Imaging with Dedicated Digital Astronomy Cameras

TCAA Guide #13

TWIN CITY AMATEUR ASTRONOMERS

ESTABLISHED 1960

IMAGING WITH DEDICATED DIGITAL ASTRONOMY CAMERAS

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ABOUT THIS GUIDE:

Imaging with Dedicated Digital Astronomy Cameras – the thirteenth TCAA guide, providing detailed information on various areas of amateur astronomy – was created to support a new phase of amateur astronomy. Digital imaging is easier than analog photography (film), and modern camera and telescope controllers are making it even easier. This guide describes how to use the ZWO ASi system, including controller, camera, filter wheel, image rotator, and focuser (the latter of which will be addressed in the next version of this guide, which is still under development).

MOTIVATION:

As I started learning about B&W, narrow-band, and one-shot color astrophotography, I decided to share as I learn to encourage others to join me. While I've created this narrative to show my learning process, I've also used AI to gather, organize, and present information… This series of articles will culminate in the publication of TCAA Guide #13: Imaging with Dedicated Digital Astrophotography Cameras.

SOURCES:

The author points out that the idea for the general layout of this guide was based on general learning about digital astrophotography. He freely acknowledged that much of the content was enhanced by querying ChatGPT for additional supporting information. He concedes that significant portions of this guide were produced in cooperation with artificial intelligence, but notes that he substantially revised most parts of it and checked everything for accuracy. All process steps were confirmed with hands-on experience. Any remaining errors are solely the responsibility of the author.

A WORD OF THANKS:

TCAA member Deva Chatrathi reviewed this document and pointed out several items that needed correction and further explanation. He also provided suggestions about how to improve the content of this Guide.

About the Author:

Dr. Carl J. Wenning is a well-known astronomy educator in Central Illinois. In the summer of 1957, he started observing the skies under his grandfather's guidance. Since then, he has been viewing the night sky for almost 7 decades. He earned a B.S. in Astronomy from Ohio State University, an M.A.T. in Planetarium Education from Michigan State University, and an Ed.D. in Curriculum & Instruction with a focus on physics teacher education from Illinois State University.

Dr. Wenning served as the planetarium director at Illinois State University from 1978 to 2001. He worked as a physics teacher educator from 1994 to 2008. After retiring in 2008, he continued teaching physics and physics education courses for another seven years. He also consistently taught astronomy and physics lab science at Illinois Wesleyan University from 1982 to 2001. He officially retired from Illinois State University in 2014 after nearly 40 years of teaching at the university level. From 2019 to 2021, he taught physics at Heartland Community College. Since 2025, he has been teaching astronomy at HCC.

Carl became affiliated with the TCAA in September 1978, shortly after he was hired at Illinois State University. Today, he is an Astronomical League Master Observer, having completed about 20 observing programs, and received the 2007 NCRAL Region Award for his contributions to amateur astronomy. He is a lifelong honorary member of the TCAA and belongs to its G. Weldon Schuette Society of Outstanding Amateur Astronomers. He served six years as chairperson of the North Central Region of the Astronomical League (2017-2023), covering Illinois, Iowa, Wisconsin, Minnesota, North and South Dakota, and the Upper Peninsula of Michigan. He co-teaches Astro Camp for youth at YMCA Camp Eberhart near Three Rivers, Michigan, each summer (2023-2025). In retirement, he now teaches Astronomy at Heartland Community College in Normal, Illinois.

During the summer of 2025, at Lisa Wentzel's urging, I acquired a ZWO ASi585MM B&W (monochrome) camera along with an ASiair mini controller. After seeing Lisa image the night sky with an identical system, I decided it would be interesting to add another dimension to my amateur astronomy. I hoped to follow in her footsteps, as well as those of earlier TCAA members such as Lee Green, Bob Finnigan, Tim Stone, and Tony Cellini, who used CCD cameras to photograph the skies. Recently, members like Lisa and Doug Reynolds have been doing advanced astronomical imaging with CMOS cameras, broadband and narrowband filters, and post-processing. I had resisted this trend for a long time because of prior experiences with astrophotography as an undergraduate in Astronomy at The Ohio State University. Still, after seeing how easy the ASiair controller made it, I decided to give it a try.

The ZWO Asi585MM camera has a planetary imaging sensor measuring 11.13 mm by 6.26 mm, with a resolution of 3840 x 2160 pixels. This results in a pixel size of 2.9 µm. A full-resolution image (1x1 binning) creates a file of about 8.3 megapixels. A chiller was added to the camera's Sony IMX585 sensor to improve its performance for deep-sky imaging. Having recently worked with this camera, its controller, and several telescopes, I can say I have learned a lot, with more to learn. In summary, here are some lessons I've gained through reading, asking experienced users questions, using AI tools like ChatGPT, and through trial and error.

Focus is essential. I start each imaging session by achieving the sharpest focus possible. This produces the smallest star images. Since stars are point sources, the smaller they appear in photos, the better the focus. Atmospheric conditions will determine how small the star images can be. On nights with average seeing, stellar images are about 2-3 arcseconds across; on clearer nights, they might be around 1 arcsecond. Precise focus is important not only for capturing realistic images but also to ensure the controller performing plate solving (finding the exact center of an image) has enough stars to work with. Out-of-focus, non-pinpoint stars cannot be used for plate solving.

A UV/IR cut filter is crucial when imaging with a monochrome camera. B&W cameras are sensitive to a wide range of wavelengths. Through experimentation, I discovered that the Asi585MM camera sensor lacks UV and IR cut filters, which can negatively affect focus. A combined UV/IR cut filter (also known as a luminance filter) blocks wavelengths that the telescope cannot focus accurately. Refractors, Schmidt-Cassegrains, and most other telescopes are designed to focus visible light (approximately 400–700 nm) onto a camera's image sensor. They *do not* focus ultraviolet (UV) or infrared (IR) wavelengths in the same position. This is because a lens focuses IR light *behind* the camera's image plane, while UV light is focused *in front* of it. Camera sensors can detect UV and IR light. If these wavelengths are not blocked, the results include bloated stars, soft images, loss of contrast, and reduced sharpness.

Focal reducers and focal ratio. A focal reducer, also called a *telecompressor*, shortens a telescope's focal length. For example, a 2000mm focal length objective with an f/10 focal ratio combined with a 0.63X telecompressor results in an effective focal length of 1260mm and an effective focal ratio of f/6.3. Focal reducers have three main effects: they reduce the focal length, widen the field of view, and make the telescope "faster." A faster system (smaller focal ratio) means shorter exposure times, a higher signal-to-noise ratio in the same amount of time, and more light captured per pixel each second.

Field flatteners are different from focal reducers. Refractors, especially ED doublets and triplets, naturally project a curved focal plane. A field flattener adds counter-curvature to create a flat field of view. Reducers and flatteners are sometimes conflated because some devices combine both functions in a single unit (*reducer–flattener*), but they are fundamentally different devices. Celestron's 0.63X telecompressor is designed to do two things: reduce the focal length of an f/10 SCT to f/6.3 *and* correct (flatten) the curved field produced by Schmidt–Cassegrain telescopes. So, although it isn't called a "field flattener," it *still* flattens the field as part of its optical design.

Field flatness is essential for capturing a good image. If accurate focus is not maintained across the entire image plane, stars—which are actually point sources—will exhibit coma near the edges. Coma is an optical aberration in which a star appears distorted into a comet-like shape instead of a point because the focal points fall on a curved field, while the imaging sensor is flat. A field flattener corrects this curvature so that light rays from all parts of the field focus on the same plane—the flat image sensor of the camera.

Back focus is critical in astrophotography under certain conditions. When telecompressors or field flatteners are used in the optical train, back focus becomes vital. Back focus is the required distance between the last optical element and the camera's image sensor. This distance must be set accurately to produce sharp, coma-free, aberration-free images across the entire imaging plane. For most flatteners and reducers used with an SCT (e.g., the Celestron 0.63X Focal Reducer/Corrector), the typical back-focus requirement is 105 mm. If the back focus spacing is too short, stars radially elongate outward from the center, corners show increased spherical aberration, and the overall image scale slightly increases. If the back focus spacing is too long, stars elongate tangentially (along the edges), corners may exhibit astigmatism, and vignetting may worsen.

Polar alignment and accurate tracking are essential. When taking exposures longer than a few seconds, field rotation becomes a concern. With an altazimuth mount, the image appears to roll. This distortion can be minimized with short exposures and further reduced by imaging specific areas of the sky, but it cannot be entirely avoided. Equatorial mounts, such as those made by Astro-Physics and Celestron, are either German equatorial (e.g., A-P 1100, CGEM) or yoke mounts (e.g., CPC). These mounts can only track celestial objects with single-axis motion when properly polar-aligned, which prevents image rotation. Longer exposures are only possible with a polar-aligned Right Ascension axis. Polar alignments within 5 arcseconds of the North Celestial Pole are acceptable, with 3 arcseconds being ideal.

Image size should roughly match a telescope's focal length. I started B&W imaging with my CPC 8" telescope at the native f/10 focal ratio, then used a 0.63X telecompressor, which gave me a 1280mm EFL and a wider field of view, but a smaller target. One of the first lessons I learned was that it's crucial to match the telescope to the object being imaged.

Within a few days of using my CPC 8", I became eager for both wider and narrower fields of view. I decided to start imaging with the 130mm A-P Starfire refractor at PSO. It has a native f/8 focal ratio and a focal length of 1080 mm. That was certainly an improvement. Still, I wanted more. In November, I bought a small refractor—the Astro-Tech 80mm ED. This one has a f/7 design with a focal length of 560mm. After mounting my AT80ED on the Celestron EdgeHD 11" at PSO, I realized I could also use the larger telescope in its native f/10 mode with a focal length of 2800mm. I also learned that the Celestron 0.63X telecompressor is not compatible with EdgeHD optics.

What are the pixel scale (arcsec/pixel) and fields of view using the ZWO Asi585MM camera with various telescopes and configurations? Table 1 (shown below) provides the necessary data. These figures assume good atmospheric seeing that produces a typical 2” star image. The telescopes listed include a mix of my personal ones (marked with an asterisk) and club telescopes, all available to club imagers.

Telescope & Configuration	Focal length (mm)	Pixel scale (″/pix)	FOV (W × H, arcmin)	Sampling with average seeing
11” EdgeHD f/10	2800 mm	0.214″/pix	13.67′ × 07.69′	strongly oversampled
8” CPC* f/10	2032 mm	0.294” pix	18.83′ × 10.59′	oversampled
8” CPC* f/6.3	1280 mm	0.467″/pix	29.89′ × 16.81′	oversampled
130mm A-P Starfire f/8	1080 mm	0.555″/pix	35.40′ × 20.00′	slightly oversampled
80mm A-T ED* f/7	560 mm	1.068″/pix	68.33′ × 38.43′	close to ideal

Table 1. *Imaging characteristics as a function of focal length for 2” seeing.*

Object size and field of view should roughly match. It’s important to select the right focal length for the camera to ensure the entire image fits within the frame without needing to stitch multiple images together. Looking at Table 1, it’s clear that observers should choose a focal length so the object being imaged fills a significant part of the picture frame; otherwise, one might end up with a large field of stars and a very tiny object that shows little detail. Of course, it’s also possible to overmagnify an object, making it so large that only part of it can be captured in a single shot. Consider the angular sizes of different subjects in Table 2 below.

- Crab Nebula (M1): ~6′ × 4′
- Ring Nebula (M57): ~3.8′ × 2.7′ (≈ 230″ × 160″)
- Andromeda Galaxy (M31): ~190′ × 60′ (≈ 3.17° × 1.0°)
- Orion Nebula (M42): ~65′ × 60′ (the bright nebula + extended emission; core is smaller ~20′)
- Omega Nebula (M17): ~11′ × 6′
- Dumbbell Nebula (M27): ~8′ × 5′
- Pleiades star cluster (M45): ~110′ across (roughly ~2° across the main bright area)
- Hercules globular (M13): ≈ 16.6′
- Trifid Nebula (M20): ≈ 28′ × 28′
- Lagoon Nebula (M8): ≈ 90′ × 40′
- Wild Duck Cluster (M11): ≈ 14.0′
- Helix Nebula (NGC 7293): The size of the inner disk is ≈ 8′ × 19′ in diameter; the outer torus is ≈ 12′ × 22′ in diameter, and the outer-most ring is ≈ 25′ in diameter.

Table 2. *Typical approximate angular dimensions (major × minor) in arcminutes for commonly imaged celestial objects. Sizes vary depending on how the object is defined (bright core vs. faint halo), so the values provided are common, conservative estimates.*

For imaging M1, M57, M17, and M27, a focal length of 2800 mm is ideal, considering the available telescopes. Larger objects like M42, M8, and NGC 7293 (the Helix Nebula) require a shorter focal length and a wider field of view to be fully captured.

Images of celestial objects can be oversampled or undersampled. Table 1 provides another insight I gained about imaging. With *oversampling*, you can end up with large files and minimal extra detail; in that case, consider binning (2×2 or more) or reducing the focal length to improve the signal-to-noise ratio and decrease data volume. With *undersampling*, stars appear blocky, and the details that the optics should reveal are not visible in the image. In this situation, increase the focal length or use a Barlow lens in the optical path.

Binning should be used to advantage, not ignored. What is binning, and how does it influence your imaging? When you "bin" sensor pixels into groups such as Bin 1 (1X1), Bin 2 (2X2), or Bin 3 (3X3), you gain control over over- and undersampling. In 1X1 binning (which is not really binning at all), each pixel on the camera's sensor array is read individually, allowing full resolution capture. This provides the lowest signal per pixel (each pixel gathers its own photons) and is ideal for high-resolution imaging and good seeing conditions. However, it also results in the highest noise per pixel but offers more detail. In 2x2 binning, groups of four pixels combine into one two-by-two "super-pixel." The effective pixel size doubles, increasing the signal by 4 (since 4 pixels are combined), thereby enhancing sensitivity and improving the signal-to-noise ratio, albeit at half the resolution (which is acceptable if you're oversampling the image). This also leads to faster image download speeds and smaller file sizes. 2X2 binning is especially useful for narrowband imaging, where filters reduce image brightness, for capturing faint targets, and for use under poor seeing conditions. Similar effects are achieved with 3X3 and 4X4 binning. Binning can also be used to advantage during plate solving. If having difficulty with too few stars recognizable in a field, binning 2X2 will increase the number of stars visible to the sensor.

It should be noted that, unlike CCDs, modern CMOS sensors perform "binning" digitally, meaning there is no true hardware binning; pixels are combined *after* readout. This leads to data reduction, a smoother noise profile, and faster downloads. However, you do NOT gain increased full-well capacity or reduced read noise, as with CCD binning. Nonetheless, this allows for faster plate solving, quicker focusing, and better matching of image scale to viewing conditions. Table 3 can help determine which binning options to consider under various seeing conditions.

Seeing Quality	**Pixel Scale Goal**	**Recommended Binning**
Excellent (0.8–1.5″)	0.3–0.8″/pixel	1X1
Average (2–3″)	0.8–1.5″/pixel	2X2
Poor (3–5″)	1.5–3″/pixel	2X2 or 3X3

Table 3. Recommended binning as a function of seeing quality.

Images of celestial objects should be dithered. In astrophotography, dithering means intentionally shifting the telescope's pointing by a small, random amount between exposures so that stars and the target fall on different pixels each time. This slight movement helps "average out" fixed-pattern noise such as hot pixels, banding, and amplifier glow when the images are later stacked, because the noise stays in the same pixel locations while the sky moves. As a result, stacking software can more effectively reject or smooth out those artifacts, producing a cleaner, smoother final image with higher signal-to-noise ratio and fewer visible defects. This can be set only in Asiair's plan mode.

Anyone who has ever used a DSLR or mirrorless camera knows about the ASA or ISO setting. ASA (American Standards Association) was the original film-speed rating that indicated how sensitive photographic film was to light; today, digital cameras use the ISO scale, which is essentially the modern continuation of ASA. In practical terms, the ASA (or ISO) setting on a DSLR controls the sensor's sensitivity: a low value such as ISO 100 means low sensitivity, producing cleaner images with little noise but requiring brighter light or longer exposures, while a high value such as ISO 3200 increases sensitivity, allowing photography in dim light but introducing more grain or digital noise. Adjusting the ISO/ASA setting is one of the three pillars of exposure—along with aperture and shutter speed—giving photographers flexibility to balance brightness, motion blur, and image quality.

Camera gain can be adjusted to improve imaging. In astrophotography cameras, gain is the equivalent of ISO/ASA, affecting the sensor's sensitivity. Changing the gain alters how many electrons each pixel in the sensor collects from incoming photons. When the image is read, each pixel's digital value or ADU (analog-to-digital units) is recorded; ADU equals Electrons multiplied by Gain Conversion. Lower gain results in fewer ADU per electron, meaning weaker amplification, while higher gain produces more ADU per electron, indicating stronger amplification.

Gain is associated with the dynamic range of the imaging sensor. Low gain produces HIGH dynamic range. Each pixel can store more electrons before saturating. This is good when imaging bright stars + faint nebulosity in one exposure. High gain produces LOWER dynamic range. Pixels saturate sooner because fewer electrons reach the maximum digital value. There is a trade-off here: low gain preserves highlights; high gain risks clipping stars. Read noise is also associated with the gain setting. High gain is associated with lower read noise, whereas low gain is associated with higher read noise. At high gain, the camera's electronics amplify the signal before readout, so the read noise becomes a smaller part of the total. High gain produces brighter-looking image for the same exposure time, whereas low gain produces dimmer image. This does *not* create more actual signal photons — just amplifies what is captured. But it does allow stacking software to make better use of low-electron signals. Modern CMOS cameras often have a "sweet spot" where read noise drops dramatically. This is called Unity Gain.

Gain can also be used to advantage. Full-well capacity is the maximum number of photoelectrons a pixel in a digital image sensor (CCD or CMOS) can hold before it becomes saturated. Each pixel acts like a tiny "bucket" that collects electrons generated by incoming light; once the bucket is full, additional electrons spill over or are lost, causing bright stars or features to be clipped and lose detail. A higher full-well capacity allows a pixel to record a wider dynamic range—capturing both faint and bright details in the same exposure—while a lower capacity fills more quickly and risks saturation. Full-well capacity is a function of gain. Low gain produces a larger effective well depth (maximum electrons per pixel), whereas high gain produces a smaller effective well depth. At high gain, fewer electrons are needed to max out the pixel's digital output. For example, with gain set to 0, the full-well depth of a pixel might be 40,000 e^-. With a gain set to 300, the full-well depth might be only 5,000 e^-. At low gain, stars are smaller and better shaped; at high gain, they are more easily blown out.

Sensor temperature can significantly impact image quality. Cooling the sensor reduces thermal noise (dark current), which can build up during long exposures and show up as graininess or hot pixels in astro-images. By cooling the sensor to a stable, low temperature (typically –10°C to –20°C), the camera produces cleaner data, significantly enhances the signal-to-noise ratio, and ensures that dark frames match your light frames because dark current varies with temperature. Typically, the temperature can be left at its default value unless there is a problem with dark current.

Exposure lengths can make a difference. Gain influences exposures. So, which is better: ten 30-second exposures or thirty 10-second exposures? When stacking images, both patterns result in 300-second images. Experience has shown that high-gain and short exposures are advantageous for planetary imaging, electronically assisted astronomy (EAA), very short deep-sky exposures, and “lucky” imaging. When read noise is minimized, the faint details become clearer. Low- to medium-gain is more suitable for traditional long-exposure deep-sky astrophotography, as it preserves dynamic range and prevents stars from saturating.

Gain plays an essential role. As we see, gain is prominent in astrophotography. You might ask, where is the “sweet spot?” There is such a spot, called “unity gain.” This is the gain setting where 1 electron is approximately equal to 1 ADU. Setting to unity gain strikes a good balance between noise and dynamic range. It is often recommended as the default for deep-sky imaging. For the ZWO ASi585MM camera, unity gain is about 250. Consider the following summary:

Low Gain (~0–100)	Medium Gain (Unity Gain)	High Gain (>300 on CMOS sensors)
✓ Maximum dynamic range ✓ Best for bright objects ❌ More read noise ❌ Needs longer exposures	✓ Best compromise ✓ Great for deep sky ✓ Good noise perfrmance	✓ Best sensitivity per second ✓ Lowest read noise ❌ Easy to clip stars ❌ Lower dynamic range

Table 4. *Strengths* (✓) *and weaknesses* (❌) *of using various levels of gain in a CMOS astronomical camera.*

In conclusion, modern CMOS sensors like those used with the Asi585MM and QHY600C, available on the 11” EdgeHD/AT80ED and the 14” iOptron telescope at PSO (compared to the club’s older CCD-based units), are highly capable, and selecting the correct gain can greatly enhance results.

There is a significant difference between CCD and CMOS cameras in astrophotography. Both types detect light electronically, but they operate in very different ways — and these differences are important in astrophotography. Here is a clear comparison. In CCD (Charge-Coupled Device) cameras, all pixels gather charge, which is then shifted across the sensor and read out through a single amplifier. These cameras are known for excellent image quality, low pattern noise, but slow readout. In CMOS (Complementary Metal-Oxide-Semiconductor) cameras, each pixel has its own amplifier and is read independently. These cameras are fast, low-power, and inexpensive to produce. They dominate the modern market. Many practical differences exist for astrophotography, summarized in Table 5.

Read Noise	Dark Current	Quantum Efficiency (QE)	Full-Well Capacity
• CCD: Higher read noise (5–10+ e^- typical) • CMOS: Very low read noise (1–3 e^- in modern astro cameras) 👉 Winner: CMOS — dramatically better for short exposures, stacking, and live stacking.	• CCD: Higher dark current unless cooled heavily • CMOS: Much lower dark current, even at moderate cooling 👉 Winner: CMOS	• CCD: Historically high QE (peak 60–80%+, sometimes >90% with back-illumination) • CMOS: Modern CMOS now equal or better; many exceed 90% 👉 **Winner: Tie (modern CMOS now surpass CCD)**	• CCD: Usually higher full-well (20k–100k+ e^-) • CMOS: Smaller pixels → lower full-well (10k–50k e^-), though improving 👉 Winner: Slight edge to CCD for dynamic range (though certain modern CMOS gain modes can match or exceed effective dynamic range of CCDs.)
Amp Glow	Download/Readout Speed	Shutter Type	Cost, Size, Power
• CCD: None • CMOS: Historically significant, but modern cameras have nearly eliminated it 👉 **Winner: CCD (but rapidly becoming a non-issue for new CMOS sensors.)**	• CCD: Slow (0.5–2 frames/sec often) • CMOS: Very fast (10–100+ FPS even at full frame) 👉 Winner: CMOS — crucial for planetary imaging	• CCD: Mechanical shutter often required for bias/darks • CMOS: Electronic shutter, no moving parts 👉 **Winner: CMOS**	• CCD: Expensive to make; power-hungry • CMOS: Cheaper; low power 👉 Winner: CMOS (overwhelming market dominance)

Table 5. *How CCD and CMOS cameras compare in eight different areas, along with an indication of any clear "winner" in each category.*

Given these parameters, image quality differs between CCD and CMOS cameras. Table 6 summarizes these differences.

CCD Strengths	**CMOS Strengths**
• Extremely uniform, clean, low pattern noise • High full-well (good for bright stars + faint nebula together) • No amp glow • Smooth background and gradients	• Very low noise resulting from shorter exposures • Fast readout during planetary/lunar imaging • Higher QE in many modern sensors • Lower cost and widely available • Back-illuminated CMOS now matches CCD quality

Table 6. *Comparison of key strengths between CCD and CMOS astronomical cameras.*

The current state of affairs favors CMOS cameras. CCD cameras are practically no longer produced for amateur astronomy. Sony ceased manufacturing CCD sensors, and nearly all manufacturers have shifted to back-illuminated CMOS, which now *surpasses CCDs in nearly every aspect*. Modern CMOS cameras (like Sony IMX series used in ZWO/PlayerOne/QHY) offer lower noise, higher quantum efficiency, faster operation, and much lower cost. While CCD cameras still serve in specialized scientific applications, CMOS has overwhelmingly replaced CCD in amateur astrophotography.

Astro-photography cameras—whether CCD or CMOS—come in two types: one-shot color (OSC) and monochrome (B&W). What's the difference, and why did I choose a monochrome camera over a color one? In astrophotography, an OSC camera is a color camera that captures red, green, and blue data in a *single exposure* using a Bayer matrix over the sensor. This makes it easier and faster to operate than a monochrome (mono) camera, which requires separate exposures through R, G, B (and often L, SII, Hα, and OIII, SHO, or Hubble palette) filters.

A mono camera captures light without a Bayer color filter array, providing it with several key advantages over color cameras. Monochrome cameras:

1. **have higher sensitivity because more light reaches each pixel.** – In other words, there is no color filter array blocking photons, allowing every pixel to gather *all* wavelengths. As a result, the sensor captures more total light, leading to a higher signal-to-noise ratio (SNR) per unit time. *Typically,* mono cameras are about 2–3 times more sensitive than the same sensor in color form.
2. **have better resolution.** – Without a Bayer matrix (which interpolates color), a mono camera captures the true full resolution of the sensor. Additionally, with a color camera, each pixel only sees R, G, or B, and the missing color information must be interpolated ("debayered"). *As a result,* mono images have sharper detail at the same pixel scale.
3. **have full control over recorded wavelengths by using filters.** – Mono cameras enable imaging with broadband filters like Luminance (L), Red, Green, Blue (RGB), and narrowband filters such as Hα (656 nm), OIII (500 nm), SII (672 nm), etc. This enables imaging under light pollution with narrowband filters, capturing nebulae structures invisible to OSC cameras, and creating Hubble palette images (e.g., SHO). Color cameras can't isolate bands as effectively because all wavelengths reach neighboring pixels.
4. **work better under light-polluted skies.** – Narrowband filters with mono cameras block most light pollution; they enable excellent imaging even in Bortle 7–9 zones and perform well under moonlight. Color cameras struggle in heavy light pollution because their RGB filters are broad and overlap.
5. **offer greater flexibility in exposure times.** – Exposures can be adjusted with filters. This means shorter exposures for bright RGB channels and longer exposures for faint narrowband filters (e.g., SII). A color camera exposes all channels equally, so imagers have *no choice*.
6. **provide superior narrowband performance.** – Mono cameras excel at capturing emission nebulae (Hα, OIII, SII), supernova remnants, and planetary nebulae. OSC cameras have weak narrowband response because color filters block 75% or more of the narrowband light, and only some pixels detect each wavelength.
7. **allow for better calibration.** – Flats, darks, and bias tend to calibrate more cleanly in mono because there is no color pattern in the sensor, and noise is more uniform.

When, if ever, is OSC the better choice? Despite the advantages mentioned earlier, one-shot color cameras are often favored when photographers need a quick, straightforward workflow, have limited time for target acquisition, want to avoid filter wheels, and prefer simple processing. Therefore, while OSC cameras offer more convenience, monochrome cameras deliver greater power.

Color images can be created with a B&W camera using filters. Several "palettes" can be used to produce appealing, informative color images from B&W sub-images. The most common palettes are LRGB (Luminance, Red, Green, Blue) and L-SII-Hα-OIII, the so-called Hubble palette. In addition to these images, other calibration frames need to be captured. These include flat, dark, and bias frames.

When capturing B&W images (which some find more appealing), a clear filter is used to block ultraviolet and infrared radiation from reaching the camera's sensor. Though invisible to the human eye, this radiation can be detected by the camera and may cause bloating of stellar images. For true-color images, the LRGB palette is employed. For aesthetic and other reasons, the Hubble palette can also be used. The Hα and SII wavelengths are close together in the red part of the spectrum, while the OIII is located in the green region. These narrowband filters assign different colors to create false-color images that highlight details not easily seen otherwise.

Light frames are your actual photos of the night sky—the images showing the astronomical object you want to capture. They include everything: the signal from stars and nebulae, noise, gradients, optical artifacts, and sensor imperfections. You take many of them (**from** dozens to hundreds) and stack them to improve the signal-to-noise ratio. Think of lights as the raw data.

Dark frames record the thermal noise, hot pixels, and amplifier glow created by the camera's sensor. Taken with the same exposure time, gain, and temperature as the light frames, they are captured with the lens or telescope covered—so no light gets in. Subtracting darks from lights removes sensor-related noise patterns. Dark frames help eliminate hot pixels, thermal noise, and amplifier glow.

Flat frames correct for optical illumination issues such as vignetting (darker corners of the image), dust motes ("donuts" from dust on the sensor or filters), and uneven illumination in the optical train. To capture flats, the front of the telescope is evenly illuminated using a light panel, T-shirt flat, or sky flat, and short exposures are used that produce about 30–50% histogram brightness. The purpose of flat frames is to correct uneven brightness and dust shadows.

Bias frames record the camera's read-out noise—the electronic noise generated when the sensor is read. They are captured with the shortest possible exposure the camera can manage. During this process, the telescope stays covered. Bias frames are used to eliminate fixed electronic noise patterns that do not depend on exposure time. The purpose of these frames is to remove readout noise and the "offset" level in each image.

Master light, dark, flat, and bias frames are created when sub-frames of each type are combined (stacked) using suitable software—both free and commercial (such as ASTAP, Siril, GraXpert, GIMP, Registax, Autostakkert, DeepSkyStacker, Photoshop, PixInsight, AstroPixelProcessor, Lightroom, and others)—to create appealing color images of deep-space objects. A different set of software can also be used to image the sun, moon, and planets from video footage (including SharpCap, FireCapture, N.I.N.A., and more).

When capturing light images, which is better, ten 30-second images or thirty 10-second images? There is a simple answer to this question. If guiding is solid and bright stars won't saturate the camera's sensor (overexpose by overflowing pixels with electrons – often limited to about its full-well capacity, which is roughly 38,700 to ~40,000 electrons per pixel), go with the fewer longer subs (10 @ 30 sec). If you expect guiding slips, lots of satellites, intermittent clouds, or you're worried about saturation, go with more subs of short duration (30 @ 10 sec). Why would this be the case? The trade-offs are numerous and important, and explained in simple language.

- **Signal-to-noise (SNR)** — for faint objects, the SNR grows with the *square root of total exposure time*. So 300 s total gives the same ideal SNR whether you do 10×30 s or 30×10 s *provided you are background-limited*.
- **Read noise penalty** — each frame adds read noise. If your camera/instrument is *not* already dominated by sky background, more frames imply more read noise contribution. So fewer, longer subs usually give slightly better SNR for the same total integration because you pay the read-noise cost fewer times. (Modern CMOS cameras like the ASi585MM have low read noise, but it still matters for very short subs.)
- **Overheads** — each exposure has overhead (camera readout, file write, dithering move). More frames mean more overhead time lost to non-imaging and a longer total session for the same on-target exposure. So fewer longer subs are more efficient.
- **Dynamic range & saturation** — longer exposures are more likely to saturate bright star cores or blow out nebulosity. If your optical train/focal length produces bright stars that saturate in 30 s, shorter subs avoid clipping and preserve linearity.
- **Practical rejection of bad frames** — more frames make it easier to remove bad frames (clouds, guiding glitches, satellite trails). With sigma-clip or median stacking, one can reject outliers more effectively when there are many frames.
- **Guiding & mount performance** — if your guider and polar alignment are excellent (or you're using AO/guiding), longer subs are safe and optimal. If your mount occasionally slips, shorter subs reduce the risk of losing many seconds to a single bad guiding event.
- **Bortle 4 / ASi585MM context** — at Bortle 4 (typical of the FGNS setting), the sky background is moderate; for many telescopes, you will be *background-limited* with exposure lengths of a few tens of seconds. With the ASi585MM's low read noise and fast readout, 30-second subs are often fine and give efficient SNR.

Practical recommendations:

- If you expect guiding problems, satellites, or want better rejection, more shorter subs are safer.
- If you want to experiment, try 10 × 30 sec as your first test (same total 300 sec). Check histograms for saturation and measure guiding drift. If you see star cores clipping or many trails/bad frames, switch to 30 × 10 sec next run.
- Also, keep in mind that appropriate gain setting is essential, and to take flats/darks/bias as needed — those choices often matter as much as sub length.

How faint can I image in terms of limiting magnitude? The faintest star one can capture in an image is determined by several factors, including telescope aperture, focal ratio, quantum efficiency, gain, binning, and sky brightness. The larger the aperture, the more light one can gather. The brightness of an image that a telescope can create on the imaging plane of a camera is inversely proportional to the square of the focal ratio. Shorter focal lengths for a given aperture produce brighter, albeit smaller, images. Quantum efficiency indicates how efficient a sensor's pixels are at converting the light that impinges upon them. Gain and binning are effectively mulifliers that determine how the sensor counts what light it does detect. The darker the sky is, the greater the contrast of stars with the background, and the higher the contrast, the more detectable they are. Controllable factors for achieving a maximal limiting magnitude (faintest star visible) are aperture, focal ratio, gain, binning, and selection of observing site. Additionally, longer focal ratios (and hence longer focal lengths) produce higher magnification, thereby increasing the contrast of a star with the night sky, making it more visible. Let's consider the use of the ASI858MM in conjunction with the AT80ED refractor at Prairie Sky Observatory.

What follows is a simple estimate of the faintest star one could *detect* (SNR ≈ 5) with an 80 mm AT80ED (f/7, 560 mm) refractor and a ZWO ASI585MM-class sensor (Sony IMX585 specs: QE ≈ 90%, FW ≈ 38–40ke, read noise ≈ 0.7–1 e^-). But first, the short answer (the example result). A single 300-second exposure (typical long sub) will have a limiting magnitude of about 10.7 (visual), with an SNR of about 5. Stacking 12 subs for a total integration time of 3600 seconds yields a limiting magnitude of about 13.4 (visual). These are order-of-magnitude estimates — real results will vary with sky brightness, seeing, optical throughput, filter, sensor cooling, and any photometric aperture.

Limiting magnitude can be increased in a variety of ways. Consider the following methods:

1. Longer total exposure increases the limiting magnitude by roughly $2.5\times\log_{10}\sqrt{t}$, where t is the exposure factor. For example, going from 300 seconds to 3,600 seconds (an exposure factor of 12) increases the limiting magnitude by ≈ 2.7 magnitudes.
2. Better sky (darker than 21.5 mag/arcsec^2) helps a lot — moving from 20 mag/arcsec^2 (Bortle 5, suburban sky) to 21.5 mag/arcsec^2 (Bortle 3, rural sky) gains ~1–1.5 mags.
3. Binning (2×2) will increase per-pixel SNR and effectively coarsen the pixel scale; this helps faint detection at the cost of resolution.
4. Higher throughput (better optical coatings, no filter vs. L-filter) increases photon rate proportionally.
5. Cooling and lower read noise help for short total exposures or when the sky background is very low (read-noise-limited regime). With an 80 mm scope and long exposures, we are usually sky-limited, so throughput and aperture become the largest factors.
6. Aperture is dominant. Doubling the aperture of a telescope from 80 mm to 160 mm increases the limiting magnitude by 1.5 magnitudes.

Now that we have the preliminaries out of the way, we can start with a detailed review of our example photographic system—the Asi585MM camera mounted on an Astro-Tech 80mm ED refractor, which rides piggyback on the Celestron 11" EdgeHD telescope in PSO. This setup is mounted on a Celestron CGEM mount that has been accurately polar-aligned (to within 3 arcmin).

Several images showing the telescope, focusing knob, filter wheel, camera, ASiair controller, piggyback setup, and CGEM mount with polar alignment.

The **AT80ED telescope** is an 80 mm f/7 ED doublet refractor known for delivering sharp, high-contrast views and images in a compact, lightweight package. Its extra-low-dispersion glass reduces chromatic aberration, making stars appear tight and well-defined, and its solid build—dual-speed focuser, retractable dew shield, and robust tube rings—makes it easy to use both visually and for astrophotography. With wide-field capability and good color correction for its class, it's a popular choice for beginners and experienced observers seeking a portable, well-performing telescope.

A two-speed focuser on the AT80ED refractor provides both coarse and fine control over focus, making it easier to achieve precise, repeatable sharpness for visual observing and astrophotography. The larger knob allows quick, broad adjustments to bring an object roughly into focus, while the smaller 10:1 fine-focus knob lets you make very subtle changes—ideal when dialing in perfect star tightness or nailing critical focus on a camera sensor. This dual-ratio mechanism reduces vibration, improves accuracy, and makes the focusing process smoother and more ergonomic, especially at high magnifications or with heavy imaging gear attached.

The **ZWO EFW** (electronic filter wheel) is a compact, USB-powered motorized wheel that holds five astronomical filters—typically LRGB or narrowband sets—and automatically rotates them into place during imaging. It uses a precise, belt-driven stepper motor with accurate indexing to keep the selected filter centered, and it's fully controllable via ASIAIR, most capture software, or ZWO drivers without requiring an external power supply. The wheel is lightweight, has threaded interfaces for easy attachment to ZWO cameras and accessories, and is built to maintain a tight, dust-resistant seal, making filter changes fast, reliable, and hands-off during an imaging session.

The **ZWO ASI585MM** is a modern monochrome astrophotography camera built around Sony's IMX585 sensor, offering high sensitivity, low read noise, and fast frame rates ideal for lunar, planetary, and electronically assisted astronomy. Its monochrome design allows the use of LRGB or narrowband filters for maximum detail and efficiency, while its 1/1.2" sensor and small pixels provide a generous field of view and fine image scale with many telescopes. The camera connects via USB 3.0 for high-speed data transfer, supports external cooling power when paired with accessories that regulate temperature, and integrates seamlessly with the ASIAIR ecosystem for fully automated imaging.

The **ZWO ASiair Mini** is a compact, Wi-Fi–enabled astrophotography controller that streamlines the entire imaging workflow by integrating mount control, camera operation, autofocus (with a supported EAF), autoguiding, plate solving, polar alignment, and image capture into a single mobile-app–driven ecosystem. Despite its small size, it provides reliable power distribution for connected devices, supports ZWO cameras and filter wheels, and offers fast, wireless control through the ASIAIR app on iOS or Android. Designed for portability and simplicity, it eliminates the need for a laptop in the field and delivers an intuitive, highly automated imaging experience ideal for travel setups, small refractors, and lightweight rigs.

All of the above ride piggyback on a **Celestron EdgeHD 11" SCT**. The EdgeHD rests on a **Celestron CGEM**. This is a robust equatorial mount designed for serious amateur astronomers, supporting telescopes up to about 40 pounds. It features precise stepper motors for smooth tracking, built-in periodic error correction, and a database-driven GoTo system for locating over 40,000 celestial objects. The mount allows for both visual observing and astrophotography, with fine control via hand controller or computer connection, and includes counterweights for balance, adjustable latitude, and solid construction for stability during long exposures.

Before moving forward, it would be wise for readers to read and thoroughly understand the ASiair control's owner's manual available through High Point Scientific. Please study all sections and be sure to watch the Sample Workflow video that the manual references. Note the links to the various section headings below:

- The ASIAir Overview
- The Short Version
- The Long Version
- Initial Hardware Setup
- Initial Settings
- Main Screen
- Planetarium (SkyAtlas)
- Settings
- Sample Workflow

Consider now the imaging system that will serve as the basis for our introduction to black-and-white digital astrophotography with a dedicated CMOS astronomical camera (not a CCD camera, a DSLR, or a mirrorless camera). The components include: an AT80ED f/7 refractor, a 5-position ZWO AFW (automated filter wheel with seven optional filters in two sets: L, R, G, B, SII, OIII, Hα, plus dark), and a ZWO ASiair585MM monochrome camera, all mounted piggyback on a Celestron 11" EdgeHD telescope, which itself is mounted on a polar-aligned Celestron German Equatorial Mount (CGEM). Powering this setup is a ZWO ASiair *mini* controller. All these items are housed at the Prairie Sky Observatory at FGNS and are available for use by property-qualified and authorized TCAA members.

Given this setup, what is the correct order of steps to obtain B&W images? To move forward, you need a mobile phone, tablet, or laptop running the ASiair app. Remember that the ZWO ASiair software is an all-in-one astrophotography control platform that simplifies imaging by managing your camera, mount, filter wheel, focuser (if we get one), and guiding system from a single mobile app. It offers an intuitive interface for polar alignment, autofocus, plate solving, autorun sequencing, guiding, live stacking, and image preview – all optimized for ZWO hardware. Designed for ease of use and portability, the software automates complex tasks while still allowing users precise control, making it simple for both beginners and advanced imagers to capture deep-sky objects efficiently and reliably.

Given the availability of this application, what are the next steps? B&W imaging is much simpler than color imaging, which requires multiple filters when using a mono camera, extensive use of the autorun function, and post-processing with software such as ASTAP, GIMP, GraXpert, and Siril. The more complex procedures will become easier to understand once the basic processes are mastered. Remember, the Sony IMX585 CMOS image sensor is sensitive to a wide range of radiation, including UV and IR. Also, keep in mind that the 585 sensor lacks a UV/IR cut filter. Therefore, B&W imaging will require a luminance (UV/IR-cut) filter to prevent ballooning of stellar images, as discussed earlier in this guide.

Because tri-color imaging requires a significant amount of background, more than can be covered in a single TCAA Guide, I recommend readers consult the following publication, which I have found very helpful: *Astrophotography Image Processing with GraXpert, Siril & GIMP: For DSLRs, Astro Cameras, Seestar and Dwarf 3* by Max Dobres FRAS.

The recently published second edition is expanded and updated for Siril 1.4. This comprehensive guide leads readers through the entire workflow of processing astrophotographs using three powerful, free software tools: GraXpert, Siril, and GIMP. By combining the strengths of these programs, imagers can achieve results comparable to those produced by expensive, professional-grade software.

This book provides clear, step-by-step instructions to help imagers turn RAW and FITS images of astronomical objects into stunning final images. Focusing on clarity and accessibility, it breaks down the main processes so even beginners can easily follow along.

In addition to traditional One-Shot Color (OSC) cameras, including dedicated astrophotography cameras and DSLRs, the guide also covers smart telescopes like the ZWO Seestar and Dwarf 3. This makes it an essential resource for various astrophotography enthusiasts. Readers will find that capturing color images with an OSC is just as easy as taking black-and-white images with the ASIair858MM camera. The QHY600C camera, which can be used with the iOptron Photron 14" housed in SGO, will be discussed in a future article, possibly Part 5 of this series.

Step-by-Step Imaging Procedure (ASI585MM + ASIAIR + CGEM)

We now present a step-by-step procedure for imaging in B&W using the Asi858MM camera, the ASIAir controller, and the Celestron CGEM mount at PSO. This assumes a typical refractor (in this case, an AT80ED) setup with a guide scope and guide camera, along with a filter wheel or a single UV/IR-blocking filter (luminance channel).

Because the 11-inch Celestron telescope supporting the AT80ED refractor is fixed, we can assume it is properly polar-aligned; it is so to within three arcminutes. The telescope is also fairly well balanced, so undue stress is not placed on the system's drive motors. Follow the numbered actions below as appropriate.

1. Connect cables (if not already done)

- **a.** Plug the ASI585MM camera into the ASIAIR (USB 3.0).
- **b.** Plug the guide camera (not currently available) into any ASIAIR (USB 2.0) port.
- **c.** Connect the mount to the ASIAIR using a USB-to-Serial cable (CGEM uses NexStar/HC serial connection via the hand controller).
- **d.** Connect the filter wheel to the ASIAIR (USB).

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2. Power up and connect app to ASIAIR

- **a.** Turn on the CGEM.
- **b.** Turn on the ASIAIR.
- **c.** Connect your phone/tablet to the ASIAIR Wi-Fi.
- **d.** Open the ASIAIR app and confirm the camera, guide camera, filter wheel, and mount are detected.

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3. Perform the CGEM alignment

- a. Set the CGEM to its home position per the calibration marks. The telescope should rest directly over the RA axis and point to the North Celestial Pole. ASIAIR does not need perfect alignment, but the mount must be initialized so ASCOM commands work.
- b. Confirm time (ALWAYs standard time; ZWO does not recognize DST) and make sure "resume prior alignment is turned off.)
- c. If using hand controller alignment, do a Quick Align. ASIAIR with then plate solve everything to sync the mount with the sky.

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4. Polar alignment (this step should be skipped as the mount is already polar aligned)

1. Go to PA tool in ASIAIR.
2. Point the scope at the recommended region near Polaris.
3. Follow the ASIAIR instructions to capture, plate-solve, rotate RA ~60°, and adjust alt/az knobs.
4. Continue until alignment error is under 1′–5′, depending on your needs.

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5. Focus the image

- **a.** Use the Preview mode on the app and the built-in focus aid.
- **b.** If using a Bahtinov mask, capture a few frames and adjust the focuser until the pattern centers.

c. Lock focus if your focuser has a lock.
d. Verify the star size by using the XXX function following plate solve on the first star. On a night of good seeing, the star sizes will be 2-3 arcseconds or smaller. Adjust the focus as necessary to get the smallest possible star size.

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6. Set up guiding (once available; skip this step for now)

a. In ASIAIR, open the Guide tab.
b. Select the guide camera and guide scope.
c. Run Calibration (mount must be tracking).
d. Start guiding and refining settings if necessary.

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7. Select your target

a. Open the Object List or Sky Atlas in ASIAIR.
b. Tap your target (nebula, cluster, galaxy).
c. Tap GoTo.
d. ASIAIR will slew and automatically plate-solve and center the target to within a few arcseconds.

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8. For simple B&W imaging, commence live stacking

a. Go to Live stacking and begin imaging.
b. Once you have achieved the image you desire, stop the imaging and save the image to file.

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9. For more complex tri-color imaging, configure imaging settings

For ASI585MM mono camera**:**

a. Exposure length: 30–300s depending on target + filters
b. Gain: typically 100–250 (experiment as needed)
c. Filters: choose L, R, G, B, or narrowband as appropriate; enable (important for noise reduction); On the ASIAIR Mini, dithering is enabled inside the Autorun (or Live Stack) settings and is applied automatically between sub-exposures when guiding is active.
d. Create an autorun plan. For example:
    - L: 30 × 120s
    - R: 20 × 180s
    - G: 20 × 180s
    - B: 20 × 180s
e. Save the plan.

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10. Start imaging

a. Double-check that guiding is running.
b. Ensure cables are free and won't snag during tracking.
c. Hit Start Autorun.
d. ASIAIR will:
    - Rotate filters automatically
    - Capture frames
    - Dither between exposures
    - Save everything to the USB drive

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11. Capture calibration frames

After your main session, take:

- Darks: same exposure and gain as lights (with scope capped)
- Flats: use a flat panel or bright sky + t-shirt
- Dark Flats: same exposure as flats (optional, depending on workflow)

ASIAIR has a Flat Wizard to automate this. See the next section about how to take advantage of this function using the 7.9-inch Flat-Man flat panel. An ASCOM-enabled PC is required to operate and adjust the flat panel.

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12. Using the ASiair Flat Wizard to Capture Flats:

1. **Set up your flat-field panel**
   Turn on your flat panel, tablet, light pad, or dawn sky flats (with a diffuser). Make sure the telescope is already focused exactly as it was for your imaging session.
2. **Go to the Calibration section**
   In the ASIair app, tap **Camera → Calibration → Flats**.
3. **Open the Flat Wizard**
   Tap **Flat Wizard**. The ASIair will take a series of quick test exposures to determine the correct brightness level. Brightness level of the Flat-Man is adjusted through the PC.
4. **Choose your target ADU**
   - The default is usually around **24,000–30,000 ADU** (for a 16-bit scale).
   - You can adjust this if needed; mid-range values avoid clipping and give clean calibration.
5. **Run the Wizard**
   ASIair automatically computes the best exposure time for each filter (mono cameras) or for your OSC setup. It will show the chosen exposure time once complete.
6. **Save & Acquire Flats**
   Tap **Start Flats**, and ASIair will capture the requested number of flat frames using the exposure it just calculated.
7. **(Optional) Capture Dark Flats / Flat Darks**
   After flats are done, ASIair will prompt you to take **dark flats**, which match the same exposure but with the scope covered.

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13. Process your images

Export subs to your computer or tablet and process in:

- Siril
- PixInsight
- DeepSkyStacker
- AstroPixelProcessor

Notes on linking the ASiair to the CGEM. Sometimes the ZWO controller will lose control of the CGEM, and it will wheel wildly about. When this happens, you need to stop the motion and rehome the 11-inch telescope, rebooting the system. CGEM goes haywire under the condition where there are two competing understandings of where the mount thinks it is pointing. To avoid this, make sure that the **Use last alignment is turned off.**