CCD (not CMOS) image sensor. This is because on CCD devices you are combining multiple signals BEFORE the read amplifier – CMOS devices combine the signals AFTER the read amplifier.

The following illustrate the effect of binning on the image. Note all images are at a gain of zero, an exposure time of 300 seconds, and no filters were used.

Bin 1

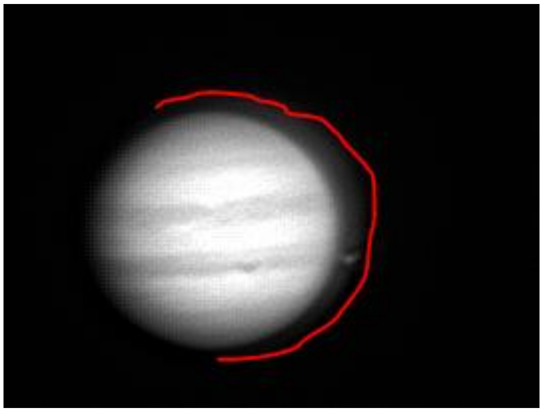
Bin 2

Bin 3

Bin 4

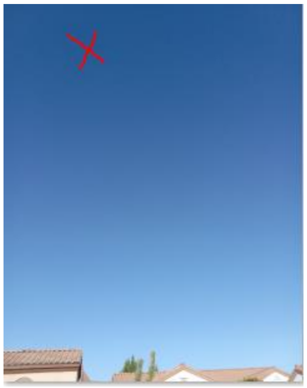
Taking Pictures Over a Hot Roof

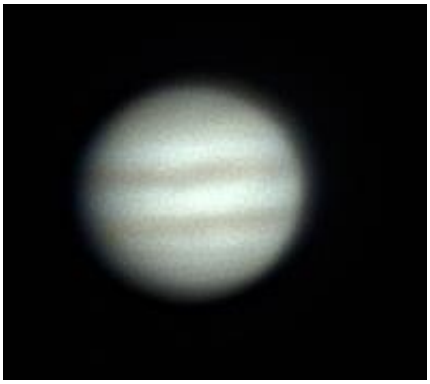
If you zoom in on the image of Jupiter taken in a prior section, you will notice a blurry 'halo' around the right side of the planet (see below left.) This was taken from a video shot from my back yard over the edge of my house roof (see below right, 'x' marks Jupiter's position.)



I was able to determine that this 'halo' was caused by the jitter introduced by the fluctuating optical lens created by the heat rising from my roof.

This was accomplished by taking the same shot the next day, but from my front yard – so that I would have a clear shot of Jupiter (see below left, 'x' marks Jupiter's position.) However, due to the position of Sirius (see below middle, 'x' marks Sirius's position) and its close proximity to a street light, I was not able to do a proper polar alignment. Even so, the jittery 'halo' effect seems to be greatly reduced (see below right.)





However, for various other reasons (like I forgot to tighten the mount bolts and then ran out of memory), the second shot is not as clear. The bottom line here is that it looks like there is some distortion due to the heat lens but it may be small enough that it is not worth the pain and bother of having to setup everything on the street out front.

Taking Pictures Low on the Horizon (w/City Light Pollution)

If your target is low on the horizon, and over city lights, it is going to be difficult to get a good picture. Here is an example of the M33 (Triangulum Galaxy) taken near the horizon over Las Vegas. On the left, you can see the original, un-processed image. On the right is the processed image, which although it has isolated the galaxy, has also eliminated almost all of remaining detail and color from the image.


You are much better taking the shot when the object is higher in the sky (and outside of the pollution cloud.) Unfortunately, depending on the target and the time of year, you may have to wait many months before it appears high in the sky.

Filters

Filters are used to eliminate certain wavelengths from passing into your eye/camera sensor and provide a variety of different functions.

Filters come in three basic sizes:

1. 1.25" (31mm) and cost around $20-$120
2. 36mm and cost around $125-$250
3. 2" (50.4mm) and cost around $250-$500

Clearly most people will want to use the 1.25" filters due to cost. The reason you would need to use the larger filters is when your camera sensor element is larger than 31mm.

Here are two excellent articles that cover pretty much everything you need to know about using filters:

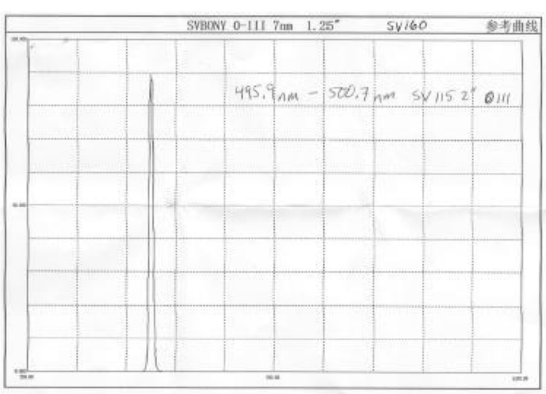
Useful filters for viewing deep sky objects
Filter performance comparisons for some common nebulae

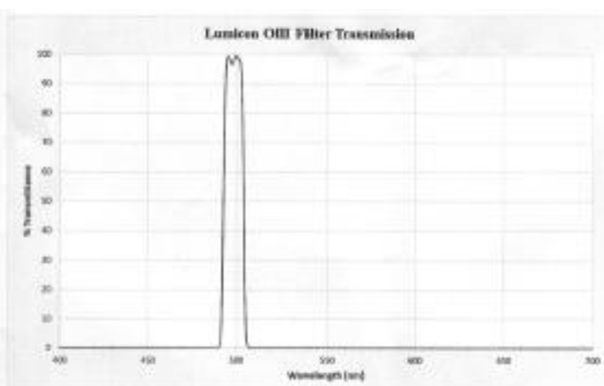
You should read these to get a good understanding of how filters work. The information that follows below are my personal observations on using filters.

Not All Filters are the Same

Here is a comparison between an SVBONY OIII ($140 Amazon) and Lumicon OIII Gen3 ($138 AgenaAstro) filter. I originally purchased the SVBONY filter and later chose to get the Lumicon after reading several reviews saying how much better it was.

You can see below that the Lumicon filter lets through much more of the desired narrow band light (10-15% more at least.) The SVBONY spec sheet is so poor that I can't even read the wavelength values on the bottom of the scale.





So, the Lumicon is a better filter AND (for some bizarre reason) actually costs less.

Camera Built-In Filters & UV/IR Cut Filters

Your camera typically has a piece of protective glass above the sensor element. This is either an IR-CUT or AR window. An AR window is coated to limit reflections but passes IR light pretty well whereas an IR-CUT window will cut off the IR part of the spectrum and limit what the camera sees to visible light only.

If you are imaging with a reflector (which can focus IR to the same point as visible light) then you should be OK with just an AR window, but if you are imaging with a refractor (which will usually focus IR to a different spot than visible light) then you'll want to add an IR-cut (or UV/IR cut) filter to avoid getting a smeared image from the IR.

It's not that one is better than the other... if your camera has an IR cut window then you don't need to bother with a separate filter, but you lose the ability to image in IR with a suitable scope.

UHC (Ultra High Contrast) Filter

UHC filters block out typical orange/yellow wavelengths of light, reducing the effect of light pollution to allow for more contrast between the 'black' night sky and the objects you want to capture. Suitable for telescopes of nearly all apertures. CCD camera users should pair their UHC filter with an IR blocking filter. Standard and modified DSLR cameras will gain from the contrast-enhancing abilities of a UHC filter, but these filters are not suitable for use with planetary webcams.

Narrow Band Filters

Narrowband filters are more discriminating, typically letting through light in the 20nm to 30nm range. The wavelength band coincides with the emission lines of hydrogen beta at 486.1nm and doubly ionized oxygen at 495.9nm and 500.7nm. These filters cut out most light-pollution lines as well as most of the continuous spectrum from stars and galaxies. So, they provide a nice dark background sky but prove of little use on objects other than emission and planetary nebulae. On those latter objects, however, narrowband filters boost the visual appearance dramatically.

General Notes about Nebulae (from link)

The emission nebula we can see emit light in 3 prominent spectral lines we can see at night:

- H-ß at 486.1nm
- O-III at 495.9nm
- O-III at 500.7nm.

Many nebulae emit light at all 3 lines. Some only emit light at H-ß, and some at only O-III. If you don't want to research the spectrum of each nebula, here is a basic guide:

- Large H-III region nebulae like M8, M20, M17, M16, M42--all 3 lines
- Most Planetary nebulae--O-III lines
- Most Wolf-Rayet excitation nebulae like NGC2359, NGC6888---O-III lines
- Supernova remnants--O-III (the Veil) or all 3 (Crab)
- Large ultra faint H nebulae normally seen in photos only--H-ß line.

What filter does them all? The narrowband filter that passes all 3 lines. Examples:

- TeleVue BandMate II Nebustar
- DGM NPB
- Astronomik UHC Visual
- Lumicon UHC
- Orion Ultrablock.

Later on, if you are looking for another, second, filter to give a trace more contrast on selected objects, try an O-III filter. Examples:

- Astronomik O-III
- Lumicon O-III
- TeleVue BandMate II O-III

Filters are used at low power (under 10x/inch of aperture usually), which means if you use high powers to look at planetary nebulae, you'd do so without a filter. The higher the power, the less effective the filter is.

H-Beta Filter

An 8-inch rich-field telescope can use the H-Beta to show larger objects like the Gamma Cygni nebular complex (IC 1318) or segments of Barnard's Loop and the California Nebula. There are other fainter targets which the H-Beta can be used on, although some require moderate to large aperture:

USEFUL TARGETS FOR THE H-BETA FILTER

While the H-Beta is probably one of the less-used nebula filters, the commonly expressed idea that it works only on a handful of objects is not necessarily true. Here is a list of some of the more prominent objects that the H-Beta may be at least somewhat useful on. Some may require larger apertures (and some may be slightly better in other filters), but a few have been seen from a dark sky site by just holding the filter up to the unaided eye and looking at the sky. Some of these will also be helped by a narrow-band filter like the Lumicon UHC.

1. IC 434 (HORSEHEAD NEBULA)
2. NGC 1499 (CALIFORNIA NEBULA, naked eye and RFT)
3. M43 (part of the Great Orion Nebula)
4. IC 5146 (COCOON NEBULA in Cygnus)
5. M20 (TRIFID NEBULA, main section)
6. NGC 2327 (diffuse nebula in Monoceros)
7. IC 405 (the FLAMING STAR NEBULA in Auriga)
8. IC 417 (diffuse Nebula in Auriga)
9. IC 1283 (diffuse Nebula in Sagittarius)
10. IC 1318 GAMMA CYGNI NEBULA (diffuse nebula in Cygnus)
11. IC 2177: SEAGULL NEBULA (Diffuse Nebula, Monoceros)
12. IC 5076 (diffuse nebula, Cygnus)
13. PK64+5.1 "CAMPBELL'S HYDROGEN STAR" Cygnus (PNG 64.7+5.0)
14. Sh2-157a (small round nebula inside larger Sh2-157, Cassiopeia)
15. Sh2-235 (diffuse nebula in Auriga).
16. Sh2-276 "BARNARD'S LOOP" (diffuse nebula in Orion, naked eye)
17. IC 2162 (diffuse nebula in northern Orion)
18. Sh2-254 (diffuse nebula in northern Orion near IC 2162)
19. Sh2-256-7 (diffuse nebula in northern Orion near IC 2162)
20. vdB93 (Gum-1) (diffuse nebula in Monoceros near IC 2177)
21. Lambda Orionis nebular complex (very large, naked-eye)
22. Sh2-273 "Cone" Nebula portion south of nebulous cluster NGC 2264

In addition, a number of the brighter nebulae like NGC 7000 or M42 will respond to H-Beta use for revealing certain specific detail, although other filters may provide a somewhat better view overall.

Many articles say that it is only useful with apertures of 8” and larger. However, several of the targets on the list were visible in an 6" f/5 and 4" f/7, so the filter has a use. But to see the Horsehead in an 8"?

That requires a VERY dark sky. I tried for 11 years with an 8" and filter and never saw it, but it was suddenly easy in the 12.5".

I have seen the Horsehead in a good pair of 6" f/5 binoculars (with filters), so I am not certain 8" is too small an aperture to see it. But I do believe you need skies of around magnitude 6.8-7 to really see it. Don't expect something small. It's almost as big as M11! And it doesn't really look like the picture--it's like a large "bite" out of IC434. If you can't see IC434, you'll never see B33, the Horsehead.

But don't fail to look at other objects in the list. NGC1499 (California Nebula) becomes EASY with the filter, even in a 6". And I've caught it with my 4" refractor as well.

OIII (Oxygen III) Filter

The most extreme narrowband filters, sometimes referred to as line filters, let through light from only one or two emission lines. The OIII filter (or Oxygen III, which stands for doubly ionized oxygen) ranks in a class by itself. It effectively doubles the size of your telescope when it comes to observing emission and planetary nebulae. Bright nebulae look stunning even from the city, and the views under a rural sky are beyond compare. An OIII filter will make faint planetaries pop into view. The filter has only one drawback: It darkens stars so much — by two to three magnitudes — that it can be difficult to find the correct field at medium and high magnification.

Neutral Density Filters

Neutral density filters are used to reduce the amount of light reaching the camera sensor when viewing very bright objects (ex: moon, sun, etc.) You may be able to get away without using this on a small aperture scope, but as the aperture gets larger the amount of light reaching the sensor overwhelms the sensor electron wells and creates a washed-out image – see below for full moon shot taken with Redcat 71.

Here is the chart showing how much light is let through an ND filter. The markings on the filters themselves are confusing because some manufacturers display “density”, whereas others display “light transmittance”, and others display both “ND Number” and “density.”

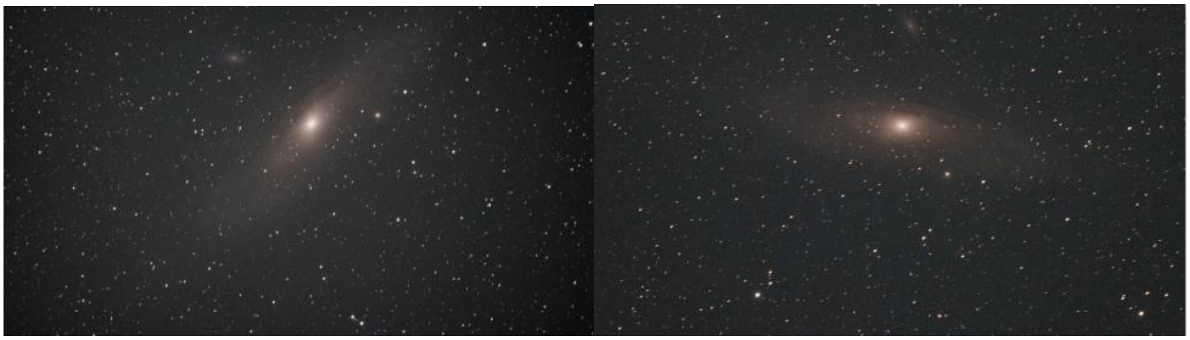
ND Number	Density	Stop	Light Transmittance
ND2	0.3	1	50%
ND4	0.6	2	25%
ND8	0.9	3	12.50%
ND16	1.2	4	6.25%
ND32	1.5	5	3.10%
ND64	1.8	6	1.50%
ND100	2.0	7	0.50%
ND200	2.5	8	0.25%
ND500	2.7	9	0.20%
ND1000	3.0	10	0.10%

12.5% transmittance is good for the moon on larger scopes, 25% may work fine on smaller scopes.

Filter Examples

UHC and UV/IR CUT Filters

I did a test comparing images of the Andromeda galaxy with no filters compared to using SVBONY UHC and Optolong UV/IR Cut filters. The results are below – the image on the left is the “no” filter image, and the right has both filters.



As you can see, there is no “dramatic” difference in my case. Even when you zoom in 5x to the bottom left corner, it appears as though the NON-filtered image has a darker background (which is the revers of what is expected.)

Nonetheless, from a human eyeball test of the full-size images, it does appear that there is a “very slight” darkening of certain regions of the image background in the image using the filters.

I ran other tests using each individual filter and found that the UV/IR Cut filter had no visible effect, and that the UHC filter was responsible for all of the “very slight” darkening effect. I suspect that UV/IR Cut filter had no effect because my camera sensor is small and does not reach to the edge of the focal area. I suspect that the UHC only had a limited effect because of my location on the edge of the desert high above the city lights.

OIII Filters

Below is a comparison of shots I took of the Orion Giant Nebula using a SVBONY UHC filter (on the left 30s exposure 252 gain) and an SVBONY OIII filter (on the right 120s exposure 450 gain.)

Note how a longer exposure and higher gain is needed with the SVBONY OIII filter due to the fact it lets less light pass through to the sensor. Note also how more subtle detail is available with the OIII filter view even though the color has been lost.

You can see the full-size images by following these links:

- Orion Giant Nebula.jpg (3840×2160) (alphaengineeringlabs.com)
- Orion Giant Nebula - OIII Filter.jpg (3840×2160) (alphaengineeringlabs.com)

Other Filter Considerations

Focus

Keep in mind that every time you add or remove a filter to your light path, it alters the back focus slightly which requires you to re-focus your objective. This is true even though you have not altered the distance from the telescope back to the camera sensor, and is due to the fact that the filter alters the path of the light rays slightly.

Size

Filters come in different sizes. I got a set from Celestron that were 11mm thick and would not fit into a standard filter wheel – I'm guessing these were meant for visual use to attach to your eyepiece. If you are planning on using these in a filter wheel for photography, make sure you get the lower profile 7mm versions.

ASIAIR (your controller may be similar) Workflows

Here are some of my notes about things that were not immediately obvious about using the ASIAIR.

- Live mode
  - does stacking for you (and can optionally save the individual frames for you so you can also stack with an external program)
- Plan mode
  - requires you to stack with an external program
  - is the only way to setup and shoot Mosaics
    - DON'T adjust your camera rotation AFTER setting up Mosaics in Plan or they will come out all screwed up.
  - allows you to shoot multiple objects automatically
    - but you may have to rotate and crop the results if the camera rotation isn't good for all the objects since it can't be changed in the plan.
    - this last point is why you want higher resolution on your camera so you can crop and not lose valid data.
    - In general, you are better off creating a different 'plan' for each of your targets rather than trying to do them all in one plan – especially if you need to rotate the camera between targets.
  - Forces a star alignment when capturing 'Light', but **NOT** 'Bias', 'Dark', or 'Flat'
    - So, if you are trying to run a "test" during the day, don't try to capture it in 'Light' or you will be stuck forever trying to get star alignment.
  - can also shoot your calibration frames.
    - They should be first in sequence so you can let it run unattended afterwards.
    - However, since Plan mode can't stack it's probably easier to do them with Live mode manually before starting your plan or after your plan completes.
  - This also may explain why Plan doesn't stack, because the calibration frames may not be available during the Plan run (if you shoot them at the end of the Plan), and certainly are not available during the Plan setup phase (if you shoot them in the Plan or after the Plan completes) so how could you specify them in the plan?
  - Every image is saved as BOTH a 'fits' and 'jpg' file. In postprocessing, the 'jpg' files are an annoyance and you need to delete them. There does not seem to be any way of getting ASIAIR to stop producing them.
  - I'm not sure if Plan mode allows you to specify "Area Of Interest" in the plan? On cameras that support it, this would be beneficial.

Polar Alignment

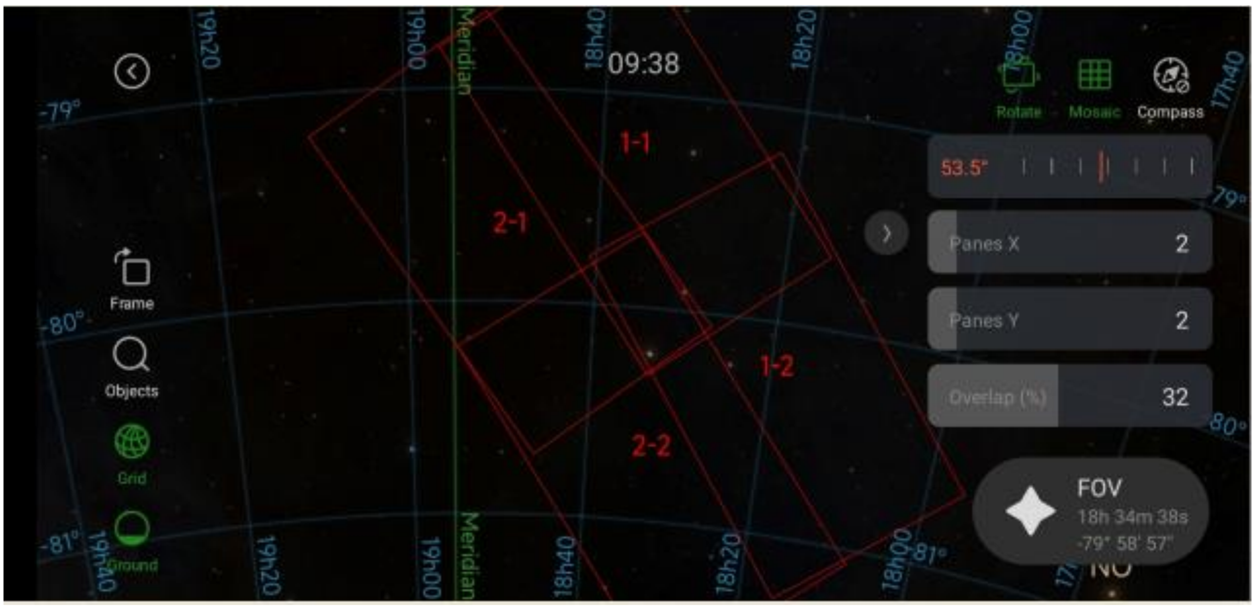
Polar alignment normally works quite well. However, I have run into a very frustrating experience using cameras with smaller sensor chips that are not square (like the ASI585MC.) In these cases, your initial PA shot will work and the second (after the mount tilts 60 degrees) will fail continuously no matter how you adjust the exposure parameters or wait for clouds to move away. In these cases, the solution is to simply rotate the camera somewhat (about 45-90 degrees seems to work generally) so that a different set of stars can be used.

Aligning the Camera Frame with your Intended Target

This is especially important if your camera sensor is not square because, although the center of the sensor will be centered on your target, your rectangular sensor may not be in the ideal rotational position to capture the target properly.

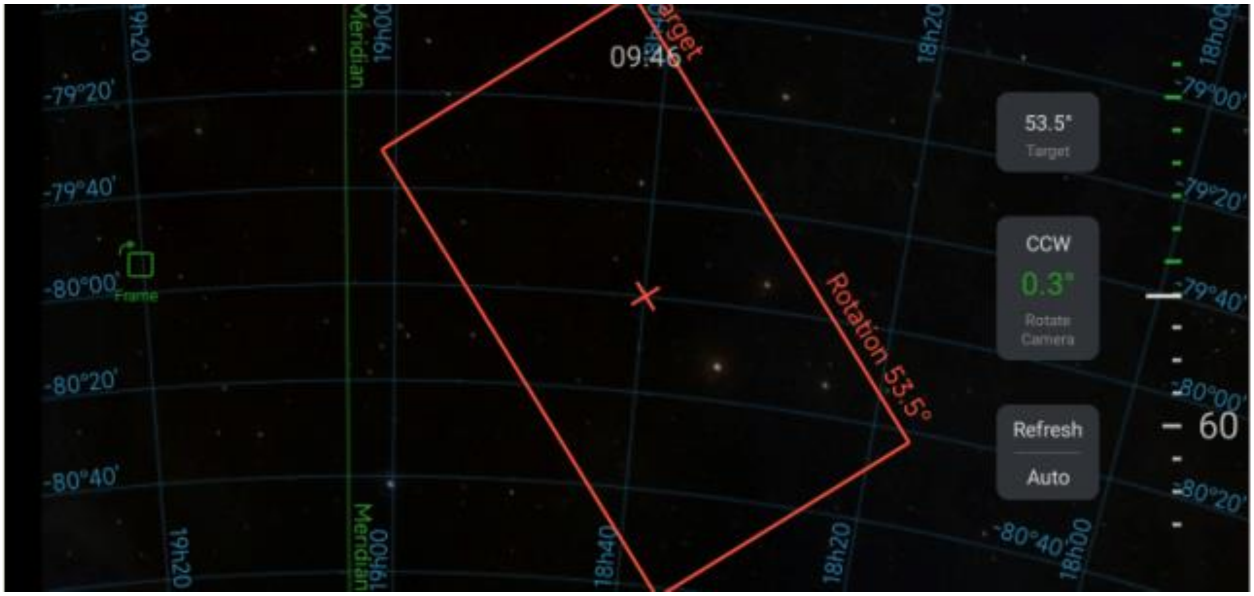
IMPORTANT NOTE: I took these screen shots while the unit was off-line so all the blue camera sensor rectangles are missing. Just pretend that they are present behind the red target rectangles.

This should be done in “Preview” mode. After you have used the “Goto” feature of the “Planetarium” to move the telescope so it is pointing to your target.



- Click on the “Rotate” button on the right top side of the screen.
- Drag the slider that appears around until the target is where you want it.
- If you plan on capturing a “Mosaic” of this object then do these additional steps.
    - Click on the “Mosaic” button and adjust the X and Y frames you want
    - Change the “Overlap” to a reasonable value like 25-30%
    - Tweak the “Rotate” slider until your mosaic is where you want it.
- You can also touch the screen to drag it around until your target is where you want it.

At this point you need to manually rotate the camera so that it matches your target frame. To do so follow the steps outlined below.



- Click on the "Frame" button on the left side of the screen.
- A slider will appear on the right side of the screen allowing you to rotate the red target frame so that the object will look good inside the target frame. If you followed the steps in the previous section your target frame is already where you want it and you can skip this step.
- When you have it where you want it, read the number out of the right-side middle box labelled "Rotate Camera" – this will tell you how many degrees you need to manually rotate your camera to be in your ideal target area.
- Physically rotate your camera, and either press the "Refresh" button repeatedly, or press the "Auto" button once to see where your camera is in relation to your target.
- When the blue Camera box lines up with the red Target box – you are done
- Click on the "Frame" button on the left side of the screen again to exit the frame mode.

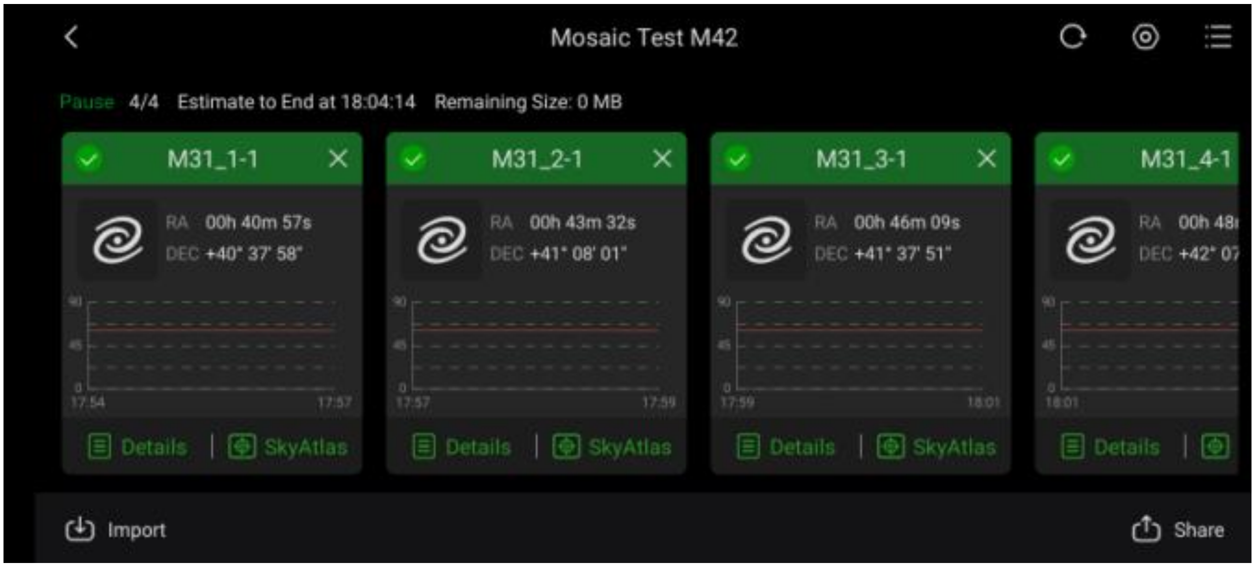
In case it is not obvious, this presents a limitation on how many targets you can setup in your "Plan" mode. This is because, in most cases, your targets will not line up exactly the same in the camera sensor frame – requiring manual adjustment between captures in "Plan" mode. For this reason, you should generally create a different plan for each of your targets.

Setting Up a Mosaic

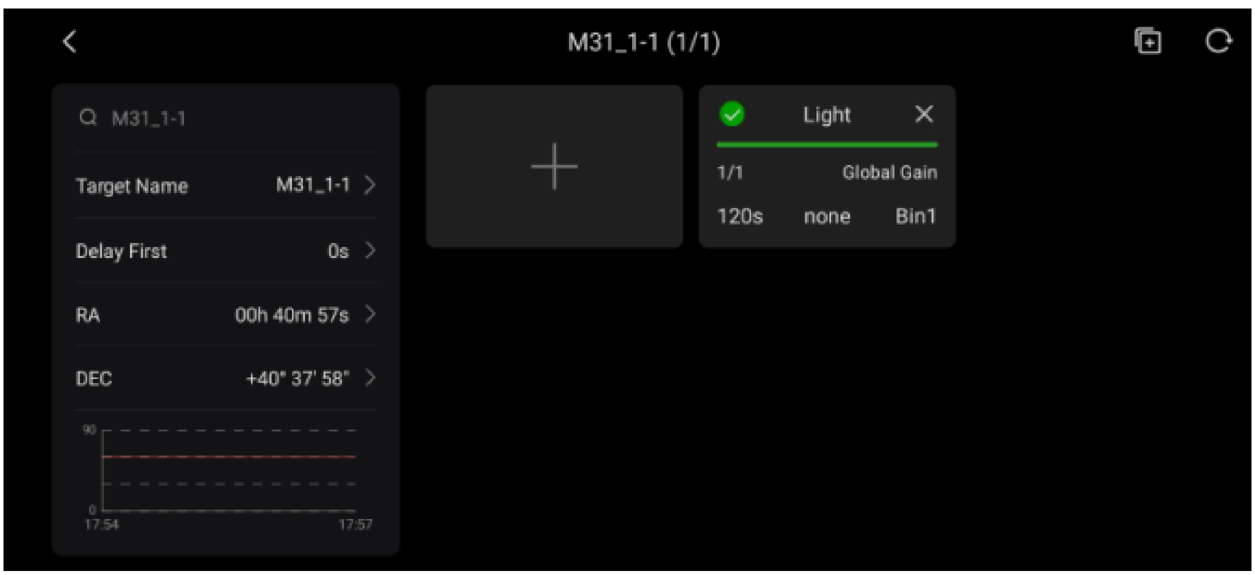
You can only do this in “Plan” mode. **Make sure you align the camera frame before doing this** or else you will end up with cockeyed mosaics like the following.

- Click on the “Planetarium”, choose your object and “Goto” it.
- Click on the “Mosaic” button.
- Choose the #of frames in the X and Y directions you want.
- Change the “Overlap” from 10% to something reasonable like 25-30%.

- Click the “+Plan” button (bottom right) and all of your “Mosaic” frames will be added to the current plan and you can see them in the gray bar (bottom left) showing 4 frames.
- Click the “<” back arrow (top left corner) to return to plan mode.
- Continued on next page…



- Click on the first "Mosaic" frame entry's "Detail" button
- Click on the huge "+" button and setup the camera settings for this image.



  - If you want all of the frames to use the same settings, then click the small "+" button in the top right and select copy to all frames.
  - Otherwise, click on the next frames and repeat the above step.

Running your Mosaic Plan

You can set your plan to run “now”, or “at a certain time” in the plan settings. What is confusing is that neither of these settings will have any effect UNTIL you press the “>” play button on the plan screen – this is what activates the plan.

At first, I thought this was stupid, but later realized that this is necessary to prevent your plan from running every night if you leave the power on and having the scope crash into adjacent objects in your house.

Different Approaches to Getting Quality Images

I've been trying to frame everything with no post processing which is why it is so difficult and requires so many different cameras and telescopes. After investigating post-processing I have come up with the following conclusions about how to go about getting good images.

You need to make the philosophical choice of which road you want to go down early on in your astronomy voyage to avoid wasting either a lot of time or money.

Little to No Post-Processing

This is what I'd call the completely "honest" picture approach – where the picture reflects exactly what you saw in your camera. This could also be called "old school" photography as this is what was done before computers became widespread.

This approach is MUCH less complicated, but MUCH more expensive as you have to buy lots of different telescopes, lenses, and cameras. And it is very difficult to get extremely wide-angle shots like the Milky Way.

Lots of Post-Processing

This is the less "honest" approach where the final image is not exactly what you saw in your camera, but has been touched up or altered in some way to make it more esthetically pleasing.

A quality high resolution camera and post processing could allow you almost the same flexibility as the "No Post-Processing" approach with much less hardware cost - i.e. one camera and one scope. The camera "Area Of Interest" feature becomes important in this mode so you are not wasting memory and bandwidth when taking images of objects much smaller than your camera max resolution.

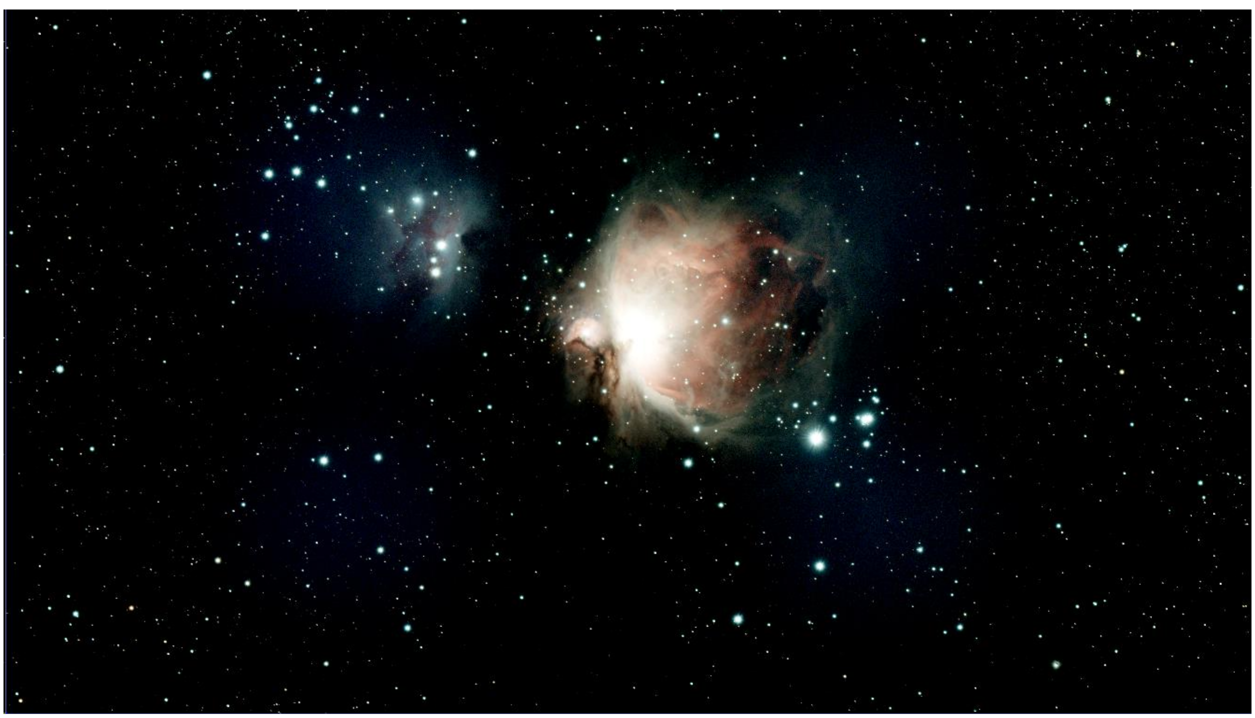
This approach requires that you use Mosaics to "stitch" together lots of small images when creating a wide angle shot. There are many programs that help you do the "stitching" work and in some cases completely automate the work. However, after reading many reviews it seems that the real-world consensus is that automatic Mosaic stitching may be a pipe dream in all but the simplest cases. In which case powerful post processing software and a large commitment of your time is a must if you do Mosaics.

This approach is much cheaper cost-wise as good post-processing software is only a few hundred dollars, but has an EXTREMELY steep learning curve. Some estimates are that it will take you many months before you can use the post-processing tools effectively.

For an in-depth look at post-processing please refer to the Post-Processing document.

The following illustrates what you can do with mosaics. Both images are captured using a Redcat71 and ASI585MC. The first image is a single shot from the camera, and the second is a mosaic composed of 4 overlapping (30% overlap) shots (2^{nd} shot has histogram adjustments.)

You can see how a wider field of view can be achieved with mosaics without any additional hardware (more telescopes) cost.



Solar Observation

Solar observation is different from stellar in many ways:

1. Since it is done during the day, you cannot perform a typical polar alignment.
2. While auto-focus might work, it is really pretty easy to focus manually.
3. Since the sun is extremely bright:
    a. You need to protect your telescope with a solar filter.
    b. You will always use the shortest exposure time possible.
    c. You must not look at the sun with your bare eyes.
    d. You don't need a large aperture telescope and can use a smaller telescope.
    e. You have to be careful not to overheat the telescope and camera internals.
        i. You need to monitor the camera sensor temperature and abort your session when the temperature gets too high. You will see it rising constantly during your session.
4. Since the sun moves at a different rate than the stars you need to change the mount tracking speed to use "solar" (rather than "stellar".)

Special Equipment

To do this requires some extra equipment as pictured below.

First of all, you will need the BuckeyeStargazer Sun Finder (mounted on top of the telescope above.) It seems odd to need a tool to "find" the sun, but since you can't look at the sun, the only way to align the scope is to use the suns image on backscreen cross hairs.

Then you will need a solar filter that is properly sized for your telescope. Since I'm using an Askar FMA180 I chose the Spectrum Telescope Glass Solar Filter: 2.75" Cell Inside Diameter # ST275G. Note that there are cheaper "film" solar filters, but I feel much more comfortable with a real glass filter as the films can crease, tear and develop pin holes that can damage your equipment. You can see the (silver) solar filter attached to the front of the telescope in the image above.

Steps to Record Video of the Sun

Here are the steps that I used to setup the equipment for solar observation. There may be better ways to do this, but this worked pretty well for me.

1. Setup your mount.
    a. If the elevation is not already set from stellar observation set this up for your location.
    b. Point the mount as close to north as you can – don't worry if you are a little bit off.
    c. Change your mount tracking setting from "stellar" to "solar".
    d. Use your mount guiding controls to have it move to the "Sun" and start tracking. Wait for it to complete.
    e. Look in the "Sun Finder" and see where the bright dot is located. If it is not in the center (and it probably isn't), then manually shift your tripod legs around little by little until the bright spot is in the center of the "Sun Finder". You may also have to adjust your elevation slightly.
2. Fine Tuning
    a. Center the sun in the camera frame
        i. Take a picture of the sun.
        ii. If it is not in the center of your frame you will need to adjust the mount slightly – this is best done with the hand controller in "slow" mode – so that the sun moves to the center of the frame.
        iii. Keep taking pictures and moving the mount until the sun is roughly in the middle of the camera frame.
    b. Focus the sun
        i. Take a picture of the sun.
        ii. Move the telescope focus a bit (roughly 5% of full travel.)
        iii. Take another picture and check to see if it is in focus yet – you should see a sharp disk with sun spots on it when it is in focus.
        iv. Keep repeating these steps until you get the sun in focus. If you are seeing the sun disk shrinking as you make each adjustment, then you know you are going in the right direction. When you see it start to grow, you know you went too far.
3. Take Pictures
    a. Normal pictures are the same as normal star pictures.
    b. Typically, you will want to take video of the sun and here the extra things to know.
        i. On my ASI585MC camera, there is a "fine tuning" control below the start/stop control which allows you to fine tune the exposure time as well as the red/blue white balance. You should play with these until the sun image looks good.
        ii. Taking the video on my ASIAIR was pretty straightforward except for the following.
            1. I used the default MPEG setting and it said it saved it but I couldn't find any recorded video. It turns out that MPEG is saved to your phone, and AVI is saved to the ASIAIR storage. So, using AVI works better for me.

Example Video and Notes

Here is an example video that I recorded – this was my first successful video which just happened to have an airplane fly in front of the sun and I left it as it seemed amusing!

Video of the Sun

This is only a getting started section and there is much more that can be done for solar observation including: specialized telescopes, filters, etc.

Sky Conditions

I finally broke down and purchased a Sky Quality Meter (Unihedron SQM-L) to see what my actual observation conditions were in my back yard. Here are the results of my observations.

- For about 40 minutes after sunset SQM is 17.83 or lower (Bortle 9) which is pretty bad.
- 50 minutes after sunset SQM rises to around 18.11-18.26 (Bortle 7) which is OK.
- If I take the reading inside a 2' tube pointing up, it rises to 21.05-21.40 (Bortle 3-4) which is quite good for city observations.

This now explains why I am getting much better images with my Redcat 71 (which has a shield tube that extends about 6" past the front lens) than my Celestron C8 (which has no shield tube, and a much larger aperture.)

I got a dew shield for my C8 (even though I don't have a dew issue) and I think this has made an improvement to the image quality – see Image Quality Progression section.