Cameras

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Overview

Cameras come in either “color” or “monochrome.”

Filters are also used to improve the image quality and take color pictures with monochrome cameras. For more information on filters see – Filters.

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 most 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.

There are several drawbacks to this method because of the Bayer Filter involved.

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. This results in longer exposure times.
2. 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.

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.

Bayer Filters

This is probably the most confusing part of understanding the differences between color and monochrome cameras.

Common Misunderstanding

I originally thought that color cameras use 4 raw sensor elements for each pixel combined with a Bayer Filter on those 4 sensor elements.

For this to work, an 8.29MPixel color camera producing an image with 3840x2160 (8.29M) color pixels – would require the underlying sensor to have 7680x4320 (33.18M) monochrome sensor elements grouped in sets of 4 to produce the actual pixels.

The problem with this is that when you look at the specs for two cameras (color vs mono) made with the same sensor, you will see that they BOTH have the same pixel size and resolution. So, it is impossible for the color camera to be using 4 raw sensor elements for each pixel.

What Actually Happens

Because both versions (color & mono) use the exact same sensor, they MUST have the same pixel size AND resolution – duh, right?

What actually happens with color cameras is that fancy "debayering" algorithms are used to convert the raw "bayered" sensor data into an RGB image. These algorithms rely heavily on interpolating what a given pixel's color value "should be" based on the surrounding raw "bayered" data values read from the sensor.

The image thus produced is a pretty close "guess" or "approximation" of the original image. In most cases, this "guess" is pretty close to reality. In other cases, there will be noticeable distortions due to the interpolation algorithms making an incorrect assumption about certain data – this is usually most noticeable along color boundaries or edges.

This is explained in much more detail in the following Cloudy Nights forum post (specifically this sub-post makes it most clear.)

Another drawback of the "bayer" mask is that only works properly when used in the visible spectrum.

This is why, if you want seriously accurate photos or you want to take pictures outside the visible spectrum, you would choose to use a monochrome camera.

However, if you just want something pretty close with less work, then you would use a color camera.

Planetary vs Deep Space Cameras

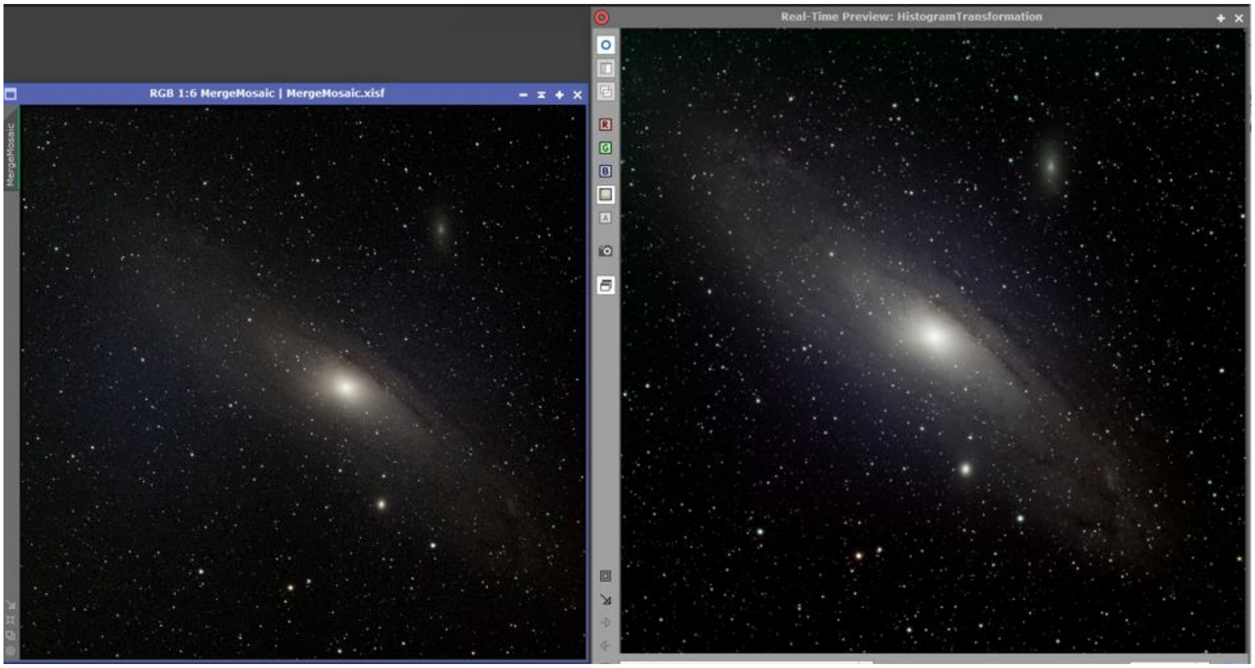
From my experience so far, it looks like planetary cameras (like the ASI585MC) are good for deep space objects with magnitude 4.5 or brighter, but are basically useless for dimmer objects. Likewise, DSO cameras are not very good for taking planetary images. So, there is no “perfect” camera and you will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

Camera Pixel Size Comparison

I initially got the ASI585MC which has a pixel size of 2.9um and took what I thought was a spectacular picture of the Orion nebula. I later got the ASI533MC Pro which has a pixel size of 3.76um, and of course was cooled giving more stable results.

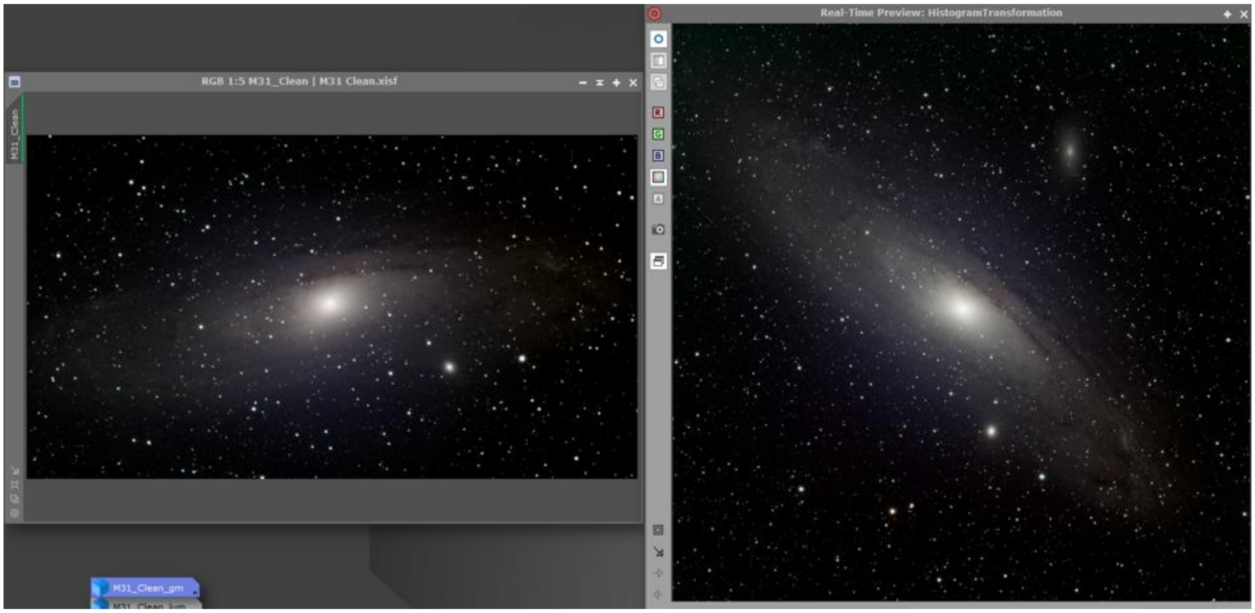
I was initially disappointed in the 533 because it did not 'seem' to me that I was getting as much detail so I decided to also buy the ASI585MC Pro (my previous camera model with the addition of cooling.) I shot a 1x2 mosaic on the 585MC Pro and compared it to the 533MC Pro image I'd shot the previous night.

On the left is the 585MC Pro shot at 252 gain, bin 1, 60 sec. On the right is the 533MC Pro shot at 100 gain, bin 1, 300 sec. The gains are the 'sweet spot' of each camera and the times were adjusted to give similar histogram results. Neither image received any post processing.



The 533 image (bigger pixels) on the right looks better and was much easier to take because it didn't require a mosaic composition. So, my thought that smaller pixels would give better shots didn't seem to pan out.

I then started wondering why it turned out this way. It then dawned on me that the 585 has much smaller well depth and dynamic range (~2.8K/11 at 252 gain) than the 533 (~11K/13.5 at 100 gain.) So, I decided to repeat the experiment with the 585 set to 0 gain (~47K/12) using a longer exposure time of 600 seconds. I didn't bother to do a mosaic for this test so the image is smaller.



This time you can see that the image quality is roughly equivalent between the two cameras. However, I still fail to see any major improvement due to the small pixel size. Since it required double the exposure time on the 585, I would have to say that the smaller pixel size is generally not worth the bother for deep space objects (but the 585 will be my camera of choice for planetary images due to other factors.)

Cooled Cameras

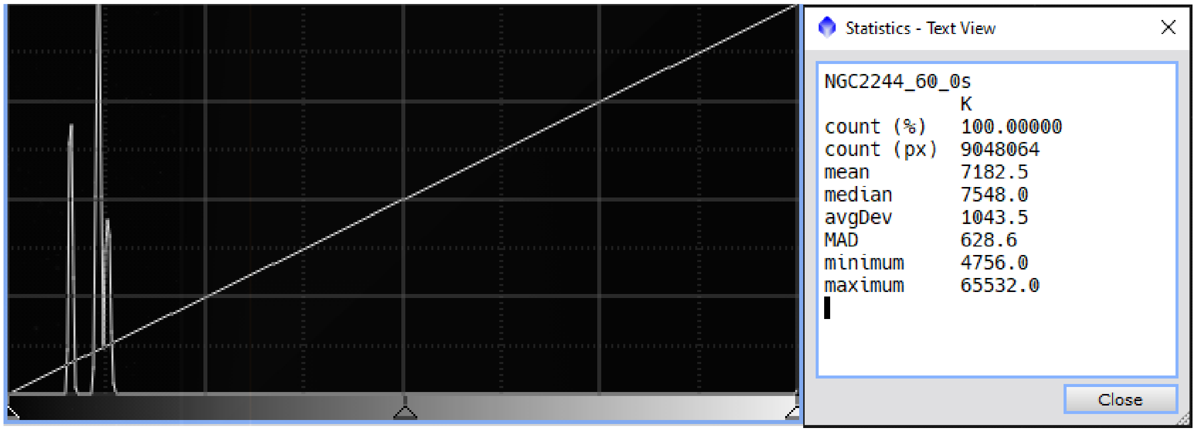
Cooled cameras allow you to take very controlled images by keeping the camera sensor at a specific temperature using an electric cooling unit. This becomes very important when you are trying to apply calibration frames to your image because the calibration frame and the image frames both need to be taken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

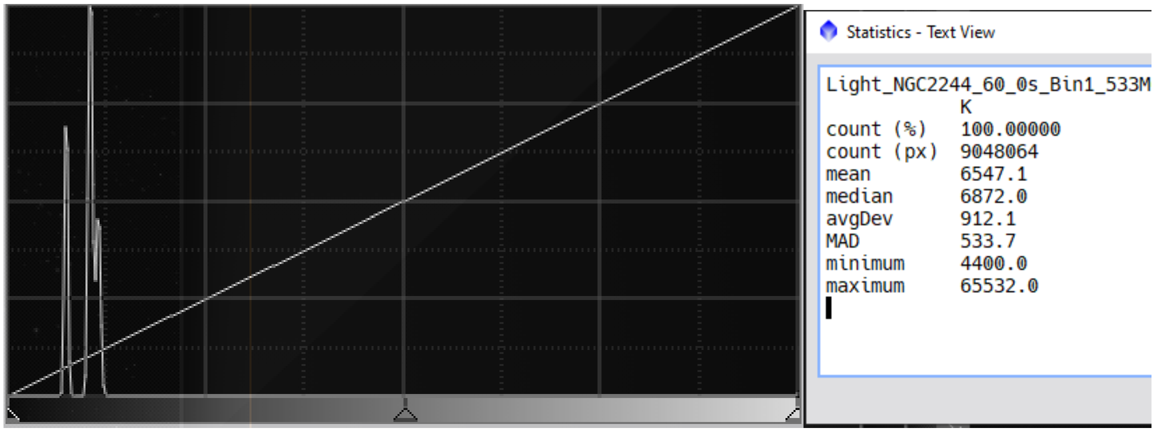
Example Showing Sensor Thermal Sensitivity

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.)



```
NGC2244_60_0s
            K
count (%)   100.00000
count (px)  9048064
mean        7182.5
median      7548.0
avgDev      1043.5
MAD         628.6
minimum     4756.0
maximum     65532.0
```



```
Light_NGC2244_60_0s_Bin1_533M
            K
count (%)   100.00000
count (px)  9048064
mean        6547.1
median      6872.0
avgDev      912.1
MAD         533.7
minimum     4400.0
maximum     65532.0
```

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

Understanding Camera Dynamic Range (DR) and Signal to Noise Ratio (SNR)

There is an excellent article here that explains this very well. I have reproduced a section of it below that I found especially enlightening.

Dynamic range is a hardware thing. It defines the range of discretely discernible tones that the device is capable of registering, and that range is limited by the camera noise (primarily read noise in the case of astrophotography.) As dynamic range tends to DROP as you increase ISO, there is a very specific consequence of that: If you do not concurrently reduce exposure time, you clip the signal more and more. At particularly high ISO settings, the read noise curve flattens out, while the saturation point continues to drop. This forces you to sacrifice more and more faint details in order to preserve brighter details...or, conversely, it forces you to sacrifice more and more bright details in order to expose more faint details.

Additionally, *sensitivity* does NOT increase with increasing ISO. Increasing ISO simply changes gain, it does not increase the amount of light you gather. Sensitivity is purely defined by two things: Pixel area (or more specifically in the context of astrophotography, image scale) and quantum efficiency. These two things affect how many incident photons actually convert to charge. It is that charge that is then amplified by gain...however gain does not actually increase the amount of sensed photons, it only multiplies the electrons released into the photodiode by those photons. If you did not sense photons for faint details, increasing gain cannot reveal them either. ISO plays no role in sensitivity.

Technically speaking, images have SNR, not dynamic range. When it comes to SNR, stacking lots and lots of very high ISO or high gain frames is actually not the same as stacking fewer low ISO or lower gain frames. And, you do need to stack LOTS AND LOTS of high ISO frames...not fewer. The reason, again, is read noise. Read noise is a time-invariant constant addition of noise to every single frame. With shorter frames, read noise is actually a larger contributor. If you look at the formula for SNR, it should become apparent why stacking more high ISO frames is not necessarily going to be as good as stacking fewer low ISO frames:

SNR = (Sobj * Csubs)/SQRT(Csubs * (Sobj + Ssky + Sdc + Nread^2))

Let's say read noise is 1.6e- at ISO 2000 and 1e- at ISO 25600. Let's say you have a 100e- object signal at ISO 2000 with a 300s exposure, a 250e- skyfog signal (say green zone), 0.01e-/s/px dark current. You gather 50 subs at ISO 2000, and 800 subs at ISO 25600 (at a sixteenth the exposure).

SNR2000 = (100 * 50)/SQRT(50 * (100 + 250 + 3 + 1.6^2)) = 5000/SQRT(50 * 355.56) = 5000/SQRT(17778) = 37.5:1

SNR25600 = (6.25 * 800)/SQRT(800 * (6.25 + 15.625 + 0.1875 + 1^2)) = 5000/SQRT(800 * 23.0625) = 5000/SQRT(18450) = 36.8:1

This is not a huge difference in SNR...it's about a tenth of a stop, however it goes to show that at the significantly higher ISO, which you are currently assuming is "more sensitive" (a common fallacy, your not the first to assume that! ;P), you are not actually gathering more signal, and because of the fact that your multiplying read noise over so many frames, you actually have less SNR in the end. However there is a much bigger problem here. If you choose to use the higher ISO...you now have EIGHT HUNDRED SUBS to deal with. You have to gather them, you have to store them, you may have to move them around from one place to another (i.e. from imaging laptop to desktop computer), you have to calibrate them all, demosaic them all, register them all, and finally integrate them all. High ISO subs, because of the increased relative noise in each, tend to be larger in terms of file size than lower ISO subs. So not only are you storing eight hundred of them, your storing eight hundred larger files than if you had used 50 lower ISO images. Let's say the files are 25 megs each for the ISO 25600 images and 20 megs each for the ISO 2000 images. By opting to use the higher ISO, you need TWENTY GIGS of storage space, vs. the mere 1 gig you would have needed with the 50 ISO 2000 subs. You need to expend significantly more CPU cycles (hours and hours vs an hour or less) and massive amounts of memory to calibrate all of those subs, and that will produce another twenty gigs worth of files (at least, FITs files for example tend to be larger, my 22.3mp 5D III ones are 86 megs, so I'd figure on ~46 megs each for a 12mp image...that means 40 gigs of data!). Demosaic those calibrated files, you have another 40 gigs of data. Register those and you have another 40 gigs of data. All told, we are now at 140 gigs of data just to acquire and pre-process 800 ISO 25600 subs. 😉

This is also a fairly idealized use case. The A7s has very low read noise at ISO 2000 thanks to it's high gain mode. Most DSLRs don't have that, and read noise tends to flatten out around ISO 1600-3200 at around 2-3e- in most cases. So imaging higher than ISO 1600 on most DSLRs often results in a much more significant hit to SNR than the more ideal case with the A7s I've demonstrated here. For example a 6D has a difference of 37.3dB @ ISO 2000 vs. 36dB @ ISO 25600, a difference of about a quarter of a stop. In the case of my 5D III the difference would be half a stop. When we are talking about very long integration times in the realm of hours here, half a stop is significant. For two hours at ISO 2000, I would need a whole extra hour at ISO 25600 to get the same SNR. It's still another 12 minutes with the A7s, and at ISO 25600, that is another 39 subs...which is another 975 megs of disk space (which then percolates along the pre-processing chain, compounding your disk space usage as you go.)

Thankfully, read noise is one of the least of our problems in most cases. Few imagers have the luxury of imaging under 22mag/sq" skies all the time, so we all suffer from some degree of light pollution. The majority of imagers are in the city, where read noise is basically meaningless in the face of massive amounts of noise from light pollution (where read noise may be 2-5e-, shot noise from LP can top 50-60e-, in a white zone it may even top 70e-). Even those imaging in a green or light blue zone are likely to have just enough LP to swamp read noise (although read noise does play a larger role when you get to skies over ~21.3mag/sq"). Dark current is also usually a more significant contributor, especially with DSLR/Mirrorless outside of winter. Dark current can potentially even become the most significant contributor to noise in yellow and green zones, or if you have a particularly noisy camera (a 6D for example, has as much as 3-5e-/s/px dark current around 26-30C!) Even with Canon cameras and the A7s, where read noise starts to ramp up as you get to lower ISO levels, read noise levels are still low enough that they don't contribute significantly compared to LP and dark current.

So, if you have the ability to track well enough for longer exposures, there are not many good reasons to gather hundreds upon hundreds of ultra high ISO subs. Because you can usually expose significantly longer per sub at lower ISO, as low even as ISO 400, having 10e- or so worth of read noise does not result in any more of a drop in SNR than you'd get by using ISO 25600 vs. ISO 2000 on an A7s. With 7.9e- RN @ ISO 400 on the A7s, you would have an SNR of 36.2:1 with a mere 9 subs. If you added one more sub for a total of 10, you would have an SNR of 38.1:1. Now you'll only use 200 megs of disk space, and pre-processing those 10 subs will take a tiny fraction of the time.

Dynamic range defines a characteristic of the camera. It's an interesting characteristic, that ultimately tells us how much of our signal we might clip if we are imaging brighter objects (big bright stars, or something very bright like Orion Nebula), but it is not nearly as important as SNR. SNR is what we as astrophotographers really care about. SNR is a characteristic of the image, of the signal our images contain. While it is possible to acquire the same SNR at different ISO settings by adjusting sub counts a little here or a little there, it tends to be far easier to use longer subs at lower ISO, and deal with storing and processing fewer of them, than shorter subs at higher ISO, and have to deal with hundreds or thousands of them.

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.

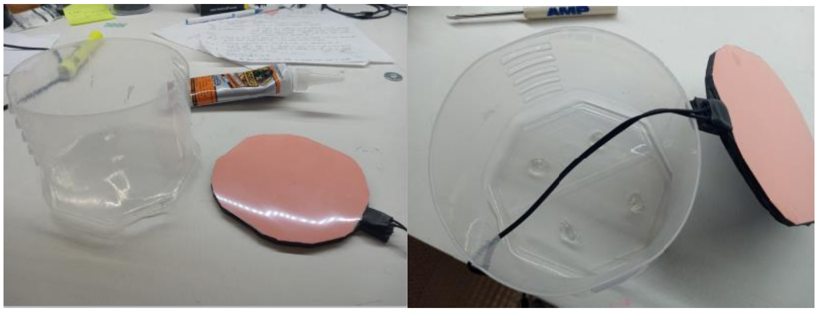
That's it! Now you can hang the assembly on your telescope objective and take your flat frames.

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.

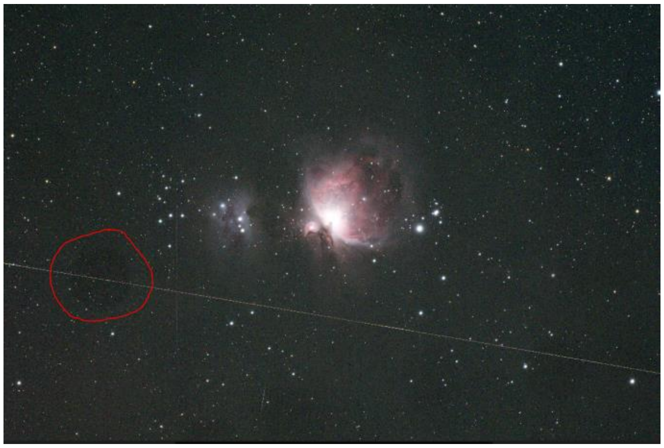
For example, when taking the ‘dark’ frames you immediately see that, even though no light is reaching the sensor, the calibration frame image is a light grey color! You would expect the image to be black, but it isn’t. So, if you want your black backgrounds to be blacker, you will want to use the dark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

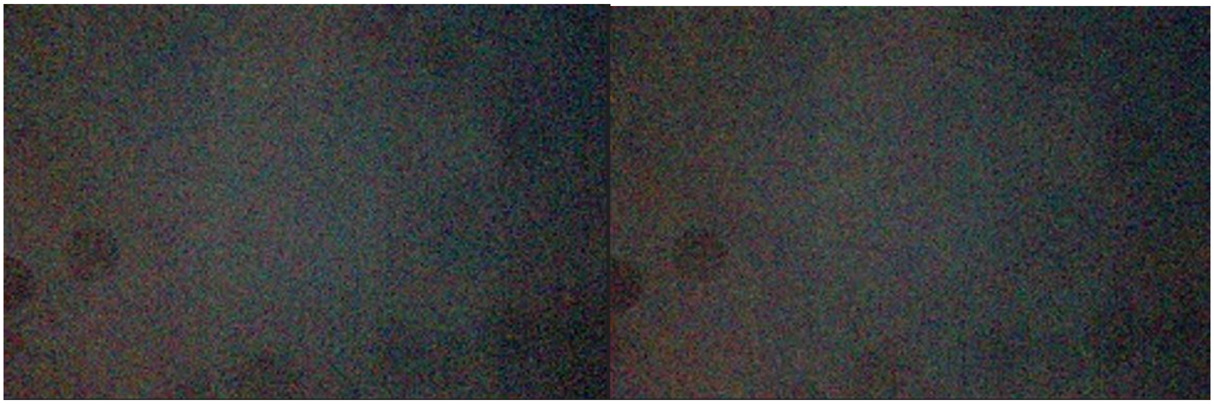
This clearly highlights why you might want to spend more money and get a camera with a “cooler” built-in so that your images are taken at a constant, lower, temperature – which causes less distortion to your final image.

Using Flat Frames to Isolate Dirt in your Light Path

After doing some quick shots testing out a new camera, I noticed what appeared to be several "circles" that appeared to be darker on the images – see example highlighted in red below.



Fearful that I had received a defective camera, I used flat frames to isolate the problem. Taking images at 0.1sec exposure resulted in the images below. The left image was the initial image, and the right image was the same setup except for the camera was rotated 15 degrees.



As can be seen the "spots" did not rotate – indicating that they are in the camera, and not the telescope. After cleaning the camera lens, it can be seen below, that all of the spots went away – thereby proving that the camera was working properly but had a dirty lens.

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.

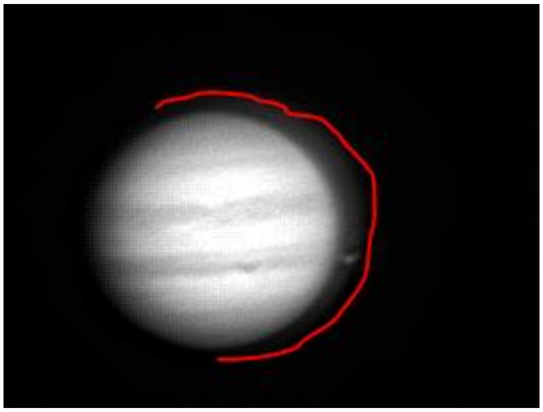
So, once you understand this the workflow everything becomes more natural. Here are the steps you should take to generate an image that you will be happy to share with people.

- 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 of the Focus Document 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.

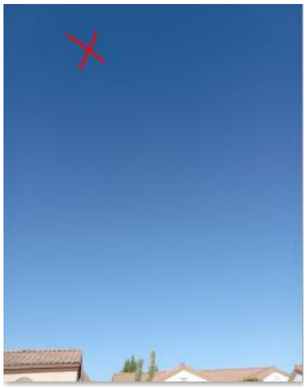
Taking Pictures Over a Hot Roof

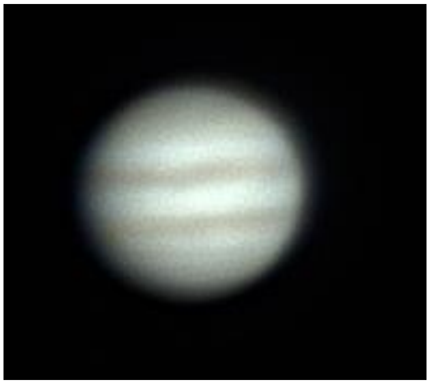
If you zoom in on the image of Jupiter taken in a prior section, you will notice a blurry 'halo' around the right side of the planet (see below left.) This was taken from a video shot from my back yard over the edge of my house roof (see below right, 'x' marks Jupiter's position.)



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.

Taking Pictures of Planets (Magnification Issues)

For more information about better ways to photograph planets see the following link: Planetary Video.

I initially started in astronomy taking pictures of the moon, Jupiter, and Saturn using some pretty basic equipment. I then moved on to more stunning DSO and got a lot of better equipment in the process. At some point I came back and tried to take a picture of Jupiter and Saturn using my new high-quality equipment. Much to my surprise, the shots were really crappy and the planets showed up as tiny dots in the frame (see Saturn below.)

This was taken with my C8 with an ASI585MC Pro directly connected to the back (no lenses between the scope and the camera.) I spent a bunch of time wondering if my scope and/or camera just wasn't right for this application but I couldn't find anything wrong with them. With an f/10 scope and camera using 2.9u pixels that seemed about as good as you could get (other scopes only go up to f/12 or so, and 2.9u was the smallest pixel size I could find.)

I even used video with AutoStakkert and then zoomed in on final image to get the following results, but it was little better and didn't show any more significant detail.

I then remembered some experiments I had done a year ago using eyepiece projection with a 25mm Televue on my C8 which produced much better results (see below taken with C8, ASI585MC, Televue 25mm eyepiece, and SVBONY variable projection eyepiece adapter.)

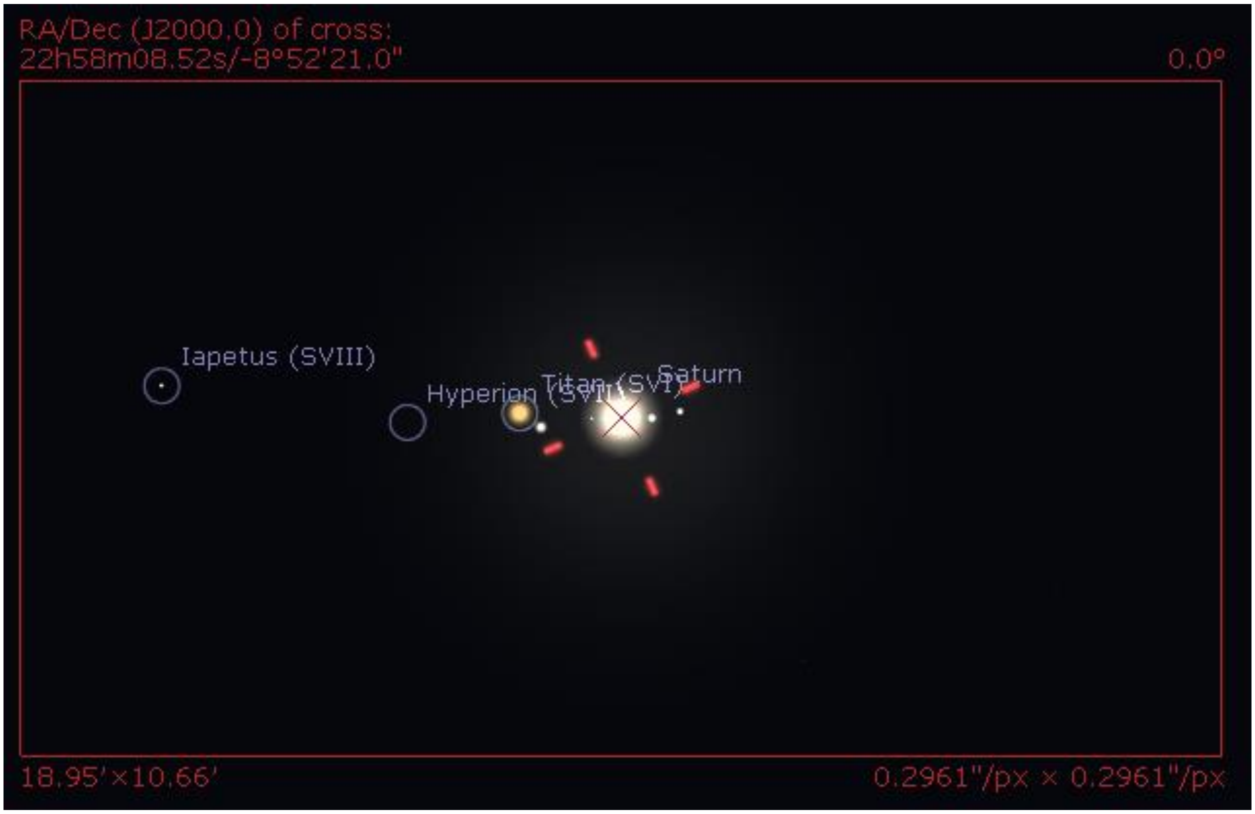
So here you can see side by side the difference (same camera – except for cooling, same telescope)

No Eyepiece Projection (tracking)   25mm Televue Eyepiece Projection (no tracking)

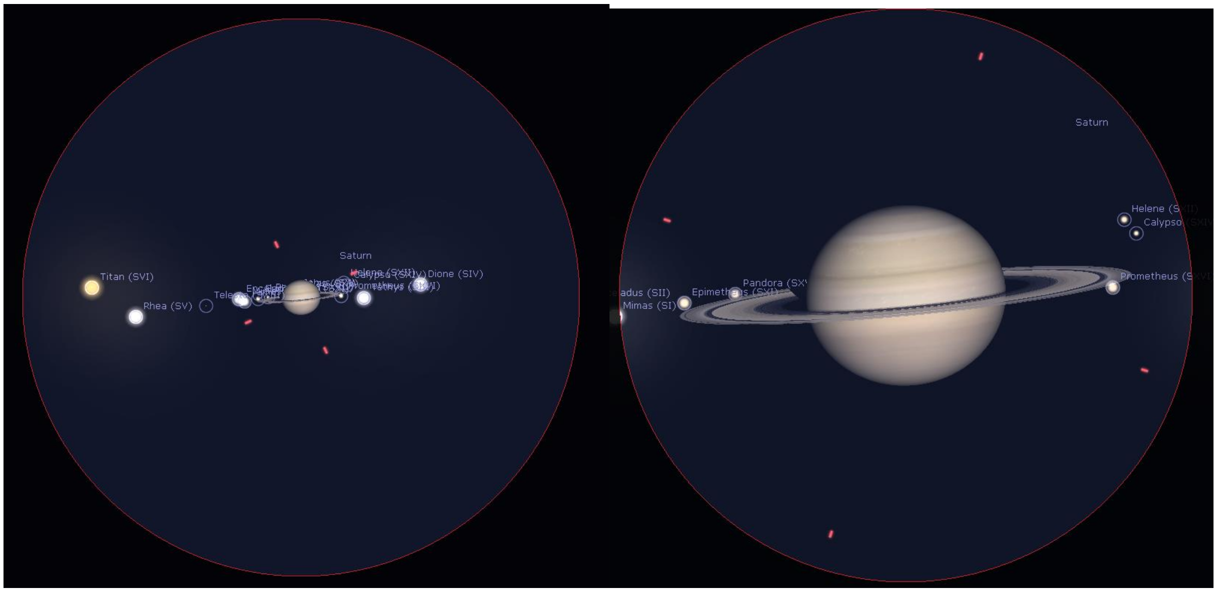
I remember that the 25mm Televue was the most magnification I could use when I took the shot on the right – because I did not yet have a tracking mount and only had a second or so to take the picture before it wandered out of frame. With a tracking mount, more magnification can be used to produce a sharper image on the camera.

The image below is the SVBONY projector – eyepiece goes in (A), camera mounts on (B). You could also use Barlow lenses, but I like this method because it allows continuous magnification over a large range simply by extending/retracting the tube.

In theory (using Stellarium simulations) this is what you would see using just the C8 and ASI585MC camera:



Versus what you would *theoretically* see by putting a 2.5mm lens in the path (left) and 2.5mm + 5x Barlow (right):



However, reality tells a different story. Trying to use a 2.5mm eyepiece on my C8 clearly exceeds the C8 maximum magnification because, even on a calm day with no wind, the image was bouncing all over the place. And it was extremely difficult to focus – without any Barlow or projection tube.

I then backed off and tried a 4.0mm eyepiece, which was more practical, but still a little unstable.

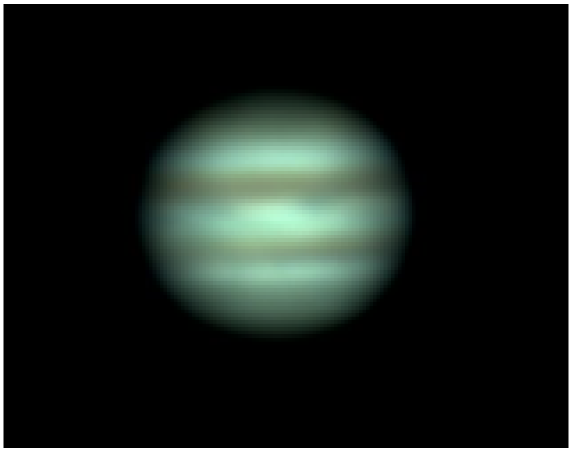
I then tried a 6.0mm eyepiece which was reasonably clear and stable. As you can see below (top image), the Stellarium simulation with 6mm eyepiece is slightly better than the no eyepiece scenario, but still not ideal. Ideally, to get good planetary shots with lots of detail would require a larger aperture scope like the C14 (bottom image – with no eyepieces.)

Taking Pictures Low vs High in the Sky

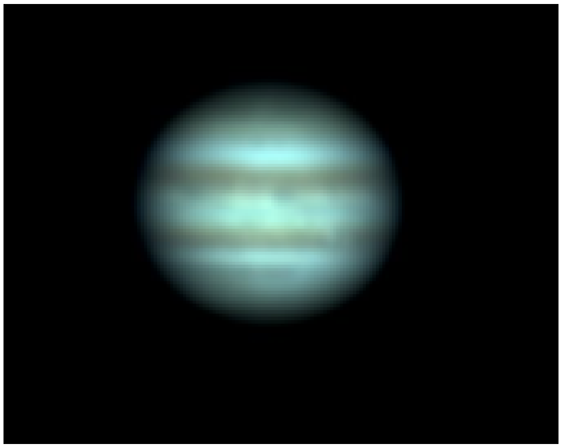
Because of the fact that you are looking through more, often swirling (due to heat eddies), air lower in the horizon, your pictures are not going to look as good as when you take them directly overhead.

The following two 5 second movie clips of Jupiter illustrate this point. Note that both sets of images were taken on the same evening through high thin clouds so they are both less than ideal.

Jupiter at about 35 degrees above the horizon: AVI Movie Clip which resulted in the following image after stacking a minute of video:



Jupiter at about 90 degrees (straight above) above the horizon: AVI Movie Clip which resulted in the following image after stacking a minute of video:



As you can clearly see, the second image is MUCH cleaner and shows more detail.