SKY & TELESCOPE

Astrophotography Primer

Your FREE Guide

to photographing the planets, stars, nebulae, & galaxies.

Astrophotography Primer

Akira Fujii

Everyone loves to look at pictures of the universe beyond our planet — Astronomy Picture of the Day (apod.nasa.gov) is one of the most popular websites ever. And many people have probably wondered what it would take to capture photos like that with their own cameras.

The good news is that astrophotography can be incredibly easy and inexpensive. Even point-and-shoot cameras and cell phones can capture breathtaking skyscapes, as long as you pick appropriate subjects. On the other hand, astrophotography can also be incredibly demanding. Close-ups of tiny, faint nebulae, and galaxies require expensive equipment and lots of time, patience, and skill. Between those extremes, there's a huge amount that you can do with a digital SLR or a simple webcam.

The key to astrophotography is to have realistic expectations, and to pick subjects that are appropriate to your equipment — and vice versa. To help you do that, we've collected four articles from the 2010 issue of *SkyWatch*, *Sky & Telescope*'s annual magazine. Every issue of *SkyWatch* includes a how-to guide to astrophotography and visual observing as well as a summary of the year's best astronomical events. You can order the latest issue at SkyandTelescope.com/skywatch.

In the last analysis, astrophotography is an art form. It requires the same skills as regular photography: visualization, planning, framing, experimentation, and a bit of luck. It's fun to buy equipment and learn how to use it. But ultimately it's you the photographer, and not your camera, that's the most important ingredient of all. ✱

Tony Flanders

Associate Editor, *Sky & Telescope*

Getting STARTED is a

There's never been an easier time to try your hand at photographing the heavens.

By Dennis di Cicco

IF YOU THINK THAT 47 YEARS of experience photographing the starry sky makes me a good candidate for introducing beginners to astrophotography, you're wrong. Digital photography has so revolutionized the way people take pictures, that my experiences as a teenager in the early 1960s conquering film-based astrophotography's formidable hurdles are now largely irrelevant. Indeed, even the typical challenges facing beginning digital astrophotographers a decade ago have fallen by the wayside. And trust me when I say all of that is good news.

By those earlier standards, today it's ridiculously easy to venture into the fascinating world of astronomical photography. Furthermore, you can do it with equipment that you probably already own. Yup, if you have just about any digital camera (and an estimated 100 million of them were purchased worldwide in 2008), you can at least try a little astrophotography without investing a cent. Just look at the examples in Sean Walker's article "Point & Shoot the Sky" beginning on page 36. All of those photographs were captured with basic point-and-shoot cameras.

Nevertheless, as with most hobbies, astrophotography offers plenty of ways for you to spend your money, especially as you advance in the field. But that too is good news compared with how things were years ago. In the '60s there was very little commercial astrophotography gear, and you pretty much needed to be a telescope maker, or at least be capable of customizing equipment, if you wanted to move up the astrophotography ladder. Today, no matter how specialized your interests, from high-resolution planetary imaging to wide-field panoramas made at special wavelengths of light, you can find commercial equipment to meet your needs. And the cost-to-performance ratio of this gear gets better by the day.

But for all the changes that have occurred over the years, one aspect of astrophotography remains the same — human nature. As much as I've thought about it, I don't know what makes somebody take up the hobby of astrophotography.

Piece of CAKE

Above: **Showing more signs of age than the telescope, the author knew in an instant that he'd taken a better picture of the Moon with his cell phone's camera than he ever managed to capture with the same scope and a film camera in the 1960s.**

Mutant genes; a knock on the head as a kid; the lure of a technical challenge; an overwhelming desire to capture some of the infinite beauty that a starry sky serves up every clear night; maybe all of the above. I'm not sure. But whatever it is that gets people to try astrophotography, there's no denying that a little success provides a powerful incentive to continue. And this is where digital photography has made some of the most dramatic changes from the ways things used to be. And nothing drove that point home to me more vividly than a casual event a few months ago.

In the early '60s, the highlight of my 13th birthday was a 60-mm refractor ordered from the Lafayette Radio catalog. I still have the telescope, and every now and then set it up in the driveway. I tell people I'm comparing its performance with that of modern equipment, but the real quest is a Twilight Zone exit from contemporary life back to my salad days of exploring the universe as a teenager. A few months ago while viewing the gibbous Moon during one of those detours from reality, it struck me that I had a camera in my pocket — my cell phone. No mystery what happened next.

It took longer to think about doing it than it did to hold the cell phone's lens up to the telescope's eyepiece and snap the shutter. The result was amazing — the picture that flashed on the phone's screen (shown at bottom on the facing page) was an order of magnitude better than anything I ever managed to shoot years ago with a film camera and the same telescope. While all levels of astrophotography have improved greatly in the interim, relatively speaking, the cell-phone picture was a far better "beginner's" shot than what I managed in the early '60s. That, however, isn't the point of this tale.

More important than the quality of the image is the excitement that comes from simply seeing it, since this alone fuels an interest in shooting more. It's human nature — success breeds success. And in the case of digital astrophotography, positive feedback is instantly available. Results that took hours to see in the '60s (or days if it involved getting color film developed) took less than a second with the cell phone.

If you've given any thought to trying your hand at astrophotography — and I presume you have if you've read this far — then go ahead. Flip through the pages that follow to get an idea of what you might accomplish with gear you already own (or are interested in purchasing), and go outside the next clear evening. You'll find out right away if you've succeeded, and I'm willing to bet you will.

Here's a closing thought; in the days when film ruled, even the world's best amateur astrophotographers couldn't compete with the images made through professional telescopes at mountain-top observatories. But that too has changed in the digital age. Today the majority of the finest images made of the heavens come from the telescopes and cameras of backyard observers. Maybe one of your future shots will be among them.

CHECK OUT:

SkyandTelescope.com/gallery

TWAN: www.twanight.org

Beginner's guide: www.astropix.com

SkyWatch *senior editor* ***Dennis di Cicco*** *had the good fortune to get in on the ground floor of digital photography in the late 1980s after amassing three decades of a now almost useless knowledge of film-based astrophotography.*

Point & Shoot the SKY

Just because you don't own a high-end camera doesn't mean you can't take great astrophotos

By SEAN WALKER

IT'S A LOVELY EVENING and there's a beautiful sight in the west. Set into a darkening twilight sky is a thin crescent Moon next to a bright planet. But the only camera you own is a small point-and-shoot digital model. To capture scenes like this, you'll need to go out and buy an expensive digital SLR (the kind with interchangeable lenses), right? Not so fast!

That little camera you've taken to the beach or Disney World can capture beautiful evening and night-sky vistas — and you don't even need a telescope! Rather than funnel money into high-end gear that you may not enjoy, try your pocket digicam on a few easy projects to see if astrophotography really appeals to you.

Most readily available digital cameras come with features that offer you greater control over your picture taking than the "auto" setting. Many models include night mode, continuous-fire shutter-release, manual exposure control, and even manual focusing. These options give you the keys to some great skyscapes.

I should mention right up front that for night-sky shooting, you'll need a tripod to hold your camera steady. I've seen small, lightweight models at department stores and drug stores for as little as $10.

Pretty Pairs

Among the prettiest astronomical events you can record with your point-and-shoot camera are conjunctions (close pairings) of the Moon and planets. As with other types of sky photography, your camera's autoexposure setting probably won't give good results (even if it has a night mode). If you can manually set your exposure length, try different values to see what works best.

If you can't set the exposure time yourself, the next-best thing is to see if your camera has an exposure-bracketing feature. This automatically shoots three frames with slightly different exposure times in rapid succession. When photographing the sky, it's always a good idea to take as many different exposures as you can. That way, at least one of them will likely capture all the detail and color you want in your image.

When shooting conjunctions, you'll often want to zoom in. Be careful: many point-and-shoot cameras have both optical and digital zoom. Optical zoom magnifies your chosen target, but digital zoom just crops in on the scene and blows up the pixels, which doesn't help at all. See if you can disable the digital-zoom function, or note how much optical zoom your camera has, and don't zoom in any further than that.

If you can see it, you can shoot it with your pocket digital camera. The author planned to capture this close conjunction of the Moon, Jupiter, and Venus with the digital SLR camera that he keeps at home. But he was caught in a traffic jam as sunset approached, so he took a short detour to New Hampshire's Canobie Lake, and snapped the scene with his handy Canon PowerShot A-85 instead.

Top: **Auroras are terrific targets for sky-shooters, but they're unpredictable. This one was captured using a Nikon Coolpix 5000.**
SkyWatch Photo: Dennis di Cicco

Middle: **Unexpected atmospheric phenomenon like this double rainbow can come and go in a matter of minutes — a great reason to keep that little camera handy!** SkyWatch Photo: Robert Naeye

Right: **Simple shots through your telescopes eyepiece can be extremely rewarding, like this image of Venus near inferior conjunction. A method of astrophotography using your camera's video function can be found on page 42.**
SkyWatch Photo: Dennis di Cicco

More Simple Shots

If you're lucky enough to be shooting during an aurora, the same technique — capturing a series of the longest exposures your camera will take — will again guarantee that you'll get a great shot.

Daytime atmospheric phenomena such as Sun pillars, halos, and rainbows can be recorded by simply hand-holding your camera. Whether shooting in automatic or manual mode, make sure you bracket your exposures to give yourself a better chance of capturing that perfect image.

Happy Trails

One of the more interesting forms of night-sky photography is capturing star trails. The idea is to keep the shutter open as long as possible to reveal the turning of the heavens over the course of an evening. Your camera's maximum exposure time may be only 10 to 15 seconds, but with the addition of one simple tool and a free computer program, you can make excellent star-trail images.

As well as your tripod, you'll need some way to hold down your shutter button so that you can record consecutive images without touching the camera repeatedly. A small bar clamp with rubber grips, sold in the tool aisle of any large hardware store for about $8, does the job perfectly.

See if your camera can be set not to display the image after every exposure. That'll avoid wasting battery power on the screen and enable you to take lots of images. And make sure you disable the flash.

Frame your target area using the camera's widest zoom angle. Try to include something in the foreground to give the composition a sense of scale; trees, hills, or other landscape features add more interest to your final picture.

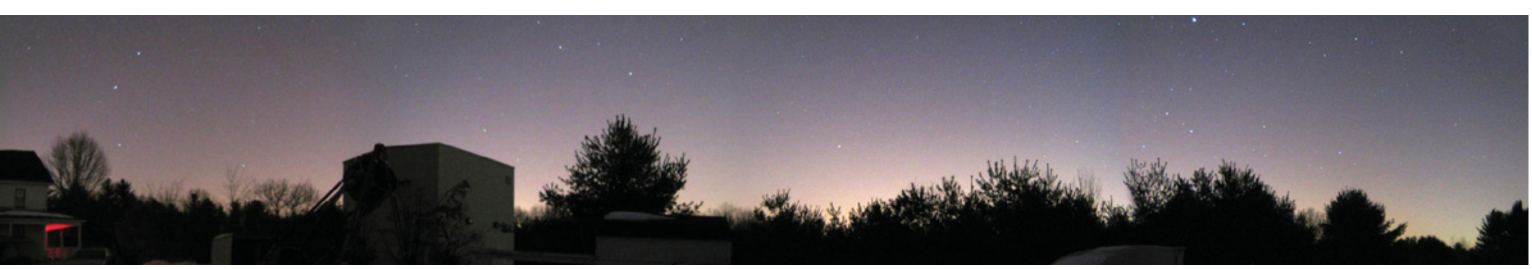
To start your image series, set your camera for its maximum exposure length (or to night mode, if you can't select a particular shutter speed), then change the ISO speed of your camera to 400. This is the digital equivalent of using faster film in your camera, making it more sensitive to low light levels than ISO 100, typically used during daylight shots. While some cameras can shoot as fast as ISO 1600, the results tend to be too noisy to be very useful. ISO 400 is a good compromise between speed and noise.

Next, set the lens focus at infinity (∞). Select the continuous-fire shutter-release function, then attach the clamp to your camera to hold down your shutter button. Shoot for at least 10 minutes — the longer, the better. Once you're done, you'll have dozens or even hundreds of short exposures with a few recognizable constellations visible in them.

Your next step is to download and install one of the free computer programs specifically written for the purpose of combining the individual frames. Startrails (www.startrails.de/html/software.html) and StarMax (http://ggrillot.free.fr) both work well and can accept files directly downloaded from your camera. These easy-to-use programs for PCs will automatically stack all your images into a final composition.

Top: **You don't need an expensive camera to take great pictures of constellations, star trails, or special sky events. *SkyWatch* senior editor Dennis Di Cicco captured this star-trail image over his house using a Casio Exilim EX-Z850 and assembled many short exposures using the software *Startrails*.**

***Bottom*:** **Panoramas can be stitched together with simple (and sometimes free) software. *SkyWatch* editor Tony Flanders took this 360° panorama of the Amateur Telescope Makers of Boston's observing site in Westford, Massachusetts, as part of a light pollution survey. He used a Canon PowerShot A-80 camera and took eight 15-second exposures.**



Cloudy sunsets can produce spectacular compositions.

Meteors & More

Meteor showers can be shot and processed exactly the same way. Pick an area of the sky that's both dark and photogenic — perhaps including your favorite constellation of the season. Keep your camera pointed at the same spot all night. Chances are a "shooting star" will eventually pass through your camera's field of view while the shutter is open. Patience is the key!

This same technique can also record passes of the International Space Station, the Space Shuttle, and flares from Iridium satellites. Check the Heavens Above website (www.heavens-above.com) or SpaceWeather.com (www.spaceweather.com) for satellite predictions for your location and plan your shots ahead of time.

Don't Scrimp

In addition to the techniques described above, don't be afraid to experiment. And remember: you aren't wasting film, so it's always better to shoot too many images and throw away the bad ones rather than to risk missing a great shot.

Chances are good you already have the tools you need to start recording memorable celestial events. Understand the limits of what you can do with your equipment and work within those boundaries, and you'll capture many rewarding mementos of your nights under the stars.

SkyWatch *imaging editor **Sean Walker** always keeps his Canon PowerShot A-85 handy for unexpected astrophoto opportunities.*

Capturing the SOLAR SYSTEM

Recording impressive portraits of the Moon and planets is surprisingly simple.

By SEAN WALKER

IT'S OFTEN SAID that we live in a golden age of amateur astronomy. Large, high-quality telescopes are readily available, and for some purposes, these instruments rival the capabilities of professional observatories. Indeed, it's not uncommon to see amateur photographs of the Moon and planets that are surpassed only by interplanetary space probes and the Hubble Space Telescope. The biggest surprise, however, is how easy and inexpensive it is to take these amazing images. If you can see the planets from your location, you can shoot them.

The best tool to record the planets through a telescope is the computer webcam. Shortly after these tiny cameras were popularized for video conferencing in the late 1990s, amateur astronomers saw their potential to record digital videos of the planets. These pioneering astrophotographers hoped that by capturing thousands of frames in rapid succession to a computer, they would be able to select the moments when the planets were least affected by atmospheric turbulence. Boy, were they right! Soon webcam imagers were routinely producing planetary images better than the finest ground-based photos from the pre-digital age.

Today, specialized planetary webcams are available for as little as $100, opening up the possibility that you can join the ranks of these elite imagers.

Which scope is best?

The best planetary images are captured through telescopes with at least 10 inches of aperture, but smaller instruments can take great shots, too. Whether you own a refractor, reflector, or compound telescope, there's plenty of detail within your reach. (If you're not familiar with these terms, read "What to Know Before You Buy" on page 22.)

Refractors are simple and rugged, but they're perhaps the least suitable design for planetary imaging. Achromats, the most inexpensive models, produce a bluish-purple halo of unfocused light around bright subjects such as the Moon and

Above: **All you need to take great shots of our planetary neighborhood is a webcam, a computer, and a telescope with a tracking mount.** ***Facing page:*** **The Moon, Mars, Jupiter, and Saturn offer tremendous detail for patient observers.**

All photographs are by the author unless otherwise noted.

Planetary webcams available today come equipped with a 1¼-inch nosepiece and fit directly into your telescope's focuser. To increase the magnification, Barlow lenses, tele-extenders, or eyepieces are placed between the telescope and camera. Photo: Alan Dyer

planets. This effect can be minimized with the use of a specialized *minus-violet filter* that will block most of the unfocused light, resulting in sharper images with less of a noticeable halo.

Apochromats are free of the halo issue, but big ones are extremely expensive. Also, refractors tend to be quite long and are not very portable in apertures of 8 inches and more. So if you're considering serious planetary astrophotography, your best choices are reflectors and compound telescopes for the same reason that professional observatories use them — they gather lots of light, yet they're short, easy to mount, and relatively cheap to make.

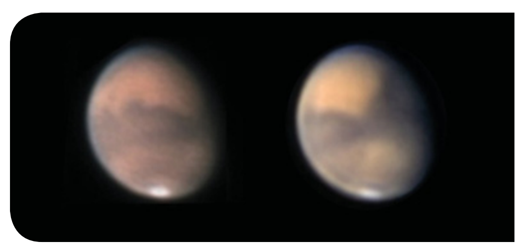
Magnification and Moving Targets

Due to the small angular size of the planets, high magnifications are necessary to record significant detail on them. Even Jupiter, the largest planet, never appears bigger than 50 arcseconds — the size of a soccer ball ¾ of a mile away. Consider the purchase of a good Barlow lens or tele-extender to increase your telescope's magnification.

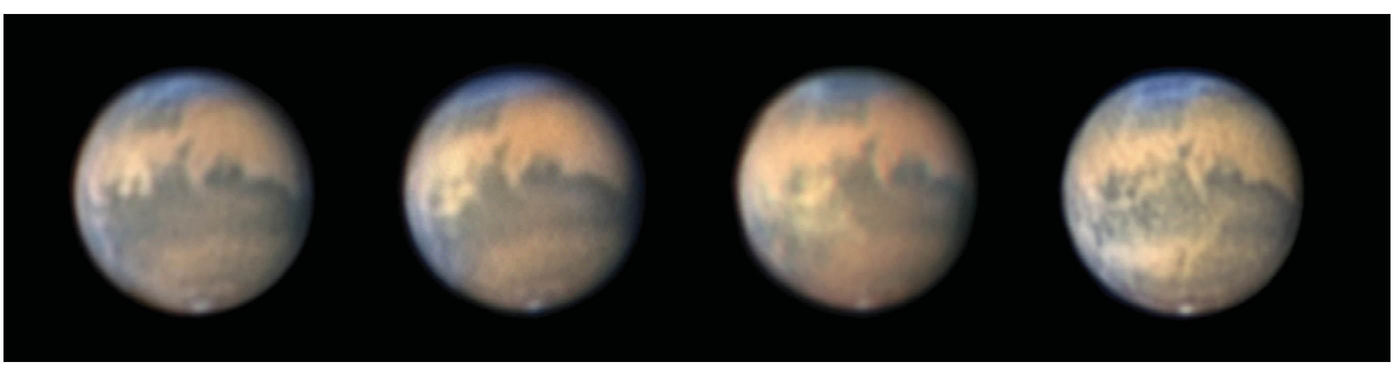
Another way to amplify your image is to shoot with an eyepiece in place, a technique known as *eyepiece projection* photography. While this technique can take advantage of eyepieces you may already own, you'll need additional adapters to connect your camera close enough to the eyepiece to come to focus.

Regardless of how you choose to increase the image scale, you'll find that a good tracking mount of some form is necessary to keep your target on your camera's tiny detector. Fortunately, because you'll be recording many video frames per second, you don't need the same kind of accuracy that's essential for multiminute deep-sky exposures (see page 48). Most of the popular planetary image-processing programs automatically align your frames, so as long as you can keep your target on the chip, you can even get away with strong wind gusts wobbling your scope!

A telescope on an equatorial mount is preferable. Altazimuth mounts, which are aligned with the ground rather than Earth's rotational axis, introduce rotation in your movie clip, which may lead to problems when stacking the resulting video. A mount with electronic correction controls for both axes is highly desirable, because you'll want to adjust the position of your target on the camera while you're shooting. And an elec-



Right: The video capabilities in many point-and-shoot digital cameras offer an easy way to start recording the planets. These two images of Mars were taken with the same telescope at matching magnifications using a Philips ToUcam 740 webcam (right) and a Canon PowerShot A-85 digital camera in video mode. *Bottom:* The major planets can change appearance day to day, so there can often be a surprise awaiting you each night. For instance, a dust storm erupted on Mars in 2005. By recording images each night, the author was able to track the process of the yellowish clouds as they moved across the globe.



The Moon offers a great target every month of the year to practice your technique, and because it's our nearest neighbor, you often don't need to magnify the image as much as the planets to capture lots of detail.

tronic focuser is highly desirable; just touching your telescope at high magnifications will induce vibrations, making it very difficult to see when it's truly in focus.

Your Digital Eyepiece

Choosing your camera can be just as difficult as choosing your scope. Many options are available today, depending on your level of interest. The original webcam that started the whole planetary revolution, the Philips ToUcam, has long since been discontinued, but it can sometimes be found on the used market for as little as $50. Nowadays, the most inexpensive camera to start shooting the solar system is Meade's Lunar and Planetary Imager (LPI), for $99. The LPI comes with everything you'll need to get started, including its own software, though it doesn't record as many frames per second as some other cameras. However, its control software *Autostar Suite* automatically registers and stacks your image during the recording, rejecting blurry frames, making the LPI one of the easiest routes to get involved with solar system imaging.

Another low-cost option is the Orion StarShoot Solar System Color Imager III ($189.95). This camera features a larger detector than the LPI, and also includes a custom version of the popular astro imaging software *MaxIm DL Essentials*.

More advanced cameras capable of capturing 60 frames per second and faster are offered by companies such as The Imaging Source (astronomycameras.com), and Lumenera (lumenera.com), and can cost as much as several thousand dollars each.

There's also another option that you perhaps already own. Many point-and-shoot digital cameras have a video mode capability. While the movie format your little camera records might not be compatible with some planetary image-processing software, it can be converted to a usable format with free software such as *VirtualDub* (virtualdub.org). Using a point-and-shoot camera will require an adapter to hold the camera close to the eyepiece.

Regardless of which camera you choose, the fundamental approach to planetary imaging is the same: capture many frames in a short period of time, and then stack the best frames of the video using the software of your choice. Cameras such as those mentioned earlier from Meade and Orion come with their own proprietary software for camera control and processing. Other options include the PC programs *RegiStax* (www.astronomie.be/registax), *K3CCDTools* (pk3.org/Astro/index.htm?k3ccdtools.htm), and *AviStack* (avistack.de). Mac users should check out *Keith's Image Stacker* (keithwiley.com/software/keithsImageStacker.shtml). All of these programs are free or very inexpensive.

Getting the best out of your equipment

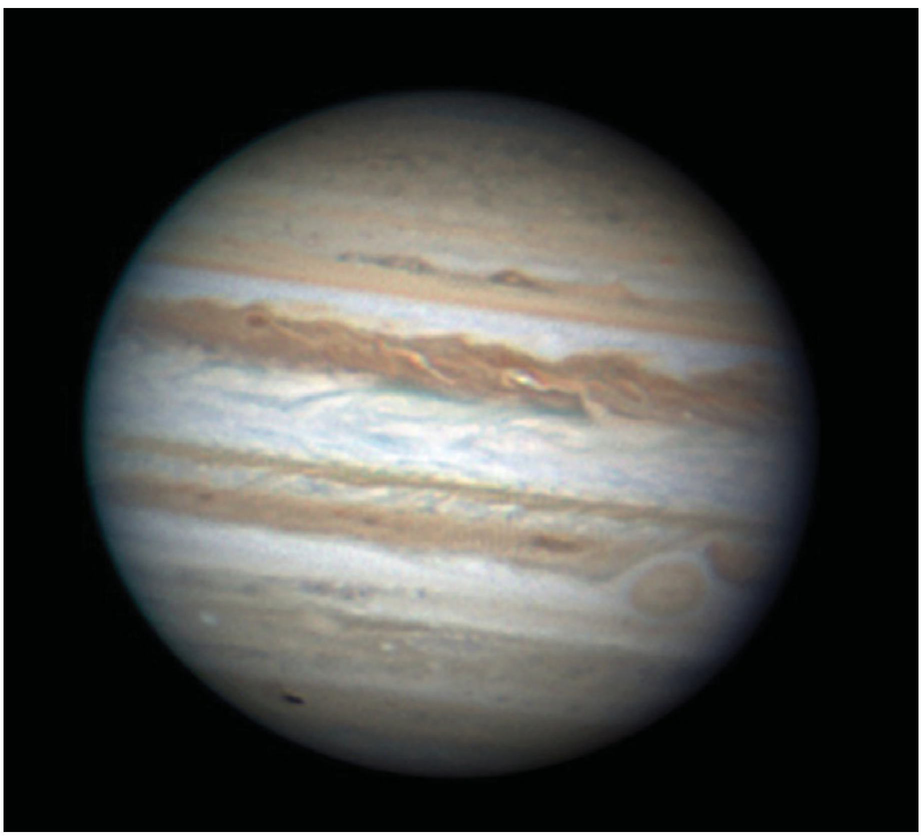
So you're ready to start shooting our solar system neighbors. Here are a few tips to get the most out of your setup.

❶ First you need to make sure that your telescope has had time to cool to match the outdoor temperature. A warm or cold telescope coming out of the house will produce thermal currents, which ruin the steadiness of your view. Allow about an hour before shooting if you take your telescope outside from a temperature-controlled environment.

❷ If you're using a reflector or compound telescope such as a Schmidt-Cassegrain, check your collimation before shooting. (See "No-Tears Collimation" on the included CD.) Even slightly misaligned optics will significantly degrade your results. This can't be stressed enough. Telescopes with movable mirrors often slip out of collimation, so taking a few minutes to check will pay dividends in your images.

❸ Avoid shooting directly over rooftops or asphalt parking lots early in the evening. Rooftops build up heat in the daylight, and then slowly radiate that heat back into the sky. The views you get over a hot rooftop will be similar to looking at something directly behind a fire. This may be unavoidable in a large city.

SATURN: You don't need a giant telescope to take great shots of the Moon and planets. The author captured this image using a 5-inch Maksutov-Cassegrain telescope and a Philips ToUCam Pro webcam in the spring of 2005.



JUPITER'S NEW BRUISE: Recording images of the planets can lead to very big discoveries. While imaging from his backyard on July 19, 2009, Anthony Wesley noticed a fresh impact scar on Jupiter (dark spot at bottom), where a large object hit the planet and exploded in its atmosphere. His discovery prompted the largest telescopes on Earth and in space to focus on the planet!

❹ Try not to overexpose the movies recorded with your webcam — there shouldn't be any white, blown-out regions in your video, because any sharpening by your post-processing software will increase that area. There's often subtle detail in the bright areas of craters on the Moon, or the polar caps of Mars, that can be revealed if care is taken to avoid overexposure. Most of the webcam-capture software that came with your camera includes a tool to monitor the histogram of your video.

❺ Finally, practice whenever you can. Just like visual observing, you learn more about your equipment's capabilities the more frequently you use them. And because planetary imaging can often take only a half-hour or so, you can take advantage of those partly cloudy nights.

Perhaps the best aspect of planetary imaging is that it's impervious to light pollution. The Moon and major planets are bright enough to be seen from even the most light-polluted cities on Earth. So as long as you have a clear shot, you have a pretty good chance of getting a respectable planetary portrait. ⭘

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*Sky & Telescope imaging editor **Sean Walker** has been capturing the planets with webcams for more than a decade.*

Deep-Sky Astrophotography Primer

Every clear night backyard observers are turning out images of the cosmos that let our imaginations soar. Here's what it takes to join them.

By DENNIS DI CICCO

SAY THE WORD ASTROPHOTOGRAPHY to even casual amateur astronomers, and chances are they'll conjure up scenes of whirling galaxies and colorful nebulae, for it's these iconic deep-sky images that let our imaginations sail across the sea of cosmic wonder. Not long ago the finest deep-sky photographs came from professional telescopes at mountaintop observatories. But digital photography has leveled the playing field, and now many of the most breathtaking images come from the telescopes and cameras of backyard observers. And, as mentioned on page 34, digital photography has also made it easier than ever for anyone to try shooting their own pictures of nebulae, star clusters, and galaxies.

Perhaps you've dabbled with simple astrophotography techniques like those described on page 36 and are looking to move on to the next stage. Or perhaps you want to leap right into deep-sky photography (plenty of people have). So the question is how do you get started?

Mounting Issues

Many beginning deep-sky photographers ask what telescope they need. But that's jumping the gun. The principal piece of equipment that every advancing astrophotographer needs is a tracking equatorial mount. That's because the biggest hurdle we face is that our targets are constantly moving across the sky. Whether our interests lie in capturing wide-field vistas of the Milky Way or close-up portraits of distant galaxies, we need our cameras and telescopes mounted on a platform that can

One of the brightest deep-sky objects in the sky, the Orion Nebula is a popular target for beginning deep-sky astrophotographers. This view was recorded with the 6-inch Ritchey-Chrétien astrograph shown on the opposite page. It's a stack of a four 30-second exposures taken with a Nikon D300 DSLR at an ISO setting of 1600.

All photos by Dennis di Cicco & Sean Walker.

accurately track the sky's east-to-west motion.

Years ago all tracking mounts were some variant of the equatorial design pioneered by the German instrument maker Joseph Fraunhofer in 1824. These have a shaft, called the polar axis, aligned parallel to Earth's axis of rotation. It turns at the same rate but in the opposite direction of Earth's rotation, thus effectively cancelling the sky's apparent motion for any telescope mounted on it. The mechanical complexities of the equatorial mount (and there are many) are weighed against the simplicity of following celestial objects by turning a single polar shaft at a constant rate. But it's not the only way to track objects.

Thanks to computer technology, many of today's motorized telescope mounts are based on an altazimuth design. They have mechanical advantages over equatorial designs, but they require driving two axes at constantly varying rates (child's play for motors controlled by a computer chip) in order to track the sky's motion. While both equatorial and altazimuth mounts will keep a telescope pointed at an object as it moves across the sky, the altazimuth design has severe limitations for astrophotographers. That's because an altazimuth mount makes the sky appear to rotate around the object it is tracking. There are workarounds for this problem, but the majority of astrophotographers find it far easier to just use an equatorial mount.

Equatorial mounts suitable for astrophotography are priced from a few hundred dollars to well into the five-figure range. In the North American market you'll find quality mounts made by Astro-Physics, Celestron, iOptron, Losmandy, Meade, Mountain Instruments, Orion Telescopes & Binoculars, SkyWatcher, Software Bisque, Takahashi, and Vixen, to name the major players.

Apart from optional features such as computerized Go-To pointing, more money generally gets you an equatorial mount with a higher load capacity and/or greater mechanical precision. Figuring what you need for load capacity is straightforward; you don't want to put a 20-pound telescope on a mount designed to hold only 10 pounds. And even when you *are* within the weight limit, the stability of a mount can be compromised as you get close to its maximum capacity. There's no penalty for having a mount that's bigger than required.

Figuring what you need for mechanical precision is a bit more complicated. Even the most accurate gears have imperfections that cause small variations in the rotation rate of the mount's polar axis. Called periodic error, this departure from a theoretically perfect drive is typically specified in arcseconds, and it gives the angular amount that a telescope appears to wobble around the point it is tracking. Good mounts today have periodic errors smaller than 20 arcseconds; and those approaching 5 arcseconds or smaller are considered excellent.

Equipment Matters

● The most important piece of equipment that astrophotographers need to move into the exciting field of deep-sky imaging is a tracking equatorial mount that allows their cameras and telescopes to follow the sky's apparent motion during long exposures. The German equatorial style of mount, shown here carrying a DSLR camera and telephoto lens, is especially popular with astrophotographers.

● Many of today's telescopes have motor-driven altazimuth mounts that keep them pointed at celestial objects as they move from east to west across the sky. The iOptron MiniTower seen here is a popular altazimuth mount that can carry a wide range of instruments. While altazimuth mounts are good for "snapshots" of the Sun, Moon, and planets, as explained in the accompanying text, they are not suitable for long-exposure astrophotography.

● You can spend a king's ransom on deep-sky astrophotography equipment, but a far more modest investment will allow you to produce excellent images. For example, the shot of the Orion Nebula on the opposite page was captured with this setup. Chinese clones of the venerable Vixen Great Polaris German equatorial mount pictured here are available for around $400, and the Astro-Tech 6-inch f/9 Ritchey-Chrétien astrograph retails for $795.

● It's a fuzzy line that separates telephoto lenses and some small telescopes. The author's 4-inch f/4 Pentax refractor is specially designed for astrophotography, and it's seen here with a high-performance Apogee CCD camera. But the refractor's optics are the same as those in the 400-mm f/4 Pentax telephoto lens made for medium-format film cameras. The telescope next to the lens is a guidescope fitted with an autoguiding camera.

When Comet Holmes underwent a spectacular outburst in October 2007 after more than 115 years of relative inactivity, the author recorded its unusual spherical appearance with his 4-inch f/4 Pentax refractor and a Nikon D200 DSLR. This view was made by combining twelve 1-minute exposures made at ISO 800.

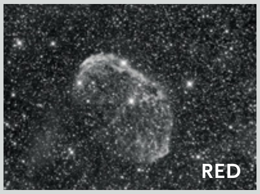
How much periodic error you can tolerate depends on the focal length of the lens or telescope you're using, as well as the length of your exposures. In simple terms, the situation is akin to conventional picture shooting with a telephoto lens; your hands shake regardless of the lens on your camera, but the motion is more obvious and likely to blur images when you're shooting with a telephoto and slow shutter speeds. Astronomical telescopes and time exposures are the ultimate in "long" telephotos and slow shutter speeds.

For many years I've used a German equatorial mount that has a rather mediocre 28 arcseconds of periodic error. Working with camera lenses up to about 180-mm focal length, I can shoot exposures many minutes long that show acceptably round stars. Longer telephoto lenses and astronomical telescopes, however, magnify the effects of the mount's periodic error and show star images that appear elongated. To solve this problem I have to guide the mount.

Traditionally, guiding was done by placing a small telescope (a *guidescope*) with a crosshair eyepiece alongside the photographic setup. You would center the crosshairs on your target or a star close to it, and during the exposure you used slow-motion controls on the mount to keep the star perfectly on the crosshair. The process was tedious and mind numbing. Fortunately, digital technology has come to the rescue.

Today, most astrophotographers have replaced the guidescope's eyepiece with a small digital camera that issues commands to the mount's drive to keep the guide star on virtual crosshairs. There are several variations on this theme of *autoguiding*. For example, some of the astronomical CCD cameras made by Santa Barbara Instrument Group (SBIG, for short) have a pair of digital sensors — one that records the image, and another, smaller one that monitors a guide star.

For astrophotography, an equatorial mount has to be set up with its polar axis parallel to Earth's axis. The process is called polar alignment, and there are a variety of ways to do it accurately, all of which are too involved to cover in detail here. Many books on astrophotography describe the process, but there's also good material suited to beginning astrophotographers in the third edition of *The Backyard Astronomer's Guide* by Terence Dickinson and Alan Dyer (2008, Firefly Books). As a bonus, this book's astrophotography section is one of the best and most up to date to appear in a general compendium on amateur astronomy. I highly recommend it.



Most of today's high-performance astronomical CCD cameras shoot monochrome (black-and-white) images. To produce a color photograph, astrophotographers make separate exposures through red, green, and blue filters and then combine them with image-processing software. This view of the Crescent Nebula (NGC 6888) in Cygnus was made with a Quantum Scientific Imaging 583 CCD camera and an Astro-Tech 8-inch f/8 Ritchey-Chrétien astrograph. The 1-hour monochrome exposures were combined with *Adobe Photoshop* to create the color view.

Optical Issues

Once you have a tracking equatorial mount with slow-motion controls set up and polar aligned, the astrophotography world is your oyster. With a suitable camera and lens attached to it, you can tackle just about every astrophotography project imaginable.

While they may seem like very different things, a telescope used for astrophotography is merely acting as a lens for your camera. Indeed, it's a somewhat fuzzy line that separates some small telescopes from traditional camera lenses.

The two most fundamental aspects of a lens or telescope are its focal length and aperture, which together determine its focal ratio (called f/number or f/stop by photographers). Mathematically, the f/ratio is simply the focal length divided by the aperture. In the world of conventional photography, lenses are described in terms of focal length and f/ratio, while in astronomy, telescopes are classed by their aperture and f/ratio. For example, I have a Pentax 4-inch (100-mm) aperture f/4 telescope designed mainly for astrophotography. It has a focal length of 400 mm. It produces the same images as the company's 400-mm f/4 telephoto lens made for medium-format film cameras.

Since the focal length of the lens or telescope determines the field of view recorded by a given camera, this is usually the parameter of most interest to astrophotographers. Because many spectacular objects such as the Andromeda Galaxy, North America Nebula, and Pleiades star cluster are relatively large, they can be captured with conventional 300- to 500-mm telephoto lenses. It's the smaller star clusters, planetary nebulae, and galaxies that are best photographed with the greater focal lengths available with telescopes.

Conventional wisdom from the days of film holds that telescopes for deep-sky astrophotography should be about f/5 or faster. This remains good advice in the digital age, but because digital chips are more sensitive than film, somewhat longer f/ratios are also viable now.

There is no all-purpose telescope for deep-sky photography, but if I had to pick one that can do a lot, I'd choose something with about 6 to 8 inches of aperture and a focal ratio of f/4 to f/8. In addition to being reasonably priced, scopes this size work well with many mid-range (think modestly priced) equatorial mounts. They can also be highly portable and easy to set up.

Camera Issues

In a perfect world, deep-sky astrophotography would be done with high-performance CCD cameras that are designed specifically for long astronomical exposures. And while it's true that most of today's elite astrophotographers use such cameras, most beginners start out with conventional DSLRs. The tradeoff in performance that comes with a DSLR is balanced by its simpler and often more intuitive operation in the field (astronomical cameras require a separate computer). Then too,

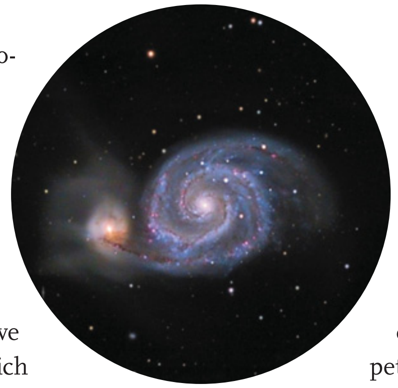
Many prominent diffuse nebulae shine with the light of hydrogen-alpha emission. Unlike cameras designed for astronomical imaging, conventional DSLR cameras have relatively low sensitivity to this deep-red wavelength. Compare these views of the Orion Nebula (Messier 42) made with a Nikon D300 DSLR and 6-inch reflector (*top*) and an SBIG ST-10XE CCD camera and 5-inch refractor.

performance is relative. Even today's run-of-the-mill DSLRs produce images that exceed the best deep-sky photographs from the film age.

Internally, the principal difference between an astronomical CCD camera and a DSLR is that astronomical cameras are optimized to reduce "noise" in long exposures. This is usually done by reducing the temperature of the image sensor with a thermoelectric cooler. Noise manifests itself as bright specks and an overall grainy appearance in images, and it becomes more noticeable in the longer exposures needed for dim subjects.

For purely technical reasons having to do with the color-filter array incorporated in the sensors of cameras that produce "one-shot" color pictures, the most sensitive cameras are monochrome — in other words, they shoot only black-and-white images. To create a color image with these cameras, astrophotographers shoot several images through different color filters and combine them with image-processing software.

Straddling the fence between DSLRs and high-performance, monochrome astronomical cameras are entry-level astronomical cameras. Most of them are cooled like their more expensive cousins, making them less noisy than DSLRs, but they often have smaller sensors. Some of them are based on the same sensors used in DSLRs and thus produce a color image with a single exposure. But it's more than just cooling that sets them apart from DSLRs. These entry-level astronomical cameras have been modified to make them far more sensitive to the deep-red wavelength of hydrogen-alpha light, which is a major component of emission nebulae. Like their high-performance counterparts, they require a separate computer, and their overall operation is much the same. The biggest difference is that models with color sensors don't need filters and multiple exposures to create color images.



The famous Whirlpool Galaxy (Messier 51) in Canes Venatici is another popular target for beginning deep-sky photographers. This view is a total of 4½ hours of exposure with an SBIG ST-8 CCD camera and 7-inch reflector.

Because entry-level astronomical cameras are often priced competitively with higher-end DSLRs, the deciding factors when purchasing a camera primarily for astrophotography are usually whether you're interested in the best performance (astronomical cameras win in this category) or you want to avoid using a computer in the field (DSLRs win here). Orion Telescopes & Binoculars has recently introduced several entry-level astronomical cameras that are setting new standards for price and performance. You'll also find advertisements and product reviews for many cameras in *Sky & Telescope*.

If you're interested in flat-out performance, then a quality, monochrome, cooled astronomical camera is the clear choice. Prices have come down significantly in the last few years, but still start at around $2,000 and head into the stratosphere. Color filters and a manually operated filter wheel start around $500 for small filters (suitable for cameras with small sensors) and also can get rather pricy for larger filters and computer-controlled wheels. The major North American manufacturers of high-end cameras include Apogee Instruments, Finger Lakes Instrumentation, Quantum Scientific Imaging, and Santa Barbara Instrument Group.

Software Issues

Ansel Adams once said that a photographic negative is comparable to a composer's score and the print to a performance. The naturalistic appearance of Adams's famous landscapes was achieved by hours of careful manipulation in the darkroom. Here, too, technology has come to the photographer's aid, with image-processing software replacing enlarging lenses, masks, and smelly chemicals.

The final touches on most of the deep-sky images found in magazines and on the web were done with conventional image-processing programs such as Adobe *Photoshop*. But in early stages, most were also processed with programs optimized for the special demands of astronomical imaging. Whole books

Attaching conventional camera lenses to astronomical CCD cameras is an excellent way to capture deep, wide-field images. This view of the dramatic hydrogen-alpha emission nebulae permeating the constellation Orion was made with a 55-mm f/2.8 camera lens fitted to an SBIG ST-8 CCD camera. It is a three-frame mosaic.

Above: **Black-and-white images of many deep-sky objects have a special beauty all their own. Furthermore, you can take many from light-polluted suburban locations by shooting through a narrowband hydrogen-alpha filter. This view of the Rosette Nebula in Monoceros was captured with a 66-mm Astro-Tech refractor, SBIG ST-8 CCD camera, Astrodon hydrogen-alpha filter, and 2 hours of total exposure.**
Below: **The Trifid Nebula (Messier 20) in Sagittarius shows a striking color combination due to its red emission and blue reflection nebulosities. It was recorded with an 85-mm refractor, SBIG ST-237 CCD camera, and 2 hours of total exposure through red, green, and blue filters.**

exist on this subject, and even the basics are too detailed to cover here. All of the major astronomical image-processing programs have websites, including *Astroart, CCDSoft, CCDStack, DeepSkyStacker, ImagesPlus, MaxIm DL, Nebulosity* (Mac computers only), and *PixInsight*. Any Internet search engine will locate the websites if you type in the software name. There are also several up-to-date books that cover image processing in detail. You'll find an excellent selection ranging from introductory level to advanced published by Willmann-Bell (www.willbell.com).

Armed with a good equatorial mount, a small telescope, and a DSLR camera, today's beginning digital astrophotographers can soon be turning out deep-sky images to rival some of the best ever made when film ruled the world. It's a great way to get started in a hobby that can last a lifetime.

SkyWatch *senior editor* ***Dennis di Cicco*** *began shooting pictures of the night sky in the early 1960s as a teenager. His reviews of astronomical equipment, especially astrophotography gear, frequently appear in* Sky & Telescope.