Introduction to DSLR-Based Astrophotography

TCAA Guide #9

TWIN CITY AMATEUR ASTRONOMERS

ESTABLISHED 1960

INTRODUCTION TO DSLR-BASED ASTROPHOTOGRAPHY

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ABOUT THIS GUIDE:

This guide – *Introduction to DSLR-Based Astrophotography* guide – is the ninth of ten TCAA guides. It was created to serve as an introduction to astrophotography using DSLR cameras and several TCAA telescopes such as its "portable" 130mm AstroPhysics *Starfire* apochromatic refractor and its Celestron 11" telescope in Sugar Grove Observatory. This Guide (and the associated course if any) assumes that the student will own a DSLR camera and know how to use it. After dealing with three basic types of DSLR astrophotography, a limited amount of post processing of images will be included. Those interested in using the more advanced telescopes and CCD cameras of Prairie Sky Observatory (90mm Hα, 11", 14" and 17") and Waynesville Observatory (10", 16", and 24") will need to enroll in a one-on-one mentoring program. The current content and course might be considered a prerequisite.

The author gratefully acknowledges the assistance of the following TCAA members who either provided guidance or conducted an editorial review: Alan Novick and David Arteman. The author also recognizes education contributions to the author by TCAA members Bob Finnigan, Tim Stone, and Scott Wade without whom this work would not have been possible.

ABOUT THE AUTHOR:

Dr. Carl J. Wenning is a well-known Central Illinois astronomy educator. He started viewing the heavens with the assistance of his grandfather in the summer of 1957. Since that time he continued viewing the night sky for more than six decades. He holds a B.S. degree in Astronomy from The Ohio State University, an M.A.T. degree in Planetarium Education from Michigan State University, and an Ed.D. degree in Curriculum & Instruction with a specialization in physics teaching from Illinois State University.

Dr. Wenning was planetarium director at Illinois State University from 1978 to 2001. From 1994-2008 he worked as a teacher educator, directing the University's physics teacher education program. Retiring in 2008, he continued to teach physics and physics education courses part-time for an additional 14 years. He also taught astronomy and physics lab science almost continuously at Illinois Wesleyan University from 1982 to 2001, and physics at Heartland Community College from 2019-2021. Over the years since his formal retirement, he has taught in Russia, Indonesia (4X), Chile (4X), Mexico, and Brazil. He fully retired from Illinois State University in the spring of 2022 after nearly 44 years of university-level teaching in Illinois. Prior to that, he taught astronomy at Alma College and Michigan State University.

Carl became associated with the TCAA in September 1978 – shortly after he came to work at Illinois State University. Today he is an Astronomical League Master Observer (having completed 15 observing programs to date), received the 2007 NCRAL Region Award for his contributions to amateur astronomy, and the Astronomical League Mabel Sterns Newsletter Editor Award in 2017 (with second place in 2015 and 2016). He is a lifelong honorary member of the TCAA and is a member of its G. Weldon Schuette Society of Outstanding Amateur Astronomers and has also received the John & Bertha Kieviet Award for leadership.

INTRODUCTION TO DSLR-BASED ASTROPHOTOGRAPHY

About this Guide and its Associated Course

This guide and its associated course titled *Introduction to Astrophotography* are not intended for the novice amateur astronomer. No one should attempt this course – or expect to read this guide with complete understanding – without having considerable background as an amateur astronomer. What follows here assumes that the reader fully understands the workings of a telescope and knows the concepts and associated terminology and equations that characterize them. The minimum knowledge that one should possess is consistent with having completed the course *Introduction to Amateur Astronomy* (TCAA Guide #1). That course and guide provides the prerequisite background information for this course and guide.

The focus of the present course will be on astronomical imaging using digital single lens reflex (DSLR) cameras. DLSRs will be used to do three types of astronomical imaging: (1) fixed landscape imaging, (2) tracked constellation and Milky Way imaging, and (3) imaging through a telescope. Work will be restricted to using tripods, motorized mounts (e.g., piggyback on telescopes), and several of the TCAA's telescopes typically used for visual purposes; that is, the Sugar Grove Observatory's (SGO) *Celestron* 11" (f/10) goto telescope and the TCAA's portable Astro-Physics 130mm (f/8) *Starfire* apochromatic refractor on an Astro-Physics mount – not a goto.)

All modern DSLR cameras make use of CMOS sensing arrays that have characteristics different from the CCD cameras use in Prairie Sky Observatory (PSO) and Waynesville Observatory (WO). Those wishing to learn more advanced techniques used at these observatories and telescopes (90mm, 10", 11", 14", 16", and 24") should contact the TCAA's Photographic Property Manager Scott Wade to arrange for an intensive one-on-one mentorship which can be arranged following the completion of this course. Such mentorship is available only to TCAA members.

The depth and breadth of this Guide and its associated course are limited. This guide makes no attempt to include film cameras, Point-and-Shoot cameras (including cell or smart phones), though many of the ideas included in this Guide do apply to such cameras. While the author might describe a myriad of equipment and techniques – some of which can be associated with these cameras – not all such information necessarily will be used in this course.

This Guide attempts to balance the theoretical with the practical. Not everything in this guide is absolutely necessary for astronomical imaging. (For instance, only limited attention will be paid to astronomical image processing.) Nonetheless, the theoretical background will provide a better sense of understanding of astrophotography and will serve as a gateway to the more advanced techniques use at Prairie Sky Observatory and Waynesville Observatory.

TCAA Guide #9 – *Introduction to DSLR-Based Astrophotography* – is not intended as a stand-alone publication. It is intended to serve as a quick start reading and is designed to augment the eBook *Photography at Night: An Introduction to Astrophotography on a Budget* by Bobby Arn. Arn's 159-page eBook (PDF), written by accomplished astrophotographer and former TCAA member, will serve as a key reference work and guide for this course. Bobby's eBook (published in 2011) was once available online for only $10 at www.AstroArn.com. He has subsequently made the book freely available through the TCAA. Readers should note that the book, though somewhat dated, provides much excellent advice. Contact the author for the appropriate PDF file of Bobby's eBook. There are many other useful resources on the internet as well and include such things as web sites and YouTube videos. See the resource section of this Guide for references.

A Word About Due Diligence and Patience – If there are two thing you will learn as you become an astrophotographer, they are due diligence and patience. There are so many different things with which to concern yourself – learning about the night sky, telescopes, mounts, mount alignment and motion, camera lenses and settings, and focusing to name but a few – before taking your first astronomical photographs. As a result, the *learning curve* in this course can be a bit steep for the uninitiated. Climbing that slope, however, will allow you to take the best possible images possible given the equipment available to you. This effort will require reading and experimentation on your part; just listening to the advice of others won't be sufficient. If you are content merely to point your camera at the night sky and randomly expose its CMOS array to starlight, then there probably isn't much need to take this course as that is something you can do on your own.

ESSENTIALS OF ASTROPHOTOGRAPHY

Definitions

We start off here with some essential definitions. Please get to know these terms and understand the definitions because these terms will be used without further definition in the following pages.

Imaging – This course will deal with taking of individual frames using a DSLR camera. The former camera will be used for making time exposures of faint deep sky objects and the latter camera will be used for creating video clips of the sun, moon, and brighter planets the individual frames of which can be refined into the best possible still image.

Imaging Medium – This course assumes that imaging will be done using only CMOS arrays that constitute the imaging medium of all modern DSLR cameras. No consideration whatsoever will be given to the use of film in this publication or the associated course. No attention will be paid to the more advanced and capable CCD imaging systems used with the TCAA's telescopes.

DSLR Cameras – Almost any camera can be used to take "simple" astronomical images. However, not all cameras are created equal. The best cameras are those that can use interchangeable lenses and be adapted to a telescope, using the telescope as a telephoto lens. This typically requires the use of a digital single lens reflex (DSLR) camera. These cameras can be outfitted with electronic cable releases as well.

DSRL Cameras

Get to Know Your DSLR Camera – This course assumes that the owner of a DSLR camera knows how to use it, including its many options. Users should know how to switch lenses, set auto/manual focus, adjust focus, turn on/off "live view," zoom "live view," download images to a personal computer, adjust exposure, adjust f-stop, and so forth. Nothing can substitute for knowing your DSLR camera well. If you don't have your camera's user guide, these usually can be readily downloaded from the internet. Become as familiar with your camera guide as well as you are with your camera.

Having a Variety of DSLR Lenses – If you want to maximize your ability to work with your camera under various settings, then you will want to own a variety of lenses with different focal lengths. While many own variable focal length lenses (zoom lenses), we recommends fix focal length lenses. These tend to be optimized for only one particular focal length. You might, once you find your preferred focal length(s) for shooting, consider purchasing one or more fixed focal length lenses. Expect to use wider angle lenses for "starscape" photography (say 15mm to 55mm lens with a full-size imaging array – 24mm x 36mm) and a minimum of 300mm to 500mm for "closer up" shots on nebulae, clusters, and galaxies.

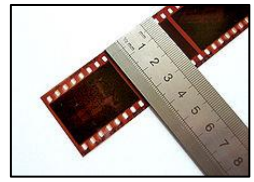
Focal Ratio – Focal ratio, commonly expressed as $f/\#$, is a ratio of focal length F, to aperture, A. Both lenses and telescopes have focal ratios. Because the aperture of a lens can be changed at will by changing the *f*-stop, lens have various focal ratios. Because telescopes have no aperture stops, they have fix focal ratios. Consider our 130mm-aperture refractor with a 1024mm focal length. It is characterized as an $f/8$. The following relationship gives the focal ratio, $f/$:

$$f/ = F/A = 1024mm/130mm = 8$$

Sizes of CMOS Imaging Arrays – The CMOS sensor array on DSLRs can vary considerably in size and resolution. The cameras we will have access to in this course are two of the following. One – a full-frame camera – is included here by way of example. Your personal camera might be the same as or similar to one of the following:

- Canon EOS 450D Rebel XSi – sensor array is 14.8mm x 22.2mm (2,848 x 4,272 or 12.1 megapixels)
- Canon EOS 5D Mark II – sensor array is 23.9mm x 35.8mm (3,744 x 5,616 or 21.0 megapixels)
- Canon EOS Rebel T7i – sensor array is 14.90mm x 22.30mm (4,017 x 6,026 or 24.2 megapixels)

Aspect Ratio – The aspect ratio of an image taken by most standard cameras is 3:2, though some are 4:3, 16:9 and so on. That is, in the case of the 3:2 aspect ratio, the long axis of a rectangular image is 50% great than the short axis. In full-frame "35mm cameras", the long (horizontal) axis of the image was 36mm and the short (vertical) axis of the image was 24mm. The so-called 35mm photographic format is named for the 35mm width (including sprocket holes) of 135 film. 35mm as a measurement has nothing to do with the size of the image fame per se.



Crop Factor – The crop factor represents the relative size of sensor arrays compared to the so-called standard 35mm "full size" sensor array of 24mm x 36mm (in the Canon EOS 5D Mark II it is actually 23.9mm x 35.8mm). The Canon EOS Rebel XSi and T7i sensor arrays are about 14.8mm x 22.2mm. Therefore, the crop factor of the XSi and T7i relative to the full-frame Mark II image is 23.9mm/14.8mm = 35.8mm/22.2mm = 1.61 approximately. That is, the 5D Mark II image scale will be 1.61 times (161%) that of the XSi and T7i. Alternatively, the XSi and T7i image scales will be 1/1.61 times (62%) that of the 5D Mark II. Sub-full-frame imaging arrays are commonly referred to as ASP-C arrays.

Angular Field of View – The field of view – the angular size of a view that is imaged can be described as a product of two linear dimensions, horizontal and vertical. For instance, if a camera's sensor array can image a field of view equal to 1.5° by 2°, then area of the field is the product of these dimensions or 3 square degrees. The field of view is inversely proportional to the focal length of the telescope used to produce the image on the imaging array. That is, longer focal length lenses will provide greater magnification of the image but a smaller fields of view and vice versa.

Calculating Angular Field of View – Knowledge of the size of a camera's sensor array and the focal length of the lens (or telescope) can be used to calculate the angular field of view. Making such a calculation takes the guesswork out of trying to determine the best lens or telescope to use to capture of image of an object of known angular size. The required formula is:

$$\theta = 57.3° * \frac{d}{F}$$

where θ is the angular field of view expressed in degrees, d is the distance along one side of the imaging array, and F is the focal length of the lens or telescope. The 57.3° comes from converting radians into degrees. Because 360° equals 2π radians, 360°/2π = 57.3°/radian is the conversion factor. Note that radians are *dimensionless* units of angular measure. So, 57.3°/radian is merely expressed at 57.3°.

Consider an 18mm-focal-length lens used with a full-frame imaging array of 23.9mm x 35.8mm. Make two calculations, one each for the short and long sides of the sensor array.

$$\theta_{short} = 57.3° * \frac{23.9mm}{18mm} = 76.1° \quad \text{and} \quad \theta_{long} = 57.3° * \frac{35.8mm}{18mm} = 114°$$

So the short axis of the image will constitute a 76.1° field of view and the long axis 114°.

Consider an 18mm-focal-length lens used with an ASP-C camera's sensor of 14.8mm x 22.2mm. Again, make two calculations, one each for the short and long sides of the sensor array using the same 18mm-focal-length lens.

$$\theta_{short} = 57.3° * \frac{14.8mm}{18mm} = 47.1° \quad \text{and} \quad \theta_{long} = 57.3° * \frac{22.2mm}{18mm} = 70.7°$$

Clearly, the full-frame camera has a much larger angular field of view than does the small ASP-C camera for the same focal length lens. The difference is equal to the 1.61 crop factor (e.g., 47.1° x 1.61 = 76.1° and 70.7° x 1.61 = 114°).

Consider a 100mm-focal-length lens used with a camera's imaging array of 14.8mm x 22.2mm. Make two calculations, one each for the short and long sides of the sensor array.

$$\theta_{short} = 57.3° * \frac{14.8mm}{100mm} = 8.48° \quad \text{and} \quad \theta_{long} = 57.3° * \frac{22.2mm}{100mm} = 12.7°$$

Here's another example with a 130mm f/8 Starfire apochromatic refractor ($F = 130mm\ x\ 8 = 1024mm$):

$$\theta_{short} = 57.3° * \frac{14.8mm}{1024mm} = 0.82° \quad \text{and} \qquad \theta_{long} = 57.3° * \frac{22.2mm}{1024mm} = 1.24°$$

Angular Terminology – Fields of view are often expressed in degrees, minutes, and seconds of arc. Recall that 1° = 60' (1 degree of arc equals 60 minutes of arc) and that 1' = 60" (1 minute of arc equals 60 seconds of arc). These conversion factors can be used to change from one unit to another. For instance, a 0.404° linear field of view is equal to 0.404° x 60'/1° = 24.24' (minutes of arc). This angular size of a camera and lens combination can be further express as a combination of minutes and seconds of arc (24' 14.4") where the 14.4" comes from 0.24' x 60"/1'.

Time Exposures – Most deep sky celestial objects (e.g., nebulas, clusters, galaxies, etc.) are dim and therefore require longer exposures in order to gather sufficient light in order to image the object being photographed. Solar system objects are much brighter and therefore require shorter exposures. The longer the time exposure, the more "precise" the telescope mount must be. That is, it must be polar aligned and turn at the sidereal rate (360° rotation in 23h, 56m, 4s) in the proper direction. The opposite is also true. Poorer guiding (or no guiding) requires shorter exposures if stars are not to appear as streaks.

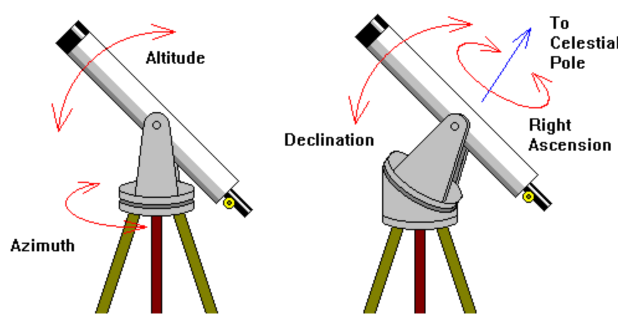
Maximum Exposure – The maximum exposure in seconds for an unguided camera keep stars from "trailing." The maximum exposure can be derived from the so-called "rule of 500."

500 / (Crop-Factor x Focal Length x cos(δ)) = Maximum Exposure (in seconds)

In this case, the delta (δ) refers to the declination of the stars at the center of a field of view. (More about this later.)

Stripped DSLR Camera – The club's Canon EOS T7i camera has been specially modified. That is, the infra-red filter normally in place over the CMOS sensor imaging array has been removed. This will allow for brighter, bolder images that are made of objects that have a lot of deep red hydrogen-alpha (Hα) radiation.

Mounts – Not all camera and telescope mounts are equal when it comes to astrophotography. Due to the necessity of taking time exposures, the traditional altazimuth (left-right and up-down) mounts simply will not work if an exposure lasts more than a few seconds. Equatorial mounts are necessary when longer exposures are taken. It should be noted that while a computer-driven altazimuth mount can track celestial objects, field rotation occurs while tracking progresses. Unless there is a way to compensate for this field rotation in an altazimuth mount, the only alternative is an equatorial mount. These mounts have their axis of rotation parallel to Earth's axis of rotation. They turn on one axis only to keep pace with the stars. See TCAA Guide #1 – *Introduction to Amateur Astronomy* – if you do not understand this concept.



Polar Alignment – Even if you have the correct type of camera or telescope mount for taking celestial images, it is imperative that the mount's polar axis be parallel to Earth 's rotation axis. If this alignment is not precise, the image will slowly shift its position in the field of view and rotate while doing so. Again, see TCAA Guide #1 – *Introduction to Amateur Astronomy* – if you do not understand these concepts.

Types of Astrophotography:

- **Fixed Tripod Imaging** – Images are typically taken using a stationary tripod turned to the night sky, often including aspects of the landscape in sky. This approach is suitable for taking short exposure photographs or long-exposure photographs where star trailing is desired. Wide to medium field of views can result depending upon the focal length of the lens used with a camera. This is the simplest form of astrophotography.

- **Piggyback Imaging** – Images are typically taken using a camera affixed with a bracket to an equatorial head, equatorially driven telescope, and equatorially driven “barn door” tracker or platforms. They can be used to make long exposures by compensating for Earth’s rotation. Images will not show noteworthy evidence of star trailing unless a long focal length lens is used. In this course you will be introduced to a motorized Astro-Physics 600E German Equatorial Mount that can be used with telescope and/or camera.

- **Telescopic Imaging** – Images are taken through an *equatorially* mounted telescope. Most imaging is done using longer time exposures. These images tend to be narrow field due to the long focal lengths of most telescopes.

Camera-Related Equipment

T-Ring – A camera specific T-ring allows one to attach a DSLR camera to accessories equipped with standard T-threads. Both a T-ring and a T-adapter are required to mount a DSLR camera to a telescope.

T-Adapter – A T-adapter allows one to attach a DSLR camera to the prime focus of a telescope. Both cameras use in this course has its own T-ring and T-adapter. If you wish to use your own camera, you will need to purchase these items.

T-Adapter with built in Barlow Lens – This combination is used to accomplish negative projection. It is used for short exposure lunar and planetary photography.

Eyepiece Projection Adapter – Eyepiece projection adapters allow one to take images through an eyepiece that increases the effective focal length of a telescope-camera combination. There are both fixed and adjustable adapters. The adjustable ones allow the distance from the eyepiece to the sensing array to be changed. This adjustment affects the image scale - the greater the distance between eyepiece and sensing array, the greater the image scale. The effective focal length is also a function of the eyepiece being used.

Electronic Cable Release – A remote timer/controller for camera used to reduce camera shake and increase the sharpness of the images that you take. It also allows you to take advantage of the “bulb” setting on your camera. Most DSLR cameras will allow for exposures of up to 30 seconds. What if you want to go beyond this? You’ll need an electronic camera release such as this one. Good electronic camera releases allow for multiple exposures, various lengths, various delays, and various interval exposures up to a certain number of frames.

C-Mount – This mount has a swivel head for the camera and a C-clamp for the base. This is the perfect way to affix a camera to an equatorial mount to an equatorially-mounted telescope for taking long exposures while tracking the sky. There are many variation of this type of mount. Make sure you acquire one with a swivel head that will allow you to turn the camera any which way you choose.

Tripod – A sturdy 3-legged camera mount will be necessary for taking pictures of the night sky. Avoid the cheap flimsy units that will sway in the wind every time the wind blows. Heads that allow you to turn the mounted camera in every which way, move up and down, and shift sideways are much to be preferred.

Mobile Phone Holder – While this course does not deal with mobile phones, those who want to try doing so using the afocal system described elsewhere in this publication are welcome to do so. For the sake of the discussion, a mobile phone holder is displayed below.

Imaging with an Electronic Cable Release

Here are the basic procedures for working with a generic electronic cable release:

Turn on your camera and adjust the camera settings as follows:

- Exposure mode: M (manual) – see the dial on top of the camera.
- Shutter speed: Bulb – turn the knurled knob near the trigger
- Interval timer: Off – not present on some cameras
- Focus mode: Manual – see side of lens for this switch if using camera lens
- Continuous: S (single frame) – go to menu for this option
- Set the image size as desired: S, M, L, RAW – go to menu for this option
- Set ISO too "high" for dim objects and too "low" for bright objects (you don't want to over intensify your image by setting the "gain" too high; this will introduce a considerable about of "noise" in your image). A good starting point is ISO 1600.

Follow these steps to use connect the electronic cable release to the camera:

1. Be certain that the camera switch is in the off position.
2. Attach the electronic cable release to the camera, and then turn the camera on.
3. Install batteries in the electronic cable release. (Please note that there is no on/off switch on some such devices, and they will deplete batteries if they are left in for an extended period of time.)

You may now use the cable release in one of two fashions:

As an automatic timer:	**As a manual release:**
4. Press the SET button to activate the electronic cable release. 5. Use the right arrow ➔ to move the indicator bar so that it under LONG (as shown in the above image). Press SET to activate the hours column. Use 🡅 and 🡇 to adjust the number of hours for the exposure. Min/max duration is 0 hours to 100 hours. 6. Press SET to move the cursor to the minute column; adjust the minutes accordingly. 7. Press SET to move the cursor to the second column; adjust the seconds accordingly. 8. Press SET once again, and time indicator will go out. The new setting will remain in effect until changed. 9. Press the TIMER START/STOP button when you are ready to take an image. The timer will start, and "TIMER ACTIVE" will flash in the panel. Shooting will end automatically. To stop early, press TIMER START/STOP button. 10. To set delay (how long to wait to take the first shot), interval (how long to wait between shots), and number of shots, make similar adjustments by placing the cursor under these headings and use arrows accordingly.	4. Press the shutter release button and push it upward to lock it into place. 5. To end the exposure, slide the shutter release button in the opposite direction to release the lock. Note that the manual shutter release can be used even if the cable release has no batteries. For additional information about using the cable release, see the owner's manual.

Fixed Tripod Imaging

Learning astrophotography is a drawn-out process. You can't learn all you need to know in one session and then go out expecting to be an expert. No, you'll need to experiment to see what works best for you and your equipment and observing conditions (e.g., light pollution, sky transparency, astronomical seeing, camera configuration, etc.).

Perhaps the best way to start doing astrophotography is to do fixed tripod imaging. Using this approach you can image some beautiful starscapes and take some simple constellation photos. You can also image star trails.

Exposure – When you are mounting your camera on a fixed tripod, the longest exposure you can take without getting star trails is determined by the focal length of the lens you use, the size of the image sensor, and the part of the sky you are imaging. While the stars appear always to be in motion, a tiny amount of trailing will be indistinguishable from the star images themselves if your exposure is not too long. Just how long is too long? One can use the "500 Rule" to determine maximum exposure.

500 / (Crop-Factor x Focal Length) = Maximum Exposure (in seconds)

Canon Rebel XSi camera using 24mm lens. Crop factor = 1.61

500 / (24 x 1.61) = 500 / 38.6 = ~13 seconds

More than that and the stars will be streaks instead of points, due to the Earth's rotation.

Now, the above formula is just a crude approximation. The maximum exposure you can get away with and not pick up star trails really depends upon the part of the sky you are imaging. If you image the area around the North Star, you can get away with longer exposures because the motions of the stars across the sky are small in a given period of time. If you are imaging along the celestial equator (roughly from east to west across the sky passing through a point about halfway up in the southern sky), your exposures will have to be of considerably less duration due to their motion of 15° of arc per hour. So, with this in mind, the equation can be modified based on the declination (angular distance north or south of the celestial equator) of the central region of the photograph. Consider this more precise version of the equation:

500 / (Crop-Factor x Focal Length x cos(δ)) = Maximum Exposure (in seconds)

Where cos(δ) is the cosine of the declination delta. What is the maximum exposure for a field centered on 40° north declination (roughly overhead in Central Illinois)?

500 / (24 x 1.61 x cos(+40°)) = 500 / (24 x 1.61 x 0.766) = 500 / 29.6 = ~17 seconds

If course, you can increase the time of your exposure a wee bit if you are willing to put up with a small amount of image trailing. It's an aesthetic consideration.

The problem with long exposures is that the stars don't stay focused on the same pixels of the camera sensor, and so the light can't accumulate. Even bright stars will seem dim with a tripod mounted camera unless you raise the ISO. Decent results can be obtained, for instance, with ISO 1600 for 15 seconds; however, this will make for a very noisy image. If your camera has Long Exposure Noise Reduction capability, you should enable that. You'll probably also need to work on the noise, as well as the color balance and contrast, in Photoshop or a similar application.

Focus – Focus can be surprisingly difficult to acquire, even with a tripod mounted camera using only its lens. It's not as easy as setting the camera lens to infinity focus, because this will change as a function of temperature. If your camera has *live view*, point it at a bright star or preferably a planet, digitally zoom all the way in, and get as good focus as you can. You might do much better with a fixed focal length rather than zoom lens, and you'll be tempted to run it full open, say at f/1.4. You will get better results at f/4 or so, because you will have some depth of field to help keep the stars focused. This also helps if the lensing system isn't perfect (e.g., coma or lens flare). Again... focused, immobile stars accumulate their light on a small set of pixels and produce more aesthetically pleasing (and realistic) results.

Light Pollution – While the Milky Way is easily visible from a "dark sky" site to cameras used for making time exposures, the sky there can actually be quite bright to your camera. Consider Sugar Grove Nature Center. It is filled with light pollution, especially to the northeast (Bloomington-Normal) and in the southwest (where a truck stop a few miles away creates a tsunami of light). Thus, your best results might require a bit of photoshop processing to make them look a bit less washed out. The spectacular Milky Way photos you see on various social media sites are invariably taken at sites with MUCH darker skies than we have anywhere in Illinois. This is a good place to practice your acquisition and processing techniques, but to get a great image of the Milky Way, you'll have to go to an International Dark Sky Park or Refuge. There are quite a few of these in the western states.

Constellation Photos – Constellation photographs can be obtained by focusing your camera with the appropriate focal length lens and shoot images of a short enough duration that star trails do not occur from the motion of the Earth. Say you want to photograph Orion, the Hunter. Orion stands 31° tall, measured from χ^2 Orionis in the north to Rigel in the south. (Such information can be obtained using the "measure from" function found on such software as SkySafari for iOS and Android.) What would be the minimum focal length lens required to capture this constellation in its entirety using a camera sensor with a crop ratio of 1.61 and a long sensor dimension of 22.2mm? Consider the following calculation:

$$\theta = 57.3° * \frac{d}{F}$$

and solve for F.

$$F = \frac{57.3° * d}{\theta} = \frac{57.3° * 22.2mm}{31°} = 41mm$$

So, any lens in your repository <u>below</u> 41mm would do the job. (Recall that as the focal length decreases, the field of view increases for a given camera.) So, a Zoom lens set at 40mm or shorter should easily capture the entirety of Orion if the camera is properly oriented. All you need do is point the camera to the sky and take an exposure. What is the maximum exposure with a F = 40mm lens so that no significant star trailing is captured? Consider the following calculation where the central stars of Orion have a declination of about 0°:

500 / (Crop-Factor x Focal Length x cos(δ)) = Maximum Exposure (in seconds)

or

500 / (1.61 x 40mm x cos(0°)) = 500 / (1.61 x 40 x 1) = 7.7 seconds

So, with exposures of, say, 7 seconds or less, you should have no discernable star trailing. The only other things to concern you self with now are the focal ratio and focus. Again, most astrophotographers will not shoot with their lenses "wide open." That is, when using an f/1.4 lens, they will often stop down the lens to, say, f/2.8, to reduce coma (misfocus near the edge due to imperfections in the lens) and to take advantage of a greater depth of field that will help minimizing problems with focus. Take multiple images at slightly different focuses to see the results. Digitally zoom in on your image screen to see if the stars are in or out of focus and adjust accordingly. Once you have achieved proper focus, shoot away!

Star Trails – Recall from the above example that with a 40mm lens, you will get discernable star trails with exposures of more than about 7.7 seconds. Some people actually want star trailing to occur, so they choose to take exposures of greater duration than this maximum. Focusing the fixed camera on the North Star will show beautiful counterclockwise motion. Additionally, the star trails so obtained will frequently show the colors of stars in a rather dramatic fashion. The amount of this counterclockwise motion is directly proportional to the duration of the exposure. It can be found with the common relationship, rate = amount x time. Keeping in mind that stars appear to revolve around the North Star (actually the North Celestial Pole which is less than 1° from the North Star) at a <u>rate</u> of about 360° in about 24 hours or about 15°/hr. (Actually, the sidereal rate is 360°/23.9344hr or 15.0411°/hr if you want to be more precise). Then, with a 15min (0.25hr) exposure, the star trails will go an angular distance of this many degrees round the NCP:

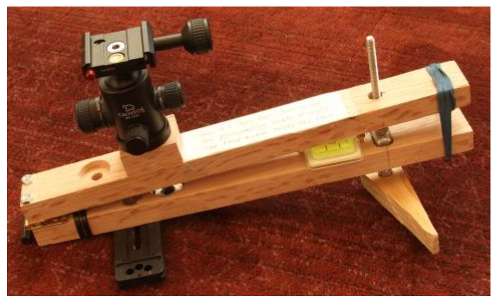
Angular distance around NCP = 15°/hr * 0.25hr = 3.75°

Time-lapse Videos – You can also use a series of still images to create a time-lapse movie, showing the actual motions of the stars. Using an intervalometer (electronic cable release) or the built-in capacity of your camera to take a series of images, you can combine the stills the into a movie using the appropriate software. For instance, if have a video editing app such as Adobe *Premiere Rush*, 300 images run at a rate of 30 frames per second will allow you produce of "short" of 10 seconds. Photographers shoot RAW images to create time lapses for a few reasons, one of which is file size. Photos are smaller than video files, which is key when your goal Is a long-period time lapse. The night capabilities of cameras with slow shutter speed compared with video recorders is another. Lastly, with more affordable gear, you can still create 4K or 6K videos at the end of the process, versus needing special, expensive video camera equipment.

With all of this knowledge and these techniques, the best way to get to learn how to do fixed mount astrophotography is to get out there and try. Yes, you might make mistakes, but you will learn from your failures. When you do make mistakes, carefully analyze them. Learn from what you have done and figure out what you must to do make it right. Only after a period of time will you become the expert fixed tripod imager you hope to be. (If you don't believe that I ever made any mistakes, see the section **10 Vicarious Lessons** further on in this Guide.)

Piggyback Imaging

There are many ways to "piggyback" a camera. Piggy backing means placing a camera atop a motorized equatorial mount of some sort, the primary purpose of which is to track the stars. For instance, you might place your camera on a dedicated mount intended only for astrophotography, or you might mount your camera atop a telescope that has an equatorial mount, or you might place your camera on a *properly oriented* homemade barn door mount. Equatorial mounts (as compared to altazimuth) are the only ones that will allow observers to track the stars.



The purpose of piggyback mounting is to track the stars as they appear to move across the sky as a result of Earth's rotational motion. Piggyback mounts complete one rotation per sidereal day compensating exactly for Earth's rotational motion. By using piggyback mounts, photographers can increase exposures dramatically without forming star trails. Increase exposure times allow for the recording of dimmer stars.

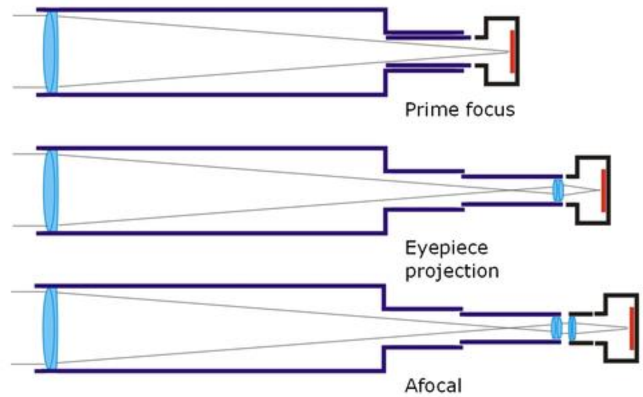
What is the maximum exposure one can make with a tracking mount? It could be as long as the night, but that's not really the case due to a number of reasons: (1) light pollution, (2) image saturation, and (3) growing dark current in the CMOS sensor array, and so forth. Suffice it to say for this level of astrophotographic work, trial and error will help you determine the length of your maximum exposure.

The thing to remember when it comes to piggyback mounting is that the camera carrier must have its rotation axis aligned parallel to Earth's rotation axis. Therefore, when the Earth spins in one direction the mount will move in the opposite direction holding the stars still in the frame of view. The so-called polar axis of the mount must point to the north celestial pole in the sky. The North Star is currently (2023.1) about 38.0 minutes of arc of the pole. This is just over one-half of one degree. Aiming your mounts polar axis at the North Star this generally sufficient for images made with cameras outfitted with comparatively short focal length lenses (say, less than 300mm to 500mm). Telescopically this is not the case. There, much better polar alignment is needed because telescopes typically have focal lengths of about 1,000mm or more.

Telescopic Imaging

Telescopic imaging is the most difficult type of astrophotography because centering and focusing sometimes very dim objects in the narrow field of view can be difficult. Also, longer focal length systems make accurate tracking a much greater problem. Problems also result from contending with magnified vibration, seeing problems, and the added expense of suitable equipment. These problems will be dealt with effectively in a follow-up mentorship using the professional imaging systems available through this course.

Imaging Configurations: There are several ways that DSLR cameras can be attached to telescopes:



- **Prime focus** – In this method the image produced by the telescope falls directly on the camera's CMOS imaging surface with no intervening optical components. This provides minimum magnification and maximum field of view with a given telescope.
- **Positive projection** – A telescope eyepiece is used to project a magnified image directly onto the camera's CMOS sensing array. Because the image is more highly magnified with a narrower field of view, this method is generally used for lunar and planetary photography. This is also known as eyepiece projection.
- **Negative projection** – Negative projection uses a negative lens (such as a T-adapter Barlow lens) to obtain a higher effective focal length. This increases the effective focal length of the telescope by 2 to 3 times. It produces larger but dimmer images on the imaging array. This approach is used as an alternative to positive projection. Most suitable for short exposure lunar and planetary photography
- **Afocal projection** – When the camera lens is not removed (or cannot be removed) a common method used is afocal projection. This is characteristic of using a cell phone to capture images through an eyepiece. In this method both the camera lens and the telescope eyepiece are attached. When both are focused on infinity, the light path between them is parallel (afocal), allowing the camera to basically photograph anything the observer can see when looking through the eyepiece. This method works well for capturing images of the moon and brighter planets, as well as narrow field images of stars and nebulae. This approach has grown in popularity with the introduction of point and shoot digital cameras since most models also have non-removable lenses. If this approach is used, a precision, adjustable (x,y,z) camera holder is called for. Afocal projection is subject to considerable vignetting of the image.

Compression – Compression uses a positive lens (also called a *focal reducer* or *telecompressor*), placed in the converging cone of light before the focal plane of the telescope objective, to reduce overall image magnification. It is used on very long focal length telescopes, such as Maksutov and Schmidt–Cassegrain designs, to obtain a wider field of view. Focal reducers are positively curved lenses that produce a shorter effective focal length of a telescope. This results in smaller, brighter images allowing for shorter exposure times, wider and flatter fields of view. Smaller star images mean crisper views, and any guiding error is less discernable. Shorter effective focal length can produce vignetting of the image, but this can be eliminated with the use of "flats" used with image processing. Telecompressor are the exact opposite of Barlow lenses (sometimes call tele extenders) which are negative lenses use to increase the effective focal length of a telescope. Telecompressors typically produce a 0.63X magnification whereas a Barlow lens typically produces a 2X magnification.

Camera Adapters – When cameras are fitted to telescopes, their lenses are generally removed, allowing the telescope to serve as the camera's telephote lens. Such adapters generally consist of a T-ring (specific to camera type) with a generic T-adapter that slides directly into the telescope's eyepiece receptacle. T-adapters come in 1.25" and 2" formats. The one required is that which fits into the telescope's eyepiece receptacle. When attached so, this constitutes a "prime focus" system. Prime focus systems are most commonly used by telescopic astrophotographers, but other approaches are also used. These will be addressed in future sections. The field of view of prime focus system depends only on the focal length of the telescope and the size of the camera's CMOS detector. Consider the following prime focus calculations.

Prime Focus Calculations

Let's now perform some sample calculations using the TCAA's AstroPhysics 130mm ($f/8$) Starfire apochromatic refractor with a camera mounted in a prime focus fashion. Consider both the telescope specifications and the image scale.

AstroPhysics 130mm (5.1") Telescope Specifications – In order to make calculations, you'll need the following information:

Aperture	130mm (5.1 inches)
Focal Ratio	$f/ = 8$
Focal Length	$F = 1024$mm (40.3 inches)

Image Scale – Image scale can be used to determine if something, say an image of the moon, can fit upon a CMOS imaging array. The formula for scale is derived from the radian formula $s = F\theta$ where s stand for the image scale, F the focal length, and θ the angular diameter of an object like the moon. θ in this case must be expressed in radians. If θ is to be expressed in degrees, then the formula must by multiplied by $\pi/180°$ or 1/57.3 Hence, $s = F\theta/57.3$. The scale per 1° is then found from $s = F/57.3$. For the TCAA's 130mm *Starfire* refractor ($f/8$) the focal length is approximately (130mm x 8) = 1024mm which at the prime focus gives an image scale of 1°= 17.9mm (or 3.36 arc minutes per mm). This can now be used to find the area of sky that a CMOS chip can image.

Nowadays, Canon manufactures their own DSLR image sensors that commonly measure 14.8mm x 22.2mm. By the above formula and with the specified telescope, this camera sensor will yield a photographic field of view of 14.8mm x (1°/17.9mm) by 22.2mm x (1°/17.9mm) or 0.83° by 1.24°. This chip in combination with the telescope is able to image the entire moon at once because the moon averages about 0.516° in apparent diameter during its closest approaches to Earth.

Now the Celestron 11" ($f/10$) telescope under the dome of Sugar Grove Observatory might or might not be able to image the entire disk of the moon. (Try the calculation yourself!) If it is not, the only way to successfully image the entire moon with this telescope and camera used in this example would be by use of a focal reducer (telecompressor) to give a shorter effective focal length. When used with a 10" $f/6.3$ telecompressor, F effectively becomes 279.4mm x 6.3 = 1760mm.

Activity: Determine the image scale and field of view for the Cannon 5D Mark II and Rebel Xsi CMOS imaging arrays used both with and with the presence of an f/6.3 focal reducer on the SGO's Celestron 11" telescope. (Note: The $f/10$ configuration has a focal length of 2,794mm. The focal reducer changes this to 1,760mm.)

Eyepiece Projection Calculations

Magnification Factor – Prime focus photography doesn't always provide a sufficiently large image scale for, say, photographing Jupiter. At prime focus Jupiter might be too small on the sensing array and so details will be missed. When doing photography with eyepiece projection, one can achieve a magnification factor by using eyepiece projection. Eyepiece projection requires a second item to work with the T-ring. This second item is the eyepiece projection adapter. These eyepiece projection adapters are screwed into the T-ring the same way the T-ring adapters are used. Then, an appropriate eyepiece is placed within the eyepiece projection adapter before mounting on the T-ring.

A magnification factor of this combination can be used to determine the new scale produced by the introduction of the eyepiece. The necessary formula is as follows:

Magnification Factor = (Distance from Eyepiece to Sensing Array / Eyepiece Focal Length) minus 1

For example, using an 18mm eyepiece and an eyepiece projection adapter providing a distance from eyepiece to CMOS detector of about 90mm (this is typically very hard to precisely quantify), the magnification factor is 4 (vis., 90/18 – 1). Using this projection lens on the SGO's Celestron 11" $f/10$ telescope gives an effective focal length of about 11,200mm (as compared to 2,790mm) and a focal ratio of about $f/40$. While this sounds extreme compared to the typical telescope focal ratio, Jupiter would still fill just over half of a typical small sensing array at this 11,200mm focal length!

Afocal Systems

Serious astrophotographers rarely use afocal imaging systems with DSLR cameras because of a very substantial mismatch between optical components. Afocal systems are commonly used with smartphones. When doing such photography (with a substantial loss of light-gathering power due to an overly large exit pupil of the eyepiece), it is best to use a cell phone holder such as shown in the Camera-Related Equipment section above.

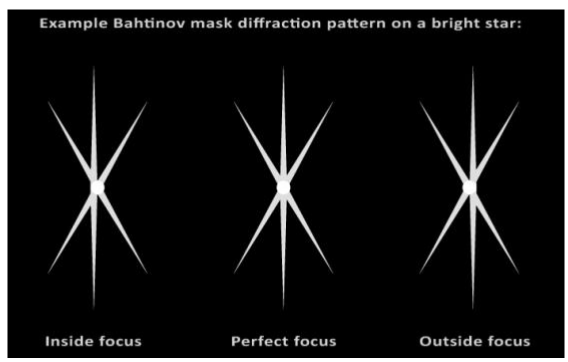
Achieving Focus with Any System

There are multiple approaches for photographing the night sky with a camera and lens, but the worst one to use is merely to hand adjust the lens until the infinity symbol (∞) aligns with an indicator mark (–) as in (– ∞). The focus of a lens system is temperature dependent, and merely focusing this way could, on better lenses, lead to "inside" or "outside" focusing. The results will be the same, however – out-of-focus stars.

When you prepare to image stars, start first by getting a clear focus using *live view*. Repeatedly image the star field and digitally zoom in on stars to see if they are in focus in the image so taken. Adjust the focus until you get pinpoint star images. The best focus is achieved when the stellar images are as small as possible. This process holds for the moon and planets as well. All are so far away that they can be considered to be infinitely far. If you want to achieve sharpest focus on the moon or a planet, focus your system first on a star and focus that. Once you have achieved stellar focus, the moon and planets will also be in focus.

Alternatively, you might want to use a lens-size Bahtinov mask for focusing your camera/lens combination to achieve the best possible focus. You can generate Bahtinov masks for lenses of different focal lengths and apertures by using an online application. Create your mask, print it on paper, and then photocopy it onto transparency film. It can then be placed over your lens.

You can either purchase a Bahtinov mask or make your own. To make one, go the following website: https://www.deepskywatch.com/Articles/make-bahtinov-mask.html



This screen – placed over the objective end of the telescope (be it an actual telescope or a telephoto lens) – produces diffraction patterns as shown in the image shown below. In the left star image, the diffraction lines do not cross at a single point; the telescope is inside focus. In the right star image, the lines do not cross at a single point; the telescope is outside focus. In the center star image, all three lines cross at a common point; the telescope is in perfect focus.

With a Bahtinov mask in place, take a short photograph of a bright star. Examine the image. Do the three diffraction images intersect at a common point? If not, turn your focusing knob a small amount and take another picture. Does the focus improve or get worse? If it improves, continue turning the focus knob in the same direction taking pictures to determine the best focus. When the focus gets worse, reverse the direction you are turning the focus knob. Continue adjusting the system until you get perfect focus.

Activity: Determine the best focus with your camera and lens/telescope combination using a Bahtinov mask.

N.B. Photographing the sun is also a possibility, but one must be absolutely certain one knows what he or she is doing. Severe and lasting damage to the eye and camera can occur if the proper solar shields are not in place. Because stars are not visible present during the day other than the sun, it's much harder to achieve a focus. The recommendation is to focus on a star by night and lock in the focus so it can be used the next day. The focus won't be perfect due to temperature differences, but close to it. At least one will know where to start when it comes to refining the focus on the sun.

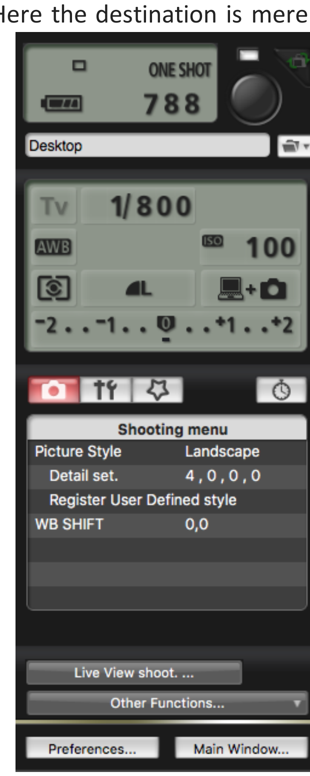
Imaging with Canon EOS Utility 2 or 3

The Canon EOS Utility 2 is an electronic version of the Canon electronic cable release. The advantage of working with a method other than the electronic cable release is that you can run the camera from a computer, seated at a table far removed from the telescope dome. (Of course, this same effect can be achieved using wireless and a smartphone today.)

The benefit of doing so is that you can see images on the computer screen (or your smartphone) rather than having to look at them at from the back of the camera which is often poorly oriented for doing so. Once you have used a computer-based controller, you will never go back to the electronic cable release unless you are doing wide field photography either from a tripod or when riding piggyback on a telescope or polar oriented observing platform. Here are the basic steps required for imaging with Canon EOS Utility 2.

1. Attach the camera to the telescope and select the imaging configuration that you prefer. (e.g., prime focus, positive projection, etc.)
2. Make sure that the camera's battery is fully charged or that a battery replacement is in place and powered up.

3. Connect the DSLR with the appropriate remote-control cable running from the laptop computer (USB) to the camera itself (mini).
4. Turn on the DSLR camera using the appropriate on/off switch.
5. Adjust the camera to the "Tv" setting (Time value).
6. Start the Canon EOS Utility 2 on the computer. The screen shown to the right will appear. → → → → → If accessories are shown, click on "Control Camera".
7. If the computer and camera are networked, you will be able to select "Camera settings/Remote shooting" on this screen. If not, check the connection. When connected, a control screen will appear that looks like this. → → → → → → → → →
8. Select destination folder for your images if you do not like what you currently see. Here the destination is merely "Desktop." It would be better to select a named and dated folder to keep your desktop uncluttered. To set a new destination, click on the folder to the right of the word "Desktop."



9. ISO generally should be set to 800 or 1600 for long-exposure deep-sky astronomical images of faint objects. Right click on the ISO setting before taking your first deep space photographs. If, on the other hand, you are photographing the moon, having too high an ISO setting will cause overexposure. Set it to 100 to 400 for bright objects. ISO effectively sets the "gain" of the sensing array. Setting it too high can cause over exposure; setting it too low can cause underexposure.
10. Note the 1/800 exposure setting. Right click on this number using your mouse to see options for new times. Use the <<, <, >, and >> settings to increase or decrease exposure time. Click on the round button at the upper right of this screen to start the exposure. Note that you cannot expose for more than 30 seconds (30") using this exposure setting. See below for longer exposures.
11. If you wish to take longer exposures, must click on the clock below the camera settings window. This will open up another window in that allows exposures using "Remote bulb shooting." Set the camera to "Manual" or "Bulb" for remote bulb shooting. Set the exposure time between 5 seconds and 99 minutes and 59 seconds. Click on "Start" to begin the exposure.
12. Start your focusing by using the Bahtinov mask. See instructions above. Once focus is established, you may experiment with exposure times to achieve your best images. Your images will be downloaded and viewed as they are taken. Make adjustments accordingly.

Image Processing

Image Adjustments – Most of us are familiar with the ways of adjusting our images using several types of software. Common adjustments are exposure, contrast, highlights, shadows, saturation, tint, and hue. We also know how to sharpen crop and resize images. Because these constitute very basic knowledge for photographers, they will not be dealt with here. *Preview* is commonly used on Mac computers to make such changes, but Adobe Photoshop and *Lightroom* also can be used.

Image Stacking – Image stacking in astrophotography consists of making a single composite image from two or more sub-images. The benefit of this procedure is to increase the signal-to-noise ratio and drawing out fainter details in the final image. Usually three types of image are required for the stacking process: light frames, dark frames and flat frames. The images containing the astronomical stack are called light frames. Dark frames are images obtained by taking images with a closed lens cap. Flat frames are produced by imaging a solid field (typically white). The dark frames are used to remove dark current, and flat frames (or merely flats) are used to reduce vignetting or varying sensitivity of a CMOS sensor array.

The Best Astrophotography Software – While there is a lot of imaging software out there, there a certain versions that offer very special tools for astronomical imaging. Some is free; some is shareware; some is freeware. While "you get what you pay for" is a common saying, it's not entirely true. There is a lot of free stuff out that that sometimes is just as good as the commercial stuff.

1. Adobe Photoshop – Powerful and professional tool
2. DeepSkyStacker – Free stacking operation
3. SiriL – Full-blown astrophotography editor
4. GIMP – Free astrophotography software
5. Adobe Lightroom CC – Custom choice for final tweaks
6. Affinity Photo – User-friendly
7. PixInsight – Perfect noise reduction and star alignment
8. Star Tools – For beginners
9. Astro Pixel Processor – The best astrophotography post-processing tools

Visit each of these products' websites to learn more. There are plenty of YouTube videos demonstrating the use of such software as well. Do take advantage of it.

A Dozen Vicarious Lessons

It is best to learn from the mistakes of others rather from your own mistakes. Mistakes can be costly, time consuming, and frustrating. Vicarious learning is much more efficient. Here are some pointers you should learn from our mistakes:

1. **Know your camera before going out.** The field is no place to learn how to operate your camera. Sit down and study the owner's manual. Make sure your practice with your camera so you know how to set ISO, f-stop, exposure, and manual focus.
2. **Know how your electronic cable release works.** When you want to take exposures exceeding 30 seconds, you'll need an electronic cable release to so do. Camera's rarely have built-in exposures in excess of 30 seconds.
3. **Know how to focus and set f/stop while in BULB mode.** BULB is part of the manual mode. When in bulb mode, how do you set focus and f/stop? You'll need to know if you take exposures of longer than 30 seconds. Default settings might not be the best.
4. **Always carry extra batteries.** There's nothing so frustrating as being ready to take some shots only to realize that your battery is "fast expiring," and you don't have a replacement. Always carry one or more fully charged spares. Even consider bringing your battery charger along just in case.
5. **Always carry extra memory chips.** Nothing worst that having a good photoshoot and realizing that your camera's memory chip can't hold another image.
6. **Always bring all your equipment.** Just like extra batteries and memory chips, it's important not to forget to bring along with your other essential bits of equipment. When you forget something is when you'll most likely need it. This includes owner's manuals for your cameras and controllers. Who knows what you'll forget mentally.
7. **Keep all your equipment in one place.** When your equipment is scattered all over the house or gathered into various boxes and bags, you are likely to overlook that one thing you will need in the field.
8. **Keep your equipment organized.** Putting things in a variety of bags and boxes is one way not to find things when you need them. Consider a good camera bag with lots of pockets and return everything to its place after use. Better yet, consider a good fishing tackle box where everything is exposed. That way, you don't have to search through lots of pockets (into which you cannot see by scanning) because you can't remember where you put something.
9. **Have a plan before going out.** Have a plan; think through all your actions. Know what, when, where, and how you plan to photograph a subject or scene. Generally you want to focus on one type of astrophotography at a time as a beginner. Get to know fix camera imaging before using a tracking mount. Get to know how to use a tracking mount before taking photographs through a telescope. Each step represent a growing level of complexity.
10. **Don't forget your tripod, camera clamps, and electronic cable release.** How many times I've brought all my camera equipment and forgotten to bring my tripod (because it's not "camera equipment"), I don't know. By thinking through what you a planning to you, you'll be more likely to remember you tripod, camera clamps, and electronic cable release.
11. **Stick with one type of astrophotography at a time.** You will be surprised at how attempting to do several sorts of astrophotography on any given evening can be confusing – at least until you get to know your systems really well. As a beginner, get to known astrophotography using your tripod. Only then move on to piggyback mounting, and then using a telescope. Each step is increasingly more complicated, and it's best to know the basics before moving on.
12. **Always carry your camera's manual with you.** No matter how well you think you know your camera, there's always something more to learn especially when trying astrophotography for the first time. There is a reason most camera manuals are a couple of hundred pages long. They are wonders of modern technology, but they sure are complicated.

Relative Image Brightness Calculation

The brightness of an image at the focal plane of prime focus imaging system is proportional to the square of the diameter of the objective lens or mirror, D^2, and inversely proportional to the square of the focal length of the objective, F^2. That is,

$$\text{Image Brightness} \propto D^2/F^2 = (D/F)^2$$

This is the same thing as saying that image brightness (IB) is proportional to the inverse-square of the focal ratio (FR) of the objective producing an image or $1/(FR)^2$. That is,

$$\text{Image Brightness} \propto 1/RF^2$$

Comparing via focal ratio the image brightness produced by the SGO's Celestron 11" HD telescope ($f/10$) with the WO's PlaneWave 20" telescope ($f/6.8$), we find the following:

$$\frac{IB_{20"}}{IB_{11"}} = \left(\frac{10}{6.8}\right)^2 = 2.16$$

Thus, the $IB_{20"} = 2.16 * IB_{11"}$. Because the image brightness of the 20" telescope is 2.16 times brighter than the image brightness produced by the 11" telescope, the 20" is capable of achieving the same image in about half the time it would take the 11" to do so. Another way of drawing the comparison is that for the same exposure, the 20" would image objects that are 2.16 times dimmer (just a tad under one magnitude) than would the 11" assuming no reciprocity failure of the imaging system. This might be a surprising difference for some. Keep in mind that image brightness depends not only on the size of the objective mirror but on the focal length as well. Consider that $F_{20"} = 3{,}450mm$ and $F_{11"} = 2{,}800mm$ approximately.

Some Useful Resources

This is just a sampling of the information you need to start imaging professionally using a DSLR camera (or other more advanced CCD cameras). You can find lots of resources with considerably more detailed information online.

For a broad introduction, consider *Getting started in astrophotography has never been easier* by Michael Covington available at: http://www.skyandtelescope.com/astronomy-resources/astrophotography-tips/deep-sky-with-your-dSLR/

Check out Jerry Lodriguss' incredibly rich and complete compilation of information from basic to advanced astrophotography through his *Astrophotography Techniques* at: http://www.astropix.com/HTML/I_ASTROP/toc_ap.html

There are many similar online resources and printed media. Check them out and become more expert.

For basic (DSLR) and more advanced (CCD) imaging techniques, check out St*arizona'*s phenomenal astronomical imaging resources available at: https://starizona.com/blogs/tutorials/

Bobby Arn's *Photography At Night: An Introduction to Astrophotography on a Budget.* See course instructor for a free copy of the eBook.

