High-resolution Lunar Photography

by Robert Reeves

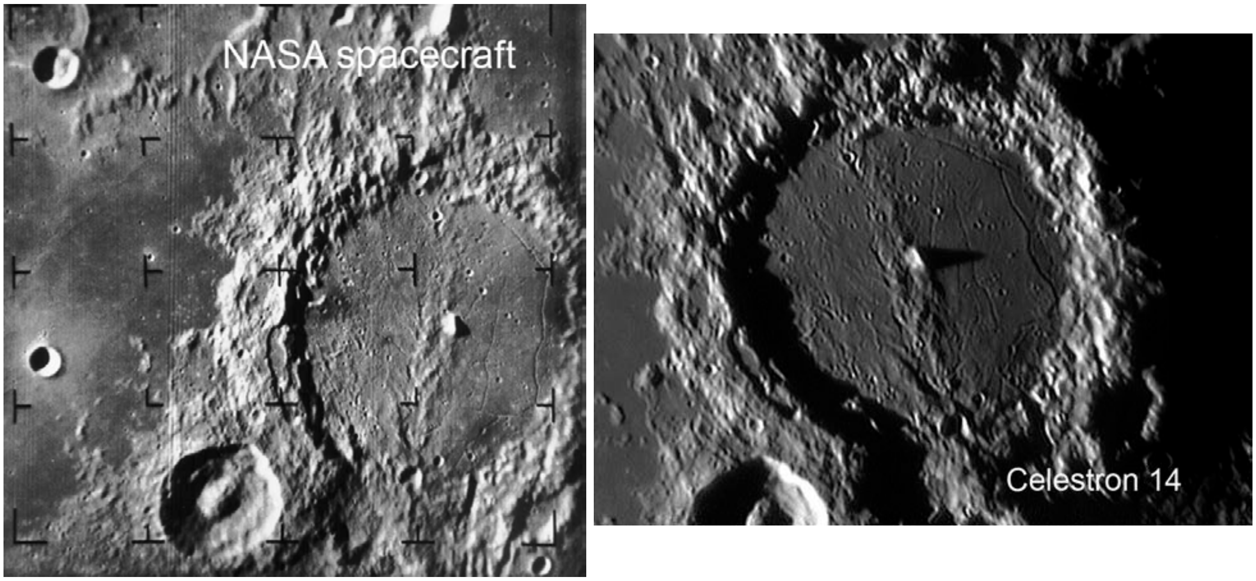
(Note: This tutorial is based my on my article "Target: Luna" appearing on page 66 of the May, 2016 issue of Sky & Telescope magazine.)

All photographs by Robert Reeves

In the late 1950s as NASA's focus centered on exploring the Moon, the technique of photographically charting the Moon was still in a surprisingly primitive state. The art and science of lunar photography had changed little during the one and one-half centuries of the chemical film era. The technique used in 1840 by the American physician John Draper to take the first lunar Daguerreotype was basically the same used to image the Moon at the dawn of the 21st century. It was amateur astronomers who sparked the paradigm shift that moved earth-based lunar photography from photographic film to electronic imaging. Astrophotographers learned that stacking and processing hundreds of digital lunar images taken through a modest telescope with an inexpensive webcam would out resolve film images taken through the world's best professional telescopes. Within a decade, webcams evolved into dedicated astronomical video cameras that allowed small amateur telescopes to produce lunar images superior to those previously produced by earth-based film photography.

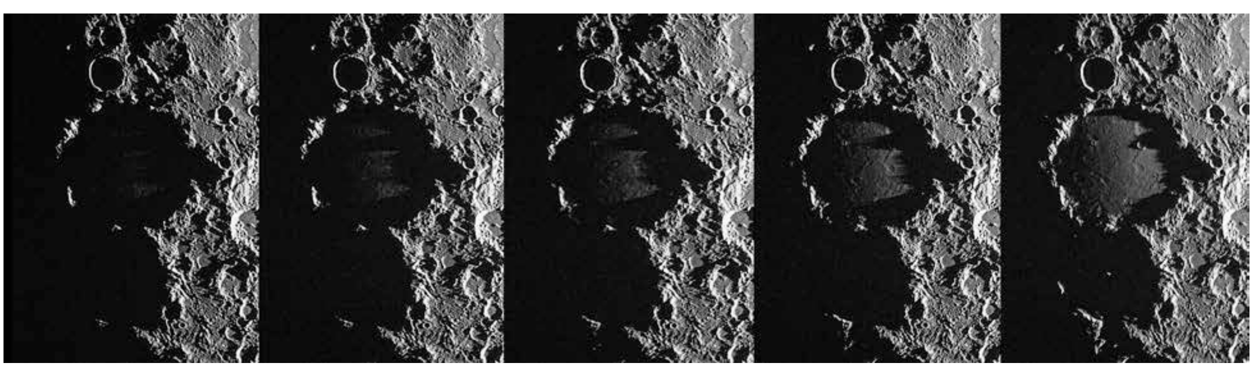
Robert Reeves specializes in high-resolution lunar photography using affordable, modest-sized telescopes. Here he poses with his Sky-Watcher 180mm Maksutov telescope and Celestron Skyris 236M camera. Together, both instruments represent a sub-$2000 imaging system (less telescope mount) that is capable of out performing the best professional telescopes that imaged the Moon using photographic film.

By using one of these digital planetary cameras along with one of several freeware software suites to process the video frames into a single stacked image, and the image enhancement techniques I describe here, you also can take stunning lunar photographs from your own back yard.



In 1965, the best images of the Moon yet attained were returned by NASA's Ranger 9 spacecraft (left image). Today amateur astronomers using electronic imaging techniques easily equal the historic NASA images (right image).

The first useful digital amateur planetary cameras were ordinary hobbyist webcams with a 640 × 480 pixel array and 5.6-micron pixels. Today, excellent digital planetary cameras are available from commercial vendors such as Basler, Celestron, Point Gray, QHYCCD, The imaging Source, ZWO Optical, and others. The Moon is basically a monochrome object, thus for lunar work a color camera is not needed. Monochrome cameras are also more sensitive, a feature useful when imaging the dim lunar terminator at high focal ratios. Modern planetary cameras use sensitive, reduced noise CMOS sensors with 1200 × 1920 pixel arrays and 2.8-micron pixels. The smaller pixels double the resolution over the initial webcams while the larger pixel arrays allow imaging five times the amount of lunar real estate. In addition, today's Super Speed USB 3 connections allow these new cameras to record 60 to 120 frames per second, allowing the capture of 3000 video frames in only 30 seconds. By using one of these digital planetary cameras along with one of several freeware software suites to process the video frames into a single stacked image, and the image enhancement techniques I describe here, you also can take stunning lunar photographs from your own back yard.



Amazing lunar images like this sequence of sunrise at Ptolemaeus crater are possible using modern electronic planetary cameras available from astronomical retailers.

Why image the Moon when space probes have mapped its surface in greater detail than any other planet? The Moon is a fascinating geological wonderland that changes day-by-day, even hour-by-hour, as the terminator shadow marches across it face. The Moon is also accessible from everywhere, even a light-polluted urban backyard. Most importantly, the quest for the finest lunar detail is a challenge that will delight all astrophotographers.

Limitations

One of the most detrimental things to high-resolution lunar photography is something we have no control over; Earth's turbulent atmosphere. Astronomers refer to the effects of our atmosphere on a telescopic image as “seeing”. We can control some of the factors that affect seeing by keeping telescope optics cool and avoiding hot concrete and asphalt, or structures that emit heat or disturb the local air flow. Check the amount of star “twinkling” as an indicator of seeing conditions and turbulence in the local atmosphere. In the northern hemisphere, the degree of “twinkling” can help you monitor the location of the jet stream. If the jet stream is passing overhead, the seeing will be poor.

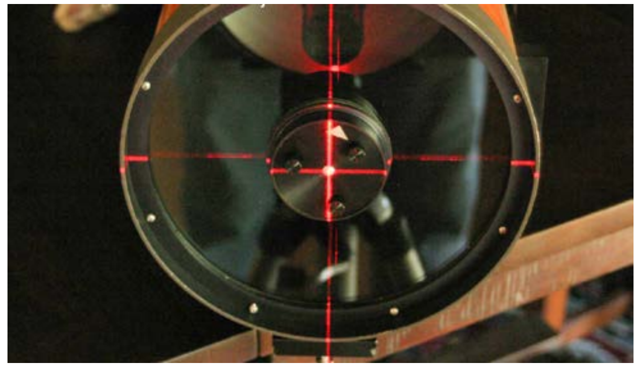
Dew is a major enemy of Schmidt-style telescopes and the slightest haze of moisture will degrade a lunar image. However, air currents created by the warmth of a dew heater will also degrade the image. For stable high-resolution images, use a dew shield to prevent corrector plate fogging. Maksutov telescopes are naturally more dew resistant than Schmidt-Cassegrains because their thicker corrector plates cool more slowly and retard the formation of dew.

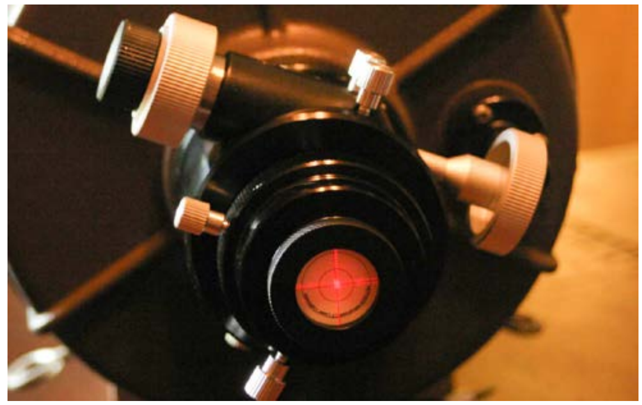
The more atmosphere we look through, the poorer the seeing becomes as more moving cells of air refract light rays. Try to shoot when the Moon is highest in the sky with the least amount of air mass between it and your camera. For planetary photography, an 8-inch telescope will often out resolve a larger telescope, in spite of the fact that resolution increases with aperture. Turbulent air “seeing cells” are relatively small, thus a larger telescope will look through multiple cells of turbulent air that compound the seeing degradation while a smaller scope may look through one cell of turbulence.

Another consequence of increased air mass is dispersion, or the smearing of colors because greater air mass progressively acts like a prism. When photographing a thin crescent moon, which by default will always be at low altitudes after sunset, this presents a challenge. At zenith, there is no dispersion, but the amount of detail smearing progressively increases to more than two arc seconds at 15 degrees above the horizon. Fortunately, the nature of processing lunar photography through stacking many video frames does much to negate the effects of dispersion. The photographer has two options to fight dispersion when the Moon is close to the horizon at dusk: shooting in daylight and using a filter. The Moon is bright enough to image during the day when the crescent phase is high in the sky. A red filter will improve daytime lunar contrast. A red filter is also useful when the Moon is at lower elevations because it removes the dispersion from refracted blue wavelengths and sharpens the image.

Equipment Preparation

There are three steps to the lunar imaging process: 1) telescope preparation, 2) image focus and capture, and 3) image processing. For high-resolution work, optical and mechanical collimation is critical. Every couple of months I use a Hotech Advanced CT laser collimator to tune up the optics on my telescope. If you use an additional aftermarket Craford focuser on your Schmidt-Cassegrain telescope, a good laser collimator will also insure it is mechanically aligned with the scope's optical axis.





The proper alignment of all telescope optical and mechanical components is critical to achieve high-resolution lunar images. The use of a laser collimator such as the Hotech Advanced CT shown here simplifies the optical alignment process by allowing it to be done indoors during the day. If using this or a similar model, follow the detailed instructions provided by Hotech to tune up telescope optics.

Monochrome planetary cameras are sensitive to infrared wavelengths, which focus on a different plane than visible light. Infrared must be removed or it will blur the image. All modern planetary cameras come with a 1¼-inch telescope adapter threaded to accept standard 1¼-inch eyepiece filters. For highest resolution with monochrome, install an infrared filter. Color cameras do not need an infrared filter because the Bayer color array filter present in color cameras effectively blocks infrared rays.

Clean optics is another prerequisite for maximum image contrast. Use a canned air blower to eliminate “dust donuts,” or the ring-shaped shadows caused by dust particles on Barlow lens elements, infrared filter, or the camera sensor.

Matching telescope and camera resolution is not as important for lunar photography as it is for deep sky work. The Moon is a linear object and stellar photography rules do not apply. For instance, my Sky-Watcher 180mm Maksutov has a theoretical resolution of 0.64 arc seconds, however, I am able to routinely photograph lunar detail that is a fraction of the telescope’s theoretical resolution.

The theme with lunar photography is seeing conditions determine what focal length to use. If the seeing is poor, use prime focus. The shorter focal length allows faster shutter speed, which helps freeze the jiggling image during poor seeing. If the seeing is good, a 1.5× Barlow will resolve more detail. If the seeing is great, a 2.5× Barlow can be used. Experience shows that under best seeing conditions, an F/25 system is optimal for the Moon.

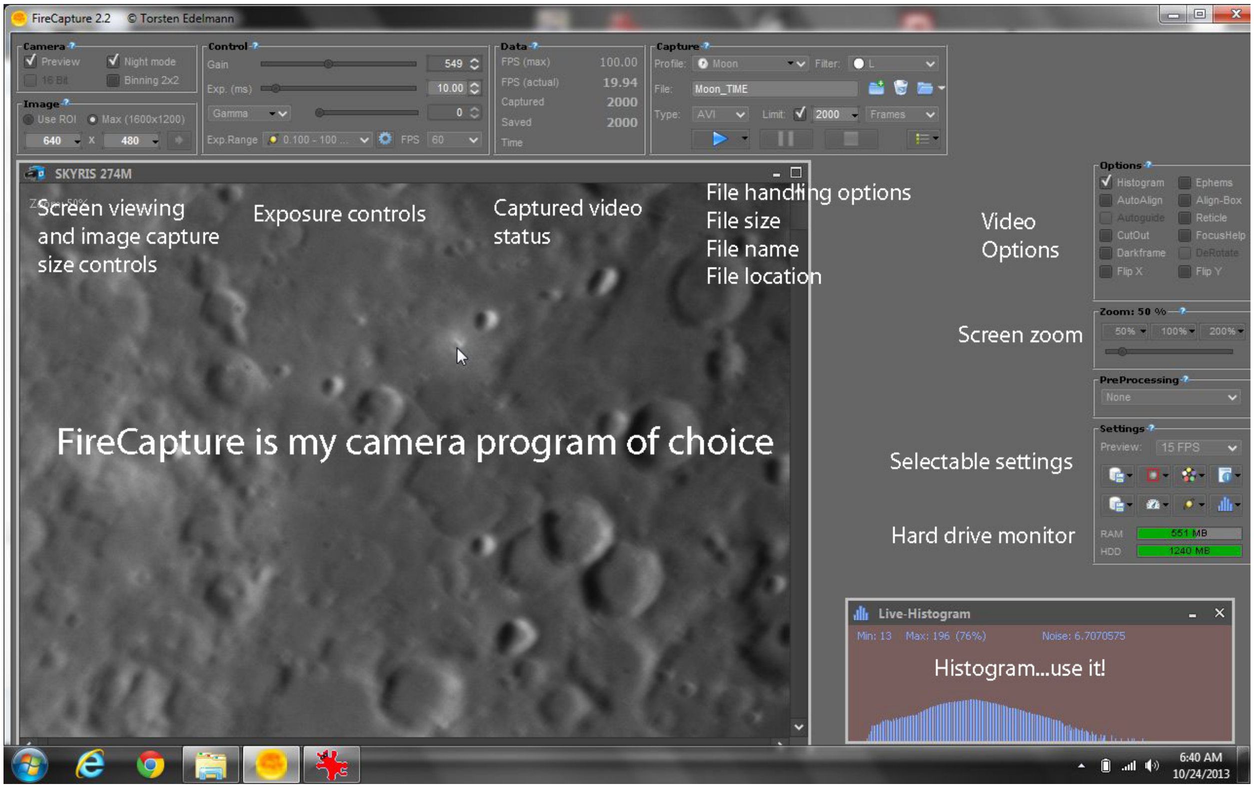
Camera Control

A telescope's native focuser is sufficient for prime focus work, but when a Barlow is added, the increased focal length introduces image shake when the focuser is touched. My solution was installing an aftermarket manual Crayford focuser with a 10-to-1 reduction gear focusing knob. I clip a clothespin to the slow motion focus knob and turn it by nudging it with my fingertip, eliminating shake induced by grasping the knob. By watching the focus on a laptop screen while nudging the clothespin, and noting the clothespin position relative to a clock face, I can log the point of best focus. If the clothespin is clocked in the same location after three focusing attempts, I can be confident that the telescope is well focused.

Focusing the camera through a very long focal length Barlow equipped system can be tricky. The use of an aftermarket reduction gear Crayford focuser helps achieve a finer focus. The use of clothespin allows the focus knob to be moved without grasping the knob and inducing vibration.

FireCapture

Every camera brand comes with its own native operating program and device drivers. However, I find the freeware program FireCapture more astronomically friendly and it interfaces with the driver for all popular cameras.



The freeware program FireCapture is an astronomically friendly camera control program that replaces the proprietary program that comes with all planetary cameras.

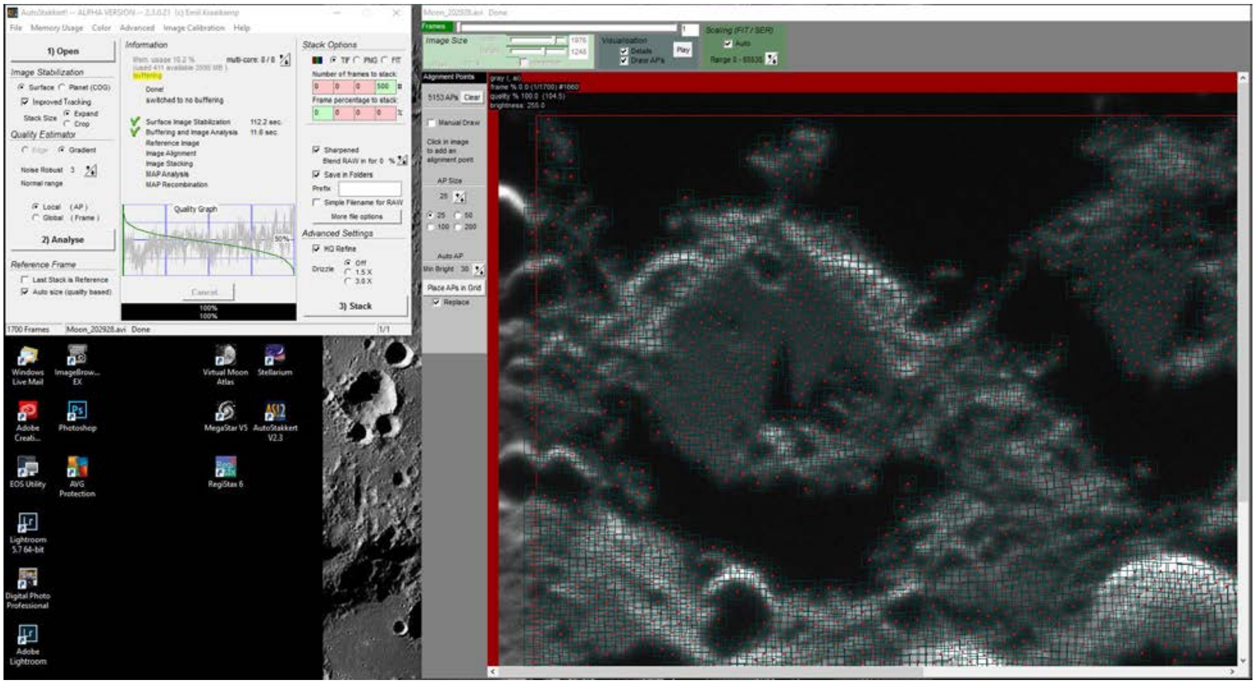
Use the image capture program's histogram feature to monitor exposure. It is difficult to properly gauge exposure by watching a bright laptop screen in the dark. I set the camera gain function at mid range and adjust the shutter speed until the right side of histogram hump is a just short of the right side of the histogram scale. Avoid running the histogram hump into the right side of the scale because once pixels are saturated to bright white at the right side of the scale, there is no detail left to process. The resulting image may appear dark, but the final stacked image can be adjusted to brighten the image. The image stacking process produces a greater effective pixel bit depth and dark areas can be stretched to recover detail. The latest version of FireCapture allows control of image gamma. Once the gain and exposure has been set, I move the gamma control slider until there are the fewest, if any at all, spikes or gaps in the histogram.

I set the camera controls to record a 3000-frame video. With today's Super Speed USB 3 connections, this typically takes about 30 to 50 seconds. This produces a 7 gigabyte video with a 1200 × 1920 pixel camera, so plenty of hard drive space is desirable. Precise telescope polar alignment is not critical for such short video captures. If there is slight image drift, during the capture I place the computer cursor on a small crater and nudge the telescope, if needed, to keep the crater centered under the cursor. If the lunar target drifts more than a few pixels during the video capture, the stacked image will have a fuzzy border.

Processing

Image stacking can be performed with either of the freeware suites AutoStakkert2 or RegiStax6, but I find a slight but noticeable improvement in image quality by first using AutoStakkert2 to stack the video frames into a single image, then using RegiStax6 for wavelet sharpening of the image if needed. I stack the best 500 out of 3000 video frames. When setting up AutoStakkert2, be sure to click on the "Improved Tracking" option in the Image

Stabilization tab. Under the Stack Option tab, set the “Blend RAW in” to zero percent. AutoStakkert2 does not have options for processing the stacked image; this is done with other software. Once the thousands of frames in an .AVI have been stacked into a single image using AutoStakkert2, the original .AVI can be deleted. All the information needed to process the image is within the single stacked image.



Stacking hundreds of video frames into a single enhanced image is performed with the freeware Autostakkert2.

Always process a copy of the stacked image, keeping the original data intact. Often, the stacked image created by AutoStakkert2 with data from with today’s CMOS planetary cameras is so good that the Registax6 wavelets processing can often be skipped. If RegiStax6 is used, remember that no two optical systems respond to RegiStax wavelets in the same way. Experimentation and experience will be your guide for Registax settings. A key element is to not over process. It is tempting to over sharpen and create an image that is too garish.

If needed, the freeware RegiStax6 can be used to sharpen details in images stacked with AutoStakkert2.

Lunar imaging has evolved beyond accepting a RegiStax6 processed image as the final photo. Like images taken by the masters of deep sky photography, great lunar images require further processing beyond stacking to eliminate artifacts and correct areas of over and underexposure and improve general image appearance. This final processing is completed in Photoshop CC. Now that Photoshop is a $10/month subscription instead of nearly $1000 for all options, the best image processing software is much more affordable. After stacking several hundred frames from a 12-bit planetary camera the effective bit depth, signal to noise ratio, and dynamic range are greater. High bit depth images can easily be stretched in Photoshop by several effective f/stops to lighten shadow areas or depress highlights.

The workflow processing steps in Photoshop should be done in a specific sequence to achieve best results. The following summarizes the processing order.

- Registax will produce an RGB color image even if the original was a monochrome image. The RegiStax image will appear black and white, but it is actually black and gray created by mixing red, blue, and green colors. Convert the image back to true black and white using Photoshop's <Image>, <Mode>, and <Gray scale> buttons.

- The best kept secret in lunar image processing is Photoshop's “Shake Reduction” filter, located at <Filter>, <Sharpen>, <Shake Reduction>. Applying this filter to your stacked image produces results similar to shooting through better seeing conditions or using a higher resolution instrument.

- Next, eliminate any image noise by either of two options. Click on <Filter>, <Noise>, and <Despeckle>. If excess noise persists, press Control + Z to undo the last operation and click <Filter>, <Noise>, and <Dust

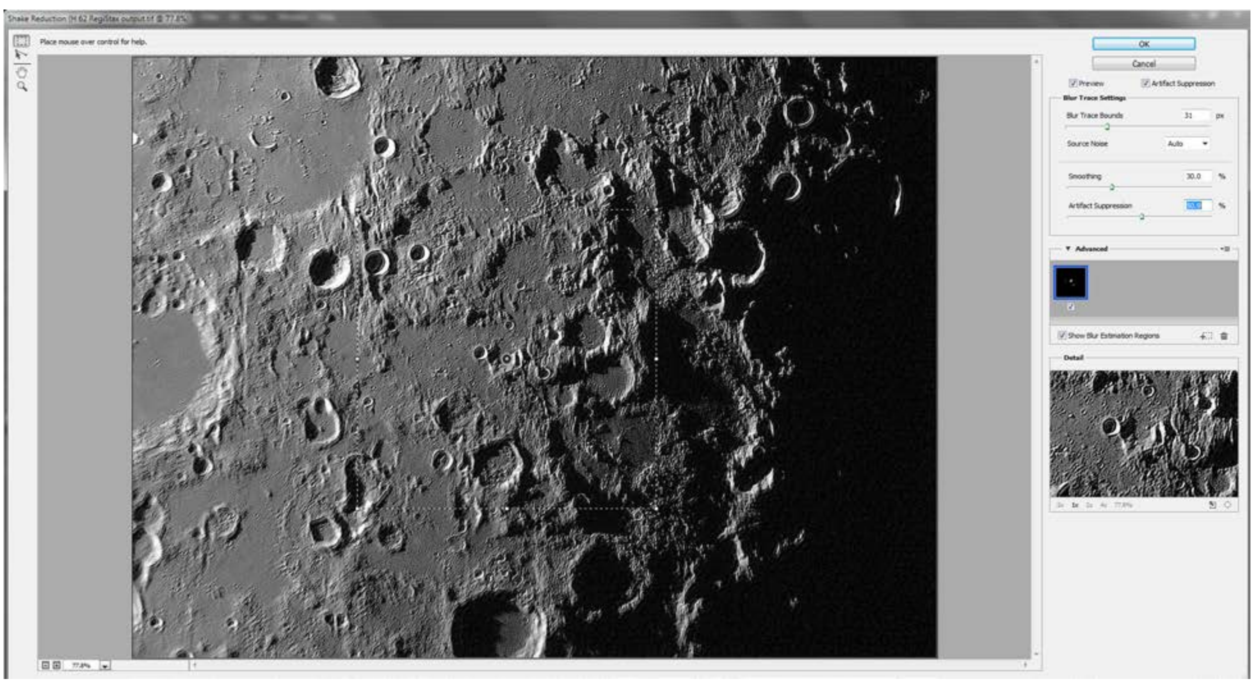
& Scratches>. Within this option set “Radius” to 1 and “Threshold” to 0. Higher settings will erase actual lunar detail. Decide which option best eliminated image noise.

- Using the crop tool in Photoshop's Tool Bar, crop off any ragged or fuzzy border around the image.

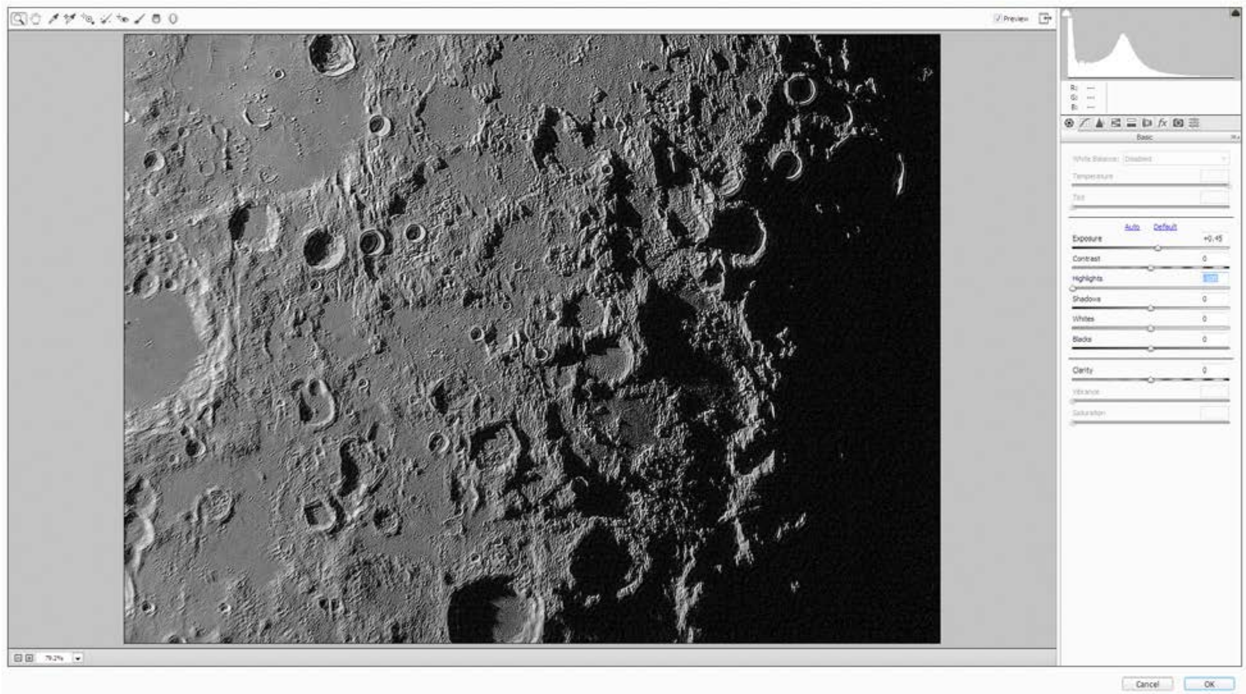
- Next click <Image> and <Image Size> to enlarge the image to 300 DPI for further processing. Be sure to click the “Resample” box and select “Bicubic Smoother (Enlargement)” in the resizing option box. On my system, this results in about 175 percent enlargement and produces a “cleaner” image once processing is complete.

- An important facet to remember: there are no gray shadows on the Moon, they are black. My mantra in lunar image processing is “Don't be afraid of the darks”. Use the Photoshop “Camera Raw” filter, located at <Filter>, <Camera Raw>, for adjustment of exposure, control of highlights and dimly exposed terminator regions, and to darken shadows. While making adjustments, use Camera Raw's histogram display to monitor the overall image exposure. There are often differences in how the image is displayed on the computer monitor and how the image will print. I get best results when placing the center of the histogram hump about two-thirds the way to the right of the display, but do not allow the histogram to go past the right side of the scale or highlights will be washed out and featureless.

- Due to the extreme contrast of lunar features, Camera Raw will not completely control shadows and some gray noise will remain. To render lunar shadows black, further processing is done with the “Burn” tool located in the Photoshop Tool Bar. Do not use the “Replace color” tool, located at <Image>, <Adjustments>, <Replace Color>, to darken shadows because it will also darken similar shade details you want to retain. When darkening shadows, set the burn tool's <Range> to “shadow' and set the <Exposure> to about five percent then darken noisy shadows with a series of sweeps with the burn tool.



The “shake reduction” filter in Photoshop dramatically improves the clarity of lunar photographs.

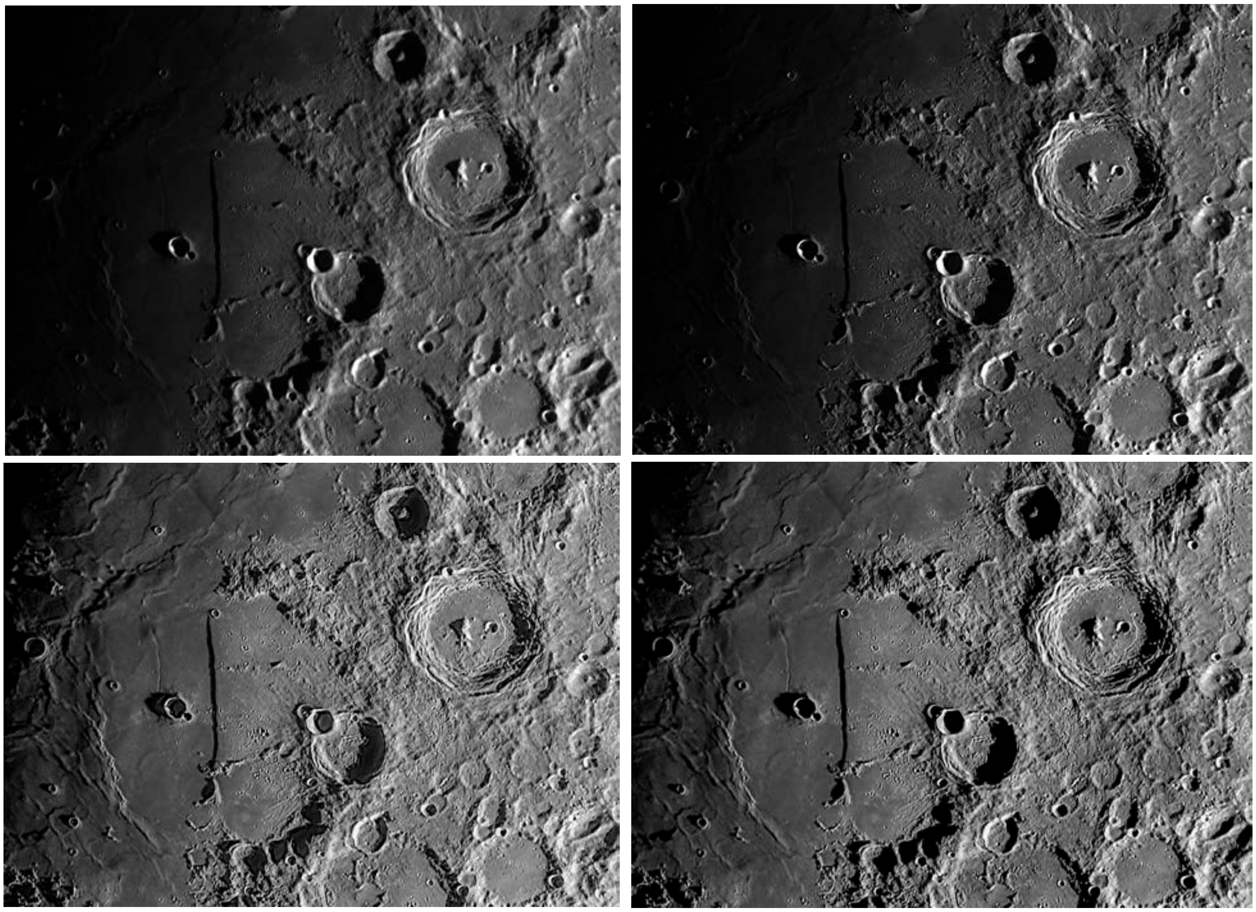


Photoshop's Camera Raw filter combines many image enhancement tools into one interface making it useful for adjusting image exposure, suppress bright highlights, brighten dim areas, and darken true shadows.

Modern lunar imaging is not possible without the amazing image stacking programs that reduce several thousand video frames into a single image. However, an unintentional side effect of the stacking process is that it creates artifacts that mimic real detail. The purpose of image processing is enhance what is real and remove what is not real. Recognizing what is not real in a lunar image is an important, but easily learned skill. The following summarizes common artifacts introduced by the stacking process.

- Gray shadows. As seen through an amateur telescope, there are no gray shadows on the Moon. They are all black.
- “Bathtub rings”, or gray concentric circles within shadowed craters.
- “Baggage tags”, or patches of false detail attached to real detail by thin bridge.
- Parallelism, or false ridges that form parallel to real details.
- False central peaks. Craters smaller than 15 miles in diameter do not have central peaks.
- Dust donuts created by dust spots on the optics.

Use the burn tool to darken gray shadows and eliminate bathtub rings and baggage tags. If the gray detail seems to melt away with several passes of the burn tool set to “shadows” at five percent exposure, it is not real and needs to be removed. Real detail that should be retained will not be affected by the burn tool. Use the eraser tool to remove parallelism and false central peaks. Use the clone tool to eliminate dust donuts, being careful not to eliminate real detail or duplicate an existing feature.



The evolution of an image through various processing steps can be seen in this sequence of four images. The raw output from the Autostakkert2 image stacking program is shown in the first frame (top left). The application of Photoshop's “shake reduction' filter dramatically improves image sharpness (top right). This is followed by exposure and tone adjustment in Photoshop's “camera raw” filter (bottom left). At this point a number of artifacts like gray shadows, bathtub rings, and false central peaks in small craters have become apparent. The final frame shows the finished artifact free image after treatment with Photoshop's “burn” and “clone” tools (bottom right).

This is truly the golden age of amateur lunar photography. The amateur, equipped with a modest affordable telescope and a modern planetary camera, can routinely record greater lunar detail than the professional did during the Apollo era. By following the image capture and processing tips outlined here, breathtaking images of the Moon are possible. Relive the most exciting times in space exploration with your own telescope and rediscover the joys of lunar photography by exploring the mysteries of our neighboring world.

Software Sources

FireCapture camera control freeware

http://www.firecapture.de/

AutoStakkert2 image stacking freeware

http://www.autostakkert.com/

Registax6 image stacking and wavelets image processing freeware

http://www.astronomie.be/registax/

Photoshop Creative Cloud image processing subscription program

http://www.adobe.com/products/photoshop.html

Equipment Used by Robert Reeves to Take the Lunar Photos in this Article

Sky-Watcher telescopes

http://skywatcherusa.com/maksutov.html

Celestron **Skyris** cameras

http://celestron.factoryoutletstore.com/cat/58205/Celestron-Imaging-Cameras.html

Hotech Advanced CT laser colimator

http://www.hotechusa.com/category-s/23.htm