



# Demystifying Image Calibration

This important step will dramatically improve your imaging results.

All deep-sky astrophotography requires some form of image calibration to remove unwanted signal. This deep photograph of the entire Veil Nebula supernova remnant in Cygnus consists of more than 17 hours of exposures through color and narrow-band filters calibrated with flat-field and dark exposures.

Just five words is all it takes to highlight one of the main things that makes astrophotography so challenging: It is dark at night. With very few exceptions, there are big differences in how to photograph dim targets under low-light conditions as compared with daytime photography.

Beyond the solar system, targets visible in the night sky are very dim and often barely brighter than the background sky. The cameras we use to image deep-sky objects are inherently noisy. And to further compound the problem, images from telescopes, astrographs, and camera lenses suffer from uneven field illumination due to a host of reasons, including varying sensitivity across your astronomical camera's CCD or CMOS detector, vignetting, and even dust on optical surfaces. These deficiencies are seen in every image that downloads from your camera's detector.

Fortunately, the standardized process known as image calibration can clean up the majority of these issues in our photos prior to combining and processing them further, which then allows you to get the most out of your astrophotography.

Raw, unprocessed deep-sky images can look quite unappealing directly out of the camera. They generally appear dark with just a smattering of stars. If you stretch that image, you'll begin to see your target, but such image manipulation reveals countless white and black specks scattered across the image. This is a combination of unwanted signal and noise that has to be removed from each of your target exposures before they can be combined and then further processed.

Most experienced deep-sky astrophotographers consider calibration an essential step in the process of making top-notch images of galaxies, nebulae, and star clusters. Although calibration isn't difficult in practice, it does require a modest investment of time to learn, and it has associated jargon that can make it seem hard. Don't let this discourage you from learning how to calibrate your images. Here's what you need to know.

### The Cleanup Crew

Three types of calibration frames are applied in the calibration routine to address specific issues unique to long-exposure astrophotography. These are known as dark frames, bias frames, and flat-field images. Dark frames are used to correct for the electronic signal that builds up over time during a long exposure. Bias frames characterize and correct readout noise — the noise generated when information on the sensor is transferred to a computer — but it is only really necessary for advanced calibration procedures when scaling dark frames made at different temperatures than the light frames were made. Flat-field images are then applied to correct for uneven field illumination, making vignetting and dust-doughnuts seem to magically disappear.

Calibration should be the first step in any image-processing workflow. This is true for both CCD and CMOS cameras, regardless of whether they are monochrome with filters, cooled one-shot color (OSC), DSLR, or mirrorless cameras.

Dark frames are captured in complete darkness (with the telescope or camera covered), at the same detector temperature and exposure duration as your target images. All other settings, such as ISO, gain, and offset (if your camera allows you to change these settings), should also be the same as for the light frames. Make sure that no light can reach the camera's sensor, and record a series of dark frames using your preferred acquisition software in the same way as you would capture light frames. You can then combine them into what's called a "master" dark frame using either an average or pixel-rejection method, which helps to remove random signal. A camera's noise characteristics will change over time, so shoot new dark frames every few months even if all other shooting parameters remain the same.

Note that off-the-shelf DSLRs and their mirrorless cousins do not include temperature regulation. When imaging with these cameras, try to match the temperature of the calibration frames to the light frames as closely as possible. You can record dark frames periodically throughout your imaging run so that their average temperature is similar to that of the light images. Another strategy for cold-weather imaging is to put the camera in the refrigerator or freezer and record dark and bias calibration frames to mimic expected nighttime temperatures.

This brings us to the third type of calibration used in deep-sky imaging, called flat-field calibration. Flat-field calibration frames are images of an evenly illuminated blank target, such as a projection screen. Their acquisition is more complex than either bias or dark frames. A properly exposed flat-field image records uneven field illumination (vignetting), regional differences in sensor response, and the shadows of dust spots, which appear as round spots when shooting through a refractor or doughnuts when imaging through reflecting telescopes.

Unlike bias and dark frames, you can acquire flat-field images with different camera settings than used for your light images, though if you shoot your flat-field frames at a different temperature, you'll need to record a full set of matching dark frames and apply them to the flats before assembling them into a master flat-field image. It's far simpler to keep temperature and other camera settings consistent with your other calibration frames. Regardless of the method used to acquire flats, the exposure time should be set to produce a moderately bright image, roughly 30% to 50% of the full-well capacity of your camera (the point at which a pixel saturates) in order to be effective in correcting your light frames.

Shooting flat-fields can be tricky. If your camera has a mechanical shutter, you'll need to expose your flats for at least several seconds in order to ensure the frame isn't affected by the brief time the shutter passes through the image. Additionally, if you are using a monochrome camera



▲ This image of the globular cluster M5 in Serpens was processed without calibration frames, showing several artifacts that are easily corrected in calibration.



▲ Dark frames record electronic signal that builds up during an exposure. A proper dark frame needs to be shot at the same temperature setting in your camera and must be exposed for the same length as the light frames it is meant to be subtracted from. The vertical lines are due to stuck pixels and are completely corrected during dark subtraction.

with multiple filters, dust motes may be in a different place on each filter. This requires a set of flats for each filter. While opinions differ on how many flat frames to acquire, I prefer 16 flat-field frames per filter to produce a good master flat.

You should acquire a new set of flat frames every time the camera is rotated on the telescope, and also when you bin (group pixels) on the detector. The focus position should be identical to that used while recording your target images. Here are three methods for shooting flats, depending on your setup and level of experience.

### Capturing Flat-Field Images

Recording good flat-field frames can be challenging — the target needs to be extremely evenly illuminated, or else it will introduce gradients across your light images. When performed carefully, these popular techniques can work well.

**T-shirt flats** A white or light-gray T-shirt can be used as a diffuser to produce a flat-field by targeting the daytime sky. Stretch two layers of a clean T-shirt over the objective of the telescope or lens and fasten it in place, ensuring there are no wrinkles. Point the telescope towards an evenly illuminated part of the sky or other bright target — an overcast sky works particularly well. Adjust the exposure time as necessary and acquire flat frames the same way you would acquire light frames.

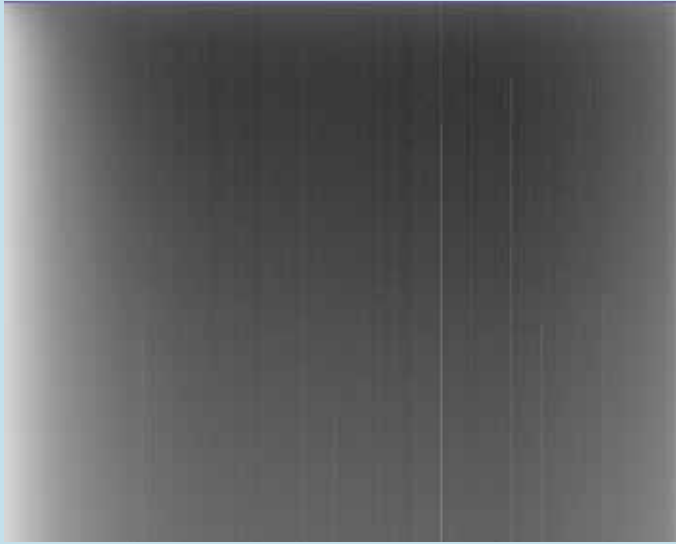


This is perhaps the least expensive and easiest method for producing flat-field images, though it can be tricky finding a good T-shirt that works well.

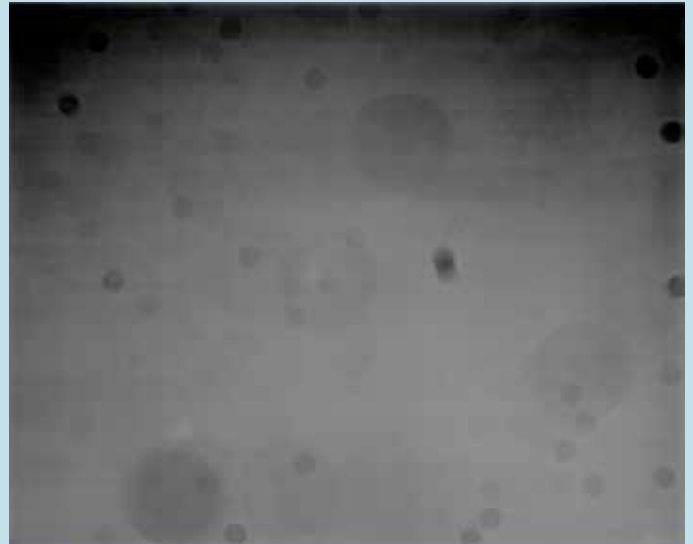
**Flat panel** An electroluminescent panel makes excellent flat-field images. Make sure the flat panel is larger than the diameter of your objective. Simply point your telescope or lens straight up and lay the panel on the dew shield or lens shade. Set the panel's brightness so that it reaches the target level of illumination with exposures of a few seconds or so. This method is low-tech and very reliable, but it does have some associated cost: Flat panels can cost up to several hundred dollars.

**Twilight flats** (sky flats) Beginning immediately after sunset on a clear evening, point your telescope or lens about 5° east of the meridian (85° altitude, 90° azimuth). This is the most evenly illuminated area of the twilight sky. You can also collect twilight flats beginning about half an hour before sunrise pointed 5° west of the meridian (85° altitude, 270° azimuth). Turn the mount's tracking off so that stars will trail and appear in different locations in each flat frame; they will average out when combined into the master flat. This method works very well, but it can be challenging since the sky brightness changes rapidly during twilight, and the window for collecting flats is brief. To simplify collecting twilight flats, consider using software to automate the process and vary the exposure times as required to keep the brightness consistent within your set of flat frames. Compared with the other two

◀ One quick and low-cost technique to record decent flat-field images involves stretching two layers of a white or light-gray T-shirt over the front aperture of the lens or telescope and exposing on the sky. New T-shirts work best, and be sure to smooth out any wrinkles. Use of an electroluminescent panel to record flat-field images can be seen on page 69.



▲ Bias frames, which are zero-length exposures, record only the readout noise generated with every exposure. Bias calibration isn't often necessary unless you need to scale dark frames.



▲ Possibly the most critical calibration frame for imagers is the flat-field image. This records uneven field illumination like vignetting seen in the corners of the image, as well as the out-of-focus silhouettes of dust specks found on any optical surfaces. The smaller the spot is, the closer it is to the camera's detector.

methods described above, twilight flats produce superior results for some of my telescopes. Like T-shirt flats, this is a low-cost option, but it is significantly more challenging.

### Applying Calibration

So now you have your calibration frames. The next step is to combine them into master calibration frames and apply those masters to your light images. Fortunately, we don't need to work with all of these files manually. Every major image-processing software package designed for astronomy includes an image-calibration function, and most also produce master calibration frames in the process. I prefer to use *PixInsight*, though excellent results can also be had with most any astronomical image-processing software.

Calibration should be the first step in any image-processing workflow. This is true for both CCD and CMOS cameras, regardless of whether they are monochrome with filters, cooled one-shot color (OSC), DSLR, or mirrorless cameras. Calibration comes before debayering, which creates a color image from the monochrome data produced by OSC, DSLR, and mirrorless cameras.

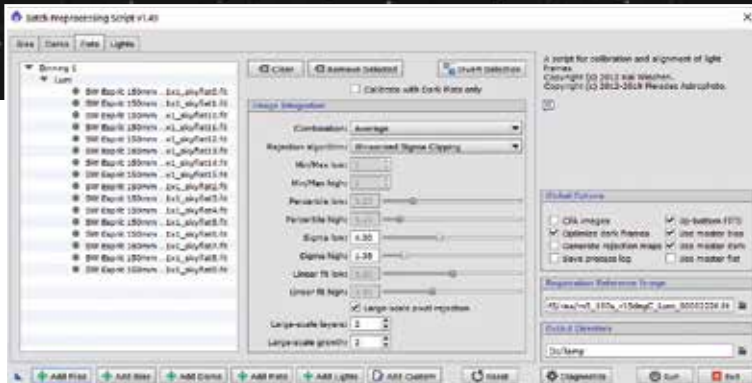
All calibration tools are used in basically the same way. First you load up your light images and dark, bias, and flat frames. Some software will automatically sort them into their respective groups; if not, you can specify file types manually. Choose a destination folder for the calibrated files, then simply apply the process. The result will be a set of fully calibrated light frames, and, for some software, a set of master

calibration frames. If your software made master calibration frames, use these on all your future images taken with the same equipment, temperature, and exposure settings, at least until a new speck of dust appears.

Although you don't need to be a computer whiz or a mathematician to successfully perform image calibration, some may want a better understanding of what's going on while the software is chugging away during an image-calibration run. Here's a peek under the hood:



► The same image of M5 as seen on page 38 appears without any artifacts after calibration with a master dark and master flat-field image.



◀ The popular image-processing program *PixInsight* handles calibration in its Batch Preprocessing scripts.

▲ After calibrating and combining all the color exposures, the author reveals thousands of faint stars in the outer halo of M5. The final result includes 8 hours and 42 minutes of exposures through LRGB filters with a QHY 16200A CCD camera and a Sky-Watcher Esprit 150-mm ED f/7 Triplet APO refractor.

First, bias and dark calibration masters are generated by averaging all the bias frames and dark frames, producing a master bias and a master dark image. The master flat-field image is usually created by subtracting the master bias from each flat frame and then averaging the bias-corrected flat frames. Users of CMOS cameras that produce unreliable results with bias correction need to make a master flat-dark and subtract it from each flat frame; These are then averaged together to make the master flat.

The target images are then calibrated using the master calibration frames: The master dark frame is subtracted from each light image, and then each light frame is divided by the master flat, producing your clean, calibrated light images that are now ready for stacking and further processing.

## Conclusion

Cameras record the precious photons that we crave, but this signal becomes tainted by undesirable signal from electronic noise and flaws in the optical train. Image processing is likely to accentuate these unwanted features if left uncorrected, leading to unsightly artifacts in processed images.

Processing calibrated data is also easier, since there are no blemishes like dust doughnuts that need additional attention. Given the huge benefits to the resulting images we produce, it's clear that it's worth investing your time to master calibration, an essential ingredient to every great deep-sky astrophoto.

■ RON BRECHER images targets from his observatory in Guelph, Ontario. See more of his images at [astrodoc.ca](http://astrodoc.ca).