Resolving Our Neighboring Worlds

MOMENTS OF CLARITY With practice and patience, you too can record highly detailed closeups of the major planets. This montage shows some of the best results the author has recorded from his backyard observatory in southern New Hampshire.

ALL IMAGES ARE COURTESY OF THE AUTHOR

Capturing high-resolution pictures of the major planets has never been easier.

The planets in our solar neighborhood have long been a major pursuit of both amateur and professional astronomers alike. But it wasn't until the end of the 20th century that amateurs' work really started to be taken seriously. The advent of digital cameras and powerful home computers and software provided backyard observers with the tools to achieve the resolution and clarity needed to produce world-class images of these distant worlds. And that prompted professional astronomers to seriously consider their work.

Today, amateurs using high-speed digital video cameras and innovative processing techniques regularly produce pictures of the major planets on par with those obtained at professional, mountaintop observatories. And it doesn't take a lot to get involved yourself. Here's how.

Aperture Is Key

The planets might be nearby (astronomically), yet they're still an immense distance away, and resolving details on their tiny disks requires a lot of magnification. Almost any type of telescope can produce pleasing views of our neighboring worlds, but you'll need an aperture of at least 8 inches to clearly record swirling clouds inside Jupiter's Great Red Spot or small storms in the atmospheres of Saturn and even Uranus.

The type of scopes best suited for planetary imaging are either a Newtonian reflector or a Cassegrain instrument. Refractors provide the greatest contrast due to their unobstructed aperture, but large refractors are very expensive, with long, heavy tubes compared to the alternatives.

The most economical approach is the Newtonian, which costs the least amount per inch of aperture. But the design's biggest weakness is that its tube can be prone to flexure, requiring frequent collimation to ensure consistent optical performance throughout the night as the instrument tracks your target across the sky. Additionally, using the scope on an equatorial mount frequently places the Newtonian's focuser at an awkward angle. Furthermore, determining which direction is up can be tricky, an important factor when using an atmospheric dispersion corrector, discussed later.

Perhaps the best compromise between aperture and tube size is a Cassegrain system that folds a long optical path into a tube some one-third the length of a comparable-aperture Newtonian and produces the image at the rear of the scope through a central perforation in its primary mirror. The Schmidt-Cassegrain telescope (SCT) is the most common Cassegrain variant that utilizes a front corrector plate to produce a wide, corrected field. Other optical designs such as the the Maksutov-Cassegrain or Dall-Kirkham optics are also suitable but less common.

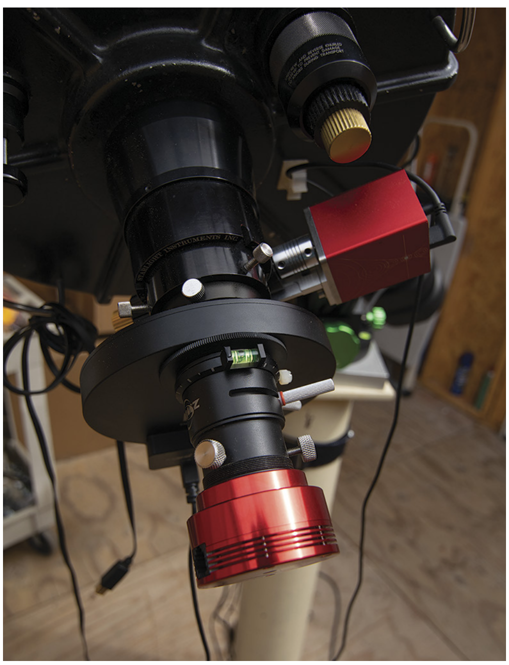
Cameras and Magnification

Regardless of which telescope you choose, there are some other accessories you'll need. The two primary ones are the camera and an amplification device like a Barlow lens. Resolving the smallest planetary details requires a long focal ratio, and commercial telescopes are typically offered with f-ratios of f/4.5 to f/11, so you'll likely need a quality Barlow lens, eyepiece-projection adapter, or other means of amplification (like Tele Vue's Powermates) to achieve the desired magnification. However, some of the cameras designed specifically for planetary imaging these days may have such small photosites (typically referred to as pixels) that additional magnification might not be needed in your particular setup. The optimum pixel scale to resolve small-scale features is about 0.1 arcsecond per pixel. To calculate this value, enter your telescope's focal length (*F*, in millimeters) and your camera's pixel size (*P*, in microns) into this equation:

$$\textit{Pixel Scale} = 206.265 \times (P \ / \ F)$$

For example, a camera with 2.76-micron pixels paired with an 8-inch f/10 SCT having a focal length of 2,032 mm produces a pixel scale of 0.28 arcsecond per pixel, which may be fine on most nights, though it will benefit from a 2× Barlow to get up to 0.14 arcsecond per pixel on particularly steady nights.

Speaking of cameras, planets are bright and typically require an exposure of just a fraction of a second to achieve adequate signal without much noise. This means you don't need a camera with active cooling, which requires additional power. However, due to Earth's turbulent atmosphere moments of steady seeing are few and far between, so it's nearly impossible to record all the small-scale detail visible in quick snapshots. To work around this issue, planetary imagers



◀ **HANDS-OFF** Manually focusing a telescope at extremely high magnification is much easier with an electronic focuser. The author uses a Feather Touch secondary focuser with a ZWO EAF stepper motor with his Celestron C14 that's controlled through a laptop. Also seen is a color filter wheel and ZWO Atmospheric Dispersion Corrector (ADC). The ADC tunes out prismatic dispersion introduced by Earth's atmosphere, leading to even-sharper results.

use the *lucky imaging* technique, in which you record a short video sequence of your target, then process the file using a computer program that selects and combines the sharpest individual frames.

There are many compact planetary cameras on the market today capable of recording hundreds of frames per second. These cameras are designed around Sony low-noise CMOS sensors and come in either monochrome (black-and-white) or one-shot color formats. Color cameras are great if you're interested in capturing images of the planets in their natural color. Monochrome models need an additional filter wheel with red, green, and blue (RGB) filters to produce color images.

Until fairly recently, monochrome cameras used with RGB filters produced the very highest-resolution images. That was because unlike the color version, monochrome cameras don't incorporate a *Bayer color filter array*, which is a grid of tiny filters layered over the detector that divides it into a pattern, with 50% of the pixels having green filters, 25% blue, and 25% red. Software then interpolates these pixels into a color image. This matrix used to produce inherently lower-resolution color images than a monochrome camera using separate color filters, but improvements in the interpolation algorithm (known as *debayering*) have made the difference negligible. But if you're trying to record planetary details in wavelengths beyond the visible spectrum, such as ultraviolet, near infrared, and the methane band that reveals features deep within Jupiter's atmosphere, then a monochrome camera is a better choice.

Besides its sensitivity characteristics, you should pay careful attention to the size of the pixels when choosing a video camera, as they're a key factor in determining the resolution of your results as noted earlier. The other feature to look for is how many frames it can record per second. You'd want to capture as many as you can in the shortest amount of time to ensure you get enough frames taken under steadier moments for stacking later.

Planetary cameras record video in AVI or SER formats, and most have the option of creating individual FITS files. Be aware that these cameras produce massive amounts of data — it's not uncommon to collect several hundred gigabytes of image data in an evening! These large files require a computer with substantial hard-drive memory space and an ultrafast write speed. When shopping for a computer, look for one with USB 3.0 ports and a high-capacity, solid-state drive (SSD), as these are capable of write speeds of hundreds of megabytes

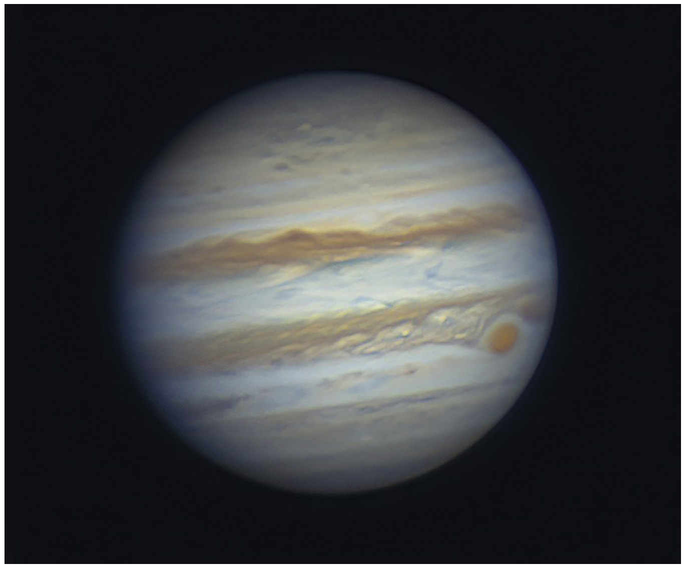
◀ **BEYOND THE VISIBLE** A monochrome camera equipped with color filters isolates individual wavelengths of light, which is particularly desirable for imaging in specific spectral regions. Certain planets, including Jupiter, Venus, and Uranus, reveal interesting details at wavelengths beyond the visible spectrum. Venus shows light and dark bandings in its cloud tops in ultraviolet light (top), which are only hinted in visible light under excellent seeing conditions (second from top). Jupiter recorded on February 3rd shows the planet in natural color (third from top) and in the methane (CH_4) absorption band at 889 nanometers (bottom), where features deeper into the planet's atmosphere appear bright.

per second. Avoid budget models that rely on cloud storage, as it's simply too much data to pass through an internet connection. If you're using an older laptop or one with a slower write speed, many planetary cameras now include onboard DDR3 RAM memory buffers, which help prevent dropping frames when operating the camera with slower write speeds.

While your camera may come with its own control software, there are a few free or inexpensive programs designed specifically for planetary imaging that feature additional capabilities, including controls for electronic focusers and filter wheels. Some also allow you to preprogram the exposure length and gain settings for each filter. *SharpCap* (**sharpcap.co.uk**) for PCs supports a wide range of camera models. Both PC and Mac users can operate their cameras and accessories with *FireCapture* (**firecapture.de**), which is perhaps the most popular and versatile program for capturing planetary data, and there's a version for Mac users. There's also *oaCapture* (**tinyurl.com/oacapture**) just for Macs.

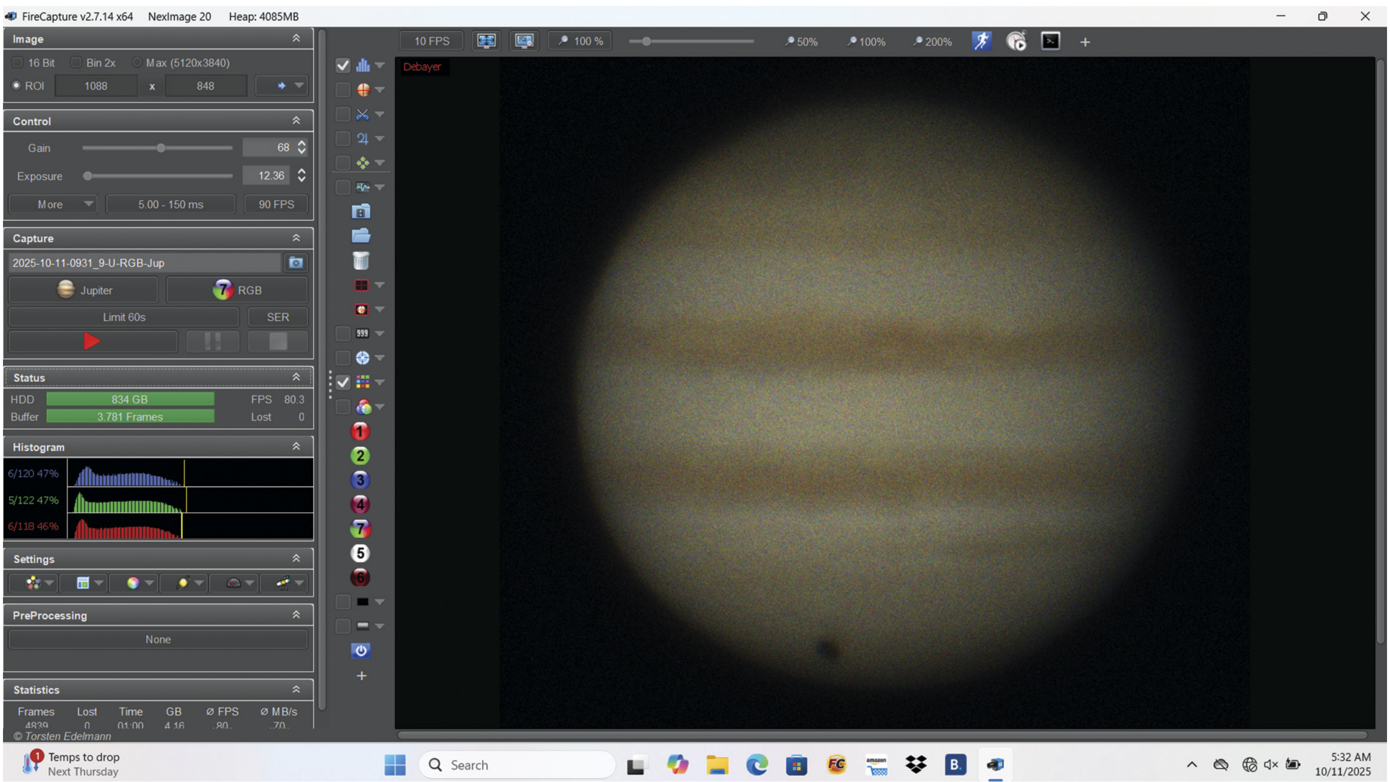
Imaging with extremely long focal lengths requires an electronic focuser. Attempting to manually focus will magnify the vibrations from your hand, producing an unsteady view that's virtually impossible to focus accurately. Also consider that you'll be refocusing many times during the night as the ambient temperature drops and seeing conditions change.

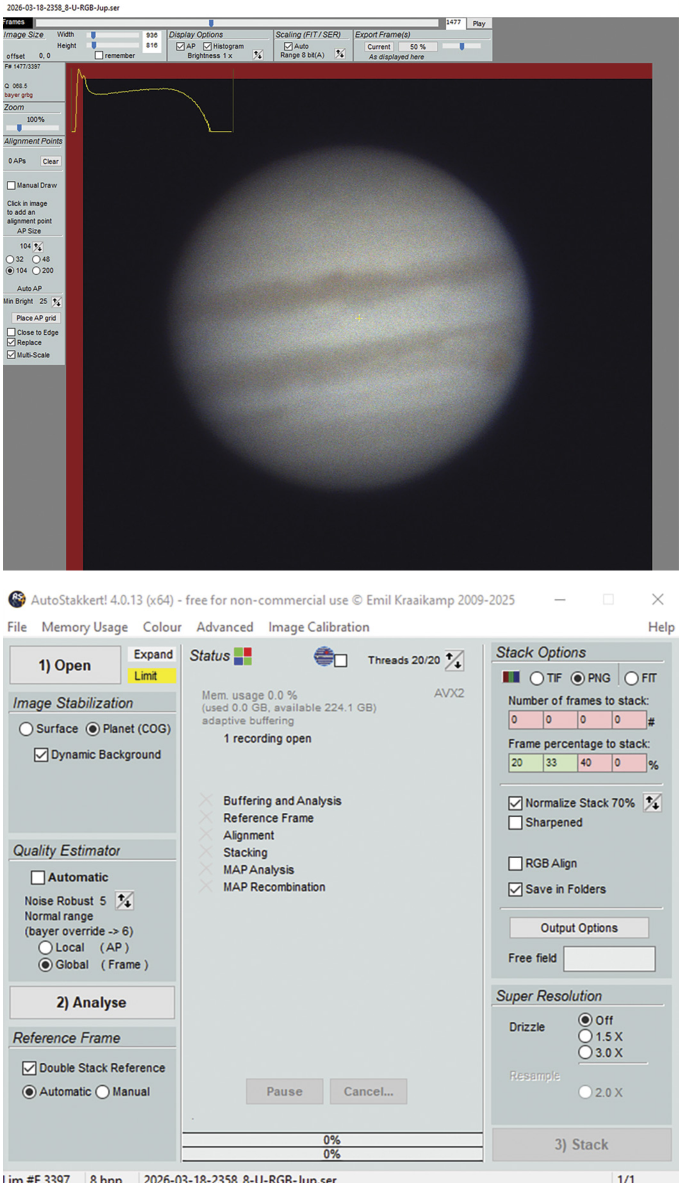
One other useful accessory is the atmospheric dispersion corrector (ADC). This device resembles a short Barlow that contains two weak prisms placed in the optical path. Earth's atmosphere is loaded with water vapor, which smears light into its component rainbow colors, a process known as *atmospheric dispersion*. The effect appears as red and blue fringing on the



▲ **PIXEL POWER** Some newer cameras are built around detectors with smaller pixels than ever before, which, in some cases, eliminates the need for additional image amplification like using a Barlow lens. The author recorded this shot of Jupiter on the evening of March 19th this year using a Celestron NexImage 20 paired with his C14 at prime focus. With its 1.4-micron-square photosites, the camera produces an image scale of 0.07 arcsecond per pixel — a bit too much magnification for this scope, though a good match for a C8 with its 2,032-mm focal length.

▼ **COMPLETE CONTROL** While some cameras come with their own software, other third-party options are available that offer much more features. *FireCapture* (**firecapture.de**), shown above, as well as *SharpCap* (**sharpcap.co.uk**) both can also operate electric focusers and filter wheels.





▲ **AUTOMATED STACKING** *Autostakkert! 4* is a popular free program that stacks videos or individual frames with very little user input.

top and bottom of your target planet, which becomes more pronounced the closer the planet is to the horizon. By adjusting the ADC, you can cancel out this chromatic smear and noticeably improve the sharpness of the image. An ADC is a worthwhile investment, particularly at more northerly locations, where the planets arc across the sky at lower elevations. It needs to be aligned with the horizon to work properly, making it challenging to use with Newtonian reflectors.

At the Telescope

Once you've put together your planetary imaging setup, you'll need to ensure all your equipment is operating as best as it can starting with collimation. Because you're imaging at an extremely long focal length, even a slight misalignment in your optics will significantly degrade the quality of your images. Be sure to check your collimation before starting an imaging run by using a bright star in the same region of the sky as your target planet. Another important step is to give the telescope ample time to reach thermal equilibrium. If your telescope is warmer than the surrounding air, it radiates heat, which can significantly blur the image. Give your telescope about an hour to cool down before starting to image.

The biggest limiting factor in the quality of your images will be the atmospheric seeing conditions at your location. It's best to monitor weather conditions using websites that cater to astronomers, such as Astropheric (**astrospheric.com)**, Meteoblue (**meteoblue.com)**, or Clear Sky Chart (**cleardarksky.com/csk**) to see how the night may progress. Keep in mind, though, that meteorology isn't an exact science. You might end up with some great moments on a night forecast to be mediocre, so it's always worth trying to image on a clear night.

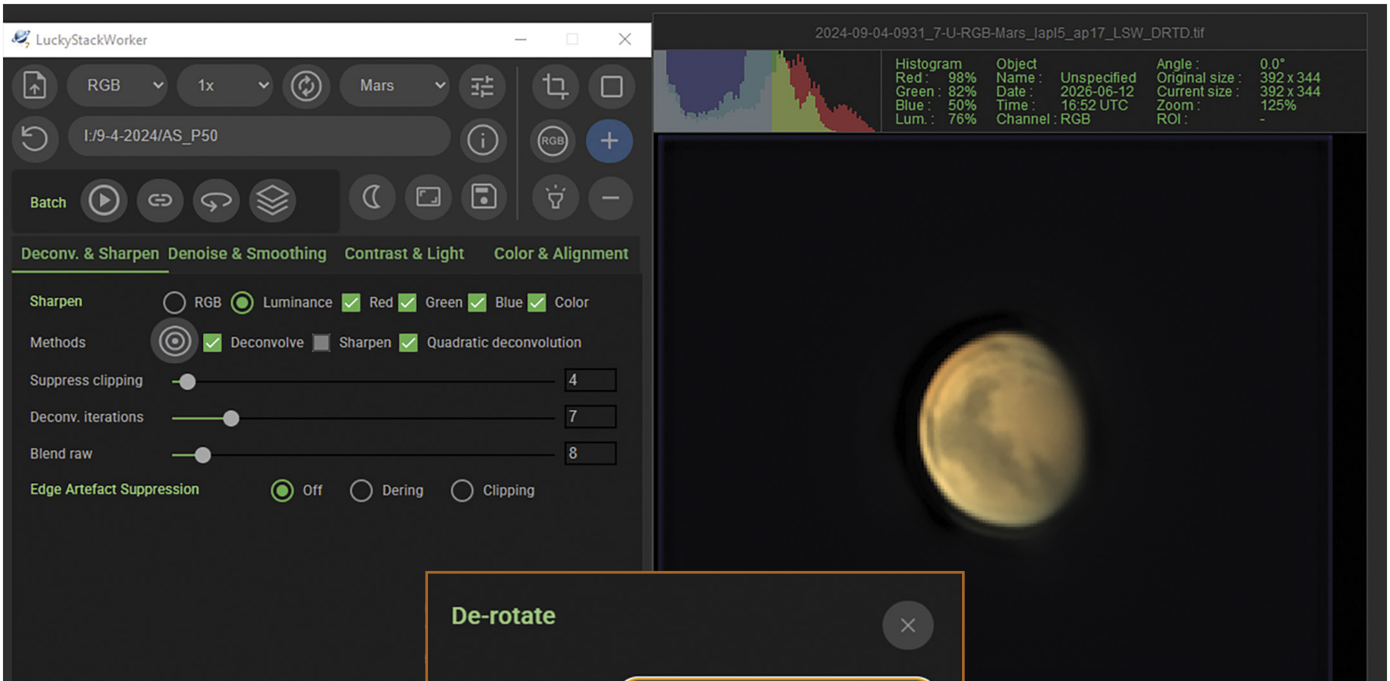
The last thing you'll need to do before hitting the record button is to focus the image. Achieving perfect focus is pretty easy under steady seeing conditions. More likely, though, is you'll end up racking the focuser back and forth, trying to find a good approximation of focus on a less-than-optimal night. It may take several minutes of trial and error to achieve sharp focus, but take as long as you need. I often refocus frequently throughout the night as the temperature falls and seeing conditions change.

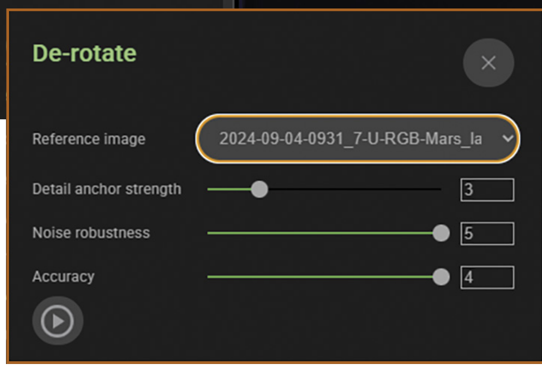
With everything ready, start recording. Keep in mind that your target is a rotating planet, so there's a limit on how long your recording can be before that rotation begins to smear the fine details you're trying to capture. For example, Jupiter rotates quickly, so I limit my videos to between 45 seconds to a minute when the seeing conditions are excellent. Saturn is noticeably smaller, fainter, and a bit slower, so I can go about 90 seconds or so before its rotation begins to affect image quality. With Mars, the limit is closer to 3 minutes. Neither Venus nor Mercury rotates fast, so you can record longer videos of each.

Video Sorting and Stacking

Once you've recorded your videos, there are several programs that make quick work of sorting and stacking them. Current PC options include *AutoStakkert! 4* (**autostakkert.com**), *AstroSurface* (**astrosurface.com**), and *RegiStax 6* (**astronomie.be/registax**). Each one will distill your video or image files into an image suitable for sharpening. Mac users also have several options, including Lynkeos (**lynkeos.sourceforge.io**) and Planetary System Stacker (**tinyurl.com/psstacker**), and Planet Stacker X (**tinyurl.com/planetstackerx**).

All stacking programs function similarly: They first evaluate and order the images or video frames, then you choose how many to include in the resulting stack. Generally, the more frames you stack, the better the signal-to-noise ratio is in the resulting image, allowing you to aggressively sharpen it, though it's not quite that simple. How many frames you





◀▲ **EASY DEROTATION** The new image-processing software *LuckyStackWorker* (**www.wilcokas.com/luckystackworker**) contains powerful deconvolution and other sharpening tools. It also includes an easy-to-use derotation feature that takes the work out of the process.

can stack will vary depending on the seeing conditions. On a good night, you might be able to use half, or more, of the frames you've acquired, but when conditions are poor, perhaps only 20% of your frames will make the cut. Adding more frames to a stack taken under poor seeing produces a smoother but blurrier result. If you're unsure of how many to stack, some programs like *AutoStakkert! 4* permit you to create several custom stacks at a time so you don't have to go back and redo the often-lengthy process.

With your data all stacked, it's time to sharpen the results using the tools in most of the programs listed above. (I prefer using wavelets and deconvolution tools in *WaveSharp*.) An additional way to get even more detail out of your planetary images recorded on a single evening is by using the technique of *derotation*, in which many stacked images taken over a long period of time are aligned on a specified longitude. This is a feature found in the freeware *WinJUPOS* (**jupos.org/gh/download**). You can find a tutorial on the technique in the May 2013 issue, page 70. There's also a new program that performs derotation on multiple images that's even easier to use than *WinJUPOS* called *LuckyStackWorker* (**www.wilcokas.com/luckystackworker**). This program automates all the manual work needed in *WinJUPOS* and also includes its own sharpening routines, though it still has some bugs to fix.

Contribute to Science

After you're done with your images, you can share them online or with any publications (we'd love to receive yours for our Gallery department). But these pictures are more than simply nice photos — they're an accurate record of a planet's appearance at a specific time and can contribute to historical records. The images you produce are of interest to professional astronomers, who cannot monitor the planets on a full-time basis. Instead, they rely on networks of dedicated amateurs in organizations such as the British Astronomical Association (**britastro.org**), the Association of Lunar and Planetary Observers (**alpo-astronomy.org**), and ALPO Japan (**alpo-j.sakura.ne.jp/indexE.htm**). These groups welcome new members and together provide almost continuous monitoring of the major planets throughout each apparition. Additionally, they provide good forums where you can discuss unusual observations with fellow imagers such as an asteroid impacting Jupiter or other transient events that you might serendipitously record.

It's a great time to start imaging the planets. While other types of astrophotography have to contend with problems like light pollution and the growing population of orbiting satellites, neither of these issues affect your pictures at all. Additionally, the major planets are just as visible from the city as they are under a dark sky. And with Saturn just past opposition, it's a great target to start honing your technique on in the early evening.

■ Senior Editor **SEAN WALKER** has observed the planets for a full Saturnian year and hopes to keep doing so for another.