IMAGE COLOR CALIBRATION

Extinction Coefficients and Weight Factors

Figure 1. Image of NGC 5139 without (left) and with (right) atmospheric transmissivity calibration

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With the availability of good telescopes and digital cameras, astro-imaging has become very popular. The Internet is replete with spectacular images of galaxies, nebulae, and star clusters. Interestingly, if you browse through the many collections of images, you'll notice that the appearance of objects can be quite different from site to site. On one site, a particular nebula may appear more bluish, on another more greenish. Artistically, "beauty is in the eye of the beholder," but you might wonder, "What's the *real* color of that object?"

This is where image calibration comes in. By calibrating the raw imagery from your camera, you can correct its color balance so that it displays a realistic representation of the imaged object. This works for both monochrome and color cameras. With a monochrome camera, we use color filters to acquire images in the red, green, and blue spectral bands. With a color camera, the raw color image can be demosaiced or debayered into separate red, green, and blue images that can then be handled the same way as images from a monochrome camera. In either case, the red, green, and blue images need to be calibrated so that, when combined, the resulting color image has the correct color balance.

Color calibration attempts to correct for two factors: the effects of the atmosphere and the characteristics of your imaging equipment. The atmospheric effect is quantified by the atmospheric transmissivity factor, A. The light from an astronomical object directly overhead (at the zenith) traverses the shortest optical path through the atmosphere to get to you. As the object gets lower in the sky, its light traverses a longer optical path through the atmosphere resulting in more scattering and absorption. So, the value of A decreases as the angle between the object and the zenith increases and we observe that the object gets proportionately dimmer. The rate at which the object dims is controlled by the extinction coefficient, k. The atmosphere affects some wavelengths of light more than others – blue light gets scattered the most and red light the least (that's why the sky is blue and the setting sun is red). Thus, the value of k will differ for the three spectral bands. As an object approaches the horizon, not only does it get dimmer but also *its color balance changes*.

The value of A doesn't change much around the zenith, so if you restrict your imaging to when an object is high in the sky, the resulting atmospheric effects will be relatively small. Sometimes, though, you don't have a choice. In April 2016 I imaged the spectacular globular cluster NGC 5139, Omega Centauri, using a QSI 583 monochrome camera with Baader RGB filters on an Orion 120 mm EON refractor. At my latitude of 33.6°N, this object doesn't get higher than nine degrees above the horizon. Figure 1 shows two versions of the processed image with and without calibration for atmospheric transmissivity. Like the setting sun, the stars in the uncalibrated version are strongly reddened by their light passing through the atmosphere. This effect has been corrected in the calibrated version, where the cluster appears as if it were directly overhead.

For color calibration, the characteristics of your imaging equipment (camera, filters) are quantified by the weight factor, W, sometimes called the "white balance." The amount of signal generated by the sensor in your camera for a given number of photons falling upon it, its "quantum efficiency," is a function of wavelength. Modern camera sensors tend to be most sensitive in the green wavelengths, but the specific spectral response varies among sensors. W is also affected by the filters you use with your monochrome camera. This includes the spectral transmissivity of the filters (how much light they pass) and their

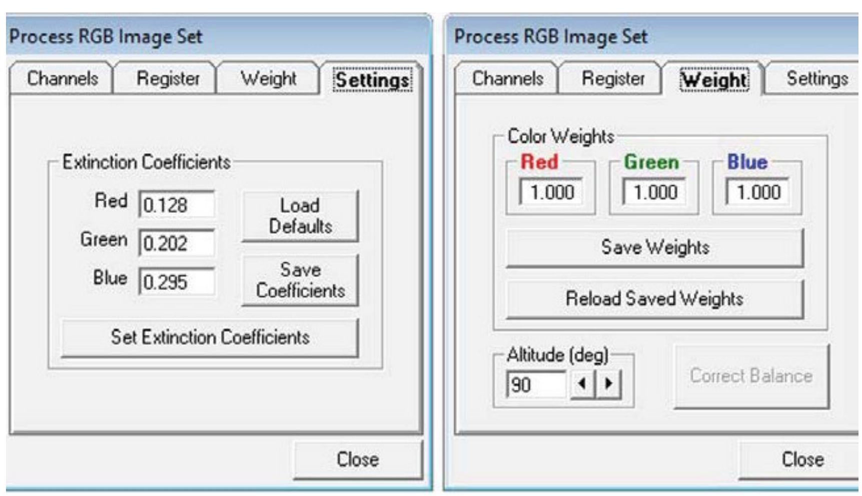

Figure 2. "Settings" and "Weight" tabs from AIP4Win showing default values for k and W

spectral bandwidth (what wavelengths of light they pass). The same is true for the array of tiny color filters on top of the sensor chip (the "Bayer pattern") in a color camera. Thus, the value of *W* will be different for the three spectral bands and *will be unique for your choice of camera and filters.*

I've written software that applies values of *k* and *W* to color calibrate my imagery, but most astro-imagers rely on commercially or freely available image processing software. Most of these software packages provide default values for *k* and *W* that you can use in calibrating your imagery. For example, Figure 2 shows the "Process RGB Image Set" panel from AIP4Win, software that is freely available through the American Association of Variable Star Observers *(aavso.org/aip4win-no-longer-requires-registration)*. Under the two tabs, you can see the default values for *k* and *W*. If you want, you can enter your own values for these factors and save them. However, using the default values will usually get you reasonable-looking images that you can later manually adjust to your liking in Photoshop.

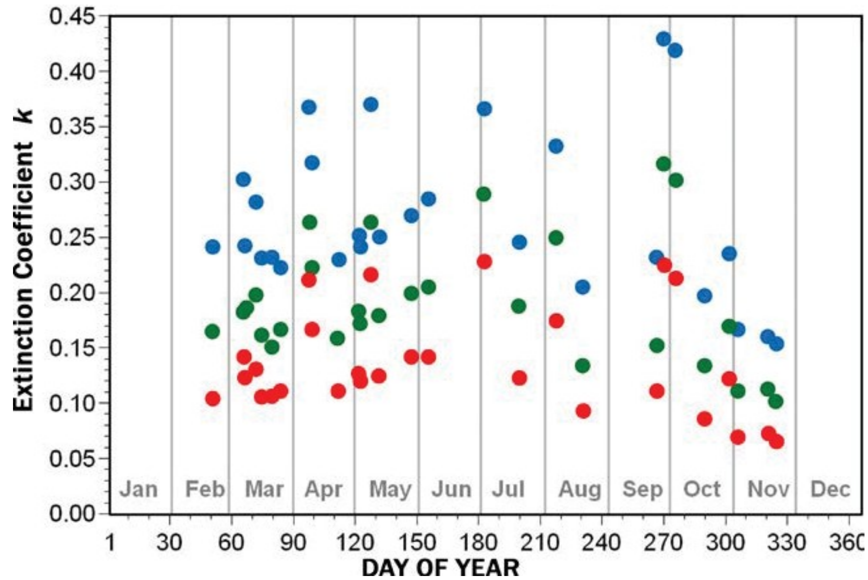

Figure 3. *k* values for the red, green, and blue spectral bands from data collected on 28 clear nights in 2015 and 2016

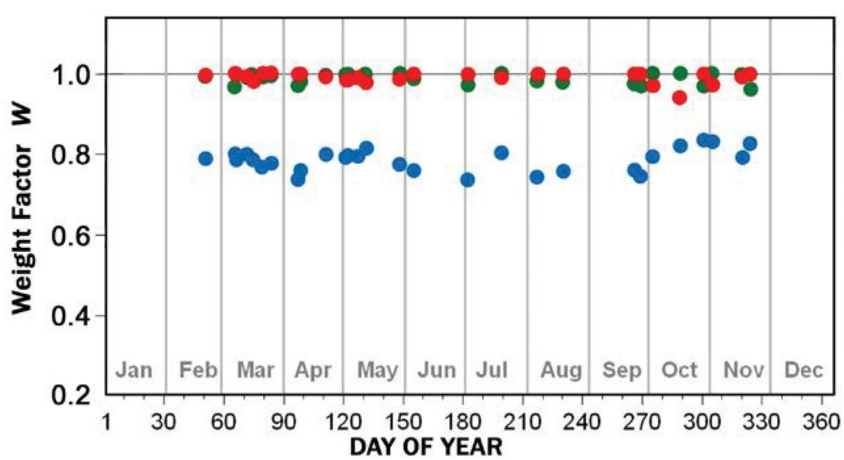

Figure 4. *W* values for the red, green, and blue spectral bands from data collected on 28 clear nights in 2015 and 2016.

But if you want to do more than make "pretty pictures" and would like your images to show the true colors of astronomical objects, you'll need to avoid subjectivity in your image processing. This includes supplying your own values for *k* and *W* that represent the atmospheric conditions when you acquired your imagery and the characteristics of your imaging equipment. In an addendum to this article *(cat-star.org/pubs/addendum_2023.pdf)*, I describe how to use astro-imagery to evaluate *k* and *W*. It's not difficult, and it'll give you something to do on those nights where the moon is bright.

So, how much can the values of *k* and *W* vary? To get a handle on this, I evaluated these factors using data collected at my location near Lubbock, Texas, on 28 clear nights during 2015 and 2016, starting in February and running through November. My region has a continental climate and an elevation of around 1 km above sea level.

Figure 3 shows values of *k* for the red, green, and blue spectral bands plotted for the dates on which the data were collected (the color of each point indicates the spectral band). The values showed considerable variation over the course of the year. Larger values tended to occur during summer, when clear nights were typically warm and humid. Smaller values tended to occur in winter, when clear nights were typically cold and dry. But, beyond this seasonal variation, there can be large day-to-day changes in *k* associated with short-term changes in atmospheric conditions. This variability makes using default values problematic for objective color calibration.

Figure 4 shows values of *W* for the red, green, and blue spectral bands plotted in the manner of Figure 3. There is no systematic variation in the values over the course of the year, and day-to-day variations are generally small, not more than about 4 percent. Unlike *k*, it is probably sufficient to use a single, average value of *W* for each of the three spectral bands. If you use the same imaging equipment every time, then this set of *W* values should be okay for all your image processing. You'll still have to determine *W* one time but, after that, you should be able to use those values until you make a change in your equipment.

It's important to note that, because the object you're imaging is constantly changing its elevation in the sky during your imaging session, the value of *A* will be different for each of your raw images. Therefore, color calibration involving *k* should be performed on your images *before* they're stacked. In contrast, since your equipment presumably stays the same during the imaging session, color calibration involving *W* can be performed after image stacking.

So, with a little effort, it's possible to obtain the information to objectively calibrate the color balance of your imagery to show astronomical objects in their true colors without any subjective fiddling with Photoshop. They'll still be pretty pictures but, for a change, realistic. *